

Doctoral Thesis

Human-Centered Mapping in Mobile Environments
(モバイル環境における人間中心マッピング)

陸 恣

Abstract

In recent years, online web mapping products have become well developed and widely used in mobile environments. Location-based mobile applications also use web mapping services to provide map-based functions. The rapidly growing user-generated geospatial content also primarily uses web mapping for base maps. However, the fast growth of outstanding web mapping products has brought up new issues in the use of maps in mobile environments, one of which is that the diversity of maps is insufficient in mobile environments. Computer-generated maps used by web mapping are accurate and generic for multiple purposes, but the diversity of geoinformation representation is insufficient to satisfy a wide variety of user groups' requirements when used for specific purposes. On the other hand, various well-designed conventional maps are still widely used in the printed media for people's daily uses, such as the maps in guidebooks and leaflets for tourism and city exploration, the maps on newspapers and in magazines for presenting arguments and proposals, and so on. Such maps often have a sense of human-centered design in map communication within a limited medium. However, they are less used in current digital mobile environments. The purpose of this research is to study, design and develop a new mapping platform for introducing human-centered maps to the latest digital mobile devices to combine the advantages of both.

Chapter 2 shows the background and problems in the dissertation, and addresses the necessity of this research. This chapter begins by reviewing both the lexical and functional traditions in conventional mapmaking to reveal that map communication is essential in human-centered mapmaking, while functionality, storytelling, aesthetics and inconsistency can be important characteristics of such maps. The bird's-eye view maps produced by the great cartographic artist, Hatsusaburo Yoshida (吉田初三郎, 1884-1955), are used as an example of well-designed human-centered maps and significant factors of these maps are addressed. It has been confirmed that rapidly developing web mapping services have had an impact on cartography and changed mapmaking and map usage. The shift of map media has brought important new features to maps, including hypermedia, dynamics, interactivity and accessibility, and, therefore, has extended the capability of map communication. However, such potential has not been well explored for human-centered maps. This research also examines the drawbacks of the currently outstanding web mapping services, which include the side effects brought to map users by the dominating products and their lack of human-centered design thinking. It has also been pointed out that the data-driven approach and technology-driven approach will misdirect the ways to achieve effective mobile mapping.

Maps should be made for humans and consider the demands and background of the users, employing a human-centered approach. Therefore, it is important to fully involve human's creativity in mobile mapping, because the machine-generated maps should not totally take the place of the human-made maps. Simply stated, human-centered maps should be made for humans and made by humans. A survey distributed to young users of mobile mapping has been conducted, and the results reveal that current web mapping does not take the place of conventional printed maps when used for specific purposes such as sightseeing. It further indicates that well-designed conventional human-made maps are preferred if the advantages of mobile devices, especially GPS positioning, can be integrated into them. Examples of existing mobile applications using maps other than web mapping have been investigated, and their limitations have been pointed out. The studies and discussions show the necessities of academic research and system development to establish and incorporate human-centered maps in mobile environments.

Chapter 3 suggests a proposal and clarifies key factors to realize a feasible platform for human-centered mobile mapping. This research has analyzed the causes of the limitations in current map applications, which include external sources, such as the deficient functions of human-centered mapmaking tools, as well as internal defects of human-centered maps, especially the difficulties of positioning because of the immeasurable distortions. Usage has been studied from both the author's and the user's viewpoint, to clarify the requirements of the expected approach. A human-centered mobile mapping framework including both authoring tools and user applications has been proposed in this research. This framework is designed for importing conventional human-centered maps to mobile devices, and converting them to interactive and geo-enabled mobile mapping by integrating geo-metadata and multimedia content to originally static maps. Geo-metadata is designed to be the key to geo-enabling the printed human-centered maps. The design of the concept model of geo-metadata is introduced in detail, including the graphic components and their georeference patterns. Frequently used geo-events and geo-interactions for interactive mapping are also enumerated and discussed. In realizing mobile mapping, practical positioning methods for distorted maps used in location-aware devices are key technologies in the proposed framework. This research introduces several different point-based and line-based methods, and discusses their usages, advantages and limitations. Among them, error analyses have been made to two-pointed based similarity transformations, and the results show that errors in this method depend on the stretch rate of the map and the distance to the line of the pair of control points.

Chapter 4 introduces the developments that have implemented the proposal of this dissertation. To implement the proposed framework and test its feasibility, a series of prototypes named **Manpo** (漫步) have been developed on Apple Inc.'s iOS platform as a

target application for walking tours. Although the functions are still simple, the prototypes have realized both authoring tools and user applications in the framework. The authoring tools recognize the whole workflow of importing walking route maps, editing geo-metadata for positioning, adding extra multimedia content, and so on, to create geo-enabled interactive mobile maps, such as *Manpo Content*. The applications of **Manpo** allow users to appreciate **Manpo content** using geo-interactive map browsing functions, and show the user's current location and moving trajectories on the maps when walking outdoors.

Chapter 5 focuses on experiments and discussions of the results. Algorithms of two-pointed based similarity transformation and line-based linear referencing are realized and implemented in the prototypes. Experiments using simulated and real trajectory data have compared the effects of different combinations of control points and lines used in the realized methods and have demonstrated the effectiveness and limitations of them. Sufficient density and reasonable distribution of control points is important in achieving a reliable positioning. Control lines are effective when they are distributed on the moving path of the users with proper setting of the buffer range. Experiments with the prototype on the mobile devices in the real world have also revealed the feasibility of the realized positioning methods in practical mobile applications. User tests by university students and completed surveys have shown the functionality and usability of **Manpo** for both authors and users. However, they also have revealed one of the limitations of the approach, which is that the quality of content, especially the reliability of positioning, is also strongly dependent upon the authors' experiences and skills. From the examination of student-created *Manpo Content*, three types of typical mistakes made by the students in geo-enabling hand-drawn maps are classified and discussed. Among them, the improper placement of control points in distorted maps is the most difficult to avoid by untrained, ordinary users. In the user tests and surveys, the students, who are used to current web mapping products, have shown their interests in **Manpo** and creativity in making their own mobile mapping. This can be considered as evidence of the potential of **Manpo's** platform to create practical, useful and welcomed human-centered mobile mapping products.

Chapter 6 concludes by presenting the contributions of the dissertation and suggested future research issues. This research has proposed and realized a pragmatic platform for human-centered mobile mapping by importing and converting printed well-designed conventional human-centered maps to geo-enabled interactive maps based on the current technological conditions. In the future, more research issues, including more accurate and reliable positioning, new tools for interactive human-centered mapmaking, platforms for publishing and sharing human-centered map content, and so on, need to be further studied and developed in order to disseminate human-centered mobile mapping and create more functional products. Finally, a new ecosystem of the human-centered mapmaking industry

should be established to fully involve the creativities of cartographers, illustrators and publishers, with the participations of civil organizations, governments, companies and research institutions, to benefit human-centered mapmakers and map users.

Table of Contents

Abstract	I
Table of Contents	V
List of Figures	VIII
List of Tables	XI
Chapter 1 Introduction	1
1.1 Background	1
1.2 Purpose	3
1.3 Academic Review	4
1.4 Structure of the Dissertation	5
Chapter 2 Cartographic Fundamentals of Human-Centered Mapping	8
2.1 Human-Centered Design Thinking in Conventional Maps	8
2.1.1 Lexical Tradition of Mapmaking and <i>Dictionary Maps</i>	8
2.1.2 Functional Tradition of Mapmaking and <i>Story Maps</i>	9
2.1.3 Human-Centered Conventional Maps – Take Yoshida’s Works as an example....	12
2.1.4 Spiral Up Evolvments of Maps.....	14
2.2 Impact of Web Mapping	16
2.2.1 Extension of Map Communication by Web Mapping.....	16
2.2.2 Drawbacks of Current Web Mapping.....	18
2.3 Necessity of Human-Centered Mobile Mapping	19
2.3.1 Hierarchy of Maps in Mobile Mapping.....	19
2.3.2 Misdirection of Non-Human-Centered Approaches	20
2.3.3 Importance of Involving Human Creativity in Mobile Mapping	22
2.3.4 Users’ Preference.....	23
2.4 Existing Mobile Applications Using Maps other than Web Mapping	26
2.4.1 Mobile Applications as Extensions of Paper Guidebooks	26
2.4.2 Native Mobile Applications Using Diverse Maps.....	27
2.4.3 Limitations of Current Applications.....	28
2.5 Conclusion	29
Chapter 3 Architecture of Human-Centered Mobile Mapping	31
3.1 Difficulties of Applying Human-Centered Maps in Mobile Mapping	31
3.1.1 Deficient Functionality of Human-Centered Mapmaking Tools.....	31
3.1.2 Distortions in Human-Centered Maps.....	32
3.2 Proposed Framework of Human-Centered Mobile Mapping	33
3.2.1 Studies on Use Cases.....	33

3.2.2 Structure of Framework for HCMM	34
3.2.3 Data Model of Geo-metadata	37
3.2.4 Geo-Events and Geo-Interactions.....	40
3.3 Positioning Methods for Human-Centered Mobile Mapping.....	43
3.3.1 Point-Based Positioning	45
3.3.2 Error Analyses of Two-Point Based Similarity Transformation.....	48
3.3.3 Line-Based Positioning	54
3.4 Conclusion	55
Chapter 4 Software Developments and Implementations.....	56
4.1 Purposes of Prototype Developments.....	56
4.1.1 Targeted Use Cases – Walking Tours	56
4.1.2 Developments for Feasibility Tests of Proposed Framework	57
4.1.3 Developments for Testing Positioning Methods	57
4.1.4 Developments for User Tests	58
4.2 Developments of Early Prototypes	58
4.2.1 Realization of Initial Browsing Functions – <i>Manpo Alpha</i>	58
4.2.2 Realization of Initial Authoring Functions – <i>Manpo Beta</i>	61
4.2.3 Extended Applications Based on Manpo – <i>Todai Kashiwa Rally</i>	65
4.3 Manpo Editor and Manpo Viewer	67
4.3.1 Design and Development	67
4.3.2 Realization of Geo-metadata	68
4.3.3 Realization of Positioning Methods	70
4.3.4 Main Realized Functions.....	71
4.4 Conclusion	79
Chapter 5 Experiments and Discussions.....	80
5.1 Experiments of Positioning Methods in Distorted Maps.....	80
5.1.1 Target of the Experiments	80
5.1.2 Materials for the Experiments	81
5.1.3 Comparison Using Simulated Moving Trajectory without GPS Error	87
5.1.4 Comparison Using Real Moving Trajectory with GPS Error	89
5.1.5 Discussions.....	92
5.2 User Tests of <i>Manpo</i>.....	93
5.2.1 Manpo Content Created by Testers	94
5.2.2 Effects of Distortions in Hand-drawn Maps.....	96
5.2.3 Effects of Improper Placement of POI's	100
5.2.4 User Test of Browsing Functions Using Modified Manpo Content.....	104
5.2.5 Discussions	106

5.3 Conclusion	107
Chapter 6 Conclusions and Future Work.....	109
6.1 Concluding Remarks	109
6.2 Future Work.....	111
References	114
Acknowledgements.....	119
Publications.....	120

List of Figures

Figure 1.1. Examples of Google Maps running on Apple Inc.'s iPhone 5 (iOS 7).....	1
Figure 1.2. Structure of the dissertation	7
Figure 2.1. A bird's-eye view map drawn by Hatsusaburo Yoshida	12
Figure 2.2. Evolutions of the appearances, media and functions of the maps with the impacts of new theories and technologies	15
Figure 2.3. Hierarchy from Computer-Centered Maps to Human-Centered Maps.....	20
Figure 2.4. Maps of the historic central area in Munich, Germany used in the questionnaire for surveying map preference	24
Figure 2.5. Examples of guidebook mobile applications	26
Figure 3.1. Structure of the framework of human-centered mobile mapping (HCMM).....	35
Figure 3.2. Processes of creating control points on distorted maps for positioning.....	45
Figure 3.3. Processes of using nearby control points to calculate the graphic position corresponding to a given geographic location.....	46
Figure 3.4. Positioning using control points on multiple maps.....	46
Figure 3.5. Two-point based positioning using a similarity transformation	47
Figure 3.6. An example of regions divided by nearest two control points in two-point based positioning, POI's in the campus map are used as control points	48
Figure 3.7. Error of the two-point based similarity transformation method in a stretched map	49
Figure 3.8. Error of the two-point based similarity transformation method in a stretched map by the distance from the line of two control points	50
Figure 3.9. Error caused by inconsistent scales.....	50
Figure 3.10. Evenly distributed control points in different density for analyses	51
Figure 3.11. Error distribution of positioning using nearest two-point based similarity transformation under different density of evenly distributed control points (as in Figure 3.10).....	51
Figure 3.12. Error distribution of positioning using nearest two-point based similarity transformation under different density of randomly distributed control points	52
Figure 3.13. Error distribution of positioning using nearest two-point based similarity transformation under different density of evenly distributed control points with randomized errors	52
Figure 3.14. Error distribution of positioning using nearest two-point based similarity transformation under different density of randomly distributed control points with randomized error	53

Figure 4.1. Data organization of Manpo Content with geo-metadata realized in Manpo Alpha	59
Figure 4.2. Main user interface of Manpo Alpha	60
Figure 4.3. Main interface of Manpo Beta for viewer's functions	62
Figure 4.4. Workflow of creating content based on analog maps with Manpo Beta	63
Figure 4.5. Workflow of adding POI with geographic coordinates to an illustrated map in a tourist guidebook	64
Figure 4.6. 東大柏ラリー viewed in Apple Inc.'s App Store	65
Figure 4.7. User interfaces and main functions of 東大柏ラリー	66
Figure 4.8. Data organization of geo-metadata in Manpo Editor and Manpo Viewer	68
Figure 4.9. Interface for editing basic information of a content set (book) in Manpo Editor	73
Figure 4.10. Interface for editing basic information of a page in Manpo Editor	73
Figure 4.11. Main interface for editing graphic components in a page in Manpo Editor	74
Figure 4.12. Interfaces for editing georeference of a graphic component in Manpo Editor	75
Figure 4.13. Interface for editing control points and lines of a mapping region in Manpo Editor	76
Figure 4.14. Main interface of Manpo Viewer	77
Figure 4.15. Viewing extra content (on the left) of a graphic component using Manpo Viewer	78
Figure 4.16. Displaying user's moving trajectories on the illustrated map (on the right) and on the web mapping (on the left, Apple's Maps) side-by-side using Manpo Viewer	78
Figure 4.17. Query nearby attractions of the book or content set using Manpo Viewer	79
Figure 5.1. The campus map of Kashiwa Campus, the University of Tokyo (left) and its area shown in Google Maps (right)	81
Figure 5.2. The placement of POI's, extra control points and control lines in the campus map	81
Figure 5.3. The placement of POI's, extra control points and control lines in geographic space shown with Google Maps	82
Figure 5.4. The experimental walking route on the campus map (left) and Google Maps (right)	85
Figure 5.5. Simulated moving trajectory on Google Maps	85
Figure 5.6. The author's experimental moving trajectory on Google Maps	86
Figure 5.7. Simulated moving trajectory displayed on Page 1 as a result of positioning using only POI's	87
Figure 5.8. Simulated moving trajectory displayed on Page 2 as a result of positioning using POI's and extra control points	88

Figure 5.9. Simulated moving trajectory displayed on Page 3 as a result of positioning using POI's and control lines	88
Figure 5.10. Simulated moving trajectory displayed on Page 4 as a result of positioning using POI's, control lines and extra control points	89
Figure 5.11. The author's moving trajectory displayed on Page 1 as a result of positioning using only POI's	90
Figure 5.12. The author's moving trajectory displayed on Page 2 as a result of positioning using POI's and extra control points	90
Figure 5.13. The author's moving trajectory displayed on Page 3 as a result of positioning using POI's and control lines	91
Figure 5.14. The author's moving trajectory displayed on Page 4 as a result of positioning using POI's, control lines and extra control points	92
Figure 5.15. Hand-drawn maps created by students in 2013	95
Figure 5.16. Hand-drawn maps created by students in 2014	96
Figure 5.17. Mistakes in the map drawn by Group 3 (2013)	98
Figure 5.18. Moving trajectory on the content of Group 3 (2013) before and after the modification.....	98
Figure 5.19. Moving trajectory on the content of Group 6 (2013) before and after the modification.....	99
Figure 5.20. Moving trajectory on the content of Group 1 (2013) before and after the modification.....	100
Figure 5.21. Moving trajectory on the content of Group 4 (2013) before and after the modification.....	101
Figure 5.22. Moving trajectory on the original content of Group 4 (2014) and the mistake in geographic coordinates of a POI	102
Figure 5.23. Moving trajectory on the content of Group 4 (2014) before and after modifying the mistake in geographic coordinates of a POI (in the red circle)	102
Figure 5.24. Moving trajectory on the original content of Group 1 (2014) and their improper placement of POI's	103
Figure 5.25. Moving trajectory on the content of Group 1 (2014) before and after modifying the placement of POI's	103
Figure 5.26. The improvement of positioning results after appending extra control points .	104

List of Tables

Table 2.1. Profile of participants answered the questionnaires	23
Table 2.2. Answers of the question “If you travel in an unfamiliar place, which of the following types of maps do you often use?”	24
Table 2.3. Answers of the preference of the two maps in Figure 2.4, under different conditions of GPS availability	25
Table 4.1. Main data fields required for metadata in the book-level.....	69
Table 4.2. Main data fields required for metadata in the page-level	69
Table 4.3. Main data fields required for metadata in the feature-level for georeferences.....	70
Table 4.4. Main data fields required for graphic components in each page.....	70
Table 5.1. The names, image coordinates and geographic coordinates of the POI’s	83
Table 5.2. The image coordinates and geographic coordinates of the extra control points	84
Table 5.3. The image coordinates and geographic coordinates of the points composing the two control lines	84
Table 5.4. The combinations of POI’s, extra control points and control lines in the pages of the experimental <i>Manpo Content</i>	84
Table 5.5. Materials used by each group in their <i>Manpo Content</i> in 2013	94
Table 5.6. Materials used by each group in their <i>Manpo Content</i> in 2014	94
Table 5.7. Distortions and mistakes in students’ hand-drawn maps in the course in 2013	97
Table 5.8. Results of the questionnaire answered by the students experienced the modified content (question: “How do you think about the accuracy of positioning on the analog maps?”).....	104
Table 5.9. Results of the questionnaire answered by the students experienced the modified content (question: “Did you follow the route? Have you ever get lost?”)	105
Table 5.10. Results of the questionnaire answered by the students experienced the modified content (question: “Do you often turn to web map when you are using the content?”)	105
Table 5.11. Results of the questionnaire answered by the students experienced the modified content (question: “Do you want to make such and better contents by yourself and share with your friends?”).....	105

Chapter 1

Introduction

1.1 Background

In recent years, online web mapping products are well developed and widely used in mobile environments. The outstanding services such as Google Maps [1] (as shown in Figure 1.1) have dramatically changed people's way of obtaining and using maps. With the help of the location-aware mobile devices like smartphones, it is easy to display the user's current location on maps and obtain location-based information and services [2]. Most of the popular location-based mobile applications also use Application Program Interfaces (APIs) of web mapping services to develop and provide map-based functions. The rapid growing user-generated geospatial content [3][4] is also presented mainly using web mapping for base maps. Such progresses in industry also have a great impact on related scientific researches. However, the quick success and popularity of outstanding web mapping products still cannot mask the following problems in the shape of map uses and the sound development of cartography in mobile environments.

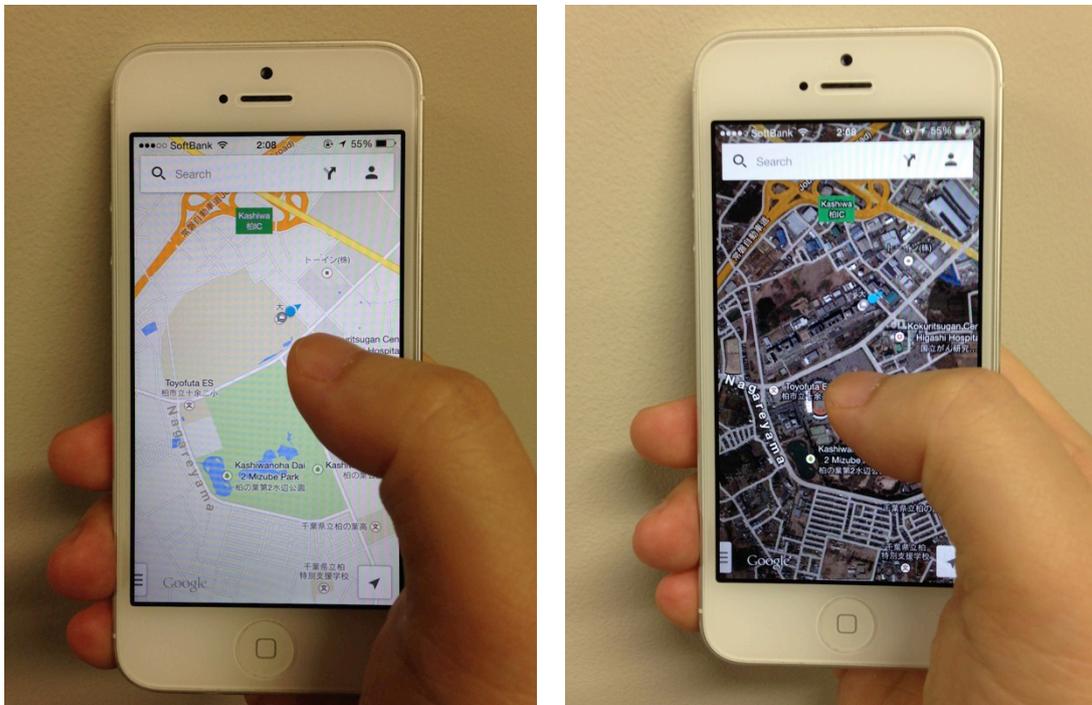


Figure 1.1. Examples of Google Maps running on Apple Inc.'s iPhone 5 (iOS 7) (Taken on June 13, 2014, of the area around Kashiwanoha, Kashiwa, Chiba, Japan. On the left is the standard map; on the right is the map with satellite and aerial imagery.)

(1) Diversity of maps and map representations is insufficient in mobile environments

The computer-generated maps used by web mapping are accurate and generic for multiple purposes, but their diversity of geoinformation representation is insufficient to satisfy a wide variety of user groups' requirements, when used for specific purposes. Although a number of companies and organizations provide web mapping services, their approaches and maps are very similar to each other. On the other hand, various well-designed conventional maps are still widely used in printed media for people's daily uses, for example, guidebooks and leaflets for tourists. Such maps often have a sense of human-centered design in map communication within a limited medium. However, they are less used in current digital mobile environments, and cannot benefit from the advantages of the latest technologies like interactivity and global positioning.

(2) Human's creativity is not fully involved in mapmaking for mobile environments

Currently, there is a huge amount of human created multimedia content in the digital world, by professionals or amateurs. Although various pieces of content are digitalized or created with the help of digital devices and computers, it is the human's creativity that has made them worthy to be viewed, recorded and purchased rather than digitalization. However, current digital maps in mobile environments are only used as backgrounds for other location-related information or user-generated content for only points of interests. Map itself is not considered as a kind of human-created content in the digital world, and many people have been already satisfied with the current computer-generated interactive maps with high accuracy and accessibility. For computers and information technologies (e.g., Geographic Information System, GIS), current digital maps that are generated from consistent and accurate geospatial databases, are easier to manage than human-made inconsistent maps. While in the analog world, there are still various well-designed maps with practicability and aesthetics created by cartographers and illustrators. Human-made maps are still more attractive than computer-made ones because they are created to suit specific purposes, users and areas. Also, they do not look the same as web mapping because modern map creators always diversify ways of communicating and entertaining effectively with map users by changing map representations depending on requirements of clients, preferences of user groups and fashions of times.

(3) The fusion of cartography and human-centered thinking is less important in research fields related to mobile mapping developments

The current web mapping is developed based on the improvement of information technologies. In essence, it seems that the craft of online mapmaking has developed without too much input the discipline of cartography itself [5]. The current researches related to

mobile mapping have focused more on the acquisition, analyses, and visualizations of new geospatial data, and applying new technologies to mobile map applications. Geospatial databases are considered as an ideal platform to realize consistent and generic information services, in which maps are regarded as only one type of computer visualization of geospatial databases. Thus, the map itself is less concerned in the research field related to mobile mapping. Sometimes, it seems that maps just need to be as realistic as possible, or visualize as much information as possible. Such data-driven approach and technology-driven approach may be efficient in scientific exploratory researches, but not effective for making practical applications for ordinary users. Current web mapping is made with less human-centered thinking, which will consider more on the demands and background of target users. The maps in mobile environments need a re-examination from the discipline of cartography.

1.2 Purpose

Current mobile mapping services are still under development and need more guidance from related disciplines, particularly cartography and information technologies. The purpose of this research is to study, design, develop and evaluate a new mapping platform for introducing human-centered maps to latest digital mobile devices so as to combine the advantages of both. To reach this purpose, the following researches are conducted.

(1) Study the cartographic fundamentals in developing human-centered mobile mapping

In order to locate the main problems need to solve in developing human-centered mobile mapping, this research reviews the cartographic characteristics of conventional human-centered maps, the new features and drawbacks of online web mapping, and the limitations of existing mobile mapping applications using maps other than web mapping services.

(2) Design a pragmatic framework of a human-centered mapping platform

A human-centered mapping framework including both authoring tools and user applications has been proposed in this research. Main issues in realizing the framework are studied to get practical solutions, which include the organization of geo-metadata and the positioning methods in distorted maps.

(3) Implement and evaluate the proposed framework through prototype development and experiments

A series of mobile applications as prototypes have been developed in this research to verify the feasibility of the proposed framework. The prototypes include implementations of both

authoring tools and user applications, and are targeted on mobile mapping content for walking tours. Experiments have been conducted to test the effectiveness of positioning methods. User tests by university students and surveys to them have been conducted to clarify the usability, functionality and limitations of the prototypes.

1.3 Academic Review

In late 1990s, with the flourishing of Internet and the growth of mobile devices, researchers have started foundational researches of using location-aware mobile devices for map-based services and supporting personal navigation. Early prototypes, such as CyberGuide [6] and GUIDE [7] projects, have utilized certain form of graphical map representation as part of their functionality in the times when display functions of mobile devices were still very limited. Together with the rapid growth of wireless Internet and mobile computing in the early 2000s, mobile maps and location-based services have been widely researched, and they were regarded as a future industry with great potential. An overview of mobile guides that rely on maps or map-like representations in providing their services is presented in [8] with discussions of technical issues and problems related to human factors. In 2005, the release of Google Maps [1] by Google Inc. has had a great impact to the related research field, and the tile-based web mapping instead of vector-based maps has rapidly become a standard of mobile maps with the flourishing of smartphones.

As mobile mapping services have become common as built-in functions of smartphones, in the field of location-based services, researchers have explored more deeply. From a technological view, [9] has concluded the design constrains on operational LBS, and [2] has drawn a conclusion of the outstanding research issues. [10] and [11] have depicted a location-aware future furthered by the privatization of mobility as data objects. The rapid growing user-generated geospatial content [12][13] and mapping using crowdsourcing [14] have become an important trend to take the advantage of web 2.0, social media [15], big data and the ubiquity of smartphones with sensors, in order to enrich the map-based content and personalize the maps. On the other hand, more and more researchers have focused on not only the technical issues, and human factors are regarded important in real applications. [16] has pointed out that Emotion is lack in the communication between human and machine, and has tried to measure user's feelings in tourist navigation. [17] has tried to identify motion and interest patterns of shoppers for personalized wayfinding. [18] and [19] have proposed to add fun into navigation and wayfinding, instead of just offering tourists the desired information. [20] has reviewed the state of science in interactive cartography.

Early as in 2004, the book *Mobile Cartography* [21] has already pointed out that principles of web mapping cannot simply be transferred to the mobile environment. As the web

mapping has become mature and mainstream at present, the book *Web Cartography* [5] has still indicated their drawbacks including the deficiency of diversity, and emphasized the relevance of cartographic principles in making functional web maps. Researchers have pointed out the limitations of current web mapping when used in pedestrian navigation and wayfinding, and [22] has developed a prototype named PhotoMap with functions of taking photos of ‘You Are Here’ signboard maps with mobile phones and using the georeferenced photos for navigation.

Maps in current web mapping are generic, accurate and consistent. However, in the daily life, specialized maps with distortions that fit the purpose and users’ customs are often used. In the area of information graphics [23], cartograms often use distorted maps for visualizing statistic data or facts. [24] and [25] have proposed methods and prototypes of generating personalized metro maps and annotations with concern of directing viewers’ attention. [26] has introduced constrained optimization in 3D urban maps for ensuring visibility of landmarks by distorting less important objects. In researches of historical maps, distortions are common, and often need to be corrected. [27] has proposed a pixel-oriented and geobrowser-friendly framework for geometric correction of measured historic maps. [28] has applied methods using Triangulated Irregular Network (TIN) for geometric corrections of historic Japanese maps. A nonlinear georeference has been applied to correct a historic small-scale Chinese map in [29]. Accurate segmentation of land regions in pre-modern large-scale cadastral maps has been researched in [30].

In 2004, Takashi Morita [31] created the term of *Ubiquitous Mapping* to refer to the use and creation of maps by users anywhere and at anytime. He has clarified the ubiquitous nature of maps, the changes from *map* to *mapping*, and the difference between GIS and ubiquitous mapping [32]. It is then extended to *ubiquitous cartography* in 2007, and five research themes are presented in [33], including (1) contextualizing the user; (2) location in 2, 3, and 4D space; (3) symbolization, multi-media presentation, and map communication; (4) real-time navigation; (5) privacy vs. science. This research is also deeply influenced by the idea of ubiquitous mapping and cartography and the proposed research agenda.

1.4 Structure of the Dissertation

The main body of this dissertation is composed of the following five chapters, and Figure 1.2 shows the overall structure:

Chapter 2: Cartographic Fundamentals of Human-Centered Mapping

Chapter 2 studies the background and problems to derive the necessity of this research by reviewing conventional mapmaking, characteristics of human-centered maps, impact of web

mapping, users' preference and existing applications.

Chapter 3: Architecture of Human-Centered Mobile Mapping

Chapter 3 proposes a framework on the basis of locating the main difficulties of applying human-centered maps on current mobile devices and studies of the use cases. The framework is clarified in details. The organization of geo-metadata and the positioning methods in distorted maps are introduced as the key factors of realizing the framework.

Chapter 4: Software Developments and Implementations

Chapter 4 introduces the prototypes developed to implement the proposed framework and to prove its capability. The processes of developments and the functions realized in each stage are introduced in details in a chronological order.

Chapter 5: Experiments and Discussions

Chapter 5 is composed by experiments of two aspects. The first aspect is the experiments of positioning methods with the comparison and discussions of the results. The second aspect is user tests by university students in both author's phase and user's phase to verify the usability and functionality of the prototypes, followed by discussions of the limitations and the findings.

Chapter 6: Conclusions and Future Work

Chapter 6 concludes the whole research as well as its contributions, and suggests the future research issues.

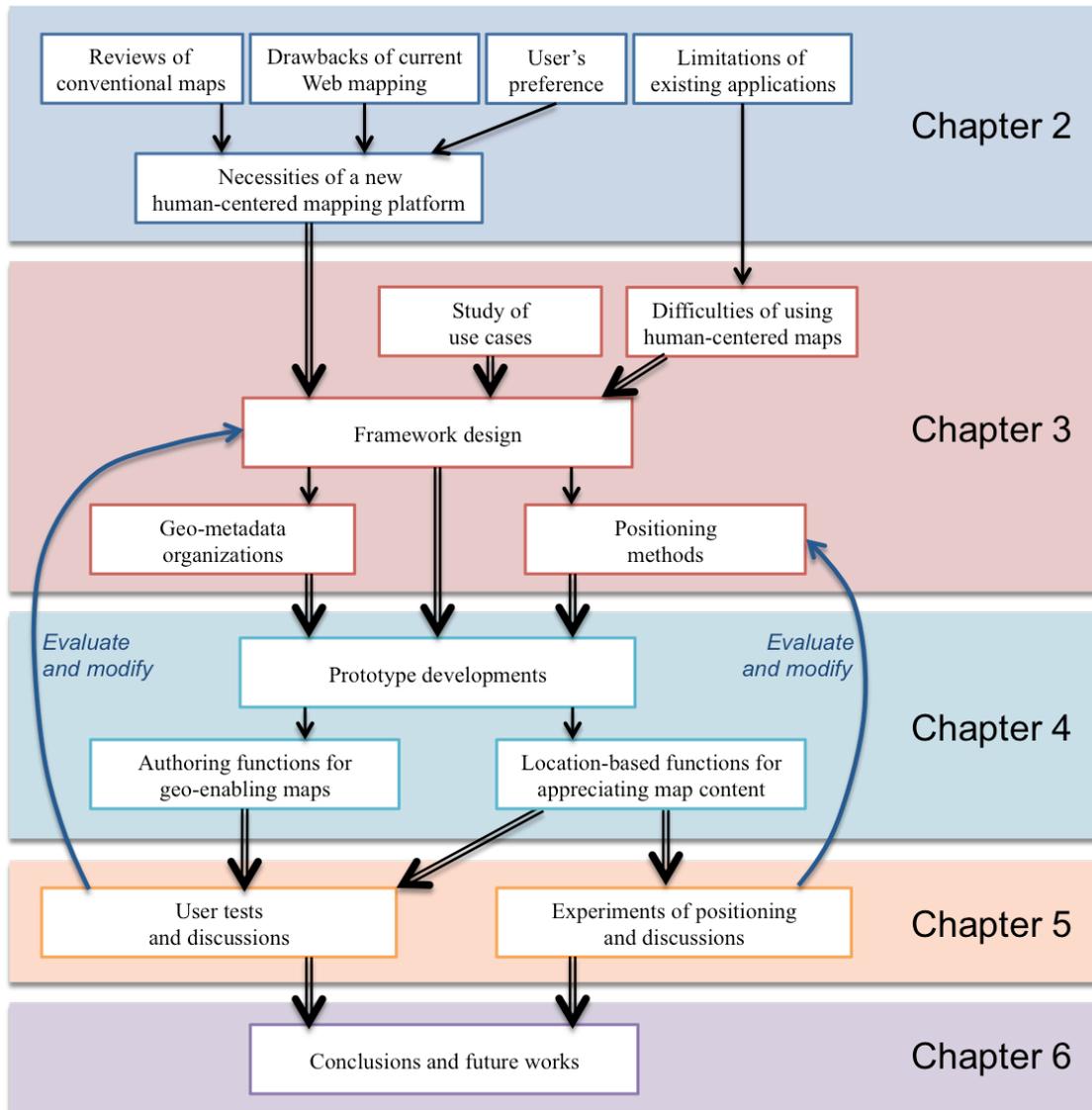


Figure 1.2. Structure of the dissertation

Chapter 2

Cartographic Fundamentals of Human-Centered Mapping

2.1 Human-Centered Design Thinking in Conventional Maps

As defined by the International Cartographic Association, a **map** is *a symbolised representation of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance*, and **cartography** is *the discipline dealing with the art, science and technology of making and using maps* [34]. Although the accurate definition of map remains an argument, its functions of geographic visualization and graphic communications for conveying spatial knowledge have been made clear in the past decades. Different viewpoints and notions of map functions have led to different traditions in conventional mapmaking. This section divides them into two main categories, lexical tradition and functional tradition.

2.1.1 Lexical Tradition of Mapmaking and *Dictionary Maps*

Under the lexical tradition, a map is considered as a symbolic visual representation of the geographic world. Modern survey technologies have enabled cartographers to focus on correctness and accuracy of map representation during the long history of cartography, with the continuously developing theories and technologies. Modern surveyed maps, like topographic maps, are supposed to represent positions, sizes and important properties of both natural and artificial geographic features, as detailed and precise as possible, according to certain projection methods and scales, using abstract and systematic map symbols. In the digital era, information technologies have brought new ways to creating storing and distributing maps as digitalized data. Surveyed map data are commonly processed and stored in computers using Geographic Information Systems (GIS) now. Computer graphics technologies are used to automatically generate map images and visualize such geospatial data under certain rendering rules. Among the digital maps, the rapid growing web mapping (online maps) services are making maps much easier to be acquired by ordinary users in recent years. Currently, such web mapping services facing ordinary users usually provide global, generic and multi-scale maps that contain common geographic features, such as rivers,

roads, terrains, political borders, and so on. Meanwhile, they provide extra media like satellite imagery, street views and photos.

From either traditional geographic maps (e.g., topographic maps) or base maps of current web mapping services, some characteristics can be found in common, which will be discussed as follows:

- **Factuality:** The maps tend to depict existing or existed features for reality objectively. The visual representations should have less subjective or emotional opinions and speculations of the cartographers. It is more important to present phenomena, but not to interpret. For example, relationships among features are implicitly represented. Thus, spatial knowledge needs to be interpreted by the reader based on comparison, calculation and certain background knowledge.
- **Neutrality:** One map should treat the presented objects fairly. Geographic features are presented as detailed as possible if applicable in certain scales; and are regarded to have the same importance in visualization if they are in the same category and similar in size. At the same time, depictions of the shapes and positions of geographic features should be as accurate as possible.
- **Consistency:** One map should maintain its consistency of the representation in two aspects. One is geometric consistency, which means fixed geometric parameters (e.g., map projection, scale, direction, and so on) are maintained in a map. The other is semantic consistency, which means the same principles and rules of map generalizations are maintained in a map. For example, the same map symbols are used for the geographic features in the same category, level or size.

Such maps are better at offering the functions of queries and exploring, rather than actively inform certain knowledge. Using a metaphor, they are not good at telling stories; they are more like dictionaries, rather than news and novels. In this dissertation, they are named as *dictionary maps*. For reading and understanding dictionary maps, humans need certain knowledge and skills to distinguish useful geographic features and spatial relationships, and then acquire spatial knowledge from them.

2.1.2 Functional Tradition of Mapmaking and *Story Maps*

Under the functional tradition, map is considered as a *graphic communication vehicle* [35] for conveying certain spatial knowledge. A map is usually designed for specific functions under

certain communicative purposes, while within the limits of its medium. In some sense, afore discussed *dictionary maps* are also functional, but designed for more generic purposes. In mapmaking, cartographers' knowledge and notions of the real world are integrated into maps intentionally or unconsciously. The subjective aspect in maps cannot be avoided even for the modern dictionary maps, because the process of map generalization is done or intervened by humans. It can be asserted that there is no truly *objective* map.

When used in people's daily life, conventional maps have a great diversity. From the viewpoint of media, maps are usually printed or painted, in different sizes, on signboards, pages of books, leaflets, posters, cards and so on. From the viewpoint of functions, they can be tourist guides (e.g., travel route with sightseeing spots), locations of objects in a certain category (e.g., shops in a market street), accesses with references (e.g., map of a company's location on a name card), facts or opinions (e.g., visualizations of statistics) and so on.

Among diverse maps, the useful ones are considered as those can make the target readers get the cartographers' information and achieve the communicative goals with easiness. As a result, the geometric accuracy of maps is not crucial in some cases. Instead, the map design in considering of the efficiency of map communication, which may include selection of objects to be depicted, choices of symbols and colors, organization of visual hierarchy, proper abstractions and exaggerations, and so on, is more important. Therefore, the well-designed communicative maps are supposed to have the following characteristics:

- **Functionality:** Purposes, target users and the information to convey of the map should be clear, and become the principle of map design. For example, it is important to choose geographic features to be depicted or omitted, emphasized or simplified. It is never as much information as possible, or as detailed as possible. Too much redundant information that is not related to the aimed purpose of the map may disturb readers' understanding. Similarly, map size, projection, scale, orientation and so on are chosen according to the map functions. Map elements, symbols, labels, colors, and so on, should be designed in considering of readability and the existing knowledge and map reading skills of the target users.
- **Storytelling:** In maps, storytelling may exist as depictions of events happening in sequence, or moving routes of persons and objects. A map designed for storytelling should be composed of only necessary and obvious geographic features such as points of interests, routes and landmarks, but it should not include unnecessary, complicated or redundant geographic features which may make readers confused. In a broader concept, storytelling also exists at the following aspects. Firstly, the exaggerations and simplifications of the depictions can easily attract readers' attention. Secondly, the

highlighted spots (e.g., landmarks) can be anchor points that are connected to readers' existing knowledge, which makes it easier to extend cognitions to unfamiliar regions [36]. Thirdly, on some maps, routes connecting the checkpoints for readers to follow and synchronize can help find the destinations when used on site [37]. Finally, maps may have characters, while some are explicitly depicted on the maps; some are implicitly referring to the readers. The importance of storytelling in maps is that it is suitable for the human nature of learning, and brings easiness for readers to interpret and memorize the information.

- **Aesthetics:** An artistic map can have impacts on users to attract them, and lead them to explore information more deeply with comfort. Artistic design according to map functions also brings benefits to communicative goals. For example, a well-designed tourist map will provide the users with good image of the future travel before travelling. Also, the artistic designed maps are good for memorizing. For instance, a line feature such as a railway should be represented as a straight or smoothly curved line, and distances between point features such as stations on a line feature should be equal. Humans tend to prefer simpler representations and patterns to acquire information easily by nature. Also, various human-made representation such as water painting and antique styles are often preferred like fashions of wearing. However, the aesthetics may bring deformations of the depictions of map objects, which often cause inaccuracy geometrically. The deformation of map representation may be inconsistent and inefficient from some specific viewpoints such as surveying, facility management and hill climbing.
- **Inconsistency:** The inconsistency in maps may also exist in two aspects. Geometric inconsistency is reflected in the inconsistent map projection, scales, directions, and so on. Semantic inconsistency is reflected in the different depictions of the objects of the same type and size (which are usually depicted equally in dictionary maps). The inconsistency is a result of multiple factors, which include the selective depictions of objects, the exaggerations and simplifications of different regions and so on. When a cartographer is trying to achieve functionality, aesthetics and storytelling in a map, consistency often has to be compromised, as geometric accuracy is not the most important purpose of making the map. However, necessary accuracy is still needed, especially the correctness of relative spatial relations is very important.

In contrast with afore discussed dictionary maps, this dissertation names such maps with clear communicative goals, specific functions and especially storytelling, as *story maps*. The

dissertation also proposes that the well-designed story maps have more human-centered characteristics and are preferred. This is because they are easy to understand and to convey the useful information to the target users, who are usually ordinary people without professional knowledge of maps and geography.

2.1.3 Human-Centered Conventional Maps – Take Yoshida’s Works as an example

The tradition of integrating cartographers’ *stories* (knowledge, notions, faith and so on) to maps have existed since ancient times, when the maps had more functions other than visual representations of the *real* world, but showed world views, religious faiths, authority of royalties and so on, with the background of certain cultures. In such maps, the inconsistency with intentions can often be found. Some may argue that the inconsistency was just caused by the undeveloped survey technologies. In fact, in the modern age, still numerous examples of story maps can be found with the occurrence of well-surveyed maps simultaneously.

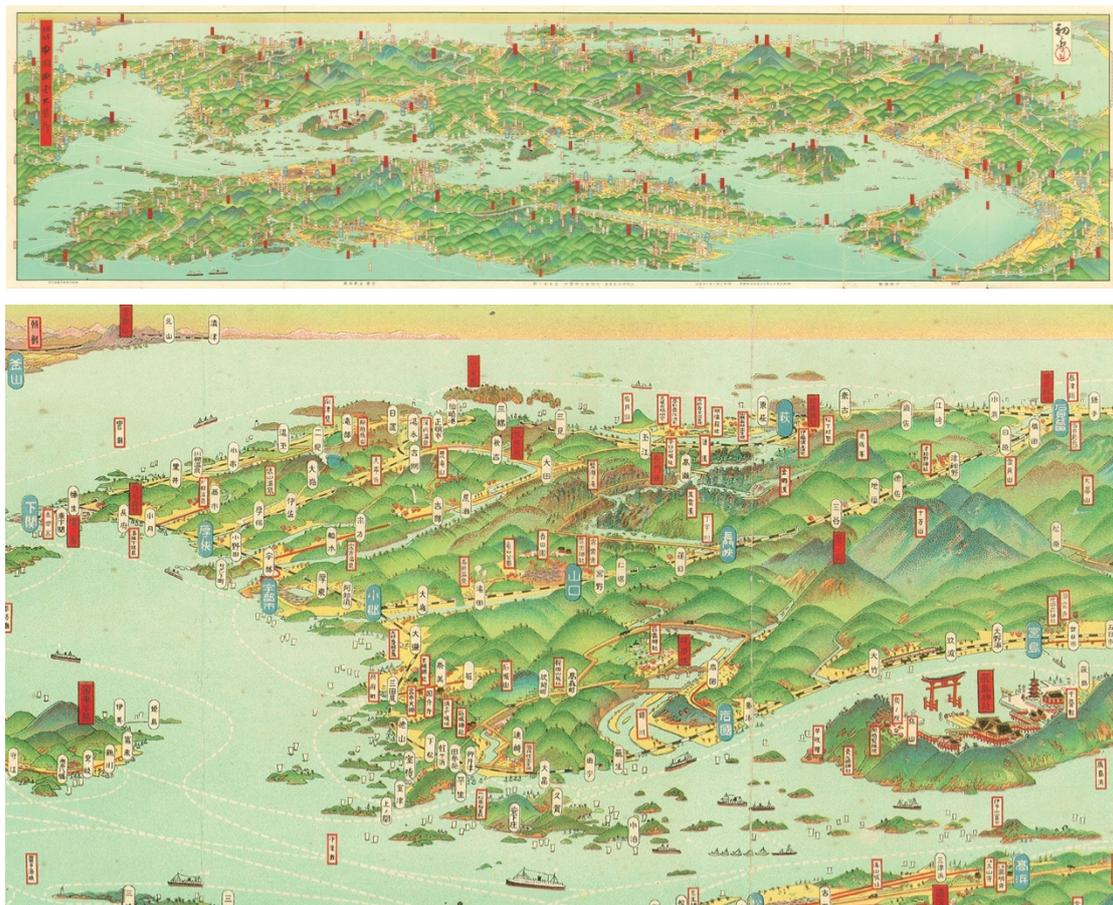


Figure 2.1. A bird's-eye view map drawn by Hatsusaburo Yoshida
(Upper: 日本鳥瞰中國四國大圖繪 published in 1927; Lower: detailed partial of the map.)

Hatsusaburo Yoshida (吉田初三郎, 1884-1955) was a Japanese cartographer famous for his works of bird's-eye view maps (Figure 2.1 shows an example). His works focused on sightseeing places, and were mainly designed for tourists. In his era, modern western geomatics and cartography have been already introduced to Japan, but his maps had very distinct personal characteristics, including the combination of Japanese painting style and western painting techniques. Unlike the current bird's-eye view maps, which mainly use one-focus perspective projections, Yoshida's maps use a multi-focus perspective, and have distinctive styles in the skillful uses of deformations.

In the overall aspect, the deformations are notable from the moving viewing points and angles, and the changing map scales. The main part of his map (usually the city or the sightseeing attractions depicted in its central part) was depicted closer to a perspective projection, while the surrounding parts were usually bent and shrunk to different viewing angles and scales from the main part. In the edge parts and on the horizon line, important cities and mountains were indicated, even if they were actually out of sight. Mount Fuji, as a special landmark with great importance in Japanese culture, was usually depicted in an exaggerated height and size, whether it was in a main position or not.

In the detailed aspect, the deformations can be found in the exaggerations and abstractions of the depictions of objects. The traffic lines like railways were generalized to straight lines or smooth curves. The rivers and roads were broadened and smoothen. The main mountains were steeper and higher. Focused spots (usually sightseeing spots of nature and artifacts) were largely exaggerated, or it can be considered that they were depicted from viewpoints much closer to the ground compared to other parts of the map. The drawings of transportation vehicles (including trains, ships, cars, and so on) were much larger than the actual sizes, otherwise they would never be seen from the map in the overall scale.

The inconsistency and deformations in Yoshida's maps are not just techniques for better appearances of the paintings. They are actually very functional under the communicative purposes, which include making practical maps and providing information of famous sightseeing spots and transportation for tourists.

Firstly, the maps highlight the objects related to the main subjects, while omitting unnecessary objects, in order to achieve better legibility for readers to pick up the main information at a glance. For example, the sightseeing spots and transportation lines were in higher visual hierarchies than other objects.

Secondly, the maps balances the detailedness of the main subjects (that directly related to sightseeing) and the wholeness of their circumambient environments. For example, the deformed depictions of distant stations, cities and even other countries connected with transportation lines actually provide the users with more knowledge of possible accesses of

the sightseeing places rather than only depict the targeted places. Another example is the representation of exaggerated sightseeing spots (e.g., a castle or a shrine). If they were depicted as their original size in the overall map scale, their details could never be appreciated from the map. It is notable that it can be interpreted as a compromise but also an optimization in a limited medium, which was static, and cannot be zoomed in and out like the current electronic maps.

Thirdly, the maps were rhetorical with aesthetics, which was also designed for communicative purposes: such as showing attractive good scenes to the potential tourists. The bird's-eye view itself was an impact when aerial photos were not common at that time. Besides, the maps provide a feeling of dynamics in a static medium through the depictions (e.g., running trains and ships). The most important thing is that Yoshida managed to merge the functional deformations seamlessly with aesthetics in a map. The maps were made visually consistent, while the geometric inconsistency was hidden behind.

In essence, Yoshida's maps can be considered as composed by several maps or views with different scales and viewpoints. Inside the views it is relatively consistent in large scales, but between the views there are inconsistency in small scales. So in the whole map there can be jumping of scales and viewpoints. Similar jumping of viewpoints can also be found in conventional Chinese and Japanese painting scrolls. When read by users, consistency all over the map is in some sense not so important in Yoshida's works, because users' eye movements and attention are also not continuous [35]. They can have the overall view of the whole map, and then focus only local area in the large-scale sub views. The gaps of scales and viewpoints are usually ignored naturally when used by human. Even if used with GPS, it is sometimes not necessary to give accurate positioning consistently all over the maps.

2.1.4 Spiral Up Evolvments of Maps

During the evolvments of maps in the history (as shown in Figure 2.2), the two traditions of mapmaking are interlaced, and their importance has been changing with the times. The forms and functions of maps and their media have shifted many times. The pristine and ancient maps were originally made for mainly communicative purposes, and were more human-centered, but they had shortages in accuracy, mobility, storage and mass production. Since the 15th century, the inventions and developments of new technologies including modern surveying and mass printing have given the mapmakers more capability to record and represent the geographic world more accurately and precisely in paper media, with the ease of rapid productions. Maps in this era have become more "earth-centered", and they have also loaded the functions of recording the geospatial data. In recent decades, with the rapid development of information and communication technologies, new tools like the Geographic

Information Systems (GIS) have separated the data recording functions and visual representation functions of maps. At the same time interactive multimedia have been brought into maps. Current under-developing digital maps look more “computer-centered” at present, because the impact brought by new theories and technologies has not been completely merged into the discipline of cartography. However, they have clearly shown a potential to let the maps focus more on its essential function, which is communication.

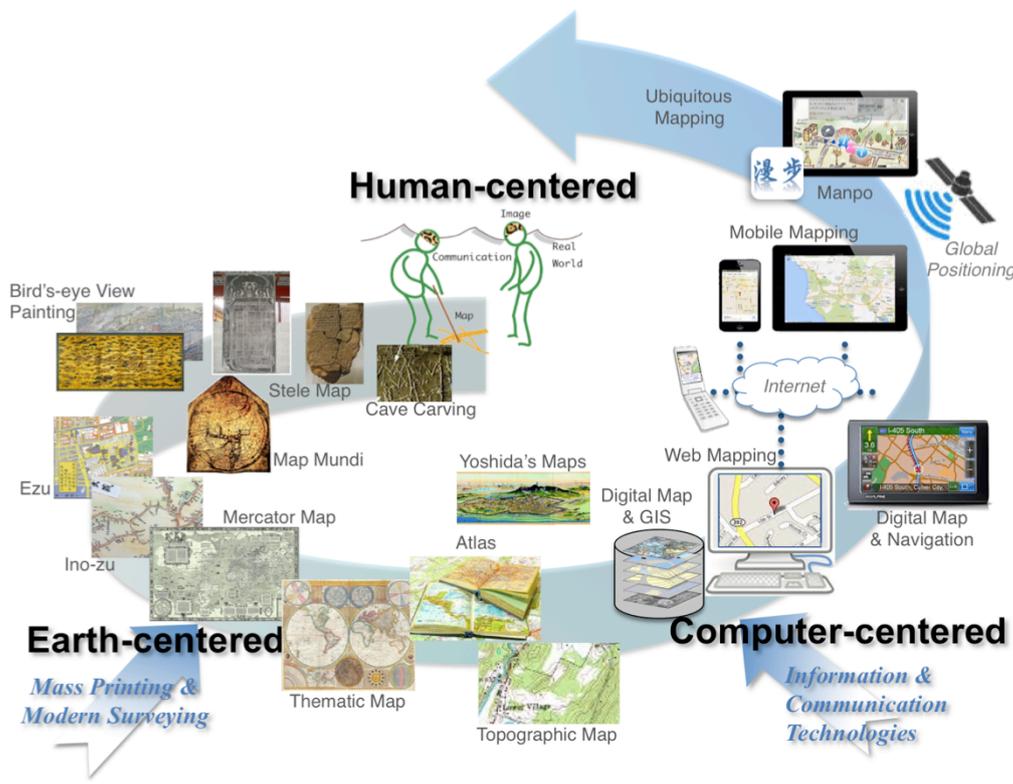


Figure 2.2. Evolutions of the appearances, media and functions of the maps with the impacts of new theories and technologies

On the other hand, although the contemporary maps in conventional media seem to care more about accuracy and factuality, the concern of human-centered map design with storytelling and aesthetics is still retained by many of present illustrated maps. Especially in Japan, the well-designed illustrated maps are still flourishing in conventional media. For example, more and more walking route maps for specified target users (e.g., young ladies, elderlies, and so on) can be found in guidebooks, magazines and leaflets in recent years. It can be believed that the retained traditions and new tendencies of making human-centered maps in conventional media are welcomed, because they have brought great diversity to map representation, and will continue to create more and more useful and interesting maps.

2.2 Impact of Web Mapping

In the digital era, information technologies have brought new methodologies of creating and storing maps as digitalized data. Surveyed map data are processed and stored in computers using Geographic Information Systems (GIS) and spatial databases. At the same time, a large amount of geospatial related attribute data of many kinds are stored in files and databases that can connect to the map data. Computer graphics technologies are used to automatically generate map images and visualize such geospatial data under certain rendering rules. The functionality of maps has been greatly advanced. For example, it becomes much more efficient in generating and modifying varied visualization of part of spatial related properties to be overlaid on existing digital geographic maps.

Among the digital maps, in recent years, the rapid growing web mapping (online maps) services are making maps much easier to be acquired by ordinary users. Currently, such web mapping services facing ordinary users usually provide global, generic and multi-scale maps that contain common geographic features. Meanwhile, the web mapping services provide other geospatial content than maps such as satellite imagery, street views and photos as well as geospatial text searching engines. Furthermore, they become gateways to other web resources related to certain locations, for example, hyperlinks on maps. The ubiquity of such web mapping services on web browsers and smartphones has already made maps daily supplies, as they are free currently. They have also enabled the development of location-based services.

The success of current web mapping services can be credited to many aspects. One of the essential reasons is that they have dramatically extended the capabilities of map communication. However, current web mapping still has a number of drawbacks, especially when considered from human-centered viewpoints.

2.2.1 Extension of Map Communication by Web Mapping

In web mapping, the media of maps have shifted from static, fixed-size printed media to dynamic, interactive multiple media. Maps have benefited from the shift of media, and notable changes can be found from the following aspects.

- **Multimedia and Hypermedia:** The visual representations used by maps are not only static graphics and texts nowadays. Maps are displayed on screens of the digital devices, which are multimedia and can connect to the Internet. The hypermedia technologies have made external links to various online resources enabled for map users. Hypermedia is the extension of hypertext through multimedia, including maps, images, sounds,

animations, and videos [38]. With hypermaps [39][40], users are able to access the latest information related to the maps for low cost and in easy ways.

- **Dynamics:** The limits of map sizes and scales have been broken through when maps have been shifted from printed media to online hypermedia. Although the size of display window area of one device may be limited, but the contents are not limited, and users can choose the window's position and size to display the needed part in a selected scale. The content of a map is dynamic, for example, presented objects can be shown or hidden, map symbols and colors are changeable, and even the maps can be animated. The dynamics are also reflected in that, the maps can be updated and kept to the latest information.
- **Interactivity:** Dynamic web mappings are usually interactive. Basically, users are able to have certain control of the maps through the interactions. For example, they can pan, zoom and rotate the maps, set visibility to map layers, and choose some objects to get more information. Moreover, some interactions are bidirectional. Users can upload their own content (e.g., photos) and make mash-up maps with the base maps provided by online services. Users can also contribute to map data for mapping services with User-Generated Content or through crowdsourcing (e.g., OpenStreetMap [41]).
- **Accessibility:** The diffusion of the Internet in daily life has brought new ways of getting maps. Portable handsets like smartphones and tablets with mobile Internet have made the web mapping services more ubiquitous. On the other hand, the Application Program Interfaces (API) of the services make it easier for users to use maps in their own web pages, applications and services. Such secondary developments also have extended map accessibility.

The new features of maps in web mapping have also extended maps' capabilities of communications, as the map communications also become dynamic and interactive. Firstly, spatial information and knowledge are presented and conveyed in dynamic and interactive ways. For example, real-time traffic information can be overlaid to maps and be updated dynamically; users can easily zoom in and out to see details and integrals of an area; and so on. Secondly, positioning technologies (e.g., GPS embedded in mobile phones) can show user's current location and past moving trajectories on maps, which can help map interpretation when used on site. Thirdly, users can to some extent actively fetch the information; instead of only receiving the information passively from printed maps.

The extension of map communications is also reflected in that the communication is not

only the unidirectional process from mapmakers to map readers any more. The communication can be between the users, when they use web mapping services to share their locations and content. Also it can be a bidirectional process between mapmakers and users, as users can feedback and even participate in mapmaking.

2.2.2 Drawbacks of Current Web Mapping

The current widely used and popular web mapping services are very successful products, and really changed the way people use maps. However, they still have a number of drawbacks, one of which is the diversity of map representations. The outstanding products (e.g., Google Maps) have dominated the maps accessible from users' devices, and have caused limitations as side effects, which may be named as "Googlization" [5] and have been concluded by some researchers.

Firstly, it becomes people's preconception that all online maps are expected to be similar as Google Maps. This is due to their first-mover advantage and current ubiquity. Although many innovative map interface and interactive features are introduced by Google Maps, the interface and map design Google uses is not infallible. Moreover, other developers of map applications may lose motivation and creativity of map interface design as well as their market.

Secondly, although Google Maps-style mash-up maps are easy to make by ordinary users and ubiquitous, the base maps provided by Google or other companies cannot meet all needs of various circumstances. On one hand, the final products will inherit improper map representations of the base maps. For example, the Web Mercator projection used by major web mapping services will cause problems if such base maps are used in small scales for thematic mapping [5]. On the other hand, the users cannot control the generalizations of base maps provided by major web mapping services. Although users can change the type of background map (e.g., aerial photography, terrain, and so on) and even the rendering styles, however, users cannot freely choose the objects or categories of features to be depicted or omitted according to their purposes of mapping. For example, it may happen that features relevant to a certain map theme are not depicted in a web mapping at all.

Thirdly, current web mapping services are designed for ephemeral uses, and always update the maps to the latest data. It is almost impossible for users to retrieve the old base maps if the expected mapping is strongly time-related. For example, the current political borders for a mapping showing facts one hundred years ago are not proper.

The shortcomings of current web mapping discussed above are more technical. Some of the problems may be solved in the future with the endeavor of the companies, and the users are given more freedom when they create their own mappings based on the services. However,

from the viewpoint of human-centered map design thinking, the base maps of current web mapping are still a kind of *dictionary maps* in essence, because of the followings,

- Functionality of the base maps is designed for generic uses and multiple purposes;
- Storytelling is almost not considered in base map representation, and less supported;
- Inconsistency are not allowed in such maps, accuracy is crucial;
- Aesthetics of map representation is less considered.

As a result, if used in the cases for which *story maps* are more suitable, current web mappings will be less effective and can hardly realize the expected communicative purposes. For example, when used as a walking route map for tourists in a sightseeing district to introduce the attractions while walking, Google Maps on a mobile phone will be less useful and attractive than a map in a tourist guidebook. In such cases, well-designed conventional printed maps are still more powerful and preferred compared to current web mappings, although the printed maps have limitations in medium. In this sense, usual approaches of simply using current web mappings for mobile mapping applications without considering specific communicative purposes can hardly lead to human-centered mappings.

2.3 Necessity of Human-Centered Mobile Mapping

2.3.1 Hierarchy of Maps in Mobile Mapping

There is a hierarchy of maps from computer-centered map data to human-centered story maps. As shown in Figure 2.3, digital map data are oriented to data storage and processing, in this hierarchy. The digital maps rendered from the map data are a kind of base maps. While used in location-aware digital mobile devices, such maps are oriented to positioning. The digital base maps are also used for creating digital thematic maps by overlaying spatial-related data on them. Such digital thematic maps are oriented to visualization.

Current web mappings mainly focus on the level of base maps. The mesh-up maps based on the digital base maps using the built-in functions or the APIs of the services can be considered as a kind of thematic maps. Because of the limitations of map projections and symbols used by the web mappings, their realization of digital thematic mapping is still preliminary. The higher levels in this hierarchy are more communication-oriented, but they are still deficient in mobile mappings currently. The target of this research is on higher levels in this hierarchy, and develops on the basis of the currently realized levels by the web mappings.

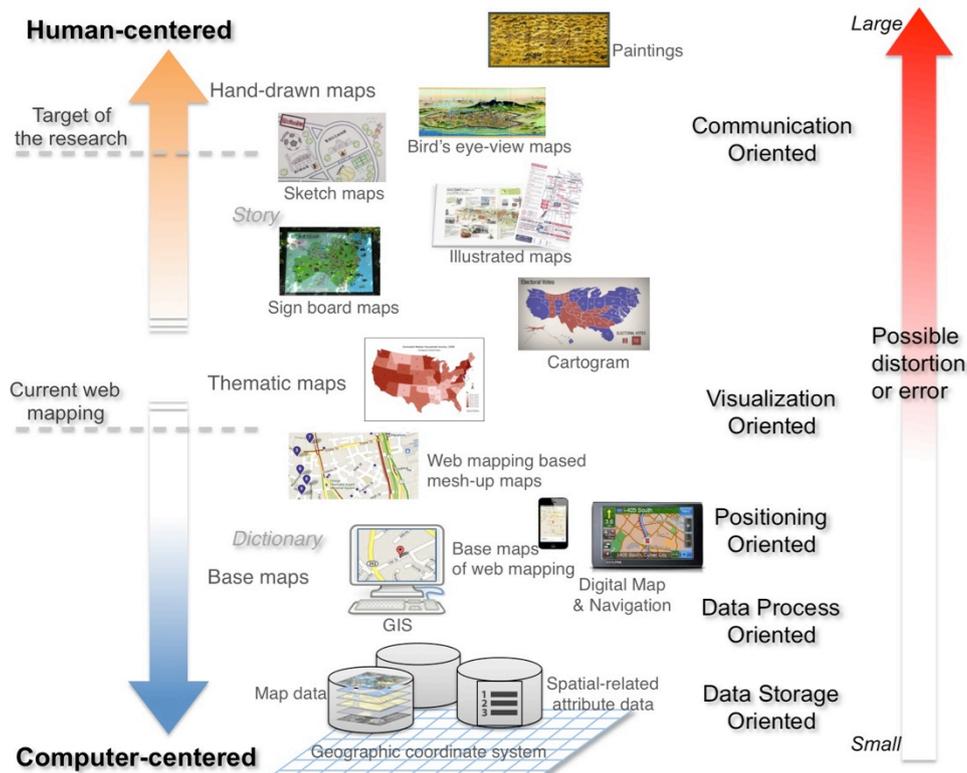


Figure 2.3. Hierarchy from Computer-Centered Maps to Human-Centered Maps

2.3.2 Misdirection of Non-Human-Centered Approaches

Nowadays, the methods for gathering geospatial data for mapping are greatly enriched from the development of technologies of sensors and data processing. As a result, mapmakers are not short of data in many aspects. Sometimes the problem may go to the opposite that there is too much data, and people need to make more and more efforts to deal with all that data in an efficient sense, mining the relevant information, linking and selecting the appropriate information for a particular scenario [42]. In some sense, this phenomenon is being described as *big data* [43]. Application developments often start from the access to certain data. Such applications are made to link the data, analyze it, and produce certain visualizations out of it. This process can be named as a *data-driven approach*.

Likewise, new technologies with potentials for particularly better map data acquisition, modeling, dissemination, visualization and interaction become available more and more quickly and need to be evaluated, addressed, and applied. Application developments often start from the availability of a new technology. Such applications are made to apply the new technologies and tend to take their advantages. This process can be named as a *technology-driven approach* [42].

Data-driven and technology-driven approaches may be good for creating experimental systems for exploratory purposes such as scientific research. However, when used for creating

map products for ordinary users, using such approaches can easily ignore the essential requirements of a human user and the original purposes of mapmaking, therefore it will lead to inefficient or even unusable results. The common mistakes under these approaches when making a mobile mapping can be listed as follows.

- **To make a mapping visualizing as much information as possible.** If the mapping is made for simple purposes, visualizing irrelevant or redundant information will weaken or even bury the main subjects that need to be visualized. This will bring difficulties to users because they need to spend more time and energy in distinguishing and extracting the main subjects from others.
- **To make a mapping as realistic as possible.** Currently, aerial photos, street views and 3D views are available in many commercial web mapping services. For some application developers, the goal turns to create a map as realistic as possible, so that users can make fully informed decisions. It is believed by them that users are able to quickly recognize landmarks from, for example, satellite imagery, and have a better grasp of locations and spatial relationships. However, it is actually very difficult for untrained users to achieve such goals. It has been shown in the researches that, having too much information at users' disposal leads to poorer decision making than if only a limited amount of data is provided [44][45].
- **To make a mapping using the latest and fashionable way of interactions.** Users who are used to current web mappings will expect to be able to interact with maps. Some application developers may also tend to integrate latest and fashionable interactive features, sometime simply because they are *cool*. However, such interactivity is only effective when it is designed to fit the purposes of the mapmaking. Too much interactivity may disturb and distract users' attention from the relevant information that the mapmaker is trying to convey, which will the mapping less effective for its purposes.

In essence, *maps are created for human*. Although the maps in mobile mapping have changed a lot with the new features including dynamics and interactivity, as a result of the abundance of new data and technologies, the goals of communication through maps remain the same. Most maps are still designed to communicate and acquire information and knowledge to their target audience. If the particular demands of target users are not included and considered with users' backgrounds, the efficiency of map communication can hardly be achieved. It is the essential weakness that the non-human-centered approaches have. Mapmakers of practical mobile mapping should apply data and technologies with the sense of

human-centered approaches, rather than let the data and technologies determine the outputs.

2.3.3 Importance of Involving Human Creativity in Mobile Mapping

Although current online web mapping services are very successful and popular in mobile devices, however, human's intelligence and creativity are not fully involved in the maps provided by them. The craft of online mapmaking has developed without too much input from the discipline of cartography itself [5]. This is not denying the endeavor made by the numerous researchers, specialists and engineers in creating and maintaining the mapping services. In fact, human's creativity is reflected in some processes of the mapmaking, including making schemes for data collecting, setting principles for data generalization, designing standards of map symbols and rendering rules, and so on. However, the maps produced in this approach are finally generated by computers under such standards, principles and rules, and become lack of diversity in map representation. This approach is good for massive production of maps, but *cannot completely take the place of human-made maps*.

If looking back to conventional mapmaking, historical connections can be found between art and cartography [46]. Cartography truly was a mix of art and science; some opine that it was more a craft than academic endeavor [47]. When creating paper maps, cartographers must take more care about representation so that relevant pieces of data will not be lost in the sea of information [5]. The concern of artistry and aesthetics has not been lost in contemporary cartographic research and mapmaking [48-51]. While at the same time, such care seems to be absent in current web mapping. Aesthetics, as is discussed in Section 2.1, is also important for maps and can contribute to better legibility. However, for the computer-generated maps, artistry can hardly be achieved. To use a metaphor, it is difficult to satisfy readers by computer-generated novels.

Currently, in conventional printed media, cartographers and illustrators are still creating well-designed maps with human-centered characteristics, which can be found in numerous books, magazines, web sites, leaflets, posters, signboards, and so on. Their creativity and intelligence should be able to be involved in creating human-centered mobile mappings. To use the same metaphor, the text of a novel may be inputted, arranged and displayed by computer, but the content (e.g., stories) is still created by the human writer. Therefore, *frameworks and tools for using human-created maps in mobile environments and for producing human-created mobile mappings should be researched*. This is also the main target of this dissertation.

2.3.4 Users' Preference

The popularity of currently dominant mobile mapping services (e.g., Google Maps) is certainly due to their advantages brought to users. However, one fact should not be ignored is that, users are actually lack of choices when they want to use maps on their mobile devices. Although there are many web mapping services available in mobile platforms, however, most of them are more or less similar to Google Maps. Developers of mobile applications using maps tend to choose the web mapping services as their base maps currently because they are easy to realize. Besides, it is easy to be integrated to developers' applications with the web mapping services, as the APIs are well developed and easy to use. Furthermore, it is more important that most of the current web mapping services are free to use.

In this research, a survey of map uses on smartphones and preference of maps for travelling has been conducted using questionnaires. The participants are undergraduate students and graduate students in Universities in Japan, and aged from 20 to 29 years old (who are usually considered to prefer new and fashionable things). Table 2.1 shows that all of the participants are using map applications on smartphones (while 93% of them are using Google Maps), and most of them are not majored in subjects related to geography or cartography.

Table 2.1. Profile of participants answered the questionnaires

Gender	Age	Specialties	Preferred web mapping service on smartphone	Frequency of using maps on smartphone
Male (15) 37%	20	Social Science (33) 80%	Google Maps (38) 93%	Almost every day (3) 7%
		Science Departments (5) 12%		Several times a week (22) 54%
Female (26) 63%	29	Spatial Information Sciences (2) 5%	Apple's Maps (3) 7%	Several times a month (11) 27%
		Others (1) 2%		Seldom (5) 12%
				Never (0) 0%

In the 40 effective responses of the question "If you travel in an unfamiliar place, which of the following types of maps do you often use?" (as shown in Table 2.2), 55% of all the participants always use maps in smartphones, which is a majority number. Meanwhile, still 63% participants often (who has chosen "Always" or "Often", the same below) use maps in guidebooks and 63% often use maps in leaflets from local information desks. This result shows that current web mappings on smartphones are often used in travelling. From some of the participants, it has been confirmed that this is mainly because the GPS positioning function is very helpful in finding current location and navigating to the destinations. Meanwhile, it shows that current mobile web mapping has not completely taken the place of conventional printed maps. It has been confirmed from some of the participants that, they use printed maps in guidebooks and leaflets mainly because such maps are designed specifically

for tourists and focus on providing detailed information of recommended local attractions. Also, it is obvious that many of the participants use both kinds of maps for travelling.

Table 2.2. Answers of the question “If you travel in an unfamiliar place, which of the following types of maps do you often use?”

	Always	Often	Sometimes	Seldom	Never
Maps in guidebooks	10 (25%)	15 (38%)	6 (15%)	9 (23%)	0 (0%)
Maps in leaflets from local information desks	9 (23%)	16 (40%)	11 (28%)	5 (10%)	0 (0%)
Maps in my smartphone	22 (55%)	11 (28%)	4 (10%)	2 (5%)	1 (3%)

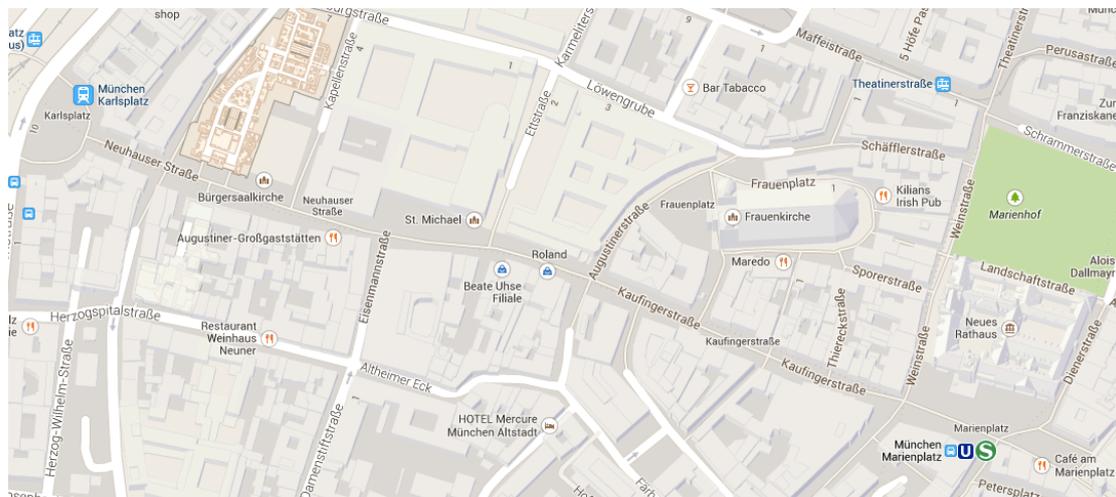


Figure 2.4. Maps of the historic central area in Munich, Germany used in the questionnaire for surveying map preference
 Upper: “Map 1” in the questionnaire, from Google Maps; Lower: “Map 2” in the questionnaire, a hand-drawn map in a tourist guidebook (provided by Shobunsha Publications Inc.).

The questionnaire asks the participants to compare the two maps shown in Figure 2.4. The

two maps are both detailed maps of the historic central area in Munich, Germany. Map 1 is taken from Google Maps, while Map 2 is taken from a tourist guidebook published in Japan. For the purpose of travelling, 31 of the 41 participants (76%) have preferred to choose Map 2. For the participants who have chosen Map 2, some of them are asked to give reasons why they make such choices freely. Nine participants have included “interesting” (or similar positive emotional expressions like “charming”, “exciting” and so on) in their answers, eleven participants have included “easy to understand”, and seventeen participants have included “detailed information for sightseeing”. For the participants who have chosen Map 1, most of them give reasons that the map is “more accurate” and “more detailed”. However, there are also 2 participants have chosen Map 2 because they think it is briefer and has landmarks, so that it may be easier to find the right way. This result shows that, when used for a specific purpose like travelling, specifically designed maps with briefness and aesthetics are preferred than detailed and generic maps.

Table 2.3. Answers of the preference of the two maps in Figure 2.4, under different conditions of GPS availability

	Map 1 is preferred	Map 2 is preferred
Both maps cannot use GPS	10 (24%)	31 (76%)
Only Map 1 can use GPS	29 (71%)	12 (29%)
Only Map 2 can use GPS	7 (17%)	34 (83%)
Both maps can use GPS	12 (30%)	28 (70%)

Then, a variable has been added to the same comparison, which is the availability of GPS positioning in these two maps. Table 2.3 shows that, if GPS positioning is available or unavailable for both maps, the preference of Map 2 almost remains the same as the previous question. While under the conditions that only one of the two maps can use GPS, the participants tend to choose the one that GPS is available. It shows that it is welcomed if GPS positioning becomes available in conventional maps, and it will make them more preferred than current web mappings.

As a result, it can be asserted that it is necessary to introduce more and more human-centered maps to mobile devices in order to benefit from the preferred representation of the maps and the location awareness of current mobile devices, and therefore, to meet users’ demands of mobile mappings.

2.4 Existing Mobile Applications Using Maps other than Web Mapping

Mapping

Currently, commercial web mapping services are most frequently used in mobile applications when they need to present information using maps. However, there are still a number of applications using various maps as alternatives or supplements to commercial web mapping. Some of such applications are designed for tourists and provide large-scale maps of sightseeing places, while some others are designed for users who are fond of maps as hobbies. Although they are still minor in the whole market, but they can be regarded as pioneers in the forward progress, and have brought diversity to mobile applications using maps. In this session, some examples of such applications will be enumerated, and their limitations will be analyzed.

2.4.1 Mobile Applications as Extensions of Paper Guidebooks

Major guidebook publishers in Japan have developed mobile applications as complement of their paper books and magazines. Their applications can be considered as extensions of digital versions of the analogue guidebooks, and usually have the functions to use cooperatively with corresponding books. Some applications simply use only web mapping to realize all map functions. However, as the publishers already have rich resources of their own published maps, such maps are also used in their applications naturally.



Figure 2.5. Examples of guidebook mobile applications

Left: “Co-trip” by Shobunsha Publications Inc.; Right: “Mapple Link” by Mapple-On Co., Ltd.

“Co-trip” is a mobile application on iOS and Android platforms made by Shobunsha

Publications Inc., by which users can buy the digital versions of the guidebook series “Co-Trip” [52]. On the digital pages, there are rectangle areas, which contain location information and links. The links include connections between the areas of POI’s information and related areas on the illustrated maps, locations on Apple’s Maps, and hyperlinks to web pages (Figure 2.5: left). According to the user’s current location obtained from GPS, the application can turn to related pages, but the location cannot be shown on the illustrated maps in the books. Apple’s Maps is used to show user’s current location, POI’s positions, and navigation routes.

“Mapple Link” is an application provided from Mapple-On Co., Ltd., which allows users to access and download digital content, such as POI’s information and maps, of the books and magazines they have bought, and the information can be referred depending on users’ locations (Figure 2.5: right). In this application, illustrated maps of local areas are used to show user’s current location and POI’s [53].

2.4.2 Native Mobile Applications Using Diverse Maps

Current native mobile applications for tourists usually use commercial web mapping APIs to develop map-based functions, such as appending icons like pins at the places of interest (POI) on the base map to provide introductions of attractions, and navigation from current location to the POI. Meanwhile, some of them have also applied maps other than the base maps provided by web mapping APIs. Such maps are usually illustrated maps in large scale of the sightseeing area, with the sightseeing spots, landmarks and travel routes vividly depicted. Some of the maps are converted from print media, while some are originally designed for electronic media.

“小田急沿線自然ふれあい歩道 お散歩ガイド” is an application provided by Odakyu Electric Railway Co., Ltd for walking tours around the railway stations of the company [54]. The application provided illustrated maps for each of the 70 walking courses. However, the maps are originally designed for printed media, and are static in the application (only zoom in and out functions are available). Positioning and other interactive map functions (such as getting detailed introductions of POI, taking photos and so on) are realized using web mapping, while the icons of POI are specially designed.

“Tokyo Shitamachi Sanpo” (東京下町散歩) is an application developed by Fasteps Co., Ltd. in cooperating with Mie Takahashi, who is a famous Japanese illustrator [55]. The application uses her hand-drawn maps of famous sightseeing places in Tokyo as base maps, which are originally designed for this application. The application can display user’s current location on the maps, and contains several interactive functions such as getting introductions of POI, taking photos of POI, and so on.

TouchChina Inc. has developed a series of mobile applications for tourists travelling in China, such as “景点通” [56]. The applications use illustrated maps for the sightseeing areas, and integrated text introductions, photos and audio guides into the POI’s on the maps. Baidu Map is used for navigating the sightseeing areas.

ATR Creative Inc. has developed a series of mobile applications such as “こちずぶらり”, which use various illustrated maps, especially historical maps in Japan, as base maps to show user’s location and POI’s on them [57]. Multiple maps from different eras of the same area can be switched, with the introductions of famous places, and they are contrasted with current maps using web mapping.

2.4.3 Limitations of Current Applications

Although there are already a number of mobile applications trying to use diverse maps alternatively or supplementally to commercial web mapping services, current ones still have limitations in usability and functionality. Especially, the lack of effective map interactivity and the insufficient of location-aware functions are two common and crucial limitations, which will be discussed in details as follows.

- **Lack of effective map interactivity.** This situation may have interlaced aspects. Firstly, many maps used by the applications are converted from printed media and are originally static. It is usually not easy for developers to add extra interactive components to the static images without disturbing the originally well-organized visualizations. Secondly, the “POI - base map” structure, which was introduced and is now being widely used by the web mapping services, become ingrained and abused in mobile map interaction. This structure is often applied in the applications using their own maps for providing extra information interactively. However, interactions based on other types of map features (not only points) are less considered.
- **Insufficient of location-aware functions.** Some of the applications provide maps without positioning functions on them and they do not have difference from using the maps on paper. It is similar to the previous limitation that, integrating positioning functions to originally static maps are not easy. Some of the applications are able to provide limited positioning functions such as displaying user’s current location on maps, invoking nearby POI, and so on. When the location-aware functions needed in the applications (e.g., turn-to-turn navigation) are beyond the capability that can be achieved using their own maps, developers usually choose to let users refer to commercial web mapping.

- **Lack of tools for user-generated mapping.** Currently, the maps and related content in the applications only come from the provider of the applications. If users have created their own maps, they will be in lack of tools for importing their maps into the mobile mapping platforms to use and share. Such tools for user-generated mapping can be an important approach for enriching the resource of diverse maps in mobile environments.

Such limitations of the applications are understandable, because the maps they used are very different. When used in mobile applications, the characteristics of human-centered maps have determined a number of difficulties that can be met by the developers. Such difficulties will be discussed in the next Chapter.

2.5 Conclusion

This chapter reviews the lexical tradition and functional tradition in conventional mapmaking to reveal that map communication is essential in human-centered mapmaking, while functionality, storytelling, aesthetics and inconsistency can be important characteristics of such maps. The bird's-eye view maps made by Hatsusaburo Yoshida are used as an example of well-designed human-centered maps. The rapid developing web mapping services has brought impact to cartography in the change of mapmaking and map uses. The shift of map media has brought important new features to maps including hypermedia, dynamics, interactivity and accessibility, and therefore has extended the capability of map communication. Despite the success of the web mapping services, this chapter examines the their drawbacks, which include the side effects brought to map users by the dominating products and their lack of human-centered characteristics. Then, it has been pointed out that the data-driven approach and technology-driven approach will misdirect the right ways to achieve effective mobile mapping, while maps should be made for human considering the demands and background of the users in a human-centered approach. Meanwhile, it is important to fully involve human's creativity in mobile mapping, because current approach of commercial web mapping services has less involved human intelligence in creating effective, diverse and artistic map representation. In a word, human-centered maps should be made for humans, and made by humans. Finally the results of a survey to young users of mobile mapping have been discussed to reveal that current web mapping has not taken the place of conventional printed maps when used for specific purposes, and the well-designed conventional maps will be preferred if the advantages of mobile devices, especially GPS positioning, can be integrated to them. In the last part, the chapter investigates good examples of existing mobile applications using maps other than web mapping, and then indicates their

limitations. This chapter has shown the necessities of academic researches and system developments to evolve a human-centered mapping in mobile environments. The next chapter will discuss the important issues in realizing a human-centered mobile mapping and propose a practical framework.

Chapter 3

Architecture of Human-Centered Mobile Mapping

3.1 Difficulties of Applying Human-Centered Maps in Mobile Mapping

Currently, the difficulties of applying human-centered maps are caused both internal and external reasons. The internal reasons come from the characteristics of the maps, especially the geometric inconsistency. The external reasons mainly come from the insufficiency of human-centered mapmaking theories and tools for new media, especially mobile environments.

3.1.1 Deficient Functionality of Human-Centered Mapmaking Tools

The current Geographic Information Systems (GIS) are already very mature in acquiring, storing, editing, processing, distributing, and visualizing spatial data, after developments in theories and applications over the past decades. The development of current web mapping is also strongly related to applications of GIS.

For the functions of mapmaking, current GIS are good at thematic mapmaking, including vector-based map data inputting and editing, layer-based map rendering with the settings of map symbols, overlaying data visualization of spatial analysis, and so on. Such tools are good at making maps for scientific researches, education, decision making for companies and governments, but are not mainly designed for making human-centered maps for ordinary use, such as for tourism.

This is because, firstly, the geometric and semantic inconsistency in the maps are not supported or allowed in current GIS. One map usually can only use fixed map projections for the whole area. Also, the symbol system and rendering rules for map features in the same category are fixed after setting, exaggerating or highlighting certain single map feature is difficult to realize. Secondly, functions for creating artistic images are barely provided in GIS. Their visualization styles are usually plain and accurate, as designed for formal usage, such as scientific visualization.

Actually, current illustrators also use computer software in creating illustrated maps, but not using GIS. Instead, the tools and skills they used are not so different from those used for creating illustrations other than maps. Such tools for making usual illustrations cannot

provide enough support for processing spatial data specifically for mapmaking. In order of that, current illustrated maps as digital images that originally created using such tools has little difference from the conventional ones made for printed media.

As a result, currently, a mapmaker can hardly find tools for creating human-centered maps originally designed with interactivity and dynamics. Therefore, the existing mobile applications discussed in Section 2.4 usually use maps either converted from printed media, or have minor difference from conventional maps.

3.1.2 Distortions in Human-Centered Maps

In Section 2.1, inconsistency is discussed as one of the characteristics of human-centered maps, and the inconsistency usually brings distortions to the maps geometrically. Such distortions are different from those caused by map projections, and are difficult to be measured and expressed using deductive approaches like formulas. The distortions in such inconsistent maps can often be found in the following aspects.

- **Exaggeration and simplification:** for example, the important areas and buildings are represented larger than their true sizes, while less important places may be shrunk, which will cause unequal scales changing on the map. Often, this will result in discrete areas in the maps using larger scales than the overall scale, while their surrounding area is compressed to maintain the visual consistency. Some maps even eliminate less important areas.
- **Embellishment:** shapes or orientations of map features may be changed for a nicer appearance. Such changes are usually greater than usual map generalizations caused. For example, a park may appear in the shape of a regular geometric figure, and roads may be smoothed to straight lines and regular curves.
- **Hand-drawn style:** hand-drawn maps have more arbitrariness and usually show less care about projections or scenography. For example, hand-drawn images in side view are often used instead of top-view shapes for important buildings, while the whole map is still treated as a top-view map. The distortion can be even greater, when the whole map is hand-drawn. It is more difficult to measure the distortion because of the arbitrariness of the painter.

Such distorted maps work well in conventional printed media, like in guidebooks and magazines. In such maps, although there may be different distortions inconsistently

distributed in different areas, it can be regarded as consistent within a certain small area. When read by users, the inconsistent gaps between relatively consistent areas in a map are in some sense not important because users concern less about them. Ordinary users like tourists do not actually need the absolute location of each geographic feature in a map, but want to find their current location and routes to main destinations easily and quickly using relative spatial relations to known geographic features including landmarks. The well-designed maps can help users pick up landmarks and routes immediately with visual significance, and also the part-whole relations of their distributions in the whole map, rather than representing detailed locations and information of numerous features exhaustively.

However, these human-centered maps may be suitable to be used by human and processed by human brains, but they may not fit to conventional geospatial processing on digital devices by computers. The distortion and immeasurable inaccuracy presents difficulties to geo-coding and positioning programs. Especially, when developers want to integrate GPS positioning functions of mobile phones to such maps, they will face difficulties in calculating the exact positions on a map corresponding to the obtained locations (usually in pairs of latitude and longitude). Section 3.3 will propose some possible and practical solutions to achieve positioning in distorted maps.

3.2 Proposed Framework of Human-Centered Mobile Mapping

3.2.1 Studies on Use Cases

To examine the typical use cases of human-centered mobile mapping (HCMM) content, following two significant phases will be considered. The first phase is for authors to create HCMM content based on human-centered maps (HC-maps), while the second phase is applying the HCMM content in mobile applications for users.

● Author's Phase

The first case is for professional authors to create refined HCMM content with well-designed HC-maps. The authors can be map designers, illustrators, guidebook publishers, local communities and so on. They have the ability to design or get the full copyright of high quality of HC-maps, and have resources or can get accesses of multimedia content, geospatial data (e.g., accurate base maps, POI databases, and so on). They also have enough budgets and human resource to execute such projects to create refined HCMM content for applications. Their HCMM content can be sold to users as guidebooks and magazines, and also can be distributed for free as leaflets.

The second case is for non-professional authors to create casual HCMM content. Such authors may not have enough resources and skills. They can obtain HC-maps by taking photos, downloading from the Internet, and even drawing by themselves. Geocoding of the HC-maps should be able to be achieved using only simple operations without professional knowledge and skills. The created HCMM content is usually for self-uses. If they want to share their HCMM content, they must make sure there are no copyright problems.

- **User's Phase**

Users may obtain HCMM content in forms of individual mobile applications, or HCMM content that can be viewed and used in a general mobile application. Users may use the HC-maps while travelling and get information interactively. Basic map operations like pan and zoom are needed, because the screen sizes of mobile devices are usually too limited to show the whole HC-map with all the details distinctly displayed. Positioning functions are needed to display a user's current location on the HC-map, and to invoke location-aware interactions. Users may also use the HCMM applications for personal memories and for sharing related data and content with friends and families. So that, they should be able to record their history data (e.g., trajectories, visited places, and so on) and to add their own created content (e.g., photos). A single map is often not enough for the purposes like traveling. Especially some sightseeing maps may intentionally eliminate less important part. In this case, functions of using multiple maps are needed.

3.2.2 Structure of Framework for HCMM

For the use cases discussed above, a practical framework for using human-centered mapping in mobile environments with consideration of feasibility under current technical condition has been proposed in the research of this dissertation. Figure 3.1 shows the overall structure of the framework. The main components in this framework will be explained in the following.

- **Authoring Tools**

The authoring tools are used by *authors* of HCMM content, and realize the functions for creating HCMM content based on human-centered maps (HC-maps). The most important function is to geocode the HC-maps, which are often distorted geometrically, such as illustrated maps. Another important function is to build interactive multimedia components into the HC-maps.

- **Mobile Applications**

End users will use the mobile applications with the HCMM content created from the

authoring tools. The basic functions should include positioning the user on an HC-map and interactive map browsing. Advanced functions may include personal content creating and sharing.

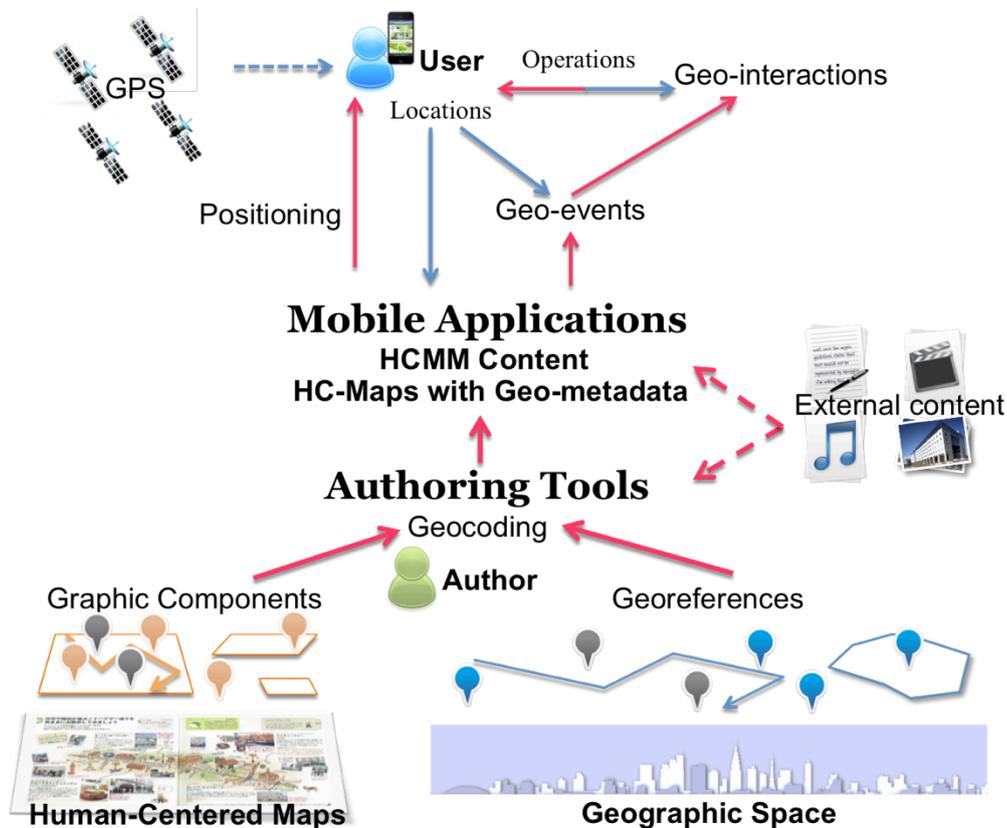


Figure 3.1. Structure of the framework of human-centered mobile mapping (HCMM)

- **Human-Centered Maps**

Maps applied in this framework are human-centered maps (HC-maps) mainly created from human's mapmaking. Especially, large-scale illustrated maps for tourists are targeted.

- **Geographic Space**

The geographic space is referred to the real world in which the applications will be used. Meanwhile it is the original real source from which HC-maps are abstracted. Places in the geographic space are connected to corresponding graphic coordinate positions on the maps through geocoding methods using georeferences connecting the geographic partial spaces and HC-maps that can be considered as graphic spaces.

- **Graphic Components**

The graphic components are representative geometric objects of pictorial elements in a map image in the form of graphic coordinates. Usually they are recorded using vector data in categories of point, line, polygon and so on, in the coordinate system of the map image. Some

of the graphic components are used for georeferences.

- **Georeferences**

The georeferences represent geographic features of the geographic space in geometric form. The georeferences can be connected to graphic components, which are defined by a list of graphic coordinates, in map images. They are usually recorded also using vector data, but in geographic coordinates (e.g., latitude and longitude). Georeferences are used for geocoding. Some of them are entity features (e.g., sightseeing spots), and can link to extra content, while some others are abstract features only for calculating in positioning.

- **Geocoding**

In this framework, geocoding refers to the process of associating the graphic components of map images to their georeferences. The geocoding method is to calculate the corresponded graphic coordinates (often expressed as X and Y in pixels on the map images) of certain geographic coordinates (often expressed as longitude and latitude) using the georeferences.

- **External Content**

Extra multimedia content, including text, photo, audio, video and so on, are supplemental to the maps to provide various kinds of information (e.g., tour guide information) interactively, according to the topics of the content. They are usually corresponded to certain locations, and linked to graphic components on the HC-maps through georeferences.

- **Geo-metadata**

It is the key component of the framework, because it makes the static human-centered maps (HC-maps) interactive and geo-enabled. Geo-metadata of an HC-map is composed by data of graphic components and georeferences. Its data model will be discussed in details in the following subsection.

- **Positioning**

In this framework, positioning refers to the process of calculating corresponded geometric coordinates on an HC-map image of a user's location by converting the geographic coordinates obtained from global positioning functions (e.g., GPS) of the user's device, using the result of geocoding. It sometimes also includes the user's moving speed, direction, and trajectories.

- **Geo-events**

Geo-events are the events triggered by the status or changes of a user's location. The

geo-events can be defined from the spatial relations between a user's location and the geographic features or regions referred by the graphic components.

- **Geo-interactions**

The geo-events will be handled by the mobile application to launch location-related interactions. The geo-interactions can be achieved by dynamic visualizations and user's operations.

3.2.3 Data Model of Geo-metadata

GIS applications usually digitalize analog maps by vectorization, which means to vectorize all symbols in a map and use certain coordinates to describe and store them. This method is suitable for well-surveyed consistent maps like topographic maps. For human-centered maps, the way of vectorization used in GIS can hardly maintain the geographic correctness because of the geometric inconsistency of the HC-maps. More importantly, the aesthetics of the HC-maps can barely be preserved in the vectorized results.

In the proposed framework, a digitalized map image imported to mobile applications is just a set of two-dimensional raster data, which may come from photograph, scanning or original digital file. In the idea case, each pixel should be mapped to a certain geographic coordinate and stored. But such time-space-consuming task is not realistic. Instead, a relatively small dataset are kept to describe the main geographic features of the map image. Such dataset is named as *geo-metadata* of the HC-map. From *geo-metadata*, geocoding is achieved for positioning when used in applications.

For this purpose, *geo-metadata* is composed by graphic components and their georeferences. Graphic components are described usually using plane coordinates up to their geometric types. One graphic component usually refers to a geographic entity or area, using certain *georeference patterns*.

For a map image, because of the possible geometric inconsistency, they may be divided into regions, while inside of each region it can be regarded as geographically consistent. Such regions are named as *geo-consistent regions*. In most *geo-consistent regions*, the exact location of any pixel is concerned and can be mapped to certain geographic coordinates. Such regions are named as *mapping regions*. Oppositely, other regions are named as *non-mapping regions*.

In a mapping region, most graphic components contained can serve for geocoding. For example, a POI is also a control point when certain positioning method is applied to the mapping region. To assist positioning and obtain better results, extra control points and lines other than the explicitly defined graphic components can be added to the region. Such control

points and lines have graphic coordinates in the map image and corresponded geographic coordinates. They are usually implicit in the final HCMM content in mobile applications, which means invisible to the end users.

The shapes of the graphic components can be various. In order to simplify them, they are usually abstracted to three basic elements as point, polyline and polygon. The graphic elements are recorded using plane coordinates, usually pixel coordinate pairs on the digitalized image of pages as (x, y) .

- **Point Element:** A point element is used to record the position of a small component on an HC-map whose shape can be ignored, such as a POI on an HC-map, a small icon and so on. One point element is defined by a coordinate pair.
- **Polyline Element:** A polyline element is used to record the position and shape a one-dimensional component on a page while its width is homogeneous or can be ignored. Graphic data of arrows in route plans, route lines on HC-maps, connecting lines between frames and so on can be recorded as polyline elements. One polyline element is defined by a series of points. The sequence of points indicates the direction of a line.
- **Polygon Element:** A polygon element is a two-dimensional component in a map image, whose shape cannot be ignored. It also includes some components in the non-mapping regions such as a paragraph of text, a picture, a frame of multiple components and so on. Its position and size can be recorded using a series of coordinate pairs.

Point, polyline and polygon are common concepts and elements used in GIS for abstracting, recording and visualizing geographic entities. In comparison to the graphic components of human-centered maps, the geographic features in GIS vector records are usually exactly corresponded to the entities. This kind of correspondence includes the proximate shapes and exact geographic coordinates, or the coordinates calculated from certain projections by mathematics. However, in geo-metadata, these elements are descriptions and abstracts of the graphics, not directly to the geographic entities. As a result, the shapes and coordinates are not exactly corresponded to the entities, and it is needed to apply certain types of *georeference* to the components to complete the correspondence from graphic elements to geographic entities or regions.

Georeference patterns define the ways in which a graphic component or a mapping region refers to corresponded geographic entity or region. Therefore, they also define the geocoding for positioning calculations applied to the component or region. The georeference data are usually recorded using pairs of latitude and longitude.

By the precision requirement of references, the georeference patterns can be divided into two groups as *precise georeferences* and *imprecise georeferences*. *Precise georeferences* apply to the cases that, firstly, the shape of a graphic component and the shape of the geographic feature are exactly corresponded, or, secondly, exact locations within the component are concerned. On the contrary, if shapes are not exactly corresponded or only relative spatial relationships (e.g. inside, outside, near and so on) are concerned, *imprecise georeferences* should be applied. Meanwhile, from the types of both target graphic components and corresponded geographic entities or regions, the frequently used types of georeference patterns can be enumerated as follows.

- **Point-Point Georeference**

Point-point georeference is applied to the point element that refers to a single geographic feature with relatively small area on the earth, for example a building, a station and so on, and its size and shape can be ignored in currently applied scales. This georeference pattern is usually applied to POI's on maps. A pair of latitude and longitude is recorded for the corresponded feature. A value of distance from the feature can also be recorded as the valid radius of the point. It is considered as a kind of precise georeferences.

- **Point-Polygon Georeference**

Point-polygon georeference is applied to the point element that refers to a surface geographic feature whose size and shape cannot be ignored in currently applied scales (e.g., a city or a country). A series of geographic coordinates records the boundary of the corresponded feature, sometime with a valid buffer range. This georeference pattern is different from usual POI's. It is considered as a kind of imprecise georeferences, as only the relative spatial relationships (e.g., inside, outside, near and so on) are considered to be meaningful.

- **Polyline-Polyline Georeference**

This type of georeference is applied to polyline elements, which may refer to actual geographic features like rivers and roads, and also to virtual lines like planned travel routes or walking paths. A series of coordinates is recorded for a polyline. The sequence of geographic coordinates should have the same direction as the sequence of graphic coordinates on the map image. For precise georeference, the inner points (or at least key points) of the two sequences should be exactly one-to-one corresponded. But this is not necessary in imprecise georeference, and is also impossible in some highly abstracted or deformed map images. In the case of imprecise georeference, linear referencing can be used to correspond any points on the polyline on a map image to its geographic polyline. A value of distance from the polyline

can be recorded to define the valid buffer area of the line.

- **Polygon-Point Georeference**

Polygon-point georeference is applied to the polygon element that refers to a point geographic feature. That means in the real world, the size and shape of the corresponded feature can be ignored in currently applied scales; while in the map image, the component is exaggerated (e.g. drawings of buildings, statures and so on) and a point is not enough for describing the graphics. A pair of latitude and longitude is recorded for the corresponded point feature. A value of distance from the feature can also be recorded as the valid radius. It is considered as a kind of imprecise georeferences, which means the exact position inside the polygon element will not be mapped.

- **Polygon-Polygon Georeference**

Polygon-polygon georeference is applied to the polygon element that refers to a polygon geographic feature. For precise georeference, certain projection or geometric transformation should be applied to the corresponded two polygons, from which the exact locations in the polygon can be calculated and mapped to the image. Therefore, the coordinates in both polygons are usually one-to-one corresponded exactly. For imprecise georeference, the exact position inside the polygon element will not be mapped, and only the relative spatial relations (e.g., inside, outside, near and so on) are considered.

- **Multi-Component Georeference**

Multi-component georeference is used for calculate the exact location of any point (pixel) within a mapping region of the map image. The effective components contained in the mapping region can provide control points or lines. Such components usually include point elements that apply point-point georeference, polyline elements that apply polyline-polyline georeference (*both* precise and imprecise georeferences can be acceptable) and polygon elements that apply *precise* polygon-polygon georeference. Extra control points and lines in the mapping regions are applied to this type of georeference and work together with the explicit components.

3.2.4 Geo-Events and Geo-Interactions

Geo-events are defined to graphic components of the map images according to their georeference types. Status of the user's location and its changes will trigger the events. These geo-events can be defined from the spatial relations between user's location and the geographic features or regions referred by the graphic components. Because one place in the

real world can be referred by several different page components, one geo-event can trigger multiple events. Frequently used geo-events are enumerated as follows.

- ***Near and Away***

This pair of geo-event types can be defined to point and polygon components in the following cases: (1) point elements applying point-point georeference and polygon elements applying polygon-point georeference with valid buffer ranges defined, (2) point elements applying point-polygon georeference and polygon elements applying polygon-polygon georeference with valid buffer range defined. The moment when the distance from user's location to the referred point or polygon is shorter than the given range, which means the user entered the buffer, the geo-event *Near* will be triggered. On the contrary, the moment when user gets out of the buffer range, the geo-event *Away* will be triggered.

- ***Along and Off***

This pair of geo-event types can be defined to polyline components applying polyline-polyline georeference with valid buffer ranges. When the distance from user's current location to the referred polyline continues to be shorter than the given range, which also means the user continues to be moving inside the buffer area of the polyline, the geo-event *Along* will be triggered. When the user's location gets out of the buffer range, the geo-event *Off* is triggered at the very moment. Recent trajectories should be used to make more precise judgment.

- ***Enter and Leave***

This pair of geo-event types can be defined to point elements applying point-polygon georeference and polygon elements applying polygon-polygon georeference. The moment when user's current location gets into the boundary of the referred polygon, the geo-event *Enter* will be triggered. On the contrary, the moment when user's location gets out of the area, the geo-event *Leave* will be triggered.

- ***Position Changed***

This geo-event can be defined to mapping regions applying multi-component georeference, and also the components in the following cases: (1) polygon components applying precise polygon-polygon georeference, (2) polyline components applying polyline-polyline georeference (either precise or imprecise). If user's location is inside of the geographic range of the mapping regions or components, when the location is updated, the geo-event *Position Changed* will be triggered, and the corresponded graphic positions in the components or mapping regions will also be updated.

The geo-events will be handled by the applications to provide certain functions according to the designs. The author's researches focus on location-based applications, therefore more concern about the geo-spatial related interactions between the applications and users. Such interactions launched by the handler of the geo-events are named as *geo-interactions*.

When user's location is obtained from the device, such as smartphones or tablets, it is usually being monitored by the applications. And then, the applications will calculate the spatial relations between the location and the components recorded in the geo-metadata, in order to find the triggered geo-events. The geo-interactions can be achieved by visualizations and user's operations. The typical interactions for each type of geo-events are listed as follows.

- ***Near and Inside***

If a user's current location gets *near* a component or *inside* the region of a component, the component should be activated. The activated components can be visually highlighted by blinking, changing color or size, or being attached by a special icon and so on, in order to attract user's attention. If the application applies multiple map images, all the components that have triggered the two geo-events should be able to fetched as results of user's query operations, or can be directly pushed to user by messages, such as a blinking icon, a merging list, and so on, with which the user can jump to the related images or components. By operating with the activated components, user can also access to extra medias, mark the history of visits, taking customized photos and so on.

- ***Away and Leave***

If a user's current location is getting *away* or *leaving* a component, the highlighted component should be reset to its normal status. Pushing prompt related to it should also be stopped. All the functions that only applied to the activated components should be disabled to the deactivated components.

- ***Along and Off***

If user's location is detected to be moving *along* a polyline component with the buffer range, the line and related components can be highlighted. For example, if the component is a planned travel route, it can be activated to guide the user to move along with it. Guidance like pushed message or audio, pictures of turning points or landmarks will be shown in certain points on the route. In this mode, if the user's location is detected to be *off* the line, a warning message should be shown.

- ***Position Changed***

If user's location is inside a mapping region on the map image, its position should be displayed on the map using a certain icon in the calculated position. When *location changed*, the display of position on the map should also be updated. Meanwhile, user's trajectory on the map should also be updated. Similar interactions can be applied to polyline and polygon components, if this geo-event applies to them and they are activated.

3.3 Positioning Methods for Human-Centered Mobile Mapping

Location-aware interactivity is one of the most important advantages that the current maps can benefit from the contemporary mobile devices like smartphones. After obtaining the current location from the device, one important user function is to visualize it on the maps. The display of user's current location as well as the moving trajectories can help map interpretation from many aspects. Firstly, showing user's location on maps can reduce the burden of recognizing the surrounding landmarks and associate them to the corresponding features on maps, because user only need to focus on the area around the displayed current location. Secondly, showing user's moving trajectories can help to confirm the moving direction and places have been past, and then to make sure current movement is on the correct route.

When APIs of commercial web mapping are used in developing mobile applications, such functions are already provided by their services. Originally, positioning is relatively easy to be achieved on the maps they are using, because the maps are geometrically consistent, and are generated using a variant of Mercator projection, which can be considered easy for calculation. However, as discussed in Section 3.1, when human-centered maps are used, their distortions must be considered in realizing positioning on them.

The positioning methods discussed in this dissertation are not referred to the methods that improving the positioning results of the mobile phones through hardware or software, but to the methods that convert the geographic coordinate positions generated by GPS functions to the graphic coordinate positions on distorted maps appropriately. The accuracy of the geographic coordinate positions given by GPS functions is not focused in the dissertation, and is not improved by the methods discussed in the following parts.

In essence, the positioning methods need to establish mappings from geographic coordinate position to a corresponding set of pixels in the map image. In some sense, this process is in common with remote sensing image correction. However, they have clear differences.

Firstly, the image correction will finally change the appearances of images to make sure the pixels in the corrected images are corresponded to geographic locations accurately, while positioning methods will not result in any change of the appearances of map images.

Secondly, the remote sensing images are consistent and the distortions in them are systematic, so the correction methods usually generate an overall formulation to be used for the whole image. However, the distortions in the inconsistent maps are not caused by systematic sources, especially for hand-drawn style maps, which usually contain more arbitrariness. It may be impossible to generate simple formulations to describe such distortions.

In a human-centered map, although there may be different distortions inconsistently distributed in different areas, it can be regarded as consistent within a certain small area. Instead of finding consistent overall formulations of distortions in each map, resolving local positioning in different small areas in a map is more suitable for human-centered mapping. Meanwhile, labor-intensive calculations must be avoided when processing real-time positioning on mobile devices.

In this research, positioning based on nearby control points is introduced as main method, supplemented by line-based positioning. Only 2-dimensional cases are considered. Some basic elements and concepts are defined as follows.

- **Location Under Positioning:** $LUP = (lat, lon)$ (lat is short for latitude, lon is short for longitude, the same below) is the geographic coordinate point needs to be converted to a graphic coordinate point on a map image.
- **Positioning Result:** $PR = (x, y)$ is the result of positioning of LUP on graphic coordinates.
- **Control Point:** a control point $CP = (Pi, Pg)$ has both a geographic coordinate point $Pg = (lat, lon)$, and a graphic coordinate point $Pi = (x, y)$, and is considered accurate. It is also named as a reference point.
- **Control Line:** a control line $CL = (Li, Lg)$ is a polyline has both sequences of geographic coordinate points $Li = (Pi_0, Pi_1, \dots, Pi_r), r \geq 1$, and graphic coordinate points $Lg = (Pg_0, Pg_1, \dots, Pg_s), s \geq 1$, and is considered accurate. The two pieces of sequences of coordinate points are not required to be one-to-one corresponded, but some coordinate points can be a kind of control points called *key points* in a control line to be one-to-one corresponded between control lines. A *key point* (including the two end points and important inner points, for example, corner points) in a control line must have a corresponding key point as the same location in another corresponding control line. The control line is also named as a reference line.
- **Point-Based Positioning:** it uses control points to estimate the graphic coordinate point (PR) of a given geographic coordinate point (LUP).

- **Line-Based Positioning:** it is used to map a given geographic coordinate point (LUP) to a corresponding graphic coordinate point (PR) on or close to a control line. This method is also called as *map matching* and *snapping* in the field of car navigations.

3.3.1 Point-Based Positioning

Basically the realization of positioning using control points contains two steps. The first step is creating control points $P_i = (x, y)$ on the HC-maps, and corresponding them to related geographic coordinates $P_g = (lat, lon)$ (as shown in Figure 3.2). In real application, web mapping can be used to input the geographic coordinates. The second step is the real-time calculation from the obtained geographic location to a graphic position on the map using the control points (as shown in Figure 3.3). When the geographic coordinates of the user's current location (LUP) are obtained from the mobile device, firstly some key parameters of the location on geographic coordinate system can be calculated from the control points using their spatial relations. Then, transformation using the parameters can be conducted on the graphic coordinate system of the map image to calculate corresponding graphic coordinates (PR). Finally the graphic coordinates can be used for display and other purposes.

In the case of using multiple maps in a set of HCMM content, control points on different maps may refer to the same geographic location, and the result of positioning can be on different maps at the same time (as shown in Figure 3.4). In applications, the control points can also be used to estimate the regional map scales, which will be useful for keeping the scale when the user switch between different maps.

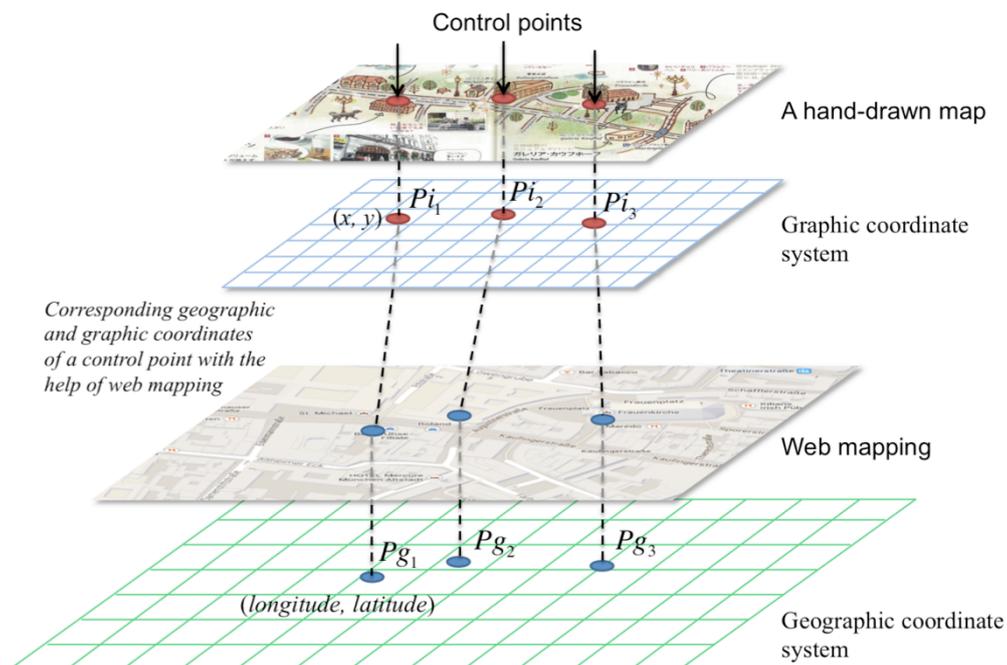


Figure 3.2. Processes of creating control points on distorted maps for positioning

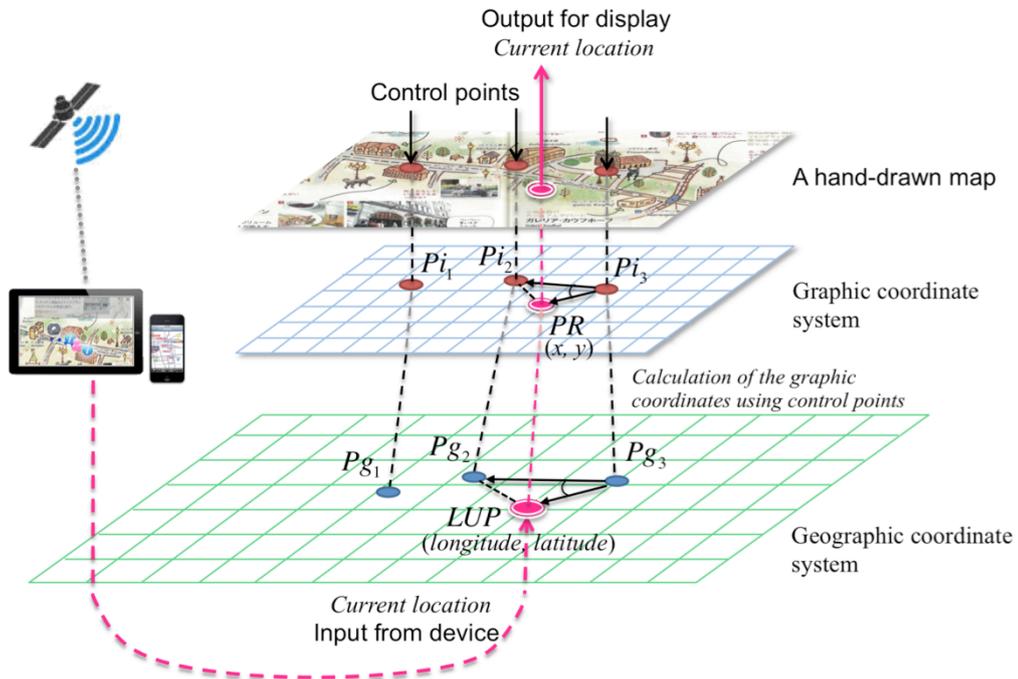


Figure 3.3. Processes of using nearby control points to calculate the graphic position corresponding to a given geographic location

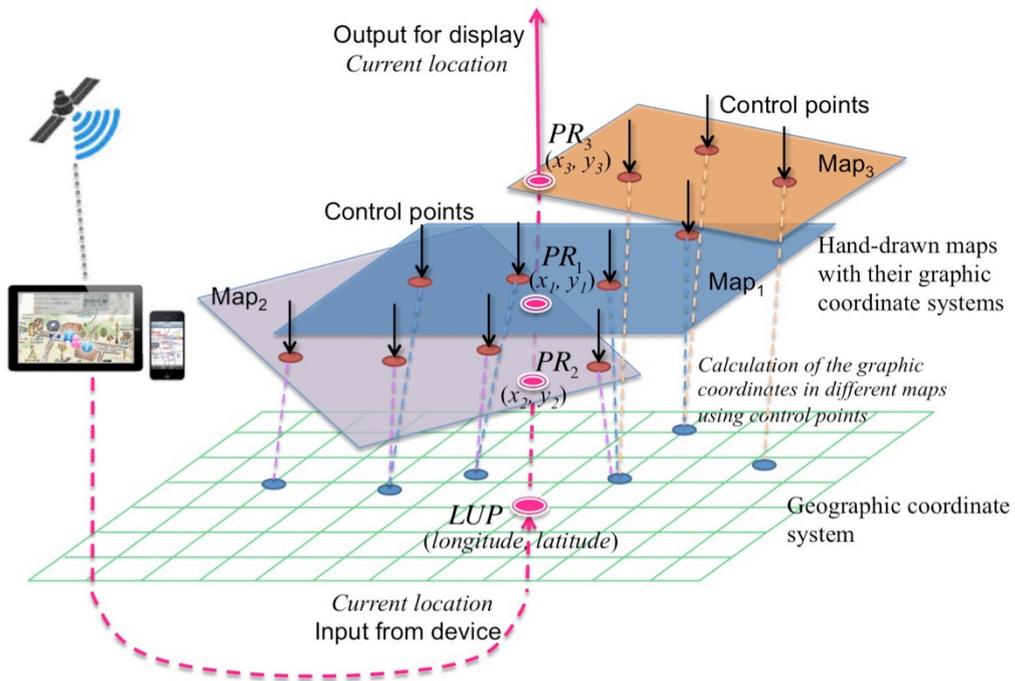


Figure 3.4. Positioning using control points on multiple maps

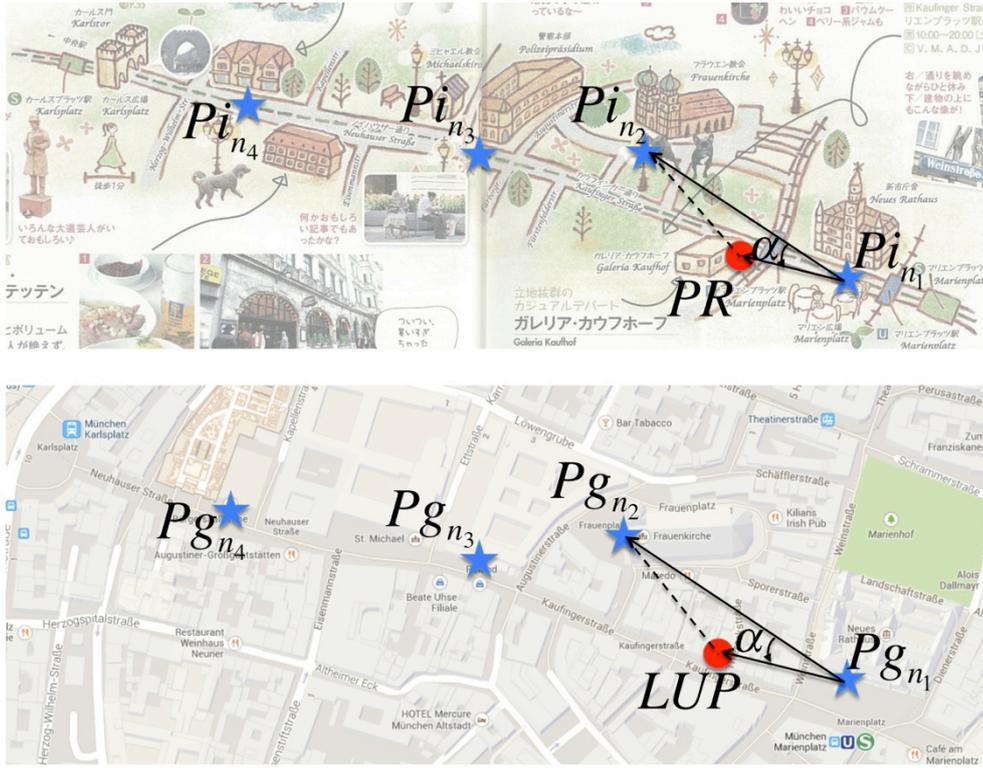


Figure 3.5. Two-point based positioning using a similarity transformation

Upper: A hand-drawn style map (provided by Shobunsha Publications Inc.); Lower: Same places on Google Maps.

In this research, a Nearest Two-Point Based Similarity Transformation is realized, applied and discussed as a main positioning method. It uses the nearest two control points of the LUP , $CP_{n_1} = (Pi_{n_1}, Pg_{n_1})$ and $CP_{n_2} = (Pi_{n_2}, Pg_{n_2})$, as basis to calculate the PR . If the three points on the map (Pi_{n_1} , Pi_{n_2} and PR) are considered to have the same geometrical relationships with their locations on the earth (Pg_{n_1} , Pg_{n_2} and LUP), the calculation simply becomes a similarity transformation, as shown in Figure 3.5.

The rotation angle α from the line segment $Pg_{n_1}Pg_{n_2}$ to the line segment $Pg_{n_1}LUP$ can be easily calculated through their coordinates. A similar transformation can be made on the map image by rotating the line segment $Pi_{n_1}Pi_{n_2}$ with the angle α , and then picking the point PR on the new line segment to make sure of the following equation (in which $Dist(A,B)$ means the calculation of distance between the two coordinates A and B):

$$\frac{Dist(Pi_{n_1}, PR)}{Dist(Pi_{n_1}, Pi_{n_2})} = \frac{Dist(Pg_{n_1}, LUP)}{Dist(Pg_{n_1}, Pg_{n_2})}$$

The transformation means the two triangles $\Delta Pg_{n_1}Pg_{n_2}LUP$ and $\Delta Pi_{n_1}Pi_{n_2}PR$ are similar. It must be noted that the triangle $\Delta Pg_{n_1}Pg_{n_2}LUP$ is actually a spherical triangle,

but when used in large-scale maps and the two control points are relatively close to each other, it can be considered the same as a plane triangle.

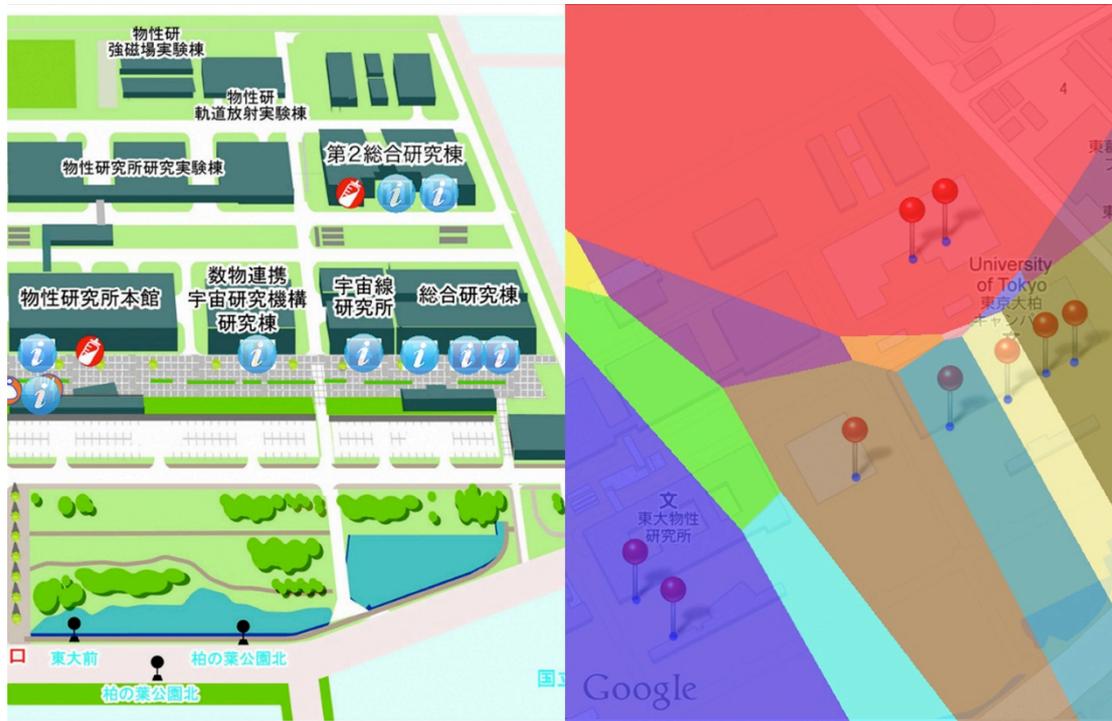


Figure 3.6. An example of regions divided by nearest two control points in two-point based positioning, POI's in the campus map are used as control points
 Left: Control points (also POI's, shown as blue icons) in part of the guide map of Kashiwa Campus, the University of Tokyo. Right: the same control shown in Google Maps, with divided regions.

It is implied that by seeking the nearest two control points for positioning, such methods actually also divide the geographic 2-D space into regions similar to Voronoi partition, and different regions use different pairs of points for a local correction. Figure 3.6 shows a real example of using the guide map of the Kashiwa Campus, University of Tokyo.

3.3.2 Error Analyses of Two-Point Based Similarity Transformation

In this research, some preliminary analyses have been made to examine the error of the two-point based similarity transformation in the situations as follows. Errors not caused by the method, such as errors of GPS and errors of control point coordinates, are not considered in the analyses here.

1. **Rotation:** the method causes no error as it keeps the same rotation.

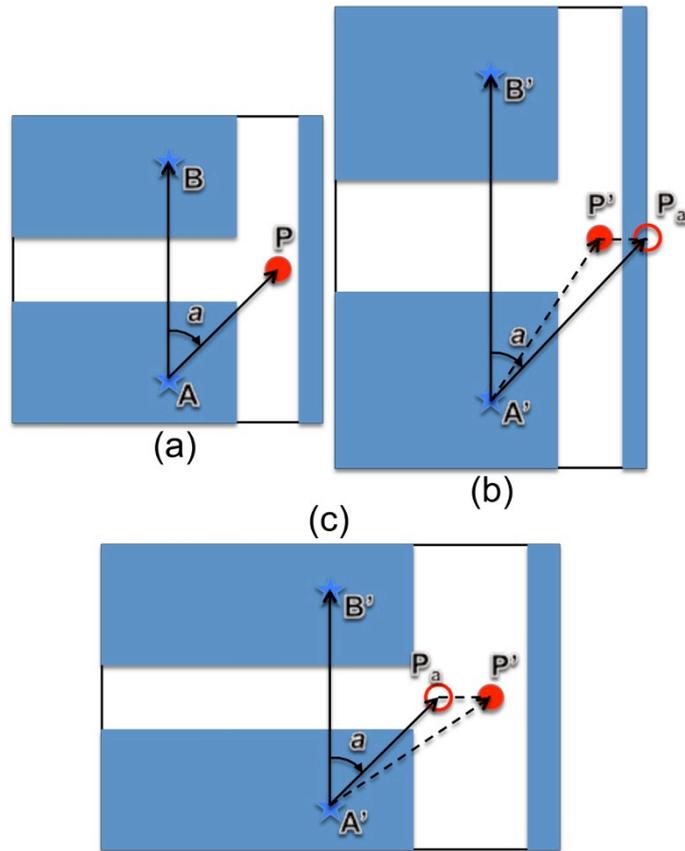


Figure 3.7. Error of the two-point based similarity transformation method in a stretched map (a) original map, (b) stretched horizontally by 40%, and (c) stretched vertically by 40%. Stretching has changed the rotation angle from vector $A'B'$ to $A'P'$. As the algorithm keeps the same rotation angle, the position will be located at P_a improperly.

2. Stretching: As shown in Figure 3.7, the original LUP point P should be at P' as the PR in the stretched maps, but the algorithm will get the result at P_a . Some numerical analyses have been conducted under this unitary situation. The results are shown in Figure 3.8 that the error increases by the distance from the line of two control points, and is also affected by the stretched rate. It can be proved using elementary geometry that, in the situation of linear, single-direction stretching, the error (Err) is only related to the stretching rate (k , proportion of elongated length in original length in the stretching direction) and the distance to the vector (h):

$$Err = k \cdot h$$

The detailed proofs of this equation of error can be found in the author's paper [58].

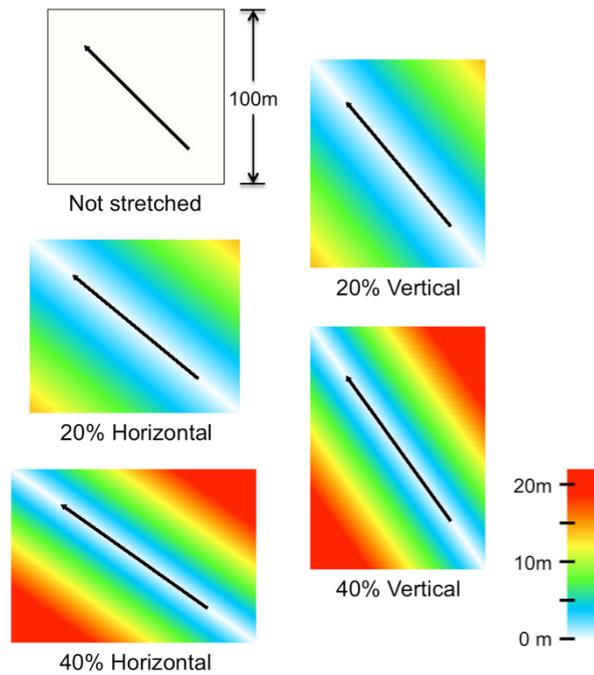


Figure 3.8. Error of the two-point based similarity transformation method in a stretched map by the distance from the line of two control points

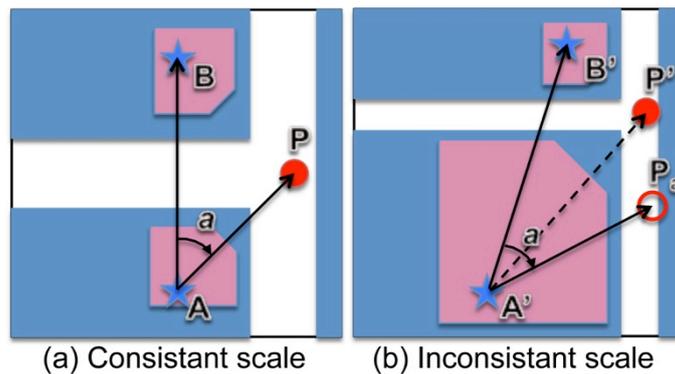


Figure 3.9. Error caused by inconsistent scales

(a) consistent scale and (b) inconsistent scale. In (b), the area around A' is exaggerated, and the scale is larger than other parts, as where B' is located. The position will be located at P_a improperly.

3. Inconsistent scales: the situation can be more complex, and Figure 3.9 shows an example. Such error is difficult to be measured and predicted, but generally, it may be acceptable when LUP is near the control points or along the lines of control point pairs, while it may become much greater if the LUP is far from the control points or lines of control point pairs. However, this rule is not guaranteed. Nevertheless, it can be inferred that if the density of control point is low in some areas, the method may use faraway control points, which may cause a significant error. As shown in Figure 3.6, some regions capture long and narrow areas. And on the edges of regions, control points are changed suddenly, which will also cause unsmooth movement of the user's location on the map.

It can be inferred from the analyses above that the density and distribution of the control points in a map will influence the positioning result. If the density of control points is higher, the average distance from a *LUP* to the line of its nearest two control points will be shorter, which means the average error will also be smaller. This research has analysed the error distribution in a unidirectionally stretched map under different distribution and density of control points.

1. Evenly distributed control points: as shown in Figure 3.10, on a map stretched 40% horizontally, five cases of evenly distributed control points with different density have been deployed. Figure 3.11 shows the result. Obviously, if the density is higher, the overall error is smaller.

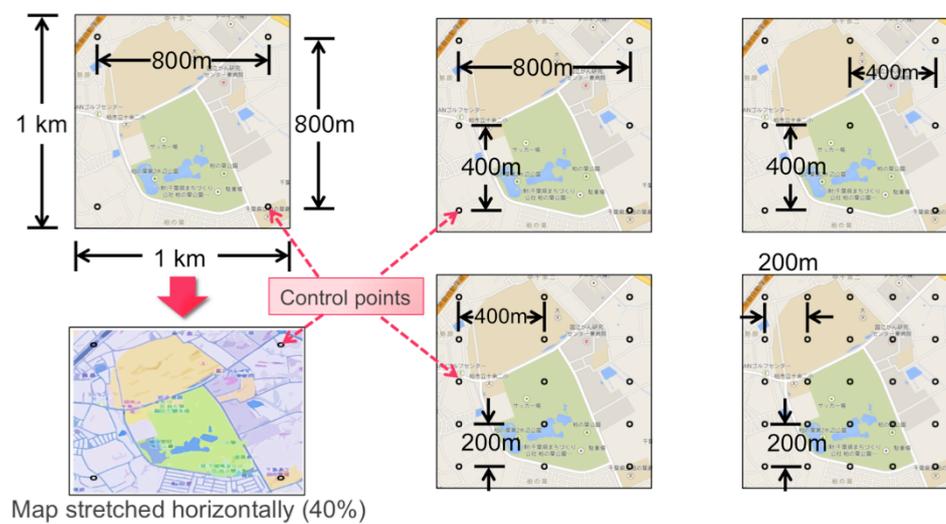


Figure 3.10. Evenly distributed control points in different density for analyses

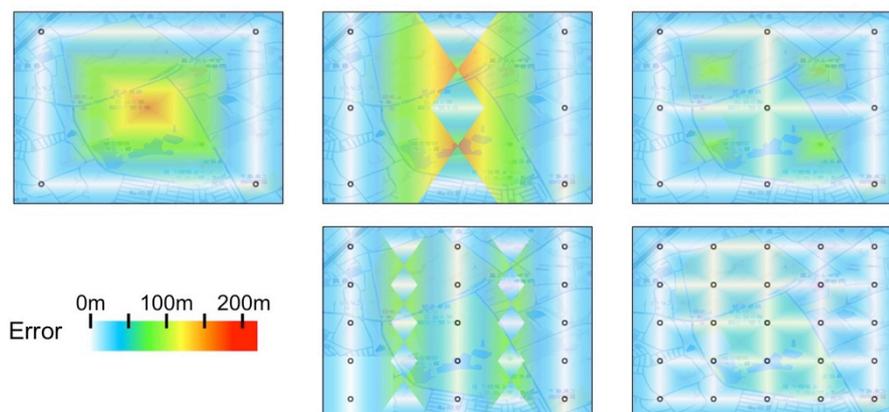


Figure 3.11. Error distribution of positioning using nearest two-point based similarity transformation under different density of evenly distributed control points (as in Figure 3.10)

2. Randomly distributed control points: as shown in Figure 3.12, different numbers of control points (10 and 20) has been put on the map. From the result, it can be found that the areas have less control points will have larger error. In the real applications like maps for

walking tours, some areas far from the moving paths are less concerned, so it is still acceptable and practical.

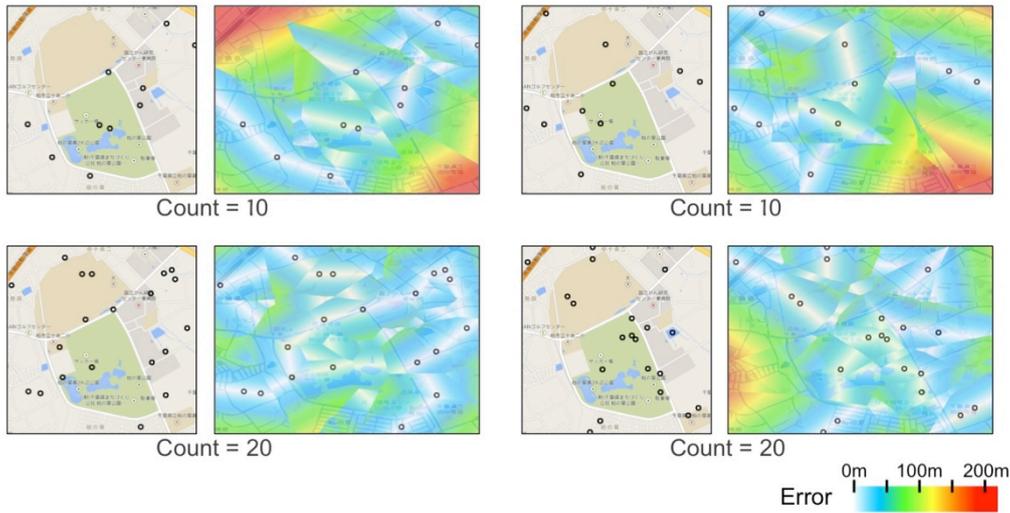


Figure 3.12. Error distribution of positioning using nearest two-point based similarity transformation under different density of randomly distributed control points

3. Evenly distributed control points with randomized errors: the two situations above are under the assumption that there is no error of the control points. As shown in Figure 3.13, after randomized errors (less than 50 meters) added to the control points, the error of positioning can be much greater if the density of control points is low.

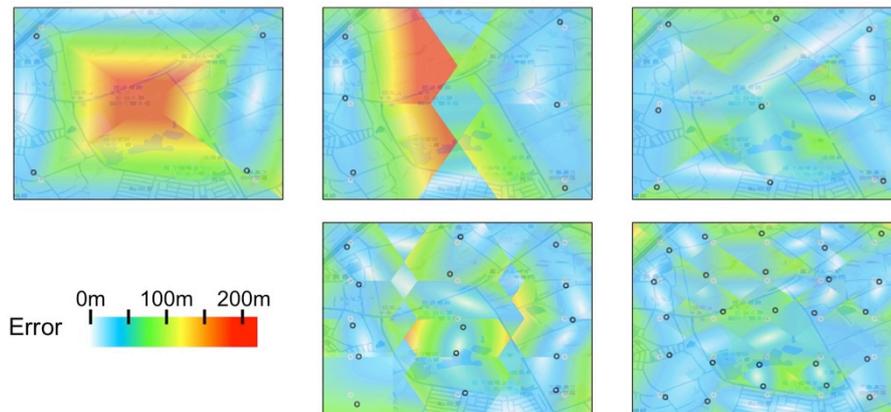


Figure 3.13. Error distribution of positioning using nearest two-point based similarity transformation under different density of evenly distributed control points with randomized errors

4. Randomly distributed control points with randomized errors: as shown in Figure 3.14, because of the limitation of the similarity transformation, if the pair of control points are close to each other, their errors will have large affect when they are used for the transformation, their effective area will acceptable error will be small. But basically if enough density of control points in the concerned areas can be maintained, the method is still usable. This issue will be further discussed in the experiments of the prototypes in Chapter 5.

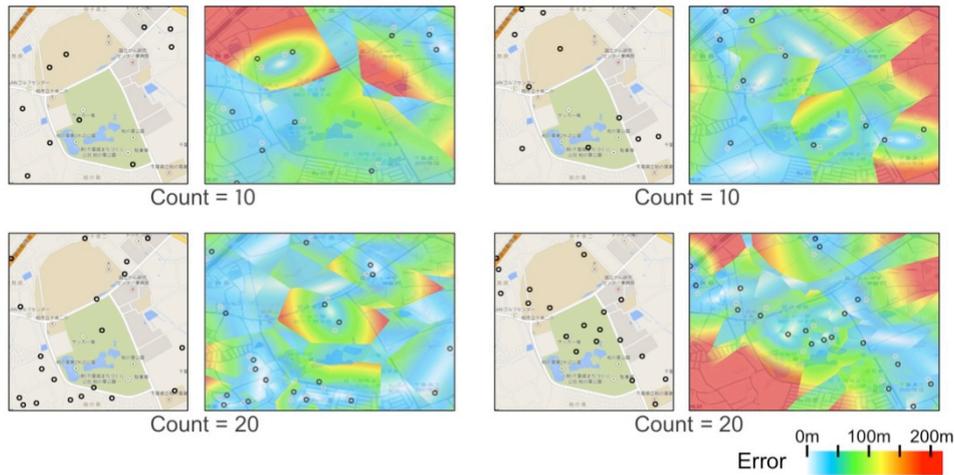


Figure 3.14. Error distribution of positioning using nearest two-point based similarity transformation under different density of randomly distributed control points with randomized error

As a result, when used in applications, the distribution of control points needs to be concerned with consideration of users' possible frequent moving areas in the maps, in order to reduce the internal error of the method. In general, the control points should be chosen at the places that are easy to confirm the positions both in the maps and the real world. Deployment of such control points is relatively easy for non-professional authors.

A possible way of reducing the error is to increase the number of control points used for positioning methods. For example, point set triangulations are obvious solutions for dividing the map to partitions using the control points as vertexes. The most frequently used one of them is the Delaunay triangulation. The triangulation should be done in both geographic 2-D space and the map image space. When the *LUP* is located inside one triangle in geographic 2-D space, it will use the three vertexes of the triangles in both geographic space and the map image for calculating the *PR*. This also implies that the area inside on triangle is regarded to have certain uniformity in distortion. The most frequently used method for calculating the distortion of two related triangles is affine transformation, which regards the inside of the triangle is deformed homogeneously. By using such transformations based on three or more points, the effects of some deformations can be reduced.

Similar approach has been used in scientific researches. Fuse and Shimizu has used Triangulated Irregular Network (TIN) and planar affine transformation to make geometric corrections of historic maps of Tokyo, in order to match them with the current maps and GIS data for further analyses [28]. For positioning methods, the deformed triangles in maps are not corrected, and it is similar to an opposite process to image corrections that the geographic coordinates in original triangles are transformed to the graphic coordinates in deformed triangles.

The deployment of control points under the three-point based methods using triangulation

should be considered differently from that under the two-point based methods. Actually, the edges of the triangles should be taken more care of instead of the positions of vertexes (although they determine each other). It is better to coincide the edges of triangles with the border of the areas in the map that each area can be considered to have homogeneous deformation inside. Otherwise, it is more possible to cause error. Another issue is that the control points should be distributed all over the map; otherwise the triangulation cannot cover enough area of the map. Usually, the edge parts of the map are difficult to be covered. As a result, three-point based positioning using triangulation is difficult to be achieved by non-professional authors. The realization and evaluation of positioning methods using three or more control points will be remained as an important future work.

3.3.3 Line-Based Positioning

In this research, line-based positioning is supplemental of point-based positioning for important moving paths in HC-maps. In line-based positioning, before calculating the exact position of PR on the line, the first issue is to judge if the LUP is on the control line or not. Geometrically, it is almost impossible that the LUP is exactly on the control line, so an effective range ER of the control line needs to be defined. If the distance from the LUP to Lg is shorter than ER , the LUP can be considered as on the control line semantically. The distance from LUP to Lg can be defined as $Dist(LUP, Lg) = Dist(LUP, LUP')$, while LUP' is a point among all points on Lg that have the shortest distance to LUP . LUP' is either one of the vertexes in Lg , or one of the feet of perpendicular from LUP to the segments in Lg . And then, PR is estimated by calculating the corresponding point on Li of LUP' on Lg .

As defined before, the key points of a control line should be one-to-one corresponded in both geographic space and map image space. These key points can be defined as $KP_i = (Pi_{k_i}, Pg_{k_i}), 0 \leq k_i \leq \min(r, s)$. LUP' must be located between two neighboring key points Pg_{k_m} and $Pg_{k_{m+1}}$. And then, the problem here is simplified to finding PR on the segment polyline from Pi_{k_m} to $Pi_{k_{m+1}}$ that corresponding to LUP' on the segment polyline from Pg_{k_m} and $Pg_{k_{m+1}}$. Such problem can be solved easily using linear referencing. By calculating the length of the polyline segments, it is easy to get the PR that satisfies the following equation:

$$\frac{Length(Pi_{k_m} \rightarrow PR)}{Length(Pi_{k_m} \rightarrow Pi_{k_{m+1}})} = \frac{Length(Pg_{k_m} \rightarrow LUP')}{Length(Pg_{k_m} \rightarrow Pg_{k_{m+1}})}$$

Similar approach is also used in map matching for vector-based map data. For example, for car navigation, the location of a car needs to be matched to the road network, which is also

called snapping. In such case, the topology of road network and morphology of trajectory is also considered for tracking the position effectively and avoiding illogical movement on the road network.

When used in positioning for human-centered mapping, usually it is difficult and not necessary to input the full road network in the maps. In real applications, control lines should be deployed along the users' moving route, and key points should be added on turning points, like corners and intersections. The effective range of the control line is theoretically the width of the route, but the possible error of the location obtained from the devices as well as the map scales should also be considered.

Line-based positioning can be used mixed with point-based positioning discussed above, in order to use the advantages of each and cover the shortcomings. For example, for a walking route map for tourists, control lines can be used for the designed routes and have higher priority, while other parts can use point-based positioning with control points.

3.4 Conclusion

This chapter at first clarifies the difficulties in applying human-centered maps in mobile mapping, which include external causes like the deficient of human-centered mapmaking tools, as well as internal defects of human-centered maps, especially the difficulties of positioning because of the immeasurable distortions.

For creating practical human-centered mobile mapping applications, use cases are studied on both author's phase and user's phase, in considering of non-professional users. Then, a framework including both authoring tools and user applications that enabling interactive human-centered maps by integrating geo-metadata and multimedia content to originally static maps are proposed, followed by introductions of its main components. As the key of geo-enabling the maps, the concept model of geo-metadata is introduced in details, including the graphic components and their georeference patterns. Frequently used geo-events and geo-interactions are enumerated and discussed

As one of the key technologies in realizing the proposed framework, practical positioning methods for distorted maps, including point-based and line-based methods, are introduced. Among them, the two-pointed based similarity transformation is discussed in details, with the error analyses. The advantages and drawbacks of the methods to be noted when used in real applications are discussed.

This chapter has established the feasibility of developing practical authoring tools for creating interactive content using human-centered maps and mobile applications for using such content on site in the real world. The next chapter will introduce the implementation of the proposed framework and the development of prototypes.

Chapter 4

Software Developments and Implementations

4.1 Purposes of Prototype Developments

In this research, the author has developed a series of prototypes for testing the feasibility of the proposed framework and the key technologies needed in implementation, and then, for user tests on purpose of developing practical applications. The prototypes are named as *Manpo* (written in 漫歩 in both Japanese and Chinese), which has a meaning of taking a ramble both on the map and in the real world.

4.1.1 Targeted Use Cases – Walking Tours

In this dissertation, the implementations are targeted on the use cases of walking tours. Walking is one of the most important activities of humans and is also major and important part of daily lives and travels. More specifically, the use cases of walking tours include using geo-enabled walking route maps in mobile applications to assist and enhance real-world experiences in walking tours, as well as making multimedia content on basis of well-designed walking route maps. The reasons of choosing walking tours include but not limited to the follows.

First of all, there is a strong need of human-centered maps in walking tours. The purposes of using maps in walking tours are very specific and practical. They include introducing the walking route and the sightseeing attractions along the route, helping users to find and follow the route, giving users good impression of the places, and so on. For such purposes, specifically designed human-centered maps are considered more powerful and preferable than well-surveyed generic maps for common uses like walking tours. However, as discussed in Chapter 3, current mobile applications for walking tours still use commercial web mapping as main maps.

The second reason is that the users, which mean the tourists having the walking tours, are usually ordinary but not professional, and may not have enough knowledge and skills to use well-surveyed maps in their tours, or some may be even not interested in such maps. They are good targets for testing the usability of human-centered mobile mapping. On the other hand, it is also easier for a non-professional author to create content on basis of the walking route maps, because they are usually for small areas and in large scale. Therefore, it is easier to get

related resources, and even to draw maps by the authors themselves.

Last but not least, there are rich resources of existing well-designed walking route maps, especially in Japan in recent years. There are a lot of walking tours organized by railway companies, local governments and communities. Many attendees are fond of such kind of activities, because it's healthy and a good chance to get more knowledge of the local places. It is also good for revitalizing local economies. Well-designed maps with walking routes are usually distributed for free in forms of leaflets. Similar maps can also be found in stations, tourist information desks, guidebooks, magazines and on the Internet.

4.1.2 Developments for Feasibility Tests of Proposed Framework

The developments are supposed to achieve an integral realization of the proposed framework, including the user functions and authoring functions. Especially, a practical realization of geo-metadata is supposed to be established. As a result the developments at least need to include:

- (1) A practical data structure of geo-metadata including necessary data for geo-enabling conventional maps, and its physical realization in mobile platforms;
- (2) A practical data organization of content including map images, geo-metadata of the maps, and multimedia files; (in the prototype **Manpo**, such datasets of content are called *Manpo Content*.)
- (3) Mobile applications on currently popular mobile platforms as viewers to use the content of (2) and to provide basic interactive map functions, especially location-aware functions;
- (4) Applications, either mobile or desktop, as editors for creating and editing the content of (2) with interactive user interfaces.

4.1.3 Developments for Testing Positioning Methods

The developments are supposed to realize the algorithms of more than one positioning methods to test their effectiveness on walking route maps. The developments at least need to include:

- (1) Real-time calculation and display of user's current location and moving trajectories on walking route maps, when used on a location-aware mobile device;
- (2) Display of user's current location and moving trajectories using commercial web mapping as comparison to (1);

- (3) Efficient functions of creating and editing control points and control lines in the authoring tools.

4.1.4 Developments for User Tests

Both the mobile applications and the authoring tools in the proposed framework are targeted to ordinary users. In order of this, the developments should not be incomplete prototypes just for scientific researches, but should have complete functions and friendly user interfaces that designed for ordinary users, although the functions may be basic and not mature. The following considerations need to be included in the developments:

- (1) Simple operations of map browsing, which will be quickly accepted if they fit users' current habits of using web mapping applications;
- (2) Effective interactions of user's current location, including display of the location, accessing to information according to the location with ease, and so on;
- (3) Simple and friendly interfaces for authors to create content interactively with ease, especially, effective but simple operations for inputting and editing geo-metadata.

4.2 Developments of Early Prototypes

The development of **Manpo** has started from some exploring and experimental prototypes with incomplete functions. During developing and testing repeatedly, the first experimental system *Manpo Alpha* supported only browsing functions for human-made distorted maps with GPS positioning on smartphones without authoring function. Then, it was extended to *Manpo Beta* for providing basic authoring functions by locating points of interest (POI's) on both distorted and surveying maps as georeferences.

4.2.1 Realization of Initial Browsing Functions – *Manpo Alpha*

The development started from March 2012, and the major functions were accomplished in May. It was developed base on Apple Inc.'s iOS 5 Software Development Kit (SDK), using Objective-C 2.0 as development language, using Apple Inc.'s Xcode 4.x as integrated development environment (IDE). It was designed to be operated on Apple Inc.'s iPhone, and was designed for 4:3 screens (mainly iPhone 3GS, iPhone 4 and iPhone 4S).

This initial version of **Manpo** is designed for assisting walking tours with one or multiple route maps. Especially, it is designed for the maps that contain given walking routes and introductions of points of interest. This prototype is supposed to be used by the participants of

the walking tours. For the purposes of research, this prototype is the first attempt of positioning on distorted maps. It is mainly for testing the feasibility of the positioning methods, and to find a possible application schema that converts static maps to interactive ones on mobile devices.

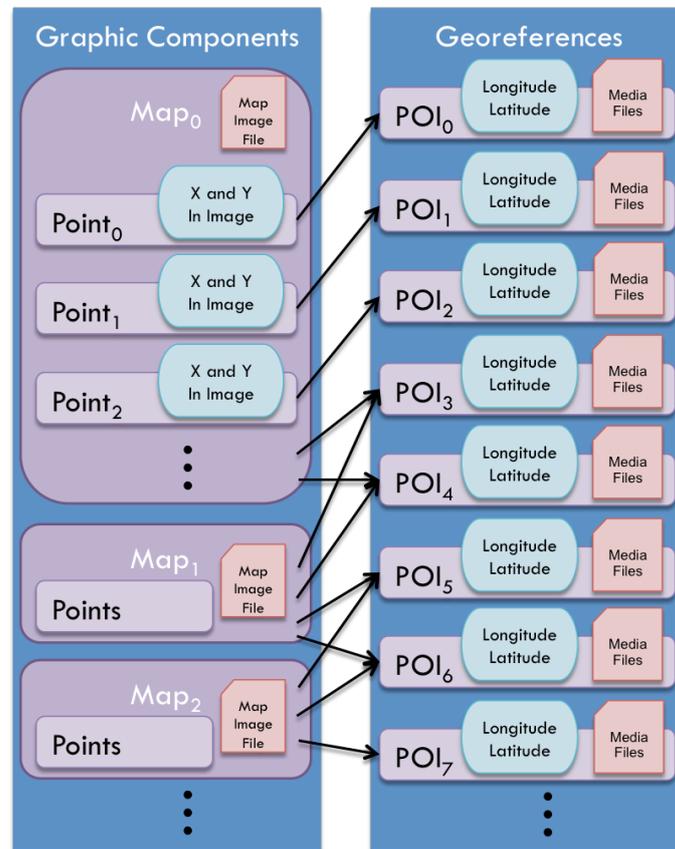


Figure 4.1. Data organization of Manpo Content with geo-metadata realized in Manpo Alpha

The prototype is built with a simple realization of *Manpo Content* with geo-metadata for the maps. The data organization is shown in Figure 4.1. As an initial realization, the geo-metadata includes only point elements, which are points of interest (POI's) with corresponded point-to-point georeferences. One POI in the georeferences can only be corresponded to only one point in graphic components, but can be used by multiple maps. Multimedia files, including texts, audios and photos, are associated to each POI. The geo-metadata is saved using property list files in the form of XML (Extensive Markup Language). All data needed for a walking tour are usually composed of in one geo-metadata file, one or multiple map image files and multiple multimedia files, are integrated to a dataset and stored in the local storage of the application on iPhone.

The positioning method used in this prototype is the nearest two points based similarity transformation method. In realization, only POI's are used as control points, so one map needed at least two POI's to enable positioning functions. This method is named as

“POI-based Inter-georeference” [58]. This design have also considered the easiness of content making.

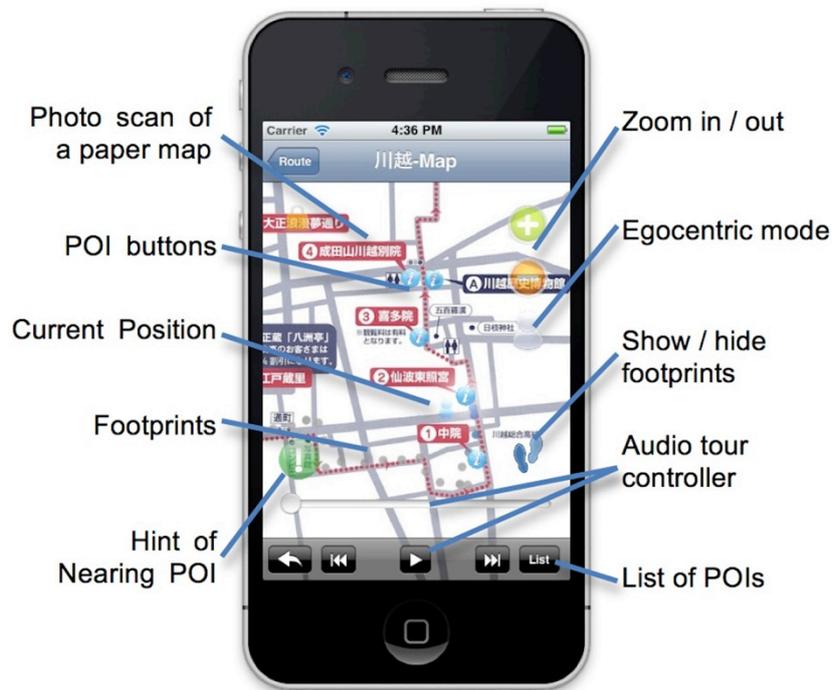


Figure 4.2. Main user interface of **Manpo Alpha**
(The map is provided by SEIBU Railway Co., Ltd.)

Manpo Alpha have mainly realized the following functions (the main user interface is shown in Figure 4.2):

- (1) Map browsing: pan, zoom in, and zoom out the walking route maps with gestures and buttons.
- (2) POI browsing: tap a “POI” button, and users can access information about it, including photos, texts, and audio. There is also a POI list with which users can position a POI in the screen center.
- (3) Show current location: if the calculated location of the user is in the range of the current map, it will be shown as an icon and is updated every second. Users can also switch between *Geocentric Mode* and *Egocentric Mode*. With the former mode, users can move the map freely; with the latter, current location will be kept at the screen center.
- (4) Record and show trajectory: user’s trajectories are recorded and shown as a series of dots on the map. By default, only the recent 10 footprints are vivid; the rest fade to grey gradually in the time order; this allows users to easily see what direction they are moving in. Users can also choose to display all footprints without the fading footprints or hide them all.

- (5) Prompt of nearest POI: if the nearest unvisited POI is in a certain range from the user, it will be activated. Its icon will be blinking, while a larger blinking button will appear near the left bottom of the screen. This function can help users to confirm the next place to visit and makes it easier to access its related content. When using a touch screen, the small icons of POI's are difficult to select, especially when they are close to each other. The big button in a fixed place can solve the problem to some extent. If the activated POI is not in the current map, a button will appear for switching maps.
- (6) Checklist of POI's: the POI invoked by the user's location can be checked in. The checked-in POI's are considered to be visited, and then their icons will fade and will not be activated anymore. The history of check-ins is recorded.
- (7) Playback functions: in playback mode, user's trajectories can be shown in order of time. Pause, forward, rewind, and speed control functions are available.

There is no specialized editor making the contents in this version. The geo-metadata and related contents are created and added to the application by the author manually using usual file tools on computers. The digital versions of free maps provided by the organizer of walking tours are used. The photos of POI's are taken by the author or from free sources of the Internet. Some audio introductions are narrated by colleagues of the author, and some are created using voice generator. The author manually inputs the geographic coordinates of each POI with the help of web maps.

Develop tests of the prototype have been conducted when the author with his colleagues and professor joined several walking tours in Japan. From the history of the user's trajectories, it can be found that the positioning is acceptable when moving along the route, because the POI's (as control points for positioning) are close to the route. In the area far from the POI's, the result is sometimes not acceptable.

4.2.2 Realization of Initial Authoring Functions – *Manpo Beta*

With the new ideas and experiences obtained from the first prototype, the author started to develop the second prototype from July 2012. The initial functions were completed in September 2012. The prototype was improved gradually in a series of tests and experiments, and a stable version was finally completed in July 2013. It was named as **Manpo Beta**. The development was based on at first iOS 5 and later iOS 6 SDK, using Xcode 4.x as IDE.

The prototype is still designed for iPhone, but the screen ratio is changed from 4:3 to 16:9 later after Apple Inc.'s release of iPhone 5. With all the functions of **Manpo Alpha** inherited, **Manpo Beta** has mainly added authoring functions for users to create *Manpo Content*. Users are supposed to be able to import conventional maps and geo-enable them on iPhone with

Manpo Beta easily and then use the contents for walking tours.

On purposes of research, **Manpo Beta** is mainly developed for testing the feasibility of realizing georeferences on conventional maps with only simple operations by ordinary users, and also the feasibility of editing the contents on mobile platforms. Also the feedbacks from various users are important to know the acceptance of the positioning results on analog maps.

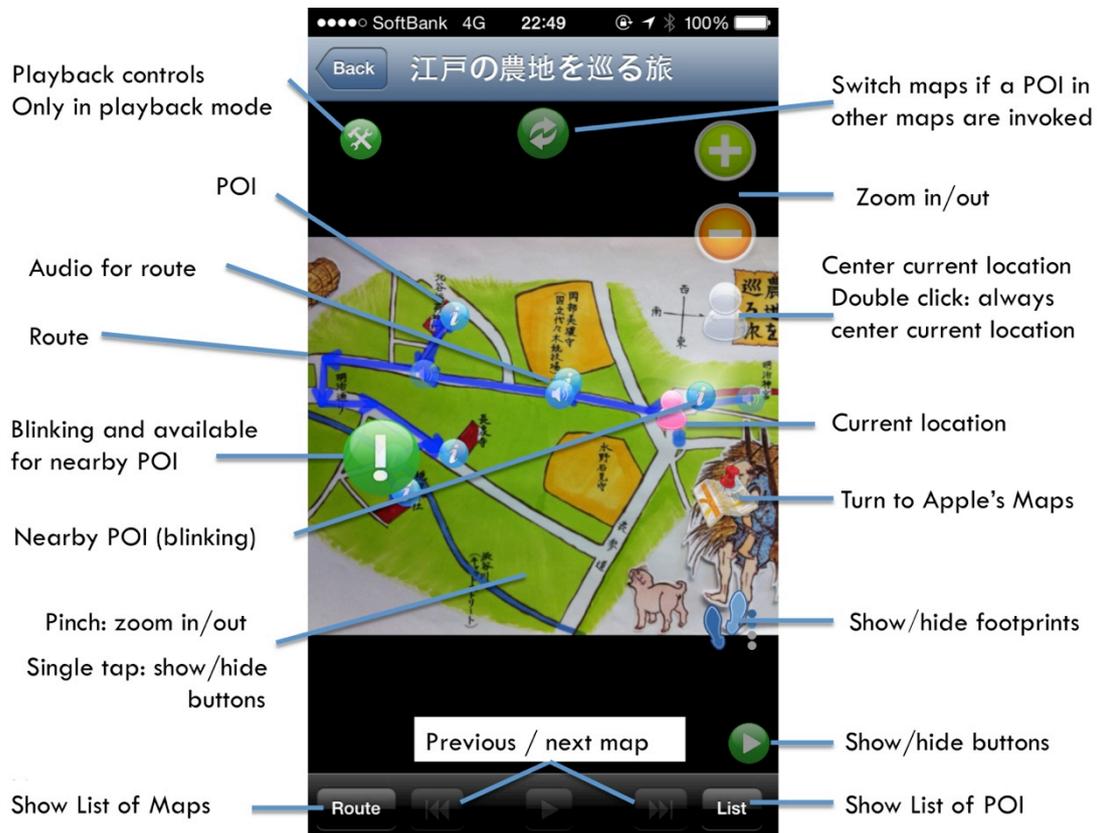


Figure 4.3. Main interface of **Manpo Beta** for viewer's functions

Compared to **Manpo Alpha**, **Manpo Beta** has not many differences when used as a *viewer* or *player*, except for the followings new functions (the main interface of **Manpo Beta** for viewer's functions is shown in Figure 4.3):

- (1) Customized POI Photos: when the POI is activated by user's location (which means the user is near the POI), user can take extra photos and store with the contents as memories.
- (2) Narrations on routes: the later version has added the support of polyline components on maps with associated audio narrations. An icon on the route is synchronized with the playing progress of the audio to show the position of current narration on maps. But georeference of polyline was not supported in this version yet.
- (3) Switching between multiple maps: although **Manpo Alpha** already supports multiple

maps, but when selected to another map, the view cannot keep the zooming scale and current location. In **Manpo Beta**, there is a new function to switch between the maps, which contain the user's current location. When switching, the map scale will be kept and the user's location will be put to the center.

For authoring functions, **Manpo Beta** supports the whole workflow of creating *Manpo Contents*, from importing analog maps to add POI's with georeferences and extra media. The workflow is shown in Figure 4.4.

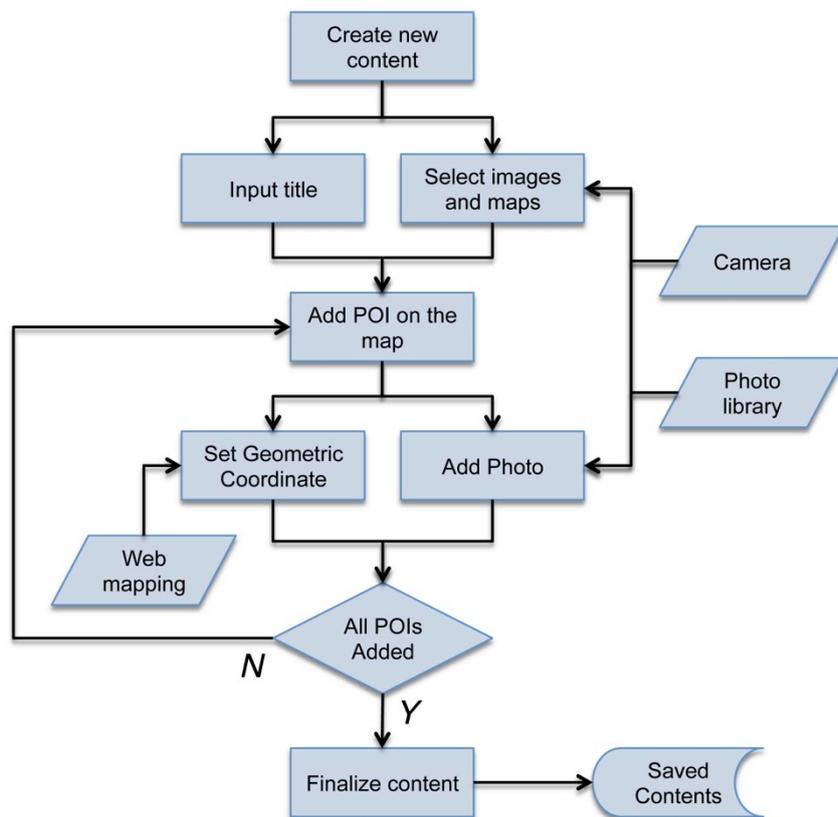


Figure 4.4. Workflow of creating content based on analog maps with **Manpo Beta**

After inputting a title, users can choose images from their photo library or take photos from guidebooks or paper maps. Then users can input and edit the geo-metadata of the maps using simple graphic user interfaces by only fingers. The key process is adding POI's and their georeferences. Figure 4.5 shows the processes of adding POI.



Figure 4.5. Workflow of adding POI with geographic coordinates to an illustrated map in a tourist guidebook
(The guidebook is provided by Shobunsha Publications Inc.)

- (1) Input the POI's position on the illustrated map by zooming and moving the map to place the position at the cross mark at the screen center.
- (2) Input the POI's position in the real world using Apple's Maps (or Google Maps if the version of iOS is below 6.0) by zooming and moving the map, and confirm the same position at the screen center.
- (3) Input the title and add media related to the POI, including photos, text, audio and so on.

The POI input process is designed for operating on touch screens. The frequently used tap or long-press gestures for inputting points on the web maps or images make it difficult to confirm the accurate positions and require more operations and cause operational errors.

Develop tests have been made by the author and his colleagues by creating various *Manpo Contents* and experience them in walking tours. The tests have been conducted in many places, not only in Japan, but also in other countries, for example, Columbus in Ohio the USA, Munich and Dresden in Germany, Plzen in Czech, Suzhou in China and so on. Except for the author and his colleagues, the first “real” users of the early version of **Manpo Beta** were some participants in a workshop of AutoCarto2012 held in Columbus, Ohio, USA in September 2012.

In 2013 and 2014, **Manpo Beta** was used as teaching appliance in two courses by University students. The classes were also treated as experiments for purposes research. The details will be discussed in the next chapter. The students' works and feedbacks have

provided important suggestions and inspirations for the author to improve and refine the prototype development. They also have shown to the author that the possibility of stimulating the creativity of ordinary users to produce more and more interesting location-based personal contents on various geo-enabled human-centered maps.

4.2.3 Extended Applications Based on Manpo – *Todai Kashiwa Rally*

Based on the approaches of **Manpo**, an iPhone application has been developed for the annual open campus event of Kashiwa Campus, the University of Tokyo, at which the author studied for a doctoral course. For the open campus event in October 2012, the iPhone application was named as “かしわラリー”, and was developed on iOS 5 SDK. For the open campus event in October 2013, the updated application was named as “東大柏ラリー”, and was developed on iOS 6 SDK. The latter one became an official version and available on Apple Inc.’s App Store for users to download and install (as shown in Figure 4.6).



Figure 4.6. 東大柏ラリー viewed in Apple Inc.’s App Store

The target users of the application are supposed to be the participants of the open campus events, usually local residents and students. The application is designed for a stamp rally event, which uses digital *stamps* instead of real physical stamps for the checkpoints in the rally. Participants are required to obtain all the stamps by getting close enough to the checkpoints and tapping a certain button on the screen of the application, and then they can get some gifts if they have collected all stamps. They are supposed to explore the campus with the help of maps and positioning functions provided by the application.

On the purposes of research, the application is developed for gathering users’ history data (based on users’ agreement), to find their behaviors in using illustrated campus maps in

mobile phone applications. Also the feasibility and acceptability of such new usage of illustrated maps with GPS are supposed to be tested. On the other hand, more efforts are required to make sure the application can be robust and user friendly enough, because it is not a prototype for research anymore, but a real application for ordinary users.

In 東大柏ラリー, the official maps of the campus are used, with photos and audio introductions of the institutions in the campus for the POI's and checkpoints. The author uses **Manpo Beta**'s edit functions to generate the data for the application. The main functions are mainly transplanted and tailored from the viewer functions of **Manpo Beta**, but it turns some of the POI's to checkpoints for stamp rally. The main differences and new functions are listed as follows (as shown in Figure 4.7):



Figure 4.7. User interfaces and main functions of 東大柏ラリー

- (1) When a user's location is near the checkpoint, a "Stamp" button will appear. By tapping the button, the user can get the stamp and more detailed information.
- (2) The photos taken by user of the checkpoint using POI's customized photo function will also be a proof of the obtained stamps.
- (3) Users could find the places of interest by reading the introductions and go to them with the help of the maps, display of current location and moving trajectories.
- (4) Their activities are recorded and can be reviewed after they finished the stamp rally. Users can choose to donate their records and upload them to the server in the author's laboratory.

4.3 Manpo Editor and Manpo Viewer

4.3.1 Design and Development

The development of the third prototype of **Manpo** started from November 2013. The main functions have been completed in April 2014, and are still under improving. It is a major upgrade of **Manpo**, and had many differences compared to **Manpo Beta**. It is actually newly developed from scratch, because old version becomes too complicated to integrate more new functions and the changes of underlying data structures. The development is based on iOS 7 SDK using Xcode 5.x as IDE. The styles of user interfaces are also changed to adapt to the interface styles of iOS 7. From this version, **Manpo** is divided into two separated applications: *Manpo Editor* and *Manpo Viewer*. The operating devices are also changed to include tablet computers.

Manpo Editor is designed to operate on Apple Inc.'s iPad having a larger screen than iPhone, and to inherit and extend **Manpo Beta**'s edit functions. **Manpo Editor** is designed to deal with more complex distorted map images, for which only POI's and the POI-based Inter-georeference for the entire image cannot meet the needs. Therefore, more types of graphic components including lines and polygons, and accordingly, more complex georeferences need to be supported. Especially, it is designed to be able to import guidebook pages and create geo-metadata for them. For this purpose, the co-existence of non-mapping regions and mapping regions should be allowed in the same image. Compared to **Manpo Beta**, users as authors are supposed to be more skilled and even professional like creators of tourist guide books, to be able to deal with all kinds of georeferences, while ordinary users are still allowed to use just simple georeferences as part of all.

Manpo Viewer is designed for end users to operate on both iPad and iPhone, and also needs to be extended from **Manpo Beta** for using new contents created by *Manpo Editor*. It is designed mainly for travelers, but not only for walking tours. Users are supposed to use digitalized and geo-enabled guidebooks with location-based functions.

For **Manpo Editor**, the tasks might become more difficult and complex because the screen sizes of smartphones are too small. It is difficult to handle, for example, the edit to complex graphic components on a map image while display other necessary information at the same time on a four-inch screen. From the reason, iPad is chosen as a target device for developing **Manpo Editor** because of a larger display area. It is also possible to reduce operations like zooming in and out the map images, frequently switching between different views, and so on.

For **Manpo Viewer**, although it is designed for both iPhone and iPad, still larger screen size is considered to be better for guidebooks. It is because users can easily read the texts and the entire page with less zoom operations. Portability may become a problem for tablets

because a user may feel more difficult to use **Manpo** on iPad compared with on iPhone while walking, but the current tablet computers become lighter, the size and weight like the latest iPad mini may be acceptable.

On purposes of researches, the new version is aimed to achieve a relatively integrated realization of geo-metadata, including various types of graphic components and georeferences. **Manpo Editor** is supposed to test the usability of making more abundant contents, and the acceptability of inputting complex graphic components and georeferences by various users. **Manpo Viewer** supposes to test the accuracy and effectiveness of positioning using multiple types of georeferences within one map image. The author also wants to realize and test more types of geo-events and corresponding geo-interactions.

4.3.2 Realization of Geo-metadata

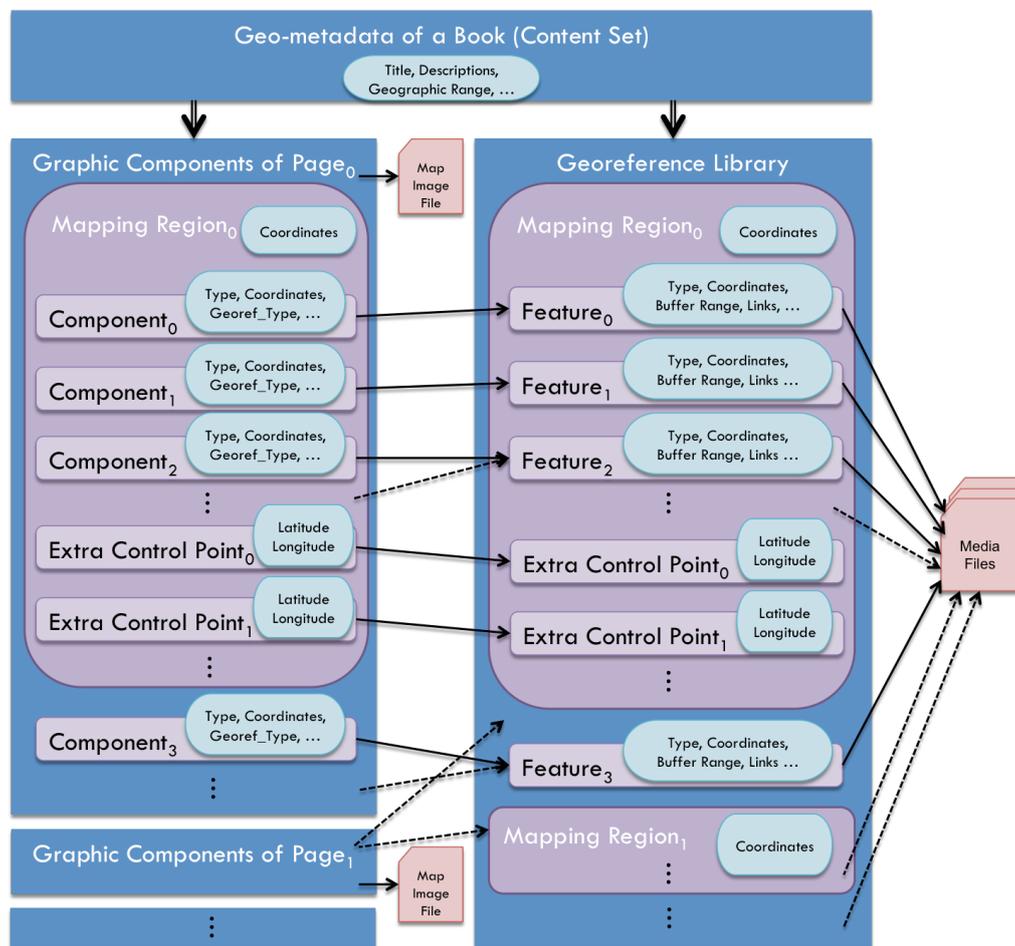


Figure 4.8. Data organization of geo-metadata in **Manpo Editor** and **Manpo Viewer**

From this version of **Manpo**, a book metaphor of book-page-component is used to describe the data organization. At a minimum, the geo-metadata record for a set of content should contain geographic descriptions at three levels: book level (or content-set level), page level

(or map level) and feature level (or component level). It basically includes the geographic range of the book, range of each page, and each feature or area's geographic definition, related page numbers and other properties. At the same time, it should also include the geometric definitions of the graphic components and their links to georeferences. The basic data structure and organization is shown in Figure 4.8. Property list files based on XML are used for physical realizations of geo-metadata.

The structure of metadata in book-level and page-level are relatively simple, as shown in Table 4.1 and Table 4.2. For feature-level, in one set of content (e.g., a guidebook), one place can be mentioned and introduced for several times in different pages. In order to reduce redundancy, one integral data set of all the geographic features and areas referred by the book should be maintained. This will also bring convenience for realizing geo-events responses for the multiple components refer to the same place. Main data fields required for the features are shown in Table 4.3.

Table 4.1. Main data fields required for metadata in the book-level

Field Name	Required	Data Type
Book_ID	Yes	String
Max_Longitude	Yes	Double
Min_Longitude	Yes	Double
Max_Latitude	Yes	Double
Min_Latitude	Yes	Double
Book_Title	Yes	String
Book_Description	No	String
Book_Icon	Yes	Image
Pages	Yes	Array
Features	Yes	Array

Table 4.2. Main data fields required for metadata in the page-level

Field Name	Required	Data Type
Page_Number	Yes	Int
Max_Longitude	Yes	Double
Min_Longitude	Yes	Double
Max_Latitude	Yes	Double
Min_Latitude	Yes	Double
Page_Title	No	String
Components	Yes	Array

For each page, the metadata file contains geometric definition of each graphic component and necessary information for georeference. The geographic feature corresponding to the component is cited using its ID ('Feature_ID') in the geographic metadata. One component

can contain several other components geometrically inside it, and in some cases, they can be used for georeference. The necessary data fields of each component are shown in Table 4.4.

Table 4.3. Main data fields required for metadata in the feature-level for georeferences

Field Name	Required	Data Type	Notes
Feature_ID	Yes	String	Unique in the book.
Title	Yes	String	Name of the feature
Feature_Type	Yes	Enum	One of 'Point', 'Rectangle', 'Polyline' and 'Polygon'.
Coordinates	Yes	Array	Pairs of longitude and latitude: Point: one pair of coordinates; Rectangle: two pairs of coordinates (composed by maximum and minimum latitudes and longitudes); Polyline: more than two pairs of coordinates; Polygon: more than three pairs of coordinates.
Buffer_Range	No	Double	Only applied to points and polylines, in meters. If not specified, the application would have a default value.
Referred_Pages	Yes	Array	A list of pages that contain the graphic components referring to this feature.
Extra_Links	No	String	Links to external resources like web pages.
Extra_Images	No	Array	Extra images
Extra_Audios	No	Array	Extra audios
Extra_Text	No	String	Extra text

Table 4.4. Main data fields required for graphic components in each page

Field Name	Required	Data Type	Notes
Component_ID	Yes	String	Unique in the book.
Component_Type	Yes	Enum	One of 'Point', 'Polyline' and 'Rectangle'.
Coordinates	Yes	Array	Pixel coordinates, pairs of x and y: Point: one pair of coordinates; Polyline: more than two pairs of coordinates; Rectangle: two pairs of coordinates (composed by maximum and minimum x and y).
Feature_ID	No	String	Refers to an item in georeference data, can be empty if the component has no georeference.
Georeference_Type	Yes	Enum	One of 'Point', 'Polyline', 'Rectangle', 'Polygon', 'Multi-Component' and 'None' (if it has no georeference).
Extra_Georeference	No	Array	Extra reference points, applied to only multi-component reference. Composed by a series of geometric coordinates and corresponding geographic coordinates.
Contained_Components	No	Array	List of the components that contained by this one.

4.3.3 Realization of Positioning Methods

Except for inheriting the POI-based Inter-georeference from **Manpo Beta**, the new version of **Manpo** has introduced more positioning methods and expected them to be able to overcome the shortages of POI-based Inter-georeference.

The usage of two-point based similarity transformation is extended to not only POI. Extra

control points, which will be invisible to final users, can be added to the maps and used for positioning. Although it may be convenient for authors to input only POI's as control points, the method has some shortcomings. Firstly, the POI's may not be the best control points, because sometimes it is not easy to confirm the exact location and make precise correspondence of POI's in map images and geographic spaces. Secondly, the distribution of POI's in a map may be not even, and some part may become lack of control points. For such problems, extra control points can be added to locations that easy to be confirmed both on the map images and the geographic spaces, such as road intersections, corners of buildings, point-shaped landmarks, and so on. At the same time, they should be deployed in places have less POI.

Except for point-based positioning, this new version also starts to support line-based positioning. A linear referencing algorithm has been developed to use the polyline components to match user's locations on them, especially for the walking routes.

Multiple mapping regions and non-mapping regions are supported, especially for the pages of guidebooks, which may have multiple maps and non-map areas in the same page. In such case, user's current location may be shown in different maps at the same time.

4.3.4 Main Realized Functions

Current **Manpo Editor** realized the whole workflow of importing map images, adding and editing graphic components, adding and editing georeferences to the components, and also adding extra media to the components. After inputting necessary information for the content (with an interface shown in Figure 4.9), user will come to a list of pages to select image of the page and input some necessary information (with an interface shown in Figure 4.10). And then, user can edit the page. The interface (as shown in Figure 4.11) includes a list of all the components in the page, information of current component, and a view of the image with graphic components explicitly displayed on it. User can add and edit components by the following steps:

- (1) Add a new component by tapping the "plus" button and select a type of it.
- (2) Edit the graphics by moving and zooming the image and tapping the buttons on the tool bar.
- (3) Add georeference (which usually means a geographic feature) to the component, by select from a list of already inputted ones or creating a new one of a chosen type.
- (4) Edit the geographic feature in another view (as shown in Figure 4.12). This step includes inputting the geographic coordinates using web maps (Apple's Maps), and inputting extra media like photos, audio and text. In this view, user can choose to

display the graphic component in map image and the geographic feature in web maps side-by-side.

User can also edit mapping regions (in **Manpo Editor** they are treated as a special type of graphic components) on a page by the following steps:

- (1) Add a new component by tapping the “plus” button and select the type as “Map”.
- (2) Edit the graphics (rectangle) by moving and zooming the image confirm two corner points.
- (3) Edit the georeferences in another view (as shown in Figure 4.13). In this view, there is a list of all the components that possible to become control points or lines for the mapping region and all the extra control points, also they are shown on the map image at the same time. User can choose to enable or disable each component by tapping in the list or in the map image. User can also input and edit extra control points to the region using the view of image and the view of web maps, which are displayed side-by-side, to input the graphic and geographic coordinates.
- (4) Newly added components will be checked if it is contained by existing mapping regions, and the application will let user to choose if use it as georeference or not.

The functions of **Manpo Viewer** is extended compare to **Manpo Beta** in the following aspects (the main interfaces is shown in Figure 4.14):

- (1) User’s location can activate and highlight multiple components in different types (as shown in Figure 4.14).
- (2) User’s position on the image is calculated base on multi-component georeferences, and can be displayed in multiple mapping regions.
- (3) User can view extra contents of a component with the view of the illustrated map or page of guidebook side-by-side, while an indicator will show the component’s position (as shown in Figure 4.15).
- (4) User can view the illustrated map or page of guidebook with the web maps side-by-side, while user’s location and trajectories are displayed in both views at the same time (as shown in Figure 4.16).
- (5) A location-based query function can be used to get a list of all activated components in different pages (as shown in Figure 4.17).

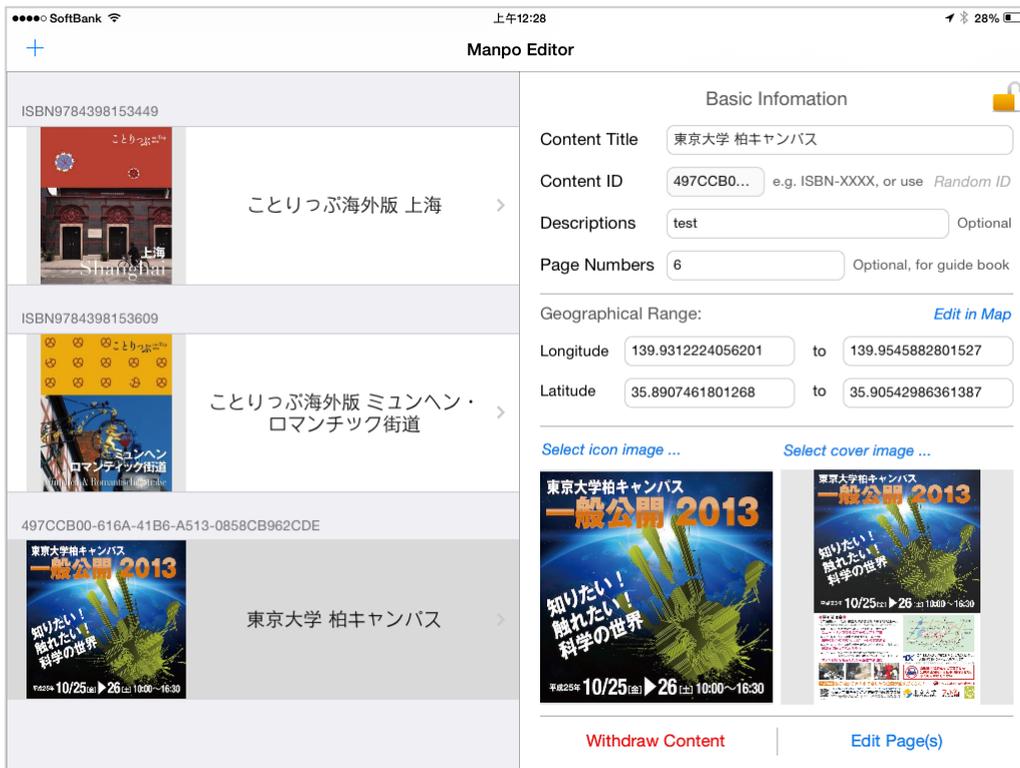


Figure 4.9. Interface for editing basic information of a content set (book) in **Manpo Editor** (On the left is a list of books, while on the right is the basic information of a chosen book.)

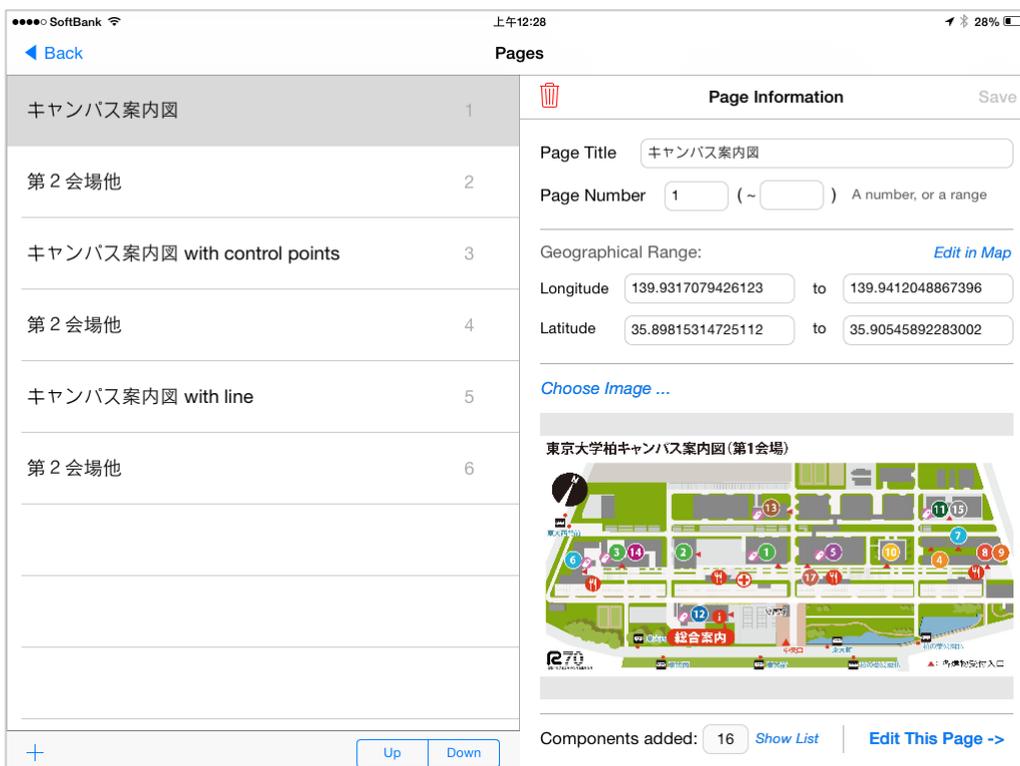


Figure 4.10. Interface for editing basic information of a page in **Manpo Editor** (On the left is a list of pages, while on the right is the basic information of a chosen page.)

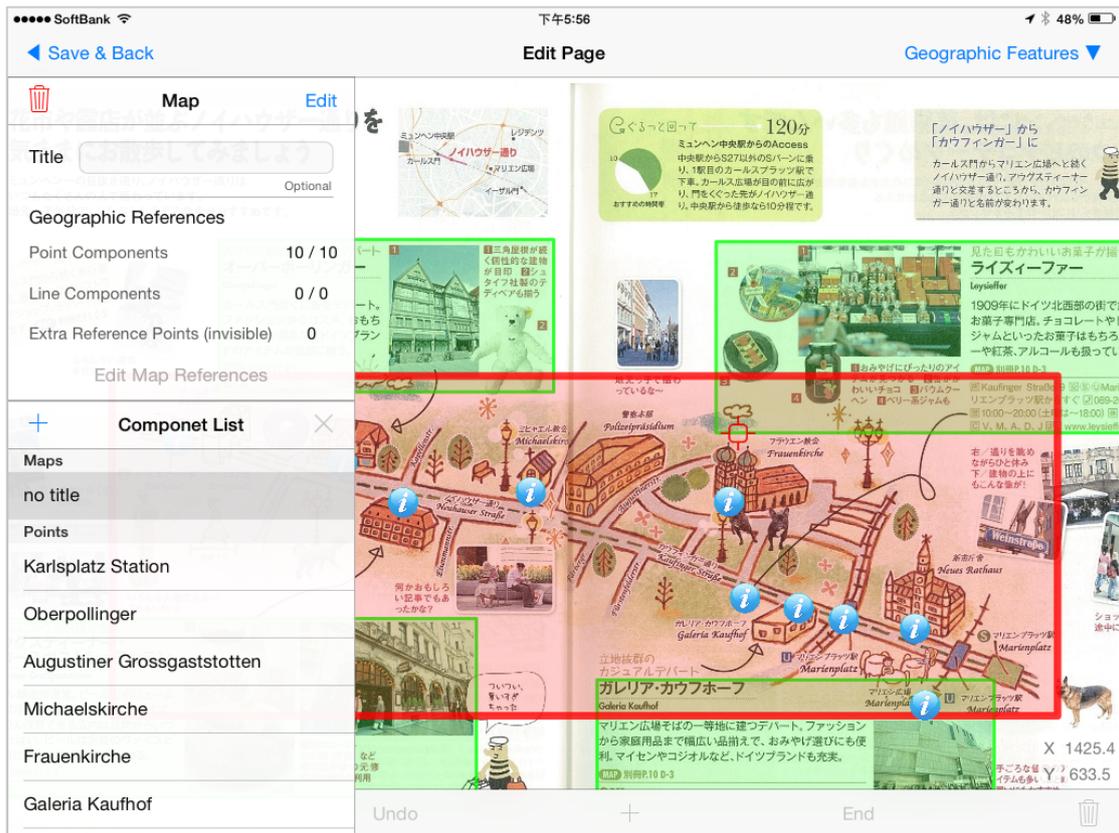


Figure 4.11. Main interface for editing graphic components in a page in **Manpo Editor** (On the left-bottom is a list of all graphic components in the image. On top of the list is the basic information of the chosen component. On the right is for displaying the image and components, in which the blue “i” icons show the point components, the green rectangles show the rectangle components, the red rectangle is a mapping region that being chosen. On bottom of the image is a tool bar for editing the graphics. The page of the guidebook is provided by Shobunsha Publications Inc.)

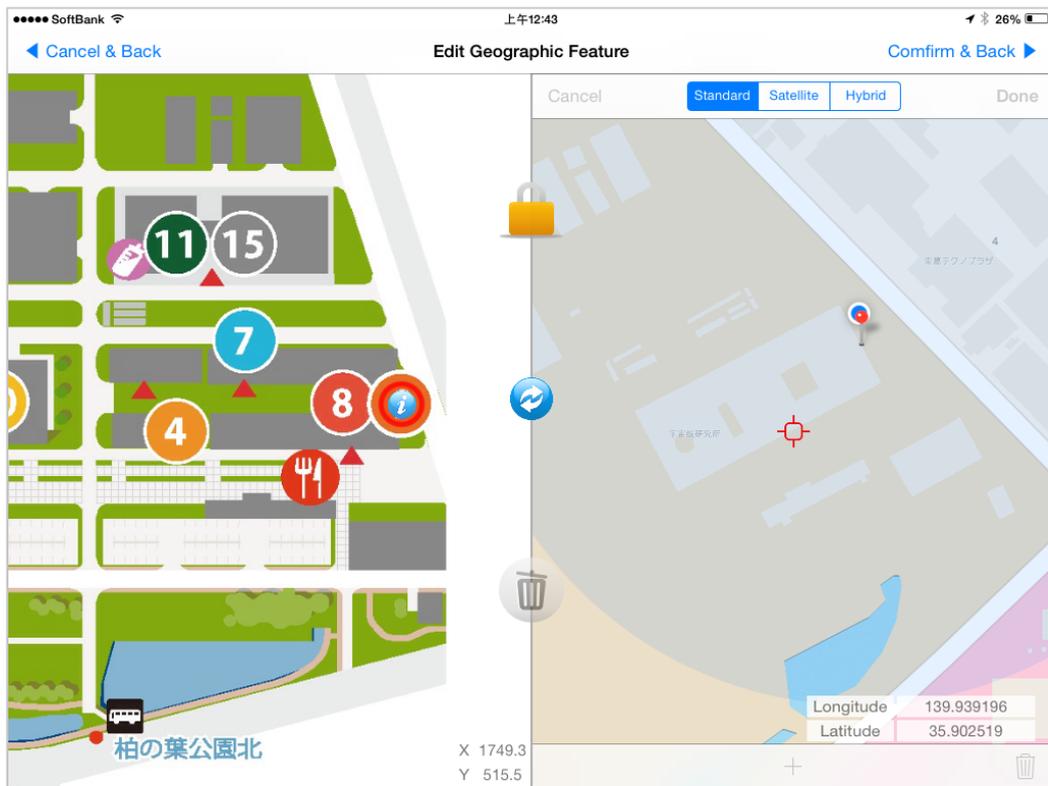
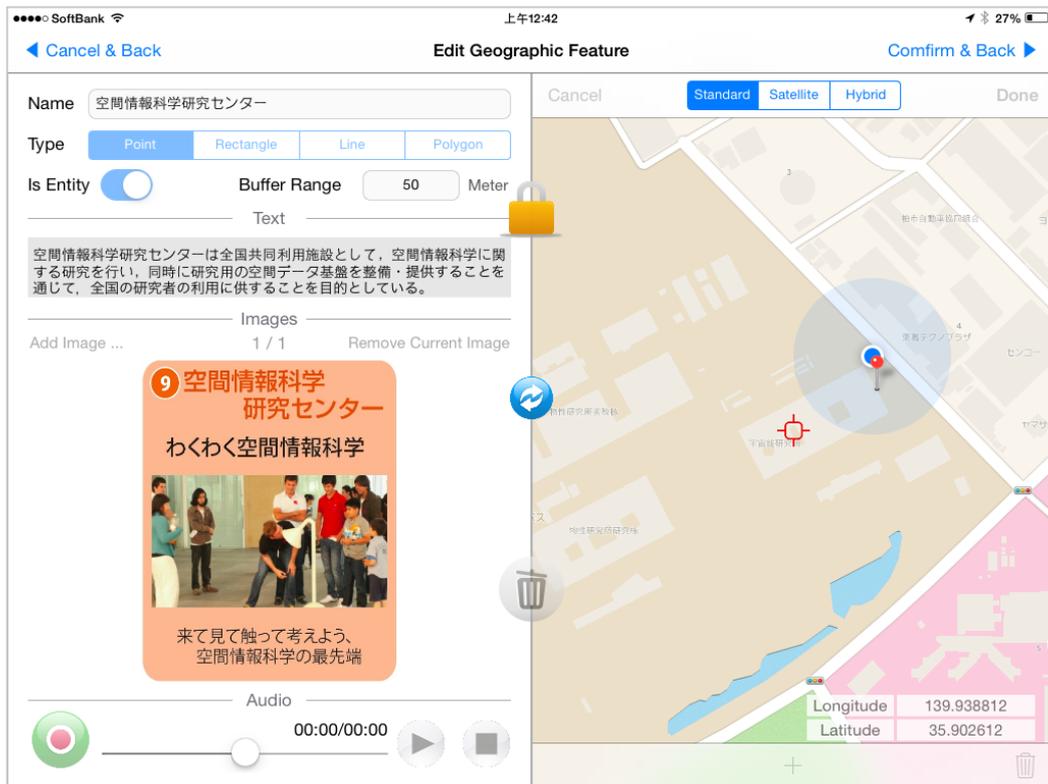


Figure 4.12. Interfaces for editing georeference of a graphic component in **Manpo Editor** (Upper: basic information and extra media of the georeference can be edited on the left, while the location of the georeference can be edited on Apple's Maps on the right; Lower: the position of the graphic component in the image is shown on the left while editing its geographic location on the right.)

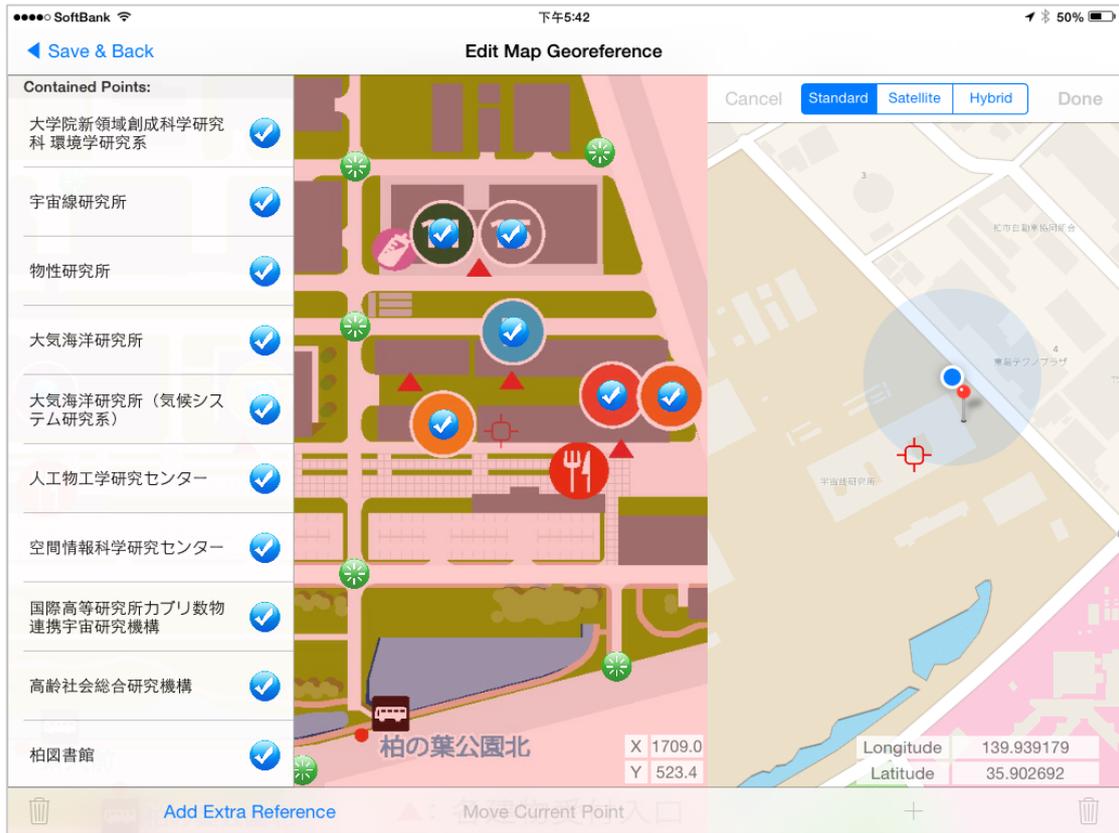


Figure 4.13. Interface for editing control points and lines of a mapping region in **Manpo Editor** (On the left is a list of all point and line components that can be used for positioning in this mapping region, as well as the extra control points. In the middle is a view for displaying the components and adding or editing the position of extra control points. On the right is a view for displaying geographic location of the chosen component, and for editing the geographic location of the chosen extra control point.)



Figure 4.14. Main interface of Manpo Viewer

(With user's current location displayed in a pink icon, trajectories displayed in dots, while the nearby two point components and two rectangle components are invoked and highlighted. The page of the guidebook is provided by Shobunsha Publications Inc.)



Figure 4.15. Viewing extra content (on the left) of a graphic component using **Manpo Viewer**



Figure 4.16. Displaying user's moving trajectories on the illustrated map (on the right) and on the web mapping (on the left, Apple's Maps) side-by-side using **Manpo Viewer**



Figure 4.17. Query nearby attractions of the book or content set using **Manpo Viewer** (Left is the list of results. The page of the guidebook is provided by Shobunsha Publications Inc.)

4.4 Conclusion

This chapter has reviewed the progresses of the developments of prototypes and applications that implemented the framework of human-centered mobile mapping and the positioning methods on distorted maps. Although the early prototypes – **Manpo Alpha** and **Manpo Beta** – are still simple in functionality, they have realized the whole workflow of geo-enabling conventional maps and integrate them to location-aware mobile applications for walking tours, and have shown the feasibility of the proposed HCMM framework with their usability. The later prototypes – the newly developed **Manpo Editor** and **Manpo Viewer** – have been extended to make a more complete realization of geo-metadata and more complex positioning methods, in order to show their capability and potential to be used for more complex and professional use cases, such as tourist guidebooks. However, such extension may be a trade-off with certain loss of usability for ordinary and non-professional users.

These prototypes also have shown the possibility of stimulating the creativity of ordinary users to produce more and more interesting location-based personal contents on various geo-enabled human-centered maps in user tests. More discussions about the experiments using the prototypes will be discussed in the next chapter.

Chapter 5

Experiments and Discussions

5.1 Experiments of Positioning Methods in Distorted Maps

5.1.1 Target of the Experiments

For testing the effectiveness and accuracy of the realized positioning methods, experiments have been conducted using **Manpo Editor** and **Manpo Viewer**. **Manpo Editor** has been used to create content applying POI's, extra control points and control lines on an illustrated map. Then, an experimental content is used by **Manpo Viewer** to examine the positioning results using simulated and real moving trajectories.

When using **Manpo Viewer** on iPhone or iPad, the error of positioning on distorted maps basically comes from three sources: (1) error inherited from device (e.g., GPS error), (2) error caused by positioning algorithms, (3) error of control points (including POI's) and lines deployments. In this experiment, the error in the deployments of control points and lines are not the target for analyses, so it is minimized as much as possible by placing the control points and lines cautiously, although it is impossible to be totally eliminated. Error caused by the positioning algorithms is focused in the experiment. For eliminating the error inherited from device, simulated moving trajectories are used. However, in real use, error inherited from device should never be ignored, so real moving trajectories collected while using **Manpo Viewer** are also examined. With the trajectory data of geographic coordinates, the following combinations of the uses of POI's, extra control points and control lines will be used to generate trajectories in image coordinates and display them on the map images:

- (1) Only POI's are used as control points;
- (2) POI's and extra control points;
- (3) POI's and control lines;
- (4) POI's, control lines and extra control points.

It must be noted that, the walking route maps designed for sightseeing are usually large-scale. This research has mainly applied the proposed framework and the positioning methods to large-scale maps. Therefore, the experiments discuss only the cases of large-scale maps, and the results may not be appropriate for small-scale maps.

5.1.2 Materials for the Experiments



Figure 5.1. The campus map of Kashiwa Campus, the University of Tokyo (left) and its area shown in Google Maps (right)



Figure 5.2. The placement of POI's, extra control points and control lines in the campus map

Table 5.1. The names, image coordinates and geographic coordinates of the POI's

Number	Name	Image Coordinates (x, y)	Geographic Coordinates (latitude, longitude)
1	大学院新領域創成科学研究科 基盤科学研究系	933.2, 482.4	35.901381,139.936045
2	大学院新領域創成科学研究科 生命科学系	591.2, 482.4	35.900801,139.934634
3	大学院新領域創成科学研究科 環境学研究系	317.5, 483.1	35.900384,139.933608
4	宇宙線研究所	1646.0, 515.9	35.902409,139.938764
5	物性研究所	1207.4, 482.4	35.901843,139.937098
6	大気海洋研究所	136.8, 514.9	35.899903,139.932885
7	大気海洋研究所(気候システム研究系)	1723.1, 413.6	35.902849,139.938858
8	人工物工学研究センター	1831.5, 483.6	35.902805,139.939324
9	空間情報科学研究センター	1897.7, 485.4	35.902913,139.939585
10	国際高等研究所カブリ数物連携宇宙研究機構	1443.8, 482.7	35.902177,139.937953
11	高齢社会総合研究機構	1645.9, 303.9	35.903136,139.938310
12	柏図書館	656.3, 739.4	35.899971,139.935566
13	環境安全研究センター	951.1, 298.6	35.902067,139.935691
14	国際センター柏オフィス(柏 IO)	393.2, 483.1	35.900479,139.933907
15	情報基盤センター	1721.2, 304.7	35.903251,139.938598

Extra Control Points

Sixteen extra control points are added to the campus map in the road corners, intersections and building's corners. As the POI's are mainly located at the belt of buildings from the left to the right in the middle part of the map, so the extra control points are placed more in the areas have less POI's. Their positions in the map image are shown in Figure 5.2 using red circles, while their locations in Google Maps are shown in Figure 5.3 using red drops. Their coordinates are listed in Table 5.2.

Control Lines

Two control lines are added to estimate the suggested walking routes. The first line (*Line 1*) is from the central entrance to POI Number Eight, and the second one (*Line 2*) is from the POI Number Eight to POI Number Twelve, as shown in Figure 5.2 using purple lines. Their geographic locations on Google Maps are shown in Figure 5.3 also in purple lines. The coordinates of the points composing the polylines are shown in Table 5.3. The effective buffer range of the two lines are set differently, for which *Line 1* is ten meters, while *Line 2* is twenty meters.

Table 5.2. The image coordinates and geographic coordinates of the extra control points

Image Coordinates (x, y)	Geographic Coordinates (latitude, longitude)
532.3, 407.5	35.900988,139.934194
1040.6, 407.8	35.901859,139.936275
1548.4, 407.5	35.902660,139.938178
1548.8, 229.9	35.903287,139.937765
1817.8, 214.4	35.903758,139.938711
1547.6, 681.4	35.901668,139.938796
1041.3, 681.7	35.900882,139.936921
1836.5, 784.2	35.901751,139.940128
1490.4, 899.0	35.900739,139.938997
1042.0, 892.5	35.900014,139.937479
355.3, 896.8	35.898797,139.934387
336.1, 704.9	35.899409,139.933907
528.9, 230.1	35.901570,139.933815
304.3, 248.7	35.901081,139.932782
1041.0, 232.0	35.902472,139.935871
1239.4, 247.3	35.902632,139.936581

Table 5.3. The image coordinates and geographic coordinates of the points composing the two control lines

Image Coordinates of Line 1 (x, y)	Geographic Coordinates of Line 1 (latitude, longitude)	Image Coordinates of Line 2 (x, y)	Geographic Coordinates of Line 2 (latitude, longitude)
1043.6, 869.4	35.900178,139.937367	1838.1, 407.6	35.903080,139.939303
1041.1, 683.3	35.900876,139.936906	1041.4, 407.6	35.901852,139.936337
1039.4, 543.1	35.901328,139.936600	533.4, 407.6	35.900944,139.934199
1358.9, 542.2	35.902178,139.938494	533.4, 682.4	35.899967,139.934856
1842.5, 543.1	35.902671,139.939601	734.3, 683.5	35.900341,139.935767

Experimental Manpo Content

With the map image, data of POI's, control line and extra control points, a set of *Manpo Content* composed by four pages has been made using different combinations of the materials. The combinations used in the pages are shown in Table 5.4.

Table 5.4. The combinations of POI's, extra control points and control lines in the pages of the experimental *Manpo Content*

Page	POI's	Extra control points	Control lines
1	○		
2	○	○	
3	○		○
4	○	○	○



Figure 5.4. The experimental walking route on the campus map (left) and Google Maps (right)



Figure 5.5. Simulated moving trajectory on Google Maps

Experimental Walking Route

For testing the effectiveness of positioning all over the map, the experimental walking route has covers the main roads inside and outside the campus in the represented area of the campus map. Figure 5.4 shows the walking route on the campus map as well as on Google Maps. In ideal case, if user follows the route, the results of positioning of user's current location and moving trajectories should be located on the routes in the campus map.

Simulated Moving Trajectory

A small program has been developed to generate simulated moving trajectories by setting key points and interpolating coordinates equally between two neighboring key points. The program runs on iOS platform and use Apple's Maps to input the key points. The time interval between two interpolated points is ten seconds, while the distance between them is around thirteen meters, as to estimate a human walking speed of 4 to 5 km/h. A randomized and evenly distributed error is added to each coordinates, in order to estimate the uncertainty of moving speed and direction. In this experiment, the up limit of the error is set to 20% of the distance between two interpolated points. Figure 5.5 shows all the 261 dots of the simulated moving trajectory used in this experiment on Google Maps.



Figure 5.6. The author's experimental moving trajectory on Google Maps

Real Moving Trajectory

The author has collected the real moving trajectory by using **Manpo Viewer** when walking in the campus following the experimental route. The locations of the device was recorded every ten seconds. Figure 5.6 shows all the 253 dots of the author's moving trajectory on Google Maps. The interruption of the trajectory is because the road was under construction when the experiment was conducted. The GPS error in this trajectory is not so significant, as

in the GPS log data, 11 out of the 253 records have the accuracy of 10 meters, while the rest 242 records have the accuracy of 5 meters. However, it can still be found from the figures that the trajectory affected by GPS error is more irregular compare to the simulated one.

5.1.3 Comparison Using Simulated Moving Trajectory without GPS Error

The simulated moving trajectory has been imported to **Manpo Viewer**. And then, each geographic coordinate in the trajectory is converted to image coordinate based on the control points or lines in each page. Finally the dots composing the trajectory are displayed on the map image using **Manpo Viewer**'s playback functions. For convenience of comparison, experimental route, which means the expected trajectory, is added to the map image, as well as the POI's, extra control points and control lines used in each page.

Page 1: only POI's are used as control points

The result is shown in Figure 5.7, and it can be easily found that the areas marked with red dashed ellipses have distinct error as the dots have distinct distances from the expected moving path. Such areas have less POI's or are far away from the POI's. On the other hand, the results in other areas are basically acceptable in use.



Figure 5.7. Simulated moving trajectory displayed on Page 1 as a result of positioning using only POI's
(The red dashed ellipses show the areas have distinct error.)

Page 2: POI's and extra control points are used

The result is shown in Figure 5.8. Comparing with Figure 5.7, the error in the same areas marked with red dashed ellipses have been reduced significantly. The use of extra control points has increased the density of control points all over the map, and increased the accuracy in the areas contain no POI's. Although the calculated trajectory cannot exactly match the

expected moving path, the overall result can be considered effective for real uses.



Figure 5.8. Simulated moving trajectory displayed on Page 2 as a result of positioning using POI's and extra control points
(The red dashed ellipses show the same areas as in Figure 5.7, where the error is reduced compare to that in Page 1.)



Figure 5.9. Simulated moving trajectory displayed on Page 3 as a result of positioning using POI's and control lines
(The red dashed ellipses show the dots matched to the line by mistake.)

Page 3: POI's and control lines are used

The result is shown in Figure 5.9. Compare to Figure 5.7, it is easy to find the dots in the trajectory are matched to the control lines when they are near the line, while in other areas the results are the same as Page 1 and inherited the same error. However, the trajectory may be matched to the control lines by mistake when the dots are just near the lines, but the moving

direction is not along the lines. The red dashed ellipses in Figure 5.9 have shown some examples of this kind of error.

Page 4: POI's, control lines and extra control points are all used

The result is shown in Figure 5.10. Similar to Page 3, the dots in the trajectory are matched to the control lines when they are near the line, while in other areas the results are the same as Page 2 and inherited the same error. Similarly, there are dots matched to the lines by mistake. Generally, the result in Page 4 can be considered as the best one in the four combinations.



Figure 5.10. Simulated moving trajectory displayed on Page 4 as a result of positioning using POI's, control lines and extra control points
(The red dashed ellipses show the dots matched to the line by mistake.)

5.1.4 Comparison Using Real Moving Trajectory with GPS Error

The author has walked in the campus following the experimental route while using the content with **Manpo Viewer**. The location of the author was shown in the map and was recorded every ten seconds. And then, using **Manpo Viewer**'s playback functions, the results of positioning are shown as the calculated dots of the author's trajectory in the four pages.

Page 1: only POI's are used as control points

The result is shown in Figure 5.11. Similar to Figure 5.7, the accuracy of the areas near the POI is better than that of the areas far from the POI. Because the GPS error is involved, the error becomes more distinct. The red dashed ellipses have shown the areas have distinct error.



Figure 5.11. The author’s moving trajectory displayed on Page 1 as a result of positioning using only POI’s
(The red dashed ellipses show the areas have distinct error.)

Page 2: POI’s and extra control points are used

The result is shown in Figure 5.12. Generally, compare to Figure 5.11, with the help of extra control points, the accuracy is significantly improved in the areas have less POI’s. As the GPS error is not distinct, the overall result is effective in practical uses.



Figure 5.12. The author’s moving trajectory displayed on Page 2 as a result of positioning using POI’s and extra control points
(The red dashed ellipses show the same areas as in Figure 5.11, where the error is reduced compare to that in Page 1.)

Page 3: POI's and control lines are used

The result is shown in Figure 5.13. Similar to the simulated trajectory, the dots in the trajectory are matched to the control lines when they are near the line, while in other areas the results are the same as Page 1 and inherited the same error. Same error of the dots matched to the control lines by mistake also happens. On the other hand, some dots are close to the lines but not matched to them, as shown in Figure 5.13 by yellow dashed ellipses. This may be a consequence of that the setting of buffer range is too small and the GPS error has made the coordinates out of the range.



Figure 5.13. The author's moving trajectory displayed on Page 3 as a result of positioning using POI's and control lines
(The red dashed ellipses show the dots matched to the line by mistake; the yellow dashed ellipses show the dots close to the lines but not matched to them.)

Page 4: POI's, control lines and extra control points are all used

The result is shown in Figure 5.14. Generally, it combined the advantages showed in Page 2 and 3 while also inherited the problems. Still, the result in Page 4 can be considered as the best one in the four combinations.

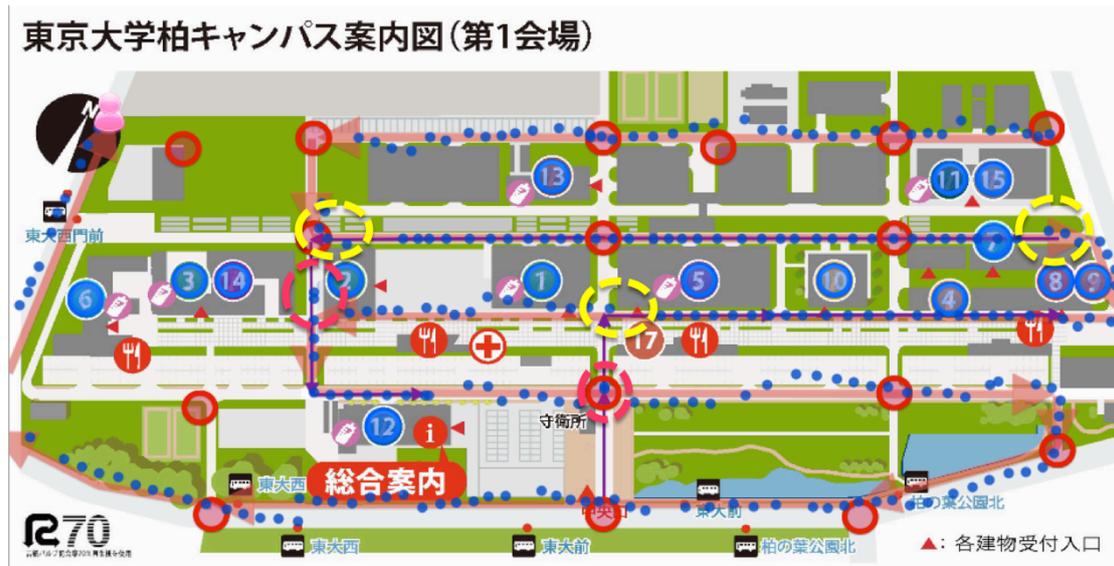


Figure 5.14. The author’s moving trajectory displayed on Page 4 as a result of positioning using POI’s, control lines and extra control points
(The red dashed ellipses show the dots matched to the line by mistake; the yellow dashed ellipses show the dots close to the lines but not matched to them.)

5.1.5 Discussions

In conclusion, while using point-based positioning methods, the density and distribution of control points are important to achieve reliable positioning accuracy. The accuracy is usually better if the density of control points is higher and the distribution of them can cover the main areas of the map, especially the areas around the main routes. According to the error analyses of the two-point based similarity transformation in Section 3.3, increasing of the density and coverage of control points will reduce the average distance from any location in the map area to the pair of control points used for calculation, thus reduce the expected error. Although in the experiment results, the calculated trajectories on the campus map cannot precisely match the expected moving path and appear in zigzag, they are still acceptable in practical uses.

For the line-based positioning, because the user’s trajectory may not be exact straight lines while the method simply drag the coordinates within the buffer ranges, this may actually cause errors. However, the display of a smoothed trajectory is more natural to users compare to a zigzag one, and the error caused by the matching is usually smaller than the two-point based positioning methods, so the introducing of control lines can actually increase the effectiveness of positioning in distorted maps. The uses of control lines are very limited to users’ moving path, such as roads, but such areas are usually more important than others in usages like walking tours. In practical uses, the involvement of GPS error makes the situation more complex. Especially the buffer range should be determined with considering of GPS error and user’s moving range (e.g. the road width). Also, the linear referencing method used

by **Manpo** is too simple to deal with the mismatching as shown in the results of experiments.

It must be noted that the effectiveness of the positioning methods is also depending on the map. When discussing the results of this experiment, it should not be ignore that the distortions in the map used are relatively small. The effects of map distortions to the positioning methods are involved in the next section, together with the cause of error ignored in this experiment, which is the placement of control points and lines.

5.2 User Tests of *Manpo*

During the development progress of **Manpo**, the authoring functions for converting conventional maps to geo-enabled interactive mobile mapping are tested by members of Arikawa Lab. in the Center for Spatial Information Science (CSIS), the University of Tokyo. However, the users in the develop tests all have had certain preconceptions of the prototype, such as the purposes and limitations. For testing the functionality and usability of the prototype, user tests are needed, especially to confirm the easiness of geo-enabling conventional maps by ordinary users who have less knowledge in the field of spatial information sciences.

During April to July in 2013, **Manpo Beta** was used as teaching appliance in a course held in Aoyama Gakuin University to the undergraduate students major in Media (who had few background in geography or spatial information sciences). Students were asked to use **Manpo Beta** to create contents for 10-minutes walking excursions of the surrounding areas near their campus. The excursions were set to focus on different themes of different eras in the history. The students worked in six groups, and have drawn their own maps by hand. They also prepared photos, texts and audios for creating POI's on the maps.

After creating *Manpo Contents* as authors, the students experienced another student or group's work as users by walking with **Manpo** in the real places. In the final classes of both courses, students made presentations to introduce their contents and experiences as both authors and users.

In their presentation, many students complained about the accuracy of positioning on their hand-drawn maps. After the class, their *Manpo Contents* were examined to find the issues, including the mistakes made by the students in creating content, which affected the quality of positioning. Then, their contents, especially the deployment of POI's, were modified and tested again.

In the year of 2014, **Manpo** was used in the same course (but for different students) in Aoyama Gakuin University. At first, the students experienced last year's *Manpo Contents*, which were already modified, as user tests of browsing functions. Then, they were also asked to create their own *Manpo Content* as user tests of authoring functions. The difference is that

they were informed about the mistakes made by last year's students before they start. Again, their contents were experienced and examined to find the relevant issues of authoring functions. The following part of this section will introduce the experiments in the two courses and the findings.

5.2.1 Manpo Content Created by Testers

In the class of 2013, six groups of the students have created *Manpo Content* using their own hand-drawn maps; while in the class of 2014, there have been four groups. Table 5.5 and Table 5.6 show the materials used by each group, and their hand-drawn maps are shown in Figure 5.15 and Figure 5.16. As the experiment used **Manpo Beta**, only POI's are used as control points for positioning, and the lines here do not have georeferences.

Generally speaking, the quality of hand-drawn maps and *Manpo Contents* in the course in 2014 is better than those in 2013, because the students in 2014 were informed about the mistakes made by the students in 2013. Still, they have problems in common. It can be found that the quality of their works, especially the usability of positioning, is strongly related to author's experience and skills. The following 5.2.2 and 5.2.3 will discuss two main issues.

Table 5.5. Materials used by each group in their *Manpo Content* in 2013

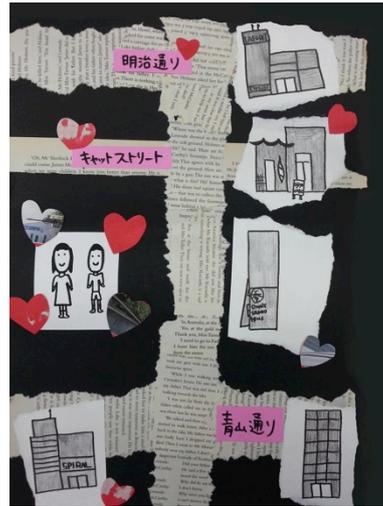
Group Title	POI's	POI's with photos	POI's with Audio	Lines	Lines with audio
1 江戸の農地を巡る旅 (A short trip to farmlands in Edo era)	6	6	6	3	1
2 青山今昔デート (A now-past date in Aoyama)	6	6	0	5	5
3 文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)	6	6	6	0	0
4 昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)	4	4	4	1	0
5 庶民から見た青山 (Aoyama in ordinary people's eyes)	4	4	4	1	0
6 通学路の歴史を知る (Finding history behind the way to school)	6	6	6	0	0

Table 5.6. Materials used by each group in their *Manpo Content* in 2014

Group Title	POI's	POI's with photos	POI's with Audio	Lines	Lines with audio
1 友達と行く！外苑前散歩 (Let's walk around Gaien-mae with friends)	6	6	6	1	1
2 青山かたちツアー (Aoyama shape tour)	5	5	5	1	0
3 シニア世代が巡る若者の街渋谷 (Introduction to Shibuya as a town of young people for seniors)	7	7	7	6	5
4 貴女に捧ぐ、癒しの明治神宮 (A tribute to elegant ladies of a healing waking at Meiji Shrine)	6	6	5	5	5



Group 1



Group 2



Group 3



Group 4



Group 5



Group 6

Figure 5.15. Hand-drawn maps created by students in 2013



Group 1



Group 2



Group 3



Group 4

Figure 5.16. Hand-drawn maps created by students in 2014

5.2.2 Effects of Distortions in Hand-drawn Maps

Although the students have done good jobs in drawing the maps, most of the six hand-drawn maps in 2013 have distinct distortions, and some even have serious mistakes, because they are not majored in Cartography or other related specialties. The problems of the six maps are listed in Table 5.7.

Take Group 3 as an example, the appearance of the map is nice and it looks provide enough geographic information like roads, stations and landmarks distinctively. However, if examined carefully and compared to surveyed map, the mistake can be easily found. As shown in Figure 5.17, compare to the same area in Google Maps, from the shapes of the roads and their relations with “青山霊園”, it can be found that the students have mistaken “みゆき通り” with “外苑西通り”. This mistake has made a large area between the two roads disappear in the map, and the spatial relations of POI's and the road are also mistaken. With such mistakes, it is almost impossible for the students to achieve good result in

Table 5.7. Distortions and mistakes in students' hand-drawn maps in the course in 2013

Group	Distortions	Mistakes
1	The roads seem to be drawn based on surveyed maps, and have less distortion. The temples and shrines are slightly exaggerated.	No obvious mistakes.
2	The streets are largely exaggerated in width. The distance between the streets キャットストリート and 明治道り is larger than usual. The buildings depicted are in side view, and the sizes are also enlarged. The two buildings at the bottom are too close to the intersection than real situation.	Some buildings are on the road.
3	The roads are wider than usual, and the places of interest and landmarks according to the theme are depicted using large drawings.	The road with tag “みゆき通り” is actually another road (外苑西通り). The area between the two roads is missing in the map (as shown in Figure 5.17). The related places of interest in or near the missing area are also depicted at the wrong places.
4	The buildings as places of interest are depicted in side view and enlarged strongly. Decorations captured large areas of the map. The geographic information is too little to judge the overall distortion.	Only the focused streets of the walking route are truncated and depicted, while others are omitted. The geographic information is too little for users not familiar to the area to locate themselves and the POI's, especially if they are not on the route.
5	The geographic information is too little to judge the overall distortion.	Too little geographic information is provided. Only one road, one river and four places of interest are depicted, while the places are not connected to the main road. It is difficult to be called and used as a map.
6	The widths of main streets are largely exaggerated. The distribution of the POI's along the street sides is basically correct	The depiction of the yellow building is on the street.

georeferencing the map. Figure 5.18(1) shows the disordered moving trajectory in actual use, while the actual trajectory on Apple's Maps is shown in Figure 5.18(2). Although the geographic locations of POI's are placed correctly (as shown in Figure 5.18(2) as red pins), it is impossible to achieve correct positioning in a wrong map. The content was modified carefully for our research by changing the POI's positions on the map while ignoring the tagged “みゆき通り”. The result in Figure 5.18(3) shows that the trajectory appears more regular and the shape is close to that on Apple's Maps, but it is almost impossible to fit it to the roads.



Figure 5.17. Mistakes in the map drawn by Group 3 (2013)

(The arrows indicate the wrong depiction of the road “みゆき通り”, which has caused the disappearing of the dashed area. Also, the positions of the two related POI’s that indicated using green and blue circles also have problems. The map used for comparison is from Google Maps.)



Figure 5.18. Moving trajectory on the content of Group 3 (2013) before and after the modification
 (1) The original content of Group 3, (2) Apple’s Maps, and (3) improved content.

Even if the map is basically correct in depictions of spatial relationships of the main features, large distortions can also bring difficulties to achieving effective positioning. Take Group 6 as an example, their map can be considered to have no serious mistakes, but the road focused in their theme are broadened distinctively. It can be found from their *Manpo Content*

that, although they have placed the POI correctly in their hand-drawn map and Apples Maps, their trajectory became disordered in actual uses, which is shown in Figure 5.19(1) and compared to Figure 5.19(3). This is mainly due to the limitation of two-point similarity transformation. When the pair of POI's as control points are actually close but depicted far from each other, the calculation of positions using them will have significant error. The POI's on different sides of the distinctively broadened road are typical examples of this effect, which are shown in Figure 5.19 by the red dashed ellipses. In such cases, the application of line-based positioning or three-point based affine transformation may be more suitable, which need to be proved by further development and experiments. The content was improved by an expert of **Manpo** under the current conditions by compromising the POI's positions on the hand-drawn map to fit the algorithm, and then make sure the trajectory is on the road. The result can be found in Figure 5.19(2).

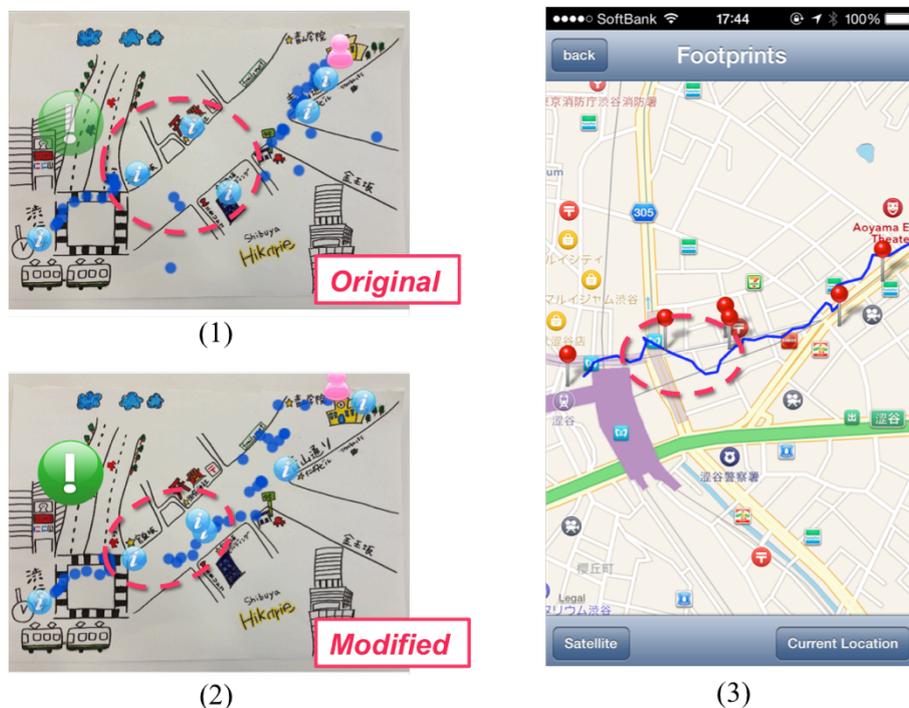


Figure 5.19. Moving trajectory on the content of Group 6 (2013) before and after the modification (1) The original content of Group 6, (2) improved content, and (3) Apple's Maps (The red dashed ellipses indicate the POI's relative distances changed by the exaggerated road width.)

The four maps drawn by the students in 2014 have become better after they were informed about the mistakes of the previous hand-drawn maps. Especially, they have paid more attention on drawing the roads correctly. As a result, except for Group 3, all the maps have no obvious mistakes.

5.2.3 Effects of Improper Placement of POI's

Except for the mistakes and large distortions in the hand-drawn maps, even if the maps have few distortions, the improper placement of POI's can also cause distinct error in positioning and even make the content unusable. Content created by Group 1 is a typical example, as the map is drawn based on surveyed map, at least the roads are more regular and accurate compare to the other hand-drawn maps. However, from Figure 5.20(1) it can be found that the trajectory is totally not on the road. After examine geographic locations of the POI's, it is made clear that most POI's are placed to wrong locations, as shown in Figure 5.20(2) and (3). Especially the three in the red dashed ellipse are totally in different and distant places. An expert of **Manpo** modified the geographic locations of the POI's, as indicated in Figure 5.20(3), and the result of positioning as the trajectory shown in Figure 5.20(4) becomes much better.

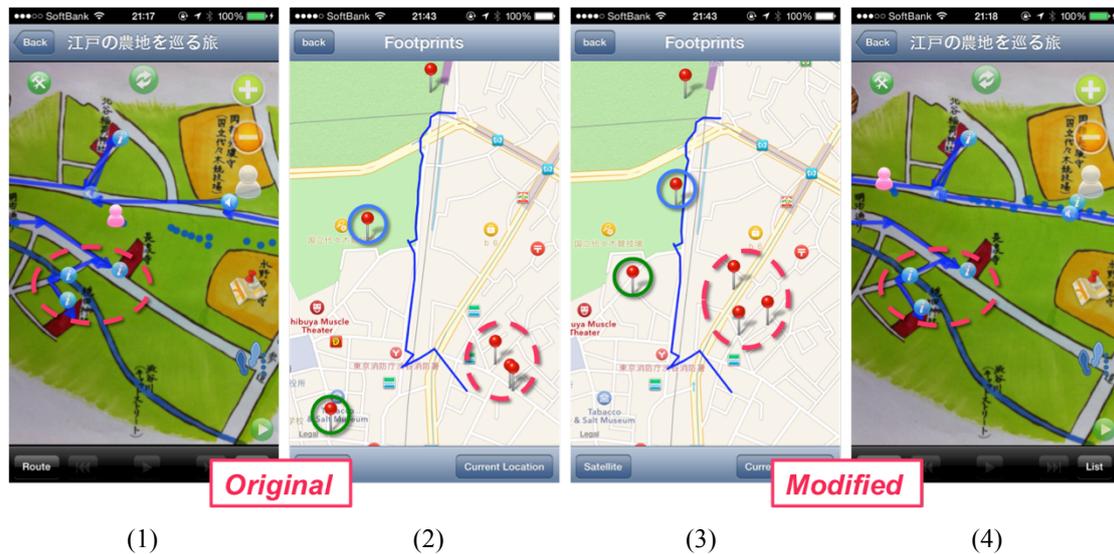


Figure 5.20. Moving trajectory on the content of Group 1 (2013) before and after the modification (1) The original content of Group 1, (2) Apple's Maps with original locations of POI's, (3) Apple's Maps with modified locations of POI's, and (4) improved content (The blue circle, green circle and red dashed ellipses indicate modifications of wrong placements of POI's.)

Another example is the content made by Group 2, which is more complex and contains different types of mistakes. The original content is shown in Figure 5.21 (1), and the trajectory is disordered when user is walking along the street. After modification, the trajectory is basically displayed on the street.

From the students' works in 2013, it can be found that the improper placement of POI's as control points means the positions of POI's on the map image and their geographic locations are not well corresponded. Such mistakes can be classified to the following types:

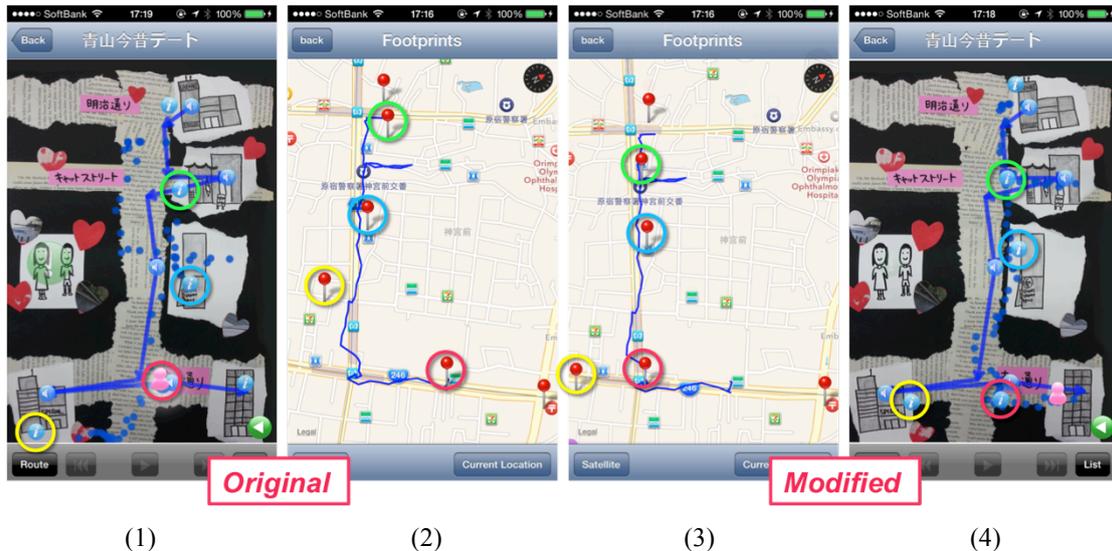


Figure 5.21. Moving trajectory on the content of Group 4 (2013) before and after the modification (1) The original content of Group 4, (2) Apple's Maps with original locations of POI's, (3) Apple's Maps with modified locations of POI's, and (4) improved content (The circles in different colors indicate the modifications of the placement of POI's both on the hand-drawn map and the geographic space.)

Type 1: Wrong geographic locations: the POI is placed to a totally different place, such as the POI in blue circle in Figure 5.21. This mistake is easy to avoid if the author input the locations of POI's carefully.

Type 2: Placing image coordinate and geographic coordinate of a POI to different parts of the same place of interest: this usually happens when the POI is used to represent a feature that is not usually presented as a point. For example, the POI in red circle in Figure 5.21 is for the street “青山通り”. The students placed it near the intersection in the hand-drawn map, but in the Apple's Map, it is in the center of the road that is far from the intersection. Author need to match the geometric and geographic positions of POI's in the same part of the feature carefully to avoid this type mistake.

Type 3: Improper placement on exaggerated drawings: the drawings of some features are largely exaggerated and cannot easily match their original shapes and locations in geographic space. For example, the POI in blue circle in Figure 5.21 is for a building, whose location can be easily confirmed in Apple's Maps, but where to put it on the exaggerated drawing of the building on the hand-drawn map becomes a problem. In **Manpo**, the placement of such POI's should consider their relative spatial relationships with other POI's and make sure such relationships in the hand-drawn map and the geographic space do not have large differences. This is for better positioning results under the limitation of positioning methods. However, to avoid such improper placement, authors need more knowledge about the mechanisms of the positioning methods.

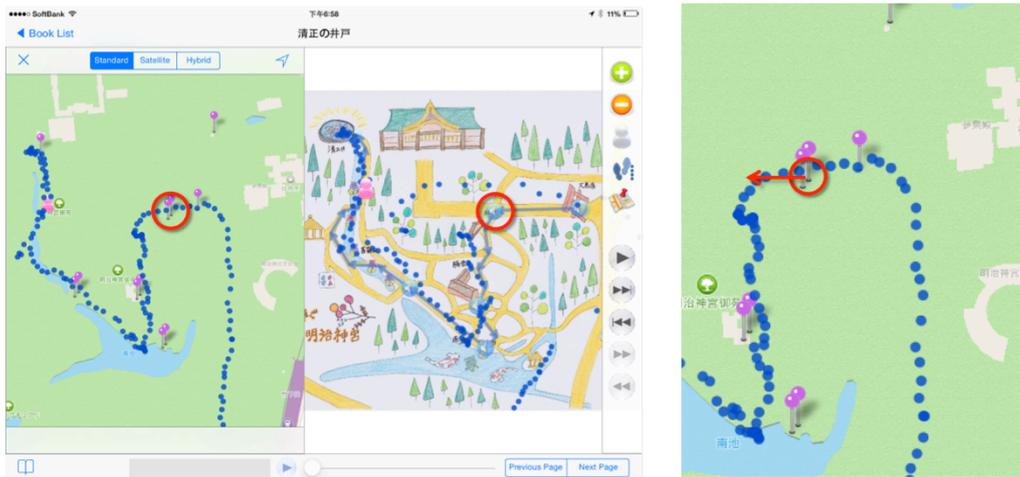


Figure 5.22. Moving trajectory on the original content of Group 4 (2014) and the mistake in geographic coordinates of a POI

In the students' works in 2014, although the overall quality is better, there are similar problems. For example, Group 4 has created a map with detailed working paths in a garden, but the walking trajectory using their content has large error in some part (as shown in Figure 5.22). It can be easily found that the error is caused by the wrong geographic location of the POI in the red circle. The students in Group 4 have made the mistake because of the insufficient information of web mapping (Apple's Maps in July 2014) about the walking paths in this area. After the POI has been modified, the result of positioning becomes better around the POI (as shown in Figure 5.23), but the right part still has large error because of the insufficiency of control points.

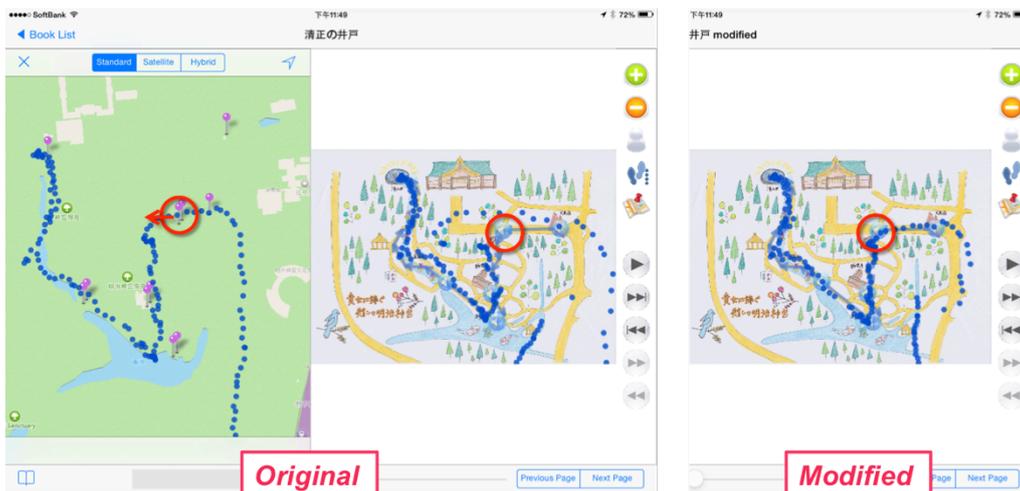


Figure 5.23. Moving trajectory on the content of Group 4 (2014) before and after modifying the mistake in geographic coordinates of a POI (in the red circle)

Typical examples of improper placement of POI's can also be found from the content created by Group 1. The hand-drawn map created by Group 1 can be considered as one of the best, in which especially the roads are represented clearly and correctly. They use drawings of the front faces to represent the buildings, and their relative positions are easy to get. However,

as shown in Figure 5.24, the result of positioning has large errors in many parts. This is because they have tried to put the POI's of some large objects, such as the sports stadiums and gyms, at the center of them. Firstly, it will become very difficult to correctly correspond their positions to their drawings on the hand-drawn map. Secondly, the POI's become far away from the walking route, which will make the possible error larger. Some POI's are not accessible, and can never be invoked by user's location. Actually, it can be found on their maps that the map creator have drawn flags with numbers on the walking route near the entrances of the stadiums as checkpoints. These flags are more suitable to be POI's and control points because their locations are easier to confirm and they are much closer to the walking route. After moving each POI to the flags, the result becomes much better (as shown in Figure 5.25).

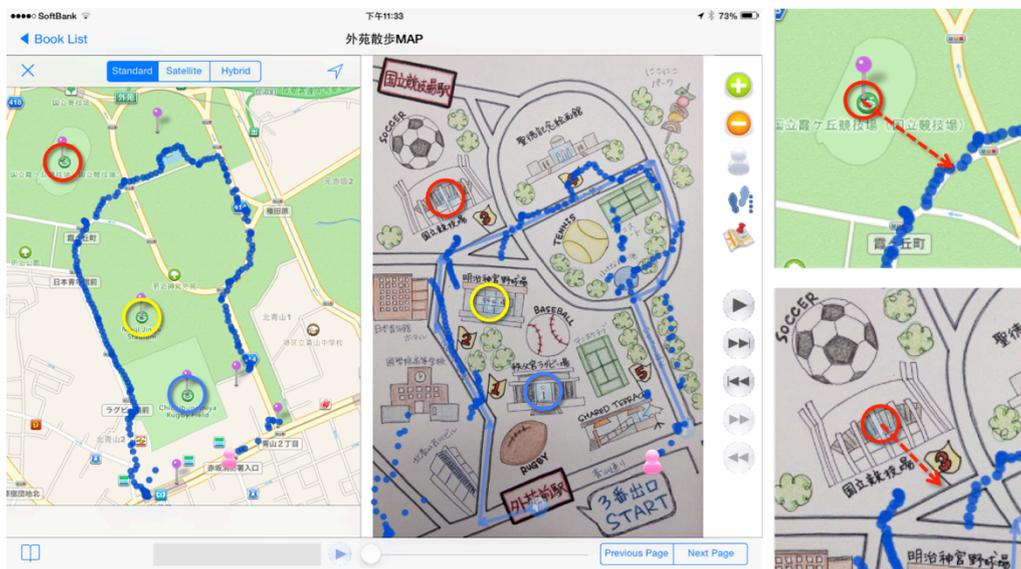


Figure 5.24. Moving trajectory on the original content of Group 1 (2014) and their improper placement of POI's

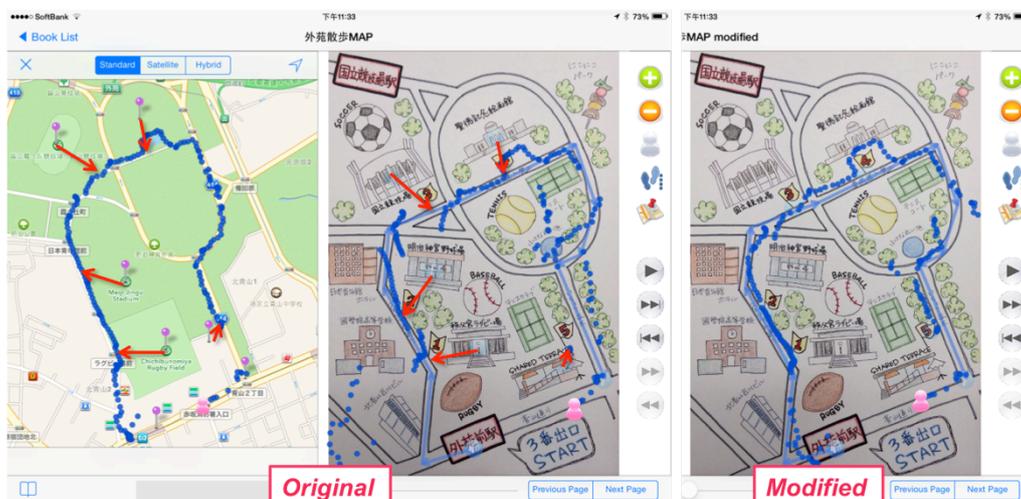


Figure 5.25. Moving trajectory on the content of Group 1 (2014) before and after modifying the placement of POI's

The *Manpo Contents* made by students in 2014 using **Manpo Beta** were converted and imported to **Manpo Editor** and **Manpo Viewer** to test the new functions of extra control points. Control points at road intersections and corners have been appended to the modified contents of Group 1 and Group 4. As shown in Figure 5.26, only small numbers (four to the content of Group 1 and three to the content of Group 4) of control points have improved the result of positioning significantly in the areas originally have no POI's.

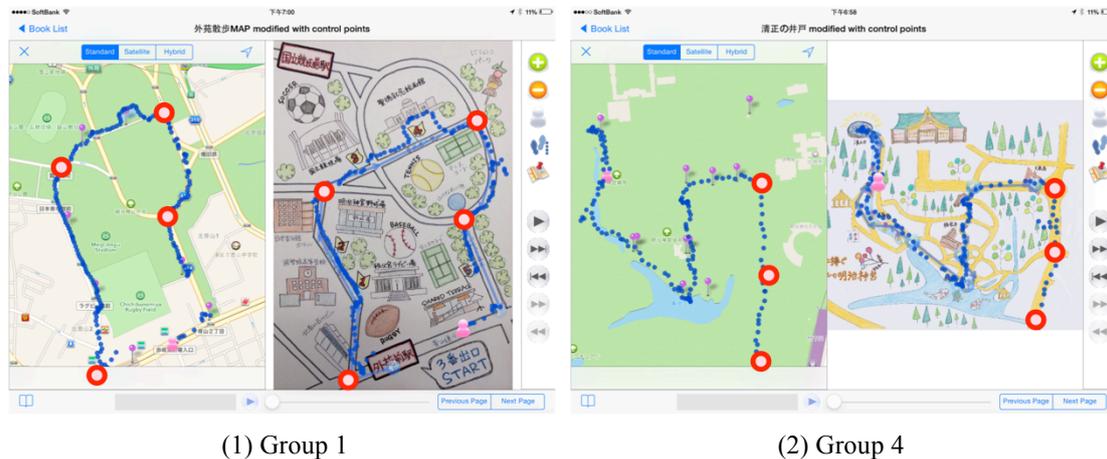


Figure 5.26. The improvement of positioning results after appending extra control points

5.2.4 User Test of Browsing Functions Using Modified Manpo Content

In the course held in Aoyama Gakuin University in 2014, the students have tried **Manpo** outdoor and experienced some of the *Manpo Content* created by previous year's students as a review of their seniors' works before they start to create their own *Manpo Content*. All of the content have been modified better than original ones, as discussed above in 5.2.2 and 5.2.3. A survey has been made through a questionnaire answered by the students, and the results are listed from Table 5.8 to Table 5.11.

Table 5.8. Results of the questionnaire answered by the students experienced the modified content (question: "How do you think about the accuracy of positioning on the analog maps?")

Content title	Number of users	Very accurate	Not so accurate, but acceptable	Not so accurate, and unacceptable	It's disturbing
青山今昔デート (A now-past date in Aoyama)	1	1	0	0	0
文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)	3	0	2	1	0
昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)	12	5	7	0	0
通学路の歴史を知る (Finding history behind the way to school)	6	1	5	0	0

Table 5.9. Results of the questionnaire answered by the students experienced the modified content (question: “Did you follow the route? Have you ever get lost?”)

Content title	Number of users	I could follow the route correctly, never got lost.	I got confused sometimes.	I often got confused.	I totally got lost in my way.
青山今昔デート (A now-past date in Aoyama)	1	1	0	0	0
文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)	3	0	3	0	0
昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)	12	10	2	0	0
通学路の歴史を知る (Finding history behind the way to school)	6	5	1	0	0

Table 5.10. Results of the questionnaire answered by the students experienced the modified content (question: “Do you often turn to web map when you are using the content?”)

Content title	Number of users	Never	Seldom	Sometimes	Often
青山今昔デート (A now-past date in Aoyama)	1	1	0	0	0
文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)	3	1	2	0	0
昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)	12	5	6	1	0
通学路の歴史を知る (Finding history behind the way to school)	6	5	1	0	0

Table 5.11. Results of the questionnaire answered by the students experienced the modified content (question: “Do you want to make such and better contents by yourself and share with your friends?”)

Content title	Number of users	Yes, I would like to try it immediately.	Yes, sounds interesting.	Anyway, not bad.	No, it's boring.
青山今昔デート (A now-past date in Aoyama)	1	0	1	0	0
文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)	3	0	3	0	0
昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)	12	3	6	3	0
通学路の歴史を知る (Finding history behind the way to school)	6	3	3	0	0

From the result of the survey, it can be confirmed that the previously almost unusable *Manpo Content* have worked well after modifications. Most students had no problem in using the positioning functions on the hand-drawn maps, and seldom turned to web maps while walking. The results of each set of content are discussed as follows:

- (1) The content “青山今昔デート (A now-past date in Aoyama)” has good reputation, but the sample is only one.

- (2) The content “文学系サブカル女子に捧ぐ (A tribute to subcultural ladies of literature)” generally has the worst performance in positioning because the mistakes in map drawing cannot be modified.
- (3) The content “昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)” seems to have better performance in positioning, but the more students turned to web maps. This is because the walking route is simple to follow, but the map provides too little geographic information, as discussed in 5.2.1.
- (4) The content “通学路の歴史を知る (Finding history behind the way to school)” has worse performance in positioning than “昭和青山 10 分散歩 (Ten minutes walking in Aoyama of Showa era)”, but less percentage of students turn to web maps, because the map provides enough geographic information for the walking tour while the positioning is also acceptable.

At the same time, it is good to see that most students are interested in making such content based on hand-drawn maps after the experiment.

5.2.5 Discussions

The user tests have shown the easiness of creating human-centered mobile mapping by ordinary users using **Manpo**'s approach. However, the quality of the content, especially the quality of positioning on distorted hand-drawn maps is not easy to achieve.

Among the mistakes made by the students, the mistakes of map drawing and the mistakes of wrong placement of POI's locations on web mapping should to be eliminated. Such mistakes can be avoided if content authors just pay more attention in drawing maps and deploying control points. The effects of map distortions and the consequent improper placement of POI's need more knowledge and experiences to deal with. The expert's modifications of the students' content and the survey after the additional experiment have shown the possibility of minimizing the error and maintaining the usability of content. However, ordinary users need to be informed more about related knowledge to get such skills. Therefore, well-designed guidelines will be important future work of this research. The guidelines should give suggestions of the principles for deploying control points more properly and accurately, in order to achieve better positioning results. Meanwhile, such guidelines will also be references to mapmakers who will design maps for **Manpo**, because they can give the implication of constraining the map distortions in a reasonable range.

In the user tests, only POI-based Inter-georeference is used. It is possible to achieve further improvement using extra control points and control lines, or even incorporating methods

using three or more control points, but this will be a trade-off of the easiness of content creating. Inputting the control points and lines also need skills and experiences.

As discussed in 3.1.2, some distorted maps can be regarded as consistent within certain small areas. When used in **Manpo**, if the pair of control points being used for positioning has crossed the inconsistent gaps and located in different consistent areas, it may cause large errors (as the example in Figure 5.19 in 5.2.2). In the future, it is possible to analyze the deformations and estimate the consistency of a map, in order to decompose the map and group the control points. Furthermore, the control points for transformations are picked up not only using distances, but also considering the consistency. It allows to eliminating some cases of positioning errors caused by using improper pairs of control points. There will be two general ways of grouping control points. The first way is from the analyses of the distortions in a map, and extracts consistent areas, then group control points in the areas. This way is more difficult to be achieved automatically by the programs, and may be more suitable for professional authors who know well of the maps they use, or for the famous maps such as Yoshida Hatsusaburo's works. The second way is from the analyses of the distribution of control points in both the graphic and geographic coordinate system (e.g., using triangulations), and then automatically groups the control points. The second way may be more general, and can be more suitable in the applications for non-professional content authors.

Last but not least, after making the content, it should be tested in the real places to see the correctness of the POI's locations and the effectiveness of positioning, and then the content can be modified and become more robust. Without this step, it is impossible to make reliable and useful human-centered mobile mapping.

5.3 Conclusion

From the experiments discussed in this chapter, it is clear that mobile positioning on distorted maps on basis of limited control points and lines is feasible. This fact is important in achieving human-centered mobile mapping, because the usability of positioning functions of mobile devices for human-centered maps and the easiness of creating human-centered mobile mapping by ordinary users are both important. Although the positioning methods realized in **Manpo** are still limited and simple, they are effective in practical uses. Their limitations and the possible ways of avoiding them are also discussed. In the future, more positioning algorithms need to be realized, tested and compared.

The user tests have shown different aspects including positive results and also problems. It is good to see that the students were able to create **Manpo** content as mobile mapping without difficulty, while the other students could enjoy their content (although had been modified by

an expert of **Manpo**) and were satisfied, because they are all real and ordinary users. This has shown the functionality and usability of the prototype. However, the mistakes made by the students as authors still presented the difficulties of creating reliable geo-enabled human-centered maps for mobile mapping by inexperienced and unskilled users. Even if the tests only require creating four to six POI's on one map, the students, who have little geographic knowledge on the mechanism of positioning, still have difficulties in achieving correct and proper POI placement. It has shown the necessity of designing effective guidelines for non-professional users to create maps with less mistakes and to deploy effective control points and lines.

Finally, it is good to see the students' creativity of making their own mobile mapping with their own maps and location-based multimedia content has been stimulated by the approaches of **Manpo**. This has shown the potential of such approaches to produce welcomed products. Such products may include various human-centered mobile mapping content and applications, the authoring tools and platforms for sharing and marketing, which can involve cartographers, illustrators, publishers, as well as companies and communities, in a new human-centered mapmaking ecosystem in the Internet era.

Chapter 6

Conclusions and Future Work

6.1 Concluding Remarks

In conclusion, this research has contributed in the following aspects:

(1) Clarifying the necessity of human-centered maps in mobile environments

Media of maps are changing from conventional printed media to rapid developing online and mobile hypermedia, but the purpose of communication still remains essential in mapmaking. The online maps, represented by currently outstanding web mapping services, has brought important new features to maps including hypermedia, dynamics, interactivity and accessibility, and therefore has extended the capability of map communication. However, this research has pointed out that the generic maps used in current web mapping are lack of diversity in map representation and are difficult to fulfill specific requirements of map communication in specific uses. Although limited by the static media, well-designed conventional maps have human-centered concerns. This research examines functionality, storytelling, aesthetics and inconsistency as important characteristics of conventional human-centered maps. Such characteristics are missing in current web mapping. This is because current approaches of mapmaking for online and mobile media consider less about human users' requirements from map communication, and human's creativity is less involved in designing diverse map representations. A survey to young mobile mapping users has shown that well-designed paper maps are still welcomed for the purposes like sightseeing, and they will be more preferred than current web mapping if the latest functions, especially GPS positioning, can be integrated.

The studies in this research have revealed the necessity of cartographic researches to combine the excellent human-centered traditions in mapmaking with the advantages of latest technologies, in order to provide more diverse and useful map products in mobile environments.

(2) Establishing a pragmatic human-centered mobile mapping framework and data model for developing practical applications

The study on good examples of existing mobile applications using maps other than web mapping has shown that the lack of effective map interactivity and the insufficient of location-aware functions are their main limitations. Such limitations are results of external

causes like the deficient of human-centered mapmaking tools, and internal defects of human-centered maps, especially the difficulties of positioning because of the immeasurable distortions. A study of use cases on both user's and author's phases has revealed the requirements in developing human-centered mapping applications and authoring tools, especially in considering of non-professional authors and users.

This research has proposed a human-centered mobile mapping framework including both authoring tools and user applications. This framework is designed for importing conventional human-centered maps to mobile devices, and converting them to interactive and geo-enabled mobile mapping by integrating geo-metadata and multimedia content to originally static maps. This research has created the concept model of geo-metadata, which includes the details composing the graphic components and georeference patterns, as the key of geo-enabling the static maps. Realizations of geo-metadata have been made in the prototype developments of this research.

(3) Researching and realizing positioning methods on distorted maps, and conducting error analyses

Positioning on distorted maps is the key technology in enabling conventional human-centered maps on the location-aware mobile devices for practical applications. Point-based and line-based positioning methods have been introduced, and their advantages and drawbacks are discussed. Among them, error analyses have been made to two-pointed based similarity transformation, and the results have showed that error of this method depends on the stretch rate of the map and the distance to the line of the pair of control points.

Algorithms of two-pointed based similarity transformation and line based linear referencing are realized and implemented in the prototypes. Experiments using simulated and real moving trajectory data have compared the effects of different combinations of control points and lines used in the realized methods, and have shown the effectiveness and limitations of them. Enough density and reasonable distribution of control points is important to achieve reliable positioning. Control lines are effective when they are distributed on the moving path of the users with proper setting of buffer range. Experiments with the prototype on the real devices in the real world have also revealed the feasibility of the realized positioning methods in practical mobile applications.

(4) Developing prototypes, realizing key functions for HCMM content authors and end users, and evaluating their usability and functionality through experiments and user tests

In this research, a series of prototypes named as **Manpo** (漫步) have been developed on

Apple Inc.'s iOS platform as an implementation of the proposed framework on target of walking tours. Although the functions are still simple, the prototypes have realized both authoring tools and user applications in the framework. The authoring tools have realized the whole workflow of importing walking route maps, editing geo-metadata for positioning, adding extra multimedia content, and so on, to create geo-enabled interactive mobile maps as **Manpo content**. The user applications can appreciate *Manpo Content* using geo-interactive map browsing functions, and showing user's current location and moving trajectory on the maps when walking outdoor.

User tests by university students and surveys to them have shown the functionality and usability of **Manpo** for both authors and users. However, they also have revealed one of the limitations of the approach is that the quality of content, especially the reliability of positioning, is also strongly depending on authors' experiences and skills. Three types of typical mistakes made by the students in geo-enabling their hand-drawn maps are discussed. Among them, the improper placement of control points in distorted maps is the most difficult to be avoided by untrained ordinary users.

In the user tests, the students, who are used to current web mapping products, have shown their interests in **Manpo** and creativities in making their own mobile mapping products. This can be encouragement to this research and has shown the potential of **Manpo**'s approaches to create practical, useful and welcomed human-centered mobile mapping products.

6.2 Future Work

(1) Realize and evaluate more positioning methods for distorted maps

In this research, only simple positioning methods are realized and tested. In the future, more positioning methods, including three-point based triangulation and affine transformation, grouping of control points according to map distortions, and so on, should be realized and compared. Because the distortions in human-centered maps are often difficult to measure, it is difficult to find a reliable positioning method that can deal with all maps. It is predictable that hybrid methods that combine different positioning methods to deal with different distortions may be a good solution. It must be noted that complex methods may provide better results, but also will affect the easiness of using, especially for ordinary users. In considering of different user groups professional authoring tools and casual tools can apply different positioning methods.

(2) Design effective user interfaces and guidelines for non-professional authors to make georeferenced maps more easily and correctly

It is usually difficult to let non-professional authors to learn enough knowledge about the

mechanism of positioning methods. Friendly and effective user interfaces need to be designed for the authoring tools to guide the authors to make correct georeferences. Well-designed and guidelines are also necessary for providing suggestions of the principles for deploying control points more properly and accurately. Meanwhile, such guidelines will also be references to mapmakers who will design maps for **Manpo** with implications of constraining the map distortions in a reasonable range.

(3) Realize network-based sharing functions and publishing platforms for human-centered map content

Prototypes realized in this research are still standalone applications. Internet based platforms are needed for authors to publish or share their created human-centered mapping, and for users to obtain the maps with content to their devices. Also, the users of the mobile mapping should be able to share their own content with other users like friends and families, which can also be realized with the help of existing well-developed social networks. The sharing may be realized in different levels, including the follows:

- Sharing the entire set of content with maps;
- Sharing one component of the content on a map, for example, a POI;
- Sharing user's location-based information, such as current location, visited POI's, history of moving trajectories and so on;
- Sharing user-generated content, for example, comments of a POI, user's photos of a POI, and even user created POI's;
- Crowdsourcing can be used for the modifications of georeferences.

In establishing such platforms, ethic problems such as copyrights of the maps and content on the maps, user's privacy of spatial information, and so on need to be well considered and researched.

(4) To extend the approach of Manpo for academic uses

In this research, the implementations of the proposed human-centered mobile mapping platform have mainly focused on its realizations in only one of the potential usages, that is, sightseeing. Actually, this framework can also be applied for academic uses, for example, for assisting field works using analog maps with GPS. In the future, if there can be the chances to cooperate with researchers on various research areas, such as archaeology, folklore, environmental studies, and so on, the proposed framework will be implemented, evaluated and improved depending on certain academic map uses. In this case, specific requirements of the research field, such as the devices, maps to use, the necessary functions, and so on, need

to be further studied to develop suitable applications.

(5) To extend the approach of Manpo for historic maps and old paintings

Historic maps are getting popular for sightseeing, especially in Japan. Users can compare the historic maps, modern maps and the current situation to imagine the things and stories in the past and appreciate the changes. Using the approach of **Manpo**, it will be much easier to find the user's current location on the historic maps and compare with modern maps with the help of GPS. Setting georeferences on the historic maps will be more difficult than on the modern maps, because of the possible changes of topology, places and names.

On the other hand, old paintings in Japan and China, especially the scroll paintings, also contain spatial information. These scroll paintings are usually from bird's-eye view and have multiple focus points. They have recorded landscapes, folk architectures, and people's activities in the history. It will be attractive if tourists can appreciate them in the real place with their locations displayed on the paintings synchronously. However, creating georeferences on the paintings will be professional work, because they are more distorted than maps and also sometimes contain fictions.

(6) Establish a new ecosystem of human-centered mapmaking industry to involve more cartographers, illustrators, publishers and organizations

Currently, free-to-use web mapping services may let users think maps should be free. However, a human created well-designed map with artistry is worth to pay. In the future, with the well-developed approaches of making and applying human-centered mobile mapping, more and more authoring tools, publishing platforms and application modes will appear. This will be able to give full play of the cartographers, illustrators and publishers, in order to involve their creativity in making more and more well-designed and useful maps, and make them be sold, applied and used by more and more applications. Finally, it will become possible to establish a new ecosystem of human-centered mapmaking industry, which will also involve civil organizations, governments, companies and research institutions. For example, it may be difficult for an illustrator to manage inputting correct geographic coordinates of numerous POI's and control points, but a public data base of frequently used POI and reference points can be provided with the help of the organizations, governments and companies.

Such ecosystem will enable diverse well-designed maps to be easily obtained and used on people's mobile devices for various fields including tourism, local economy revitalization, education, and so on. At the same time it will make new profits to the cartographers, illustrators, publishers, companies and the society.

References

- [1] Google Inc. (2005) Google Maps. <https://maps.google.com>.
- [2] Jonathan Raper, Georg Gartner, Hassan Karimi and Chris Rizos (2007) A Critical Evaluation of Location Based Services and their Potential. *Journal of Location Based Services*, 1(1): 5-45.
- [3] Bernd Resch (2013) People as Sensors and Collective Sensing: Contextual Observations Complementing Geo-sensor Network Measurements. In: Jukka Krisp (ed) *Progress in Location-Based Services, Lecture Notes in Geoinformation and Cartography*. Springer, London, 391-406.
- [4] Jesse Rouse, Susan Bergeron and Trevor Harris (2007) Participating in the Geospatial Web: Collaborative Mapping, Social Networks and Participatory GIS. In: Arno Scharl and Klaus Tochtermann (eds) *The Geospatial Web*. Springer, London, 153-158.
- [5] Ian Muehlenhaus (2014) *Web Cartography: Map Design for Interactive and Mobile Devices*. CRC Press, Boca Raton.
- [6] Gregory Abowd, Christopher Atkeson, et al. (1997) Cyberguide: A mobile context-aware tour guide. *Wireless networks*, 3(5): 421-433.
- [7] Keith Cheverst, Nigel Davies, et al. (2000) Developing a context-aware electronic tourist guide: some issues and experiences. In *CHI '00: Proceedings of the SIGCHI conference on Human factors in computing systems*, New York, NY, USA, 2000, 17-24.
- [8] Jürg Baus, Keith Cheverst, and Christian Kray (2005) A survey of map-based mobile guides. In: L. Meng, T. Reichenbacher, A. Zipf (eds) *Map-based mobile services*, Springer Berlin Heidelberg, 193-209.
- [9] Jonathan Raper (2007) *Design constraints on operational LBS*. Springer Berlin Heidelberg.
- [10] Matthew Wilson (2012) Location-based services, conspicuous mobility, and the location-aware future. *Geoforum* 43(6): 1266-1275.
- [11] Matthew Wilson (2014) Geospatial technologies in the location-aware future. *Journal of Transport Geography*, 34: 297-299.
- [12] Jesse Rouse, Susan Bergeron, Trevor Harris (2007) Participating in the geospatial web: collaborative mapping, social networks and participatory GIS. *The Geospatial Web*, Springer

London, 153-158.

- [13] Bernd Resch (2013) People as sensors and collective sensing-contextual observations complementing geo-sensor network measurements. *Progress in Location-Based Services*, Springer Berlin Heidelberg, 391-406.
- [14] Andrew Hudson-Smith, Michael Batty, Andrew Crooks, et al. (2009) Mapping for the masses accessing Web 2.0 through crowdsourcing. *Social Science Computer Review*, 27(4): 524-538.
- [15] Glen Farrelly (2014) Irreplaceable: the role of place information in a location based service. *Journal of Location Based Services* (online), <http://dx.doi.org/10.1080/17489725.2013.879217>.
- [16] Takumi Ichimura, Kosuke Tanabe and Issei Tachibanan (2012) Tourist Navigation in Android Smartphone by using Emotion Generating Calculations and Mental State Transition Networks. Joint 6th International Conference on Soft Computing and Intelligent Systems (SCIS) and 13th International Symposium on Advanced Intelligent Systems (ISIS), IEEE, 1578-1583.
- [17] Alexandra Millonig and Georg Gartner (2011) Identifying motion and interest patterns of shoppers for developing personalised wayfinding tools. *Journal of Location Based Services* 5(1): 3-21.
- [18] Hirofumi Eguma, Tomoko Izumi, and Yoshio Nakatani (2013) A Tourist Navigation System in Which a Historical Character Guides to Related Spots by Hide-and-Seek. *Conference on Technologies and Applications of Artificial Intelligence (TAAI)*, IEEE, 337-342.
- [19] Ken Tanaka and Yoshio Nakatani (2010) Sightseeing navigation system that promotes interaction with environment by restricting information. *International Conference on Systems Man and Cybernetics (SMC)*, IEEE, 453-458.
- [20] Robert Roth (2014) Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*, 2013 (6): 59-115.
- [21] Tumasch Reichenbacher (2004) *Mobile cartography: adaptive visualisation of geographic information on mobile devices*. München: Verlag Dr. Hut.
- [22] Johannes Schöning, Antonio Krüger, et al. PhotoMap: using spontaneously taken images of public maps for pedestrian navigation tasks on mobile devices. *Proceedings of the 11th international Conference on Human-Computer interaction with Mobile Devices and Services*. ACM, 2009 (14).

- [23] Sandra Rendgen and Julius Wiedemann (2012) *Information Graphics*. Taschen.
- [24] Hsiang-Yun Wu, Shigeo Takahashi, et al. (2013) Spatially efficient design of annotated metro maps. *Computer Graphics Forum*. Blackwell Publishing Ltd, 32(3pt3): 261-270.
- [25] Hsiang-Yun Wu, Shigeo Takahashi, et al. (2012) Travel-route-centered metro map layout and annotation. *Computer Graphics Forum* 31, 3 (2012), 925–934.
- [26] Daichi Hirono, Hsiang-Yun Wu, Masatoshi Arikawa and Shigeo Takahashi (2013) Constrained optimization for disoccluding geographic landmarks in 3D urban maps. *Visualization Symposium (PacificVis)*, 2013 IEEE Pacific: 17-24.
- [27] Asanobu Kitamoto and Yoko Nishimura (2009) Geometric Correction of Measured Historical Maps with a Pixel-Oriented and Geobrowser-Friendly framework. *Proceedings of the 22nd International Symposium on Digital Documentation, Interpretation & Presentation of Cultural Heritage*, Kyoto, Japan.
- [28] Eihan Shimizu and Takashi Fuse (2005) A Method for Visualizing the Landscapes of Old-Time Cities Using GIS. In: Atsuyuki Okabe (ed) *GIS-based Studies in the Humanities and Social Sciences*, CRC Press, London, 265-278.
- [29] Alexander Akin and David Mumford (2012) “Yu laid out the lands”: georeferencing the Chinese Yujitu [oMap of the Tracks of Yu] of 1136. *Cartography and Geographic Information Science* 39(3): 154-169.
- [30] Nam Wook Kim, Jeongjin Lee, et al. (2014) Accurate segmentation of land regions in historical cadastral maps. *Journal of Visual Communication and Image Representation*, 25(5): 1262-1274.
- [31] Takashi Morita (2004) Ubiquitous Mapping in Tokyo. *First International Joint Workshop on Ubiquitous, Pervasive and Internet Mapping (UPIMap2004)*, Tokyo.
<http://www.ubimap.net/upimap2004/html/papers/UPIMap04-A-01-Morita.pdf>.
- [32] Takashi Morita (2005) A Working Conceptual Framework for Ubiquitous Mapping. *Proceedings of the 22nd International Cartographic Conference*.
<http://cartesia.org/geodoc/icc2005/pdf/oral/TEMA12/Session%203/TAKASHI%20MORITA.pdf>.
- [33] Georg Gartner, David Bennett, and Takashi Morita (2007) Towards ubiquitous cartography. *Cartography and Geographic Information Science* 34(4): 247-257.
- [34] Bengt Rystedt et al. (2003) *A Strategic Plan for the International Cartographic Association 2003-2011*, International Cartographic Association.

http://icaci.org/files/documents/reference_docs/ICA_Strategic_Plan_2003-2011.pdf.

- [35] Alan MacEachren (1995) *How Maps Work: Representation, Visualization, and Design*. The Guilford Press, New York.
- [36] Reginald Golledge (1999) *Human Wayfinding and Cognitive Maps*. In: Reginald Golledge (ed) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. The Johns Hopkins University Press, Baltimore, 5-45.
- [37] Ariane Etienne, Roland Maurer, Joséphine Georgakopoulos and Andrea Griffin (1999) *Dead Reckoning (Path Integration), Landmarks, and Representation of Space in a Comparative Perspective*. In: Reginald Golledge (ed) *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. The Johns Hopkins University Press, Baltimore, 197-228.
- [38] Michael Peterson (2007) *Elements of Multimedia Cartography*. In: William Cartwright, Michael Peterson and Georg Gartner (eds) *Multimedia Cartography*. Springer, Berlin Heidelberg, 63-73.
- [39] William Cartwright (2007) *Development of Multimedia*. In: William Cartwright, Michael Peterson and Georg Gartner (eds) *Multimedia Cartography*. Springer, Berlin Heidelberg, 11-34.
- [40] William Cartwright and Michael Peterson (2007) *Multimedia Cartography*. In: William Cartwright, Michael Peterson and Georg Gartner (eds) *Multimedia Cartography*. Springer, Berlin Heidelberg, 1-10.
- [41] OpenStreetMap Foundation (2006) *OpenStreetMap*. <http://www.openstreetmap.org/>.
- [42] Georg Gartner (2013) *The Relevance of Cartography*. ArcNews, Esri. <http://www.esri.com/esri-news/arcnews/winter1314articles/the-relevance-of-cartography>.
- [43] James Manyika, Michael Chui, Brad Brown et al (2011) *Big Data: the Next Frontier for Innovation, Competition, and Productivity*. McKinsey Global Institute.
http://www.mckinsey.com/Insights/MGI/Research/Technology_and_Innovation/Big_data_The_next_frontier_for_innovation.
- [44] Gerd Gigerenzer (2007) *Gut Feelings: The Intelligence of the Unconscious*. Penguin Group, New York, p280.
- [45] Malcolm Gladwell (2005) *Blink: The Power of Thinking Without Thinking*. Back Bay Books, New York, p296.
- [46] Ronald Rees (1980) *Historical Links between Cartography and Art*. *Geographical Review*,

70(1): 60-78.

- [47] Nat Case (2007) Taking Apart Cartography: Our Field as a Graphic Tradition. North American Cartographic Information Society (NACIS) Annual Conference, October, St. Louis, MO. <http://nat.case.home.mindspring.com/nacis07G.pdf>.
- [48] John Krygier (1995) Cartography as an Art and a Science?. *The Cartographic Journal*, 32(6): 3-10.
- [49] Denis Cosgrove (2005) Maps, Mapping, Modernity: Art and Cartography in the Twentieth Century. *Imago Mundi: The International Journal for the History of Cartography*, 57(1): 35-54.
- [50] Alexander Kent (2005) Aesthetics: A Lost Cause in Cartographic Theory?. *The Cartographic Journal*, 42(2): 182-188.
- [51] Mark Monmonier (2007) Cartography: the Multidisciplinary Pluralism of Cartographic Art, Geospatial Technology, and Empirical Scholarship. *Progress in Human Geography*, 31(3): 371-379.
- [52] Shobunsha Publications Inc. (2012) Co-Trip. <http://co-trip.mapple.net/appli/info.asp>.
- [53] Mapple ON Co., Ltd (2012) Mapple link. <http://ma1.mapple.net/review/>.
- [54] Odakyu Electric Railway Co., Ltd (2012) 小田急沿線自然ふれあい歩道 お散歩ガイド. <http://www.odakyu.jp/walk/smartphone/>.
- [55] Mie Takahashi (2010) Tokyo Shitamachi Sanpo. http://www.miesan.jp/mei_jiangsansaito/iphone_topikkusu.html.
- [56] TouchChina Inc. (2012) 景点通. <http://www.itouchchina.com/products/jingdiantong>.
- [57] ATR Creative Inc. (2012) Kochizuburari. <http://www.atr-c.jp/burari/product/oldmap/chizuburari.html>.
- [58] Min Lu and Masatoshi Arikawa (2013) Location-Based Illustration Mapping Applications and Editing Tools. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 48(2): 100-112.

Acknowledgements

This dissertation would not have been possible without the guidance of my committee members, help from colleagues, and supports from my family and wife in the past three years.

It is with immense gratitude that I acknowledge the support and help of my Professor Masatoshi Arikawa. He has never hesitated to give me valuable suggestions, to share his inspirations, and to correct my mistakes. Discussions with him are always enjoyable and helpful. He has provided me with the precious chances to have broader vision and deeper thinking in my research. I would also thank him for his consideration and patience in supporting my life in Japan as a foreigner.

I would like to express my sincere thanks to all the committee members of my dissertation, Professor Takashi Morita in Hosei University, Professor Shigeo Takahashi, Professor Shin'ichi Konomi and Professor Masahiro Fukuda in the University of Tokyo, for their guidance and advice.

I am indebted to Professor Atsuyuki Okabe, who gave me the precious chance to use my prototypes in his classes and make experiments and surveys. I would also give many thanks to the students in the classes for their cooperation in the experiments and feedbacks for improving my developments.

I would like to sincerely thank my previous supervisor, Professor Yuefeng Liu, in Peking University, who has kept cooperating with me after my graduation from master's program, and given me kindly concern and suggestions.

I consider it a pleasure to study and work together with my colleagues and fellow students, including Dr. Ken'ichi Tsuruoka, Hideki Kaji, Tomoyo Sasao, Mariko Shibasaki, Taiki Yoshimura and Ruochen Si.

I would like to thank Shobunsha Publications Inc. and Seibu Railway Co., Ltd. for providing illustrated maps and guidebooks, which are very important materials in this dissertation.

Finally, this thesis is dedicated to my parents and my wife, who have given me the steadiest supports to be a researcher. Especially to my wife, Ting Li, although we have stayed apart in different countries for most time in the three years, she has always stood by me and given me the warmest concern and encouragement.

Min Lu
June, 2014

Publications

Published Papers

1. Min Lu and Masatoshi Arikawa (2013) Location-Based Illustration Mapping Applications and Editing Tools. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 48(2): 100-112.
2. Min Lu and Masatoshi Arikawa (2013) Map-Based Storytelling Tool for Real-World Walking Tour. In: Jukka Krisp (ed) *Progress in Location-Based Services*, Springer, Berlin Heidelberg, 435-451.
3. Min Lu and Masatoshi Arikawa (2014) Walking on a Guidebook with GPS: A Framework Geo-Enabling Pages with Illustrated Maps in LBS. In: Chun Liu (ed) *Principle and Application Progress in Location-Based Services*, Springer, Switzerland, 243-264.

Oral Presentations

1. Min Lu and Masatoshi Arikawa (2013) A Mobile Service for Sharing Personal Content with Analogue Maps Alternative to Web Mappings. Meeting of ICA Commission of Map and Internet. Plzen, Czech. August 22-24.
2. Min Lu and Masatoshi Arikawa (2013) まちあるきを対象にした、アナログ地図をモバイルデバイスで利用可能にするモバイルツール. 日本地図学会 2013 年定期大会, Kashiwa, Japan. August 1-2.
3. Min Lu and Masatoshi Arikawa (2013) 古代蘇州の都市空間の変遷 - 中国の古地図と風俗画から. 日本地図学会 2013 年定期大会, Kashiwa, Japan. August 1-2.
4. Min Lu and Masatoshi Arikawa (2012) Stage-Structured Mobile Storytelling with Art Maps. Seventh International Conference on Geographic Information Science. Columbus, Ohio, USA. September 18-21.
5. Min Lu, Masatoshi Arikawa and Ken'ichi Tsuruoka (2012) POI-based Inter-Georeference for Enabling Picture Route Maps in Location-based Mobile Services for Walking Tours. Japan Cartographers Association Convention 2012. Kawasaki, Kanagawa, Japan. August 23-24.

Poster Presentations

1. Min Lu and Masatoshi Arikawa (2014) Geo-interactive Guidebook Services: Design and Development of LBS Applications Featuring Geo-enabled Illustrations. Japan Geoscience Union Meeting. Yokohama, Japan. April 28 - May 2.
2. Min Lu and Masatoshi Arikawa (2013) Location-based Learning with Diverse Maps Applying Gamification Strategies. Japan Geoscience Union Meeting. Chiba, Japan. May 19-24.
3. Min Lu and Masatoshi Arikawa (2012) A Framework Enabling Art Maps on Mobile Devices for Walking Tours. The 2012 AutoCarto International Symposium on Automated Cartography. Columbus, Ohio, USA. September 16-18.
4. Min Lu and Masatoshi Arikawa (2012) Designing Stories within Mappings for Enhancing Real World Experience. Japan Geoscience Union Meeting. Yokohama, Japan. May 20-25.