Doctoral Thesis

Collaborative Mobile Map Collaging for Local Knowledge Sharing

（地域知共有のための協調的モバイル地図コラージング）

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Abstract

Local knowledge is unique to a given culture and society. The sharing of local knowledge contributes to the development of local community activities. Local people have played important roles in sharing their knowledge to drive regional activation, such as through tourism planning, creation of local recycling-oriented societies, and local bus services management. There are problems with local people's participation in local knowledge sharing. First, local information in such media as books, signboards, and web sites is not widely known, noticed, or sought by people with little background knowledge, thus affecting the efficient spread and use of local knowledge. Second, there is a lack of communication and cooperation among different local communities, preventing the wide sharing of local knowledge.

As important tools for spatial communications, maps play key roles in local storytelling, such as local navigation, introducing local information, and inspiring people to visit local areas. Nowadays, web mapping and mobile mapping are popular and widely used for the advantages of convenient access through the internet and powerful location-based services; however, they are not detailed in local areas and lack local information and knowledge, such as culture, history, and nature for storytelling. Currently, a trend of story mapping is emerging that provides mashup maps. Combined from multiple sources, they integrate multiple media types – such as text, photos, movies, sounds, and webs with location data – which are useful for creating spatial storytelling. Such story mapping services have deficiencies in local knowledge sharing due to the limitation of web mapping as base maps to represent local storytelling, in addition to the difficulty of using digital technology for geography and archeology researchers and non-professional local people who are not skilled in GIS (Geographic Information Science). Conversely, local analogue maps, such as illustrated maps and map signboards, are still popularly used for such purposes as local travelling, walking tours, and environmental education. Many local communities have created and published paper-based analogue maps for activities such as walking tours and lifelong education. Analogue maps are considered to have better local area content for both users and creators; however, most of the local communities have been used to analogue maps and overlooked digital technology, which is capable of enhancing current local knowledge sharing through the better presentation of mobile and authoring environments. Such new environments enable local people to more easily and efficiently experience spatial storytelling, in addition to having creative opportunities to contribute to local map creation and location-based storytelling application development, using mashup content compiled from paper-based local knowledge materials, including analogue maps, photos, and text.

This thesis proposes a new framework of map collaging for local people to participate in local knowledge sharing through the mashup of various georeferenced local analogue maps, created by different local communities with photos, text, and audio to convey local knowledge of different topics, eras, and areas. The framework dynamically combines and organizes the relations among different local maps, in addition to automatically managing the map switch and information narration for local area navigating and location-based spatial learning for tourism and life-long learning. It also provides easy functions for producing map-collaging content, involving the cooperation of local communities and the participation of local people to share their knowledge, thereby enriching collective local knowledge for promoting local development.

The thesis makes three principal contributions to realizing the framework of map collaging: (1) proposing methods for accurate positioning on and overlaying of analogue maps with distortions, (2) constructing models for visual and cognitive continuity management of presenting and switching multiple maps for local storytelling, and (3) implementing easy software tools to enable people to make map collaging content for sharing their knowledge.

Accurate positioning and map overlaying are the foundations of the mobile environment application of map collaging. Therefore, the thesis first introduces the methods for accurate positioning and map overlaying in Chapters 2 and 3.

Chapter 2 introduces polyline-based georeferencing, which uses polylines as spatial references to connect analogue map images with the base mobile mapping. Algorithms to calculate positions, directions and map overlaying based on polyline georeferences are proposed. Experiments and simulations prove that the new method realizes accurate and robust positioning along the polylines for georeferencing, and reasonable map overlaying on the focus point (e.g., the user's position).

Chapter 3 explains semi-georeferencing for building connections among local analogue maps, which supports position transferring and map overlaying among the local analogue maps. Semi-georeferencing enables positioning on old maps, on which it is difficult to find spatial objects corresponding to the base maps for georeferencing, through other georeferenced maps. It also contributes to improving positioning and map overlaying accuracy.

Local analogue maps have different map presentations, scales, and alignments, which are not designed for combined use; consequently, discontinuities are caused in map cognition with simple overlaying of the local analogue maps.

Chapter 4 explains a research study on new models to manage continuities among multiple maps for storytelling, with easy-to-follow map presentation and smooth map switching. Spatial triggers are applied to cue local stories on different maps with spatial trajectories, with which proper maps will be presented and related information displayed or narrated automatically according to users' positions and trajectories. A model of using various factors for user-friendly map collaging presentation and smooth map switching is proposed. Experiments with web questionnaires and users' operations on map collaging are conducted, through which factor-value combination for managing map collaging continuity is determined.

Chapter 5 explains the software architecture and the implementation of the experimental application MapCollaging. Data structure, user interfaces, and interaction methods are designed for map collaging browsing and editing. For browsing multiple maps, it provides such functions as map switching, map transparency, and visibility controlling. For the editing component, basic functions are provided for adding polyline-based georeferences, placing POI (Point of Interest) icons on maps, setting spatial triggers, etc. Moreover, guidance functions of computer-aided map georeferencing are developed, such as enhancing the base maps with user trajectory, presenting hints to assist finding corresponding polylines, automatic polyline bundling, and a sequential guiding function. User experiments demonstrate feasibility of the application for users to browse and edit map collaging content.

Chapter 6 introduces fieldwork experiments for map collaging. With the cooperation of local communities, the map collaging content and walking tour application KashiwaWalk are made for Kashiwa City, and experimental map collaging content is made by the Shiroi City local people. The fieldwork indicates the feasibility of local storytelling through map collaging and local people's participation in map collaging content making.

Chapter 7 draws conclusions on the contributions of the thesis, and considers future research opportunities. This research proposed a computer-based framework for local knowledge sharing through mapping services with multiple local maps. It achieves learning and experiencing local knowledge in the real world, and supports local people's participation in sharing personal knowledge with others through the system. In the future, improvement will be made to the framework of map collaging to facilitate wide use of the framework for local knowledge sharing to activate and promote development of local areas.

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Chapter 1 Introduction

1.1 Local Knowledge Sharing and People's Participation

Knowledge is a justified personal belief that increases an individual's capacity to take effective action (Huber, 1991; Nonaka, 1994). Knowledge resides in the user and not in the collection of information (Churchman, 1972), which means that information is useful only when it is actively processed in an individual's mind, and that knowledge must be communicated in a manner as to be interpretable and accessible in order for one person's knowledge to be useful to another individual (Alavi and Leidner, 1999). Knowledge sharing, the movement of knowledge across individual and organizational boundaries, into and from repositories, and into organizational routines and practices (Bock, Zmud, Kim, et al, 2005), is a major focus area for knowledge management (Hendriks, 1999), and is fundamental to a firm's ability to create and sustain competitive advantage (Grant, 1996). It is found that organizations with an environment in which knowledge is shared among employees and used by recipients appear to be more productive (Amayah and Nelson, 2010).

Local knowledge, also noted as indigenous knowledge, is unique to a given culture or society, and is the information base for a society to facilitate communication and decision-making (Warren, D. M., and B. Rajasekaran, 1993). Local people have played important roles in sharing personal knowledge in local development on a variety of aspects, such as tourism planning (Haywood, 1988; Keogh, 1990; Simmons, 1994; Jamal and Getz, 1995), building of recycling-oriented society (Shigefumi, 2003), local bus management (Taniuchi, Inoi and Nitta, 2010), and so on.

Knowledge sharing and local people's participation are important for local development. However, there are also barriers that exclude participation of local people, such as, the lack of broader involvement, the formality of some consultation forums (Wood, 2002). For example in the local people's participation in tourism planning, operational, structural and cultural limits are found in many developing countries (Tosun, 2000); also local people's unfamiliar with available information may have an overall adverse effect on local people's perceptions and general opinions in tourism planning (Keogh, 1990).

When researching on Kashiwanoha area in Kashiwa City, Chiba Prefecture in Japan, some problems in local people's participation in local knowledge sharing are found. Kashiwanoha is rich in local knowledge in history, there was a Kashiwa Airport of Japanese Army during the World War Ⅱ; two large parks full of natural resources are situated here, Kashiwanoha Park and Konbukuroike Nature Park, which are convenient for nature studies; in academic aspects, there are two campuses belonging to the University of Tokyo and Chiba University. However, few people, even those who have lived or worked in Kashiwanoha for a long time, know the story of Kashiwa Airport, or the Konbukuroike Nature Park. Three main reasons that cause the problems are summarized as follows.

The first problem is the narrow access to the local knowledge. Local governments, communities and organizations have made many materials on different platforms for introducing the knowledge of Kashiwa Airport, such as books, signboards, walking tour maps, websites and so on. However, such materials are not known, noticed, searched, or used by ordinary people who have little initial knowledge about the local knowledge.

The second problem is the lack of cooperation among local communities. Each local community creates and manages their own local knowledge, and there are inadequate connections among different local knowledge. For example, currently Kashiwanoha Park and Konbukuroike Nature Park each has its own map, but there are more visitors to Kashiwanoha Park than Konbukuroike Nature Park. People will have more chances to know Konbukuroike Nature Park if the two parks collaborate and knowledge about Konbukuroike can be shared together with the information of Kashiwanoha Park.

The third is an inadequacy of local individuals' participation. On one hand, there are local communities and organizations such as Kashiwa History Club and UDCK devoting local knowledge to researching and sharing. For example, Kashiwa History Club has many research results in Kashiwanoha area in forms of maps and books (Figure 1.1), and holds activities like walking tours to share their knowledge. On the other hand, there is lack of access for local individuals to participate in local knowledge sharing.

(Provided by Kashiwa History Club)

Figure 1.1 Examples of published materials of Kashiwa History Club

1.2 Knowledge Sharing with Maps

1.2.1 Analogue Maps for Local Storytelling

Storytelling is a common and efficient way for knowledge sharing. People have used stories to convey information, cultural values, and experiences as long as they have been around (Gershon and Page, 2001). Storytelling was once regarded informal or skepticism for knowledge sharing, but is now recognized to be valuable in knowledge sharing environment (Mitchell, 2005). It is suggested that sharing experiences through storytelling has various benefits on building trust, cultivating norms, transferring tacit knowledge, facilitating unlearning, and generating emotional connections (Sole and Wilson, 1999; Ohler, 2006). Maps are important tools for spatial communication and are used for local storytelling.

Local analogue maps are the illustrated maps, guidebooks, map signboards and so on that are specifically designed for certain local area. Such maps are thematic for local famous and unique stories, and are drawn artistically with diverse styles in different places, and sometimes are exaggerated with distortions to emphasize the main area and main objects. There are two common ways for local analogue maps to share local knowledge to people. One is to inspire people with an overall image of the local area (Figure 1.2). Such maps create images of local areas in people's minds, such as the beautiful nature, interesting history, and so on, to attract people to visit the places. The other is to lead people with courses drawing on maps (Figure 1.3). The maps show suggested courses that lead people to enjoy the local knowledge from one spot to another in the real places. These two ways are not exclusive, and a local analogue map can use both ways to tell local stories.

Local analogue maps are popularly used for the purpose of tourism, environmental education and so on, and are welcomed by local communities in their activities, like the walking tours. Local governments and communities also make analogue maps for attracting visitors and to carry out local activities. However, local analogue maps have relatively narrow accesses to acquirement and limited map extent and they do not support user interactions or location-based services, which limit the usage of the analogue maps for efficient local knowledge sharing.

(http://www.spoon-tamago.com/2014/03/03/birds-eye-view-maps-cartographer-hatsusaburo-yoshida/)

Figure 1.2 Illustrated map storytelling by inspiring

(Shiroi City Walking Map, provided by Shiroi City Office)

Figure 1.3 Illustrated map storytelling by leading

1.2.2 Widely Used Web and Mobile Mapping

Nowadays, web and mobile mapping, like Google Maps, are widely used for the advantages of ubiquitous access through the Internet, seamless mapping services that cover almost world wide, powerful location-based services (LBS) and the convenience of mashup with other kinds of media.

With large amount of users, web and mobile mapping is also extended for users' participation in geo-information donating and map making. In the field of Geographic Information Science (GIS), the topic "Volunteered Geographical Information" (VGI) has captured many researchers' attention (Goodchild 2007a, 2007b; Sui, 2008; Haklay and Weber, 2008; Elwood, 2009). Mobile GIS is important tool for users with the ability to collect, upload, and demonstrate the geographic information (Song and Sun, 2009). As VGI applications, like OpenStreetMap (OSM), have contributed to enhancing geographic data, there are also increasing concerns on the quality, reliability, and overall value of the data (Andrew and Miriam, 2008; Haklay, 2010).

Web and mobile mapping are convenient tools for general map using, but have deficiencies for local storytelling and knowledge sharing. Firstly, web and mobile mapping are for general users and are not detail in local areas spatially or thematically for local story sharing. Secondly, the machine made web and mobile mapping are rigid with linear objects presented with polylines, and similar map drawing styles in different places, which is less attractive compared with local analogue maps. Thirdly, the dominant web and mobile services cause "Googlization" phenomenon (Muehlenhaus, 2014; Lu, 2014), which limits the diversity of maps, and indirectly prevents people using local illustrated maps.

1.2.3 A Trend of Story Mapping

In recent years, a trend of story mapping comes into being. Story mapping integrate web and mobile mapping with multi-media information for telling spatial related stories.

The web mapping and mobile mapping are widely used as the *base maps* for story mapping. The base maps themselves are created for general-purpose use without specific stories, and are used as platforms to carry components for storytelling, such as texts, images, videos, and so on.

There are various ways to integrate the base maps with stories, such as imbed the base maps on website, connect the base maps to texts or images with hyperlink, annotate multi-media information on the base maps, and so on. The followings list three typical types of story mapping:

- **Map-Illustrated Storytelling**
  Thematic web mapping are linked to online articles to illustrate stories told by the articles (e.g. Esri's Story Maps, Figure 1.4). For the map-illustrated storytelling, the story is mainly told by the text of the article, and the web mapping provides interactive illustrations for certain parts of the text.
  This kind of map storytelling usually deals with large areas and global issues instead of stories of local areas. It also requires relatively professional knowledge and skills to make the thematic web mapping for storytelling.

(The story of *Significant UK Hydrocarbon Discoveries and Fields* by Exprodat Consulting Ltd. http://ecl.maps.arcgis.com/apps/MapJournal/index.html?appid=62fb25ad7869454dbe8580da4957198b/)

Figure 1.4 Esri's Story Maps as an example of map-illustrated storytelling

- **Location-enhanced Storytelling**
  With multimedia enhanced points of interest (POI's) annotated on the base maps, web mapping tells stories with locations of a series of events (e.g. knight lab's StoryMapJS, Figure 1.5). Location enhanced storytelling mainly tells stories through sequences of multi-media illustrations of the POI's, while the base maps are used for indicating locations of the POI's.
  One problem of location-enhanced storytelling is that the base map is relatively simple. The base maps are not detailed enough in local areas, such as in the campuses, parks, mountains and so on, and they are only used for indicating the locations of the POI's with little additional information and knowledge about the POI's.

(The story of Sochi 2014 Olympic Touch Relay Highlights by knight lab.
https://storymap.knightlab.com/)

Figure 1.5 Knight lab's StoryMapJS as an example of location-enhanced storytelling

- **GPS-enabled Mobile Story Mapping**
  GPS-enabled mobile story mapping uses location-based services (LBS) to present related information for storytelling based on the user's location (e.g. Niantic's Field Trip, Figure 1.6). It enables users to experience the stories in the real word, but it also has the problem of the simplicity of the base maps, which are neither detailed enough spatially nor thematically in the local areas for local storytelling.
  Recently, there are researches that combine local analogue maps with mobile mapping enabling LBS on local analogue maps by mapping the user's position from the base maps to the analogue maps through georeferences (Schöning et al. 2009; Lu and Arikawa, 2013b), but the distortions of the analogue maps affect the positioning accuracy and stability, also the related researches combine local analogue maps to the base maps independently with little connections among different local analogue maps for continuous guidance throughout a whole trip that involves different local areas and maps.

(The preview of Field Trip in Google Play.
https://play.google.com/store/apps/details?id=com.nianticproject.scout&hl=en/)

Figure 1.6 Example of GPS-enabled mobile story mapping

The story mapping, which builds the links of spaces and stories in users' minds, provides a promising way for local knowledge sharing with mapping and location-based services, but deficiencies such as simple background map, unstable positioning on the analogue maps and the complexity in map editing for local people need to be solved for more attractive local storytelling and more participations of local people in donating their local knowledge.

1.3 Motivations for the Research on Map Collaging

Local people's participation in local knowledge sharing is important for local development and maps play important roles in local knowledge sharing. Current maps and mapping services have limitations for local knowledge sharing, which results from the mismatches on the following three aspects.

(1) Mismatches between spatial navigation and spatial storytelling. Spatial navigation is based on GPS locations on geometrically correct base maps, while storytelling is presented on distorted analogue maps. Conventional web and mobile mapping, as well as story mapping based on web and mobile mapping, are widely used for the ability of ubiquitously positioning and navigating, which is suitable for widely disseminating local knowledge, but the general-purpose base maps limit the ability for local storytelling. Local analogue maps that specifically designed for the local areas are good at local storytelling and suitable for the trip with guiders' leading and explanation, but without LBS, it is relatively difficult for individuals to travel with the analogue maps and it prevents the quick and wide spread of local knowledge without the access through the Internet for the analogue maps. Also, the distortions of local analogue maps prevent accurate and stable positioning on the analogue maps for the combination of the analogue maps with web and mobile mapping.

(2) Mismatches among discontinuous local analogue maps and continuous local spatial cognition during travelling. Local communities focus on their own materials creating and there is lack of cooperation among different communities. The local analogue maps are designed for each local area independently with different presentations, map alignments, suitable scales, and are provided in different places. Each map is good for storytelling for the certain area, but for people travelling through different local areas, who need continuous guidance, it is inconvenient for them to collect, carry and use many different local analogue maps. The different map styles also make obstacles in seamless map overlaying for combining multiple local maps continuously on mobile devices.

(3) Mismatches between professional technical users and local researchers and volunteers without professional GIS or IT knowledge and skills. Scientific methods and tools in the fields of GIS and computer sciences for georeferencing, image cognizing, 3D modeling and so on can be used to create accurate analogue maps and story mapping of local areas, but such methods are aimed at professional users in the field of GIS, and the tools, like ArcGIS, are too expensive and technical for researchers and volunteers without the specific skills to use, which prevents the wide participation of local people for knowledge sharing.

Aimed at the above problems, this thesis researches on a framework for efficient local knowledge sharing with continuous combination of multiple local analogue maps and mobile mapping for local knowledge learning, and provide easy methods and tools enabling local people to participate in sharing their personal knowledge to involve cooperation among local governments, communities and individuals for local development.

On one hand, the thesis researches on accurate and stable positioning on local analogue maps and continuous map combination of the local analogue maps, which are important for user-friendly local travelling and spatial learning with mobile devices.

On the other hand, considering the purpose of knowledge sharing and ordinary local people as target users, the thesis also researches on usability of the framework for ordinary people by keeping the balance between the georeferencing accuracy and the easiness of user's operation, instead of pursuing definite mathematical accuracy for professional spatial analysis and surveying.

1.4 Proposal of Map Collaging for Local Knowledge Sharing

To solve the problems of current maps and mapping services in local knowledge sharing, this thesis proposes a new framework of *map collaging*, by which users can easily get access to and learn local knowledge, and they can also create content to contribute their personal knowledge to enrich the local knowledge.

Collage is the process of using fragments of found images or materials and gluing them to a flat surface to portray phenomena (Kisber and Poldma, 2010). The framework will automatically combine various map images with photo images, texts and audios, and manage the relations among them dynamically. The framework focuses on local areas, such as a city, districts in a city, towns or villages, and the maps used in the framework include mobile mapping as the base maps, and different kinds of maps include paper maps, bird's-eye view maps, map signboards, areal photos, landscape paintings, and so on.

As shown in Figure 1.7, the framework acts as a node to connect the different participants in local knowledge sharing. The framework involves local governments, communities, organizations and individuals to contribute their knowledge, resources (e.g. maps and photos), and work of making map collaging content to enrich the content in the framework. Therefore the map collaging content in the framework is the result of the collaborations of all the participants in the content contributions. With the implementation of smartphone application, the framework enables mobile map collaging browsing and editing. It enables positioning and directing for navigation with maps of the local areas, and user location aware automatic knowledge narration function for users to experience local knowledge during local travelling. Users can also collect materials like maps and photos and contribute to making map collaging content during their trips in the local areas. The local knowledge shared by the local people can be used for local communities for heritage protection, tourism planning, facility managing, and so on for promoting local development.

Figure 1.7 A framework of map collaging for local knowledge sharing

The map collaging framework is supposed to contribute to the local knowledge sharing with map collaging in the following four aspects:

(1) Mobile using environment with LBS on multiple local maps. The mobile using environment for the traditional analogue materials enlarges the accessibility of local knowledge to users. LBS on local analogue maps let people learn local knowledge along their trips in the local area. Also, the use of multiple maps enriches topics of local knowledge to be present. For example, with multiple maps, it is able to present the changes of an area by time.

(2) Continuous multiple map presentation and switching. The overlaying of different kinds of local maps will cause discontinuities in map presentation and map switching, such as margins and seams of overlaid map images, inconsistent map alignments and scales after map switching, and so on. This thesis analyzes different factors that effects on map collaging presentation and map switching, and the combinations and value settings of parameters are determined by experiments, to achieve continuous presentation and map switching of different maps in map collaging.

(3) Location-based knowledge presentation and narration. Local stories are separated on different local maps. This thesis researches on using spatial triggers to cue local stories on different maps with spatial trajectories, with which proper maps will be presented and relative knowledge will be narrated automatically to users when they are travelling in the local areas. In this way, local knowledge will be positively told to users, instead of passively being searched by users.

(4) User-friendly tools for map collaging content browsing and editing. Apart from functions for browsing multiple maps for enjoying local knowledge, the thesis designs tools for non-professional users to make map collaging content to share their knowledge with others. Basic functions are provided for adding map images, editing polyline georeferences, annotating POI's on maps, setting spatial triggers and so on. Besides, functions of assisting users to make map georeferencing are developed to help users to make map collaging content easily. These tools provide access for local people to participate in local knowledge sharing by contributing map collaging content they made.

1.5 Structure of the thesis

Figure 1.8 shows the structure of the thesis:

Chapter 1 introduces the importance of local knowledge sharing for the development of local areas and the limits of current maps and mapping services for local knowledge sharing, and proposes a new framework of map collaging for involving local people in local knowledge sharing.

Chapter 2 and 3 propose polyline-based georeferencing and semi-georeferencing for positioning and map overlaying of analogue maps, which provides foundation of location-based services on multiple local analogue maps for the framework.

Chapter 4 discusses continuity management of different local analogue maps for smooth map switching and user context aware storytelling with heterogeneous local analogue maps.

Chapter 5 introduces the designs of the interfaces for map collaging browsing and editing, and the implementation of the application of *MapCollaging*.

Chapter 6 explains two fieldwork experiments with local communities for testing feasibilities of the framework on local knowledge sharing.

Chapter 7 draws conclusions of the contributions of the thesis and plans for the future work of the research.

Figure 1.8 Structure of the body part of the thesis

Chapter 2 Map Collaging with Polyline-based Georeferencing

This research combines maps of different styles, such as illustrated paper maps, areal photos, map signboards and so on, to enrich local knowledge information, and integrates the analogue map images with base maps (in this study, Apple Maps are used as the base maps) to enable LBS on the analogue maps. This chapter introduces the framework of map collaging with polyline-based georeferencing, explains methods to calculate position, direction and map overlaying with polyline georeferences, and analyzes the accuracy of the polyline-based georeferencing for map collaging.

2.1 Related Work on Map Georeferencing

Schöning et al. (2009) proposed methods to use GPS equipped mobile phones to take, georeference, and display You Are Here (YAH) maps. They proposed two ways of georeferencing YAH maps: two point referencing and smart alignment. The methods enabled the positioning on the map images, but the prerequisites for the two kinds of georeferencing are critical. The two point referencing method is only available for north-up maps and the smart alignment method requires that the user's traces overlap with the spatial extend of the photo of the map. According to the paper, only 81% maps they collected meet the first requirement and fewer than half (48%) maps meet the second requirement. Morrison et al. (2011) developed an AR application MapLens that could timely overlay location-based medias on the paper map image. It uses predetermined map data files to position media on the right places on the map. It enriches the content of original maps. However, the application works with the combination of a mobile phone and a real map, which makes the application inconvenient to use. Besides, the application supports the searching function from map positions to media, but does not support searches from the medias to map positions. Wang et al. (2012) proposed a three point referencing method to calculate user's location on the image of site maps. They tried to increase the positioning accuracy by weighting the GPS locations according to the GPS accuracies when calculating the user's location on map images. However, the improvement of positioning accuracy is limited. On one hand, factors other than GPS errors, like the distortions of the map images, are not considered. On the other hand, introducing a third referencing point does not necessarily increase the positioning accuracy. Actually, if the third point itself has a relatively large error, it would on the contrary decrease the positioning accuracy. Lu and Arikawa (2013a, 2013b, 2014) studied on integrating illustrated maps on tour guidebooks with mobile devices. They georeferenced maps illustrating texts and images of guidebooks for positioning and storytelling. They also enabled users to make georeferencing for spatial references and POI's. However the editing tools are difficult for ordinary users to operate, and the positioning results calculated by the two point referencing are not stable.

The related researches have provided many ideas on integrating analogue maps with mobile devices to enrich the analogue maps with LBS and multimedia. However, still several problems need to be solved.

The main problem is the accuracy of positioning on the map images on mobile devices. Many researches use points as referencing objects to calculate positions. As Lu and Arikawa (2013b) indicated, the error of point-referencing positioning increases with the distortions of map images and the distance from the user's location to the line formed with the nearest two points. Thus, users will find themselves drift off the right positions when they are moving far from the reference points. Besides, at the time when the reference points for calculating user's position change, there will be a distinct jump of the user's trajectories on the map image.

The second problem is the lack of directing. The map images are always shown in the same directions as they were made, and user's directions are not indicated. Directions are important in navigation to assist spatial decisions, and showing directions is a basic function on web and mobile mapping. User's directions are needed on analogue map images for user-friendly navigation, and in some contexts, map images should be aligned egocentric to help users define directions.

The third problem is the lack of connections among different maps. The switching among maps is static, which break the continuity in navigations and storytelling. To ensure continuous navigation and storytelling, a natural, smooth and dynamic switching among maps with different extent areas, scales and topics are required.

2.2 Structure of Map Collaging

As shown in Figure 2.1, the structure of map collaging consists of three hierarchies of contents: raw data, georeferenced maps, and routes.

Raw data are the data without explicit geo-information, such as images, texts and audios, and are used as the materials to make up map collaging. Images include map images and POI images. Map images are those for which location-based services will be provided, and POI images are used for illustrating POI's. Texts and audios can be used for additional introductions for POI's.

A georeferenced map image uses georeferences to build connections with digital base maps to enable location-based services like positioning and directing on the map images, and overlaying of different analogue map images. In this research, polylines are used for georeferencing analogue map images.

A route is a combination of different georeferenced maps, which enlarges the extent area and enriches the spatial information of single georeferenced maps, for local storytelling through places with different maps. Routes can be designed for contexts such as walking, cycling, driving, giving presentations, and so on. In a map collaging route, one *main map* on the top layer is presented more solidly, and a route can contain *background maps* under the main map which are presented semi-transparently.

Figure 2.1 Data Structure of Map Collaging

2.3 Polyline-based Georeferencing

Point-based georeferencing is well applied in orthogonalization of areal photos and satellite images with systematic distortions, but for mapping services on analogue maps images with irregular distortions, the positioning results are not accurate or stable. As paths (e.g. roads) are important spatial references to form the image of the cities (Lynch, 1960), this thesis proposes polyline-based georeferencing to improve positioning accuracy along paths.

As shown in Figure 2.2, a polyline georeference is built with a pair of corresponded polylines on the base maps and on the target analogue map image. The end points of the pair of polylines should refer to the same positions in the real world, and the order of the start point and the end point should be kept. Due to the possible inconsistent distortions on the base maps and on the target map image, it is not require that the inner points of the pair of polylines to be the same number or in the exact same places.

(The left map is the target map provided by Kashiwa History Club; the right one is the base maps of Apple Maps)

Figure 2.2 Polyline georeference

2.4 Position Calculation

Positioning is one of the most important functions of LBS. The accuracy of positioning has a direct effect on the quality of LBS. This chapter use polyline references to improve the accuracy and stability of positioning results. The processes of calculating positions based on referencing polylines mainly contain two steps.

The first step is to find the nearest referencing polyline on the base map from user's location, and the corresponded polyline on the target map. A polyline is noted by its two end points. As shown in Figure 2.3, U is the user's location on the base map, AB is the nearest polyline on the base map, $A'B'$ is the corresponded polyline on the target map.

The second step is to map the geo-coordinates of user's location to the target map. The length of a polyline is noted as L. As shown in Figure 2.3, V is the snapped point from U to AB, calculate the corresponded point V' on $A'B'$, so that $\frac{L_{AV}}{L_{AB}} = \frac{L_{A'V'}}{L_{A'B'}}$. And calculate user's location on the target map (noted as U') by making perpendicular vector starting from the point V' to the same side of U to AB, so that $\frac{|UV|}{L_{AB}} = \frac{|U'V'|}{L_{A'B'}}$.

(a) Objects on the base map **(b)** Objects on the target map

Figure 2.3 Calculating user's position on target maps using referencing polylines

There are two cases that require special processes to calculate positions on map images. One is the case that the foot point of user's location is out of the referencing polyline on the base map. As shown in Figure 2.4, the point U is out of the polyline AB. In this case, line AB and $A'B'$ are used as references to calculate the position on the target map by the relation that $\frac{|AV|}{|AB|} = \frac{|A'V'|}{|A'B'|}$ and $\frac{|UV|}{|AB|} = \frac{|U'V'|}{|A'B'|}$.

(a) Objects on the base map **(b)** Objects on the target amp

Figure 2.4 The case that the foot point of user's location is out of the referencing polyline on the base map

The other case is that the calculated foot point is overlaid with the end points or inner points on the referencing polyline on the target map. In this case, the snapped point is slightly moved along the referencing polyline to avoid end points and inner points (refer to Figure 2.5).

Figure 2.5 The case that the calculated foot point overlays with the endpoints or middle points of the referencing polyline on the target map

2.5 Direction Calculation

Directions are used to indicate the user's facing direction, align map images, and overlay maps. Directions of the polylines on the base maps and on the target map image should be first obtained to calculated angles for indicating the user's direction, aligning and overlaying map images. The following four steps are used to calculate directions of the polylines on the base maps and on the target map image.

First, find the nearest referencing polyline from user's location on the base map and the corresponded polyline on the target map. As shown in Figure 2.6, AB and $A'B'$ are corresponded polylines on the base map and on the target map (inner points of the polylines are not presented because direction calculating only requires using the end points of the referencing polylines).

Second, transfer the locations of the end points of the polylines to plane rectangular coordinate system with projections that keep directions consistent (e.g. Mercator projection). As shown in Figure 2.6(a), the geo-coordinates of A and B are noted as (lat_1, lon_1) and (lat_2, lon_2), and the projected coordinates are noted as (x_1, y_1) and (x_2, y_2).

Third, calculate the direction of the referencing polyline on the base map. As shown in Figure 2.6(a), the angle from the map north direction to the vector AB is noted as α, which can be calculated by Equation 1:

$$\alpha = \begin{cases} arccos\frac{y_2-y_1}{\sqrt{(y_2-y_1)^2+(x_2-x_1)^2}}, & (y_2 \geq y_1) \\ arccos\frac{y_2-y_1}{\sqrt{(y_2-y_1)^2+(x_2-x_1)^2}} + 2\pi, & (y_2 < y_1) \end{cases} \quad \cdots\cdots\cdots (1)$$

(a) Direction relations on the base map **(b)** Direction relations on the target map

Figure 2.6 Calculating directions of referencing polylines

Fourth, calculate the direction from the up direction of the target map to the corresponded polyline on the target map. As shown in Figure 2.6(b), the coordinates of A' and B' are noted as (x'_1, y'_1) and (x'_2, y'_2), and the angle from the upward direction of the target map to the vector $A'B'$ is noted as β which can be calculated by Equation 2:

$$\beta = \begin{cases} arccos\frac{y'_2-y'_1}{\sqrt{(x'_2-x'_1)^2+(y'_2-y'_1)^2}}, & (y'_2 \geq y'_1) \\ arccos\frac{y'_2-y'_1}{\sqrt{(x'_2-x'_1)^2+(y'_2-y'_1)^2}} + 2\pi, & (y'_2 < y'_1) \end{cases} \cdots\cdots\cdots (2)$$

Then the angle to rotate map image geocentrically (north-up) can be calculated by Equation 3:

$$\theta_g = \alpha - \beta \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

With the direction of the device (note as γ, which can be sensed by the compass sensor in the smartphone), the angle for ego-centralizing the target map (note as θ_e) is given by Equation 4:

$$\theta_e = \gamma - \beta + \alpha \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

The current rotation degree of the map image is noted as ω. Then the angle to rotate the map image to map-centric direction (the original direction of the map image, noted as θ_r) is given by Equation 5:

$$\theta_r = -\omega \cdots\cdots\cdots\cdots\cdots\cdots (5)$$

And the angle to indicate user's direction on the device (noted as θ_u) can be calculated with Equation 6:

$$\theta_u = \omega - \theta_e = \omega - \gamma + \beta - \alpha \cdots\cdots\cdots\cdots (6)$$

2.6 Maps Overlaying

As the extent area and spatial stories of a single map are limited, in order to cover larger areas and provide more comprehensive stories, a collaboration of multiple maps are needed. There are discontinuities in map projections, directions and topics among different maps. To ensure smooth and natural switches among different maps, maps should be well arranged so that the spatial relations among the maps are kept correct.

Widely used web and mobile mapping combines tiles of maps seamlessly. A seamless map combination requires consistent map projections among different maps. Maps in map collaging have different map distortions, which prevents seamlessly combination of different maps. And irregularly

distorted illustrated maps are not suitable for a seamless overlaying on base maps through geometric corrections to unify the map projections, which will cause deformation of the map images, and affect the original design for storytelling. As shown in Figure 2.7, an illustrated map looks more distorted after geometric correction according to base maps.

(a) Original map image **(b)** Map image overlaid through geometric corrections
(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.7 Distorted analogue map not suitable for overlaying on base maps

To prevent deformation of the original map images, three kinds of transformations are employed in the map collaging with polyline-based geocoded map images: translation, symmetric scaling, and rotation. Any transformation that is possible to deform the original maps is not used, such as unsymmetrical scaling, skew and non-affine transformations. Figure 2.8 shows the transformations applied to the map images and examples of those not applied.

(a) translation **(b)** symmetric scaling **(c)** rotation

(d) unsymmetrical scaling **(e)** skew **(f)** non-affine transformation

Figure 2.8 Transformations applied in map collaging (a, b ,c) and those not applied (d, e, f)

Because of the different map projections and distortions of the target maps, it is usually not possible to overlay two maps seamlessly. This research proposes a focus point based map overlaying to overlay different maps.

Among the target maps, one works as the main map, and other maps are arranged based on the main map. The processes to arrange a background map based on the main map contain the following five steps:

First, overlap centers of the main map and the background map, and calculate the user's positions on both maps. As shown in Figure 2.9(a), the red map is the main map and the green map is the background map; O and O' are the center points of each map; U and U' are the user's positions on each map.

Second, scale the background map to make its scale the same as the main map. As shown in Figure 2.9 (b), AB and CD are the polylines on the two target maps. $A'B'$ and $C'D'$ (not shown on the figure) are noted as the corresponded polylines on the base map. Scale the background map so that $\frac{L_{AB}}{L_{A'B'}} = \frac{L_{CD}}{L_{C'D'}}$. The user's current position on the second map is U'_s.

Third, rotate the background map to the same direction of the main map. As shown in Figure 2.9 (c), the user's current position on the background map is U'_r.

Fourth, move the background map to overlay the user's positions on the two maps. As shown in Figure 2.9 (d), O' is the center point of the background map, and $x_{o'} = x_o + x_u - x_{u_{r'}}$, $y_{o'} = y_o + y_u - y_{u_{r'}}$.

Finally, rotate the main map and the background map together by the user's position according to the real north direction, as shown in Figure 2.9 (e).

The arranged map collages ensure a dynamic switch among different maps. The user's positions on the screen, map scales and map directions will be retained before and after switching, which makes the switching process smooth and natural.

(a) Overlap map centers **(b)** Scale the second map **(c)** Rotate the second map

(d) Overlap user's positions **(e)** Align the map collages

Figure 2.9 The processes of arranging a second map based on a main map

2.7 Experiments and Analyses

2.7.1 Experiments on Position Calculation

As is mentioned, the positioning accuracy is essential for LBS. Experiments are carried out to test the positioning accuracy of the proposed algorithm. A walking trajectory is recorded, as Figure shown in 2.10.

(The base map is Apple Maps)

Figure 2.10 The walking trajectory on the base map

The trajectory locations are mapped to the target map with point-based georeferencing and polyline-based georeferencing.

A photo image of a map signboard of the University of Tokyo Kashiwa Campus has been used. The control points are the end points of the polylines for georeferencing (Figure 2.11). The results of mapped trajectories on the target map image using points and polylines are shown in Figure 2.12.

Points for georeferencing Polylines for georeferencing
(Source: map signboard of UT Kashiwa Campus)

Figure 2.11 Points and polylines for georeferencing

(a). Results based on point references **(b).** Results based on polyline references
(Source: map signboard of UT Kashiwa Campus).

Figure 2.12 Comparison of the positioning results based on point references and polyline references

Statistics of the errors of the point-based georeferencing results (using algorithm proposed by Lu and Arikawa, 2013b) and polyline-based georeferencing results are calculated. As shown in Figure 2.13, the distances from the trajectory points to the referencing polylines m (noted as m_b on the base map, m_p on the point-based georeferenced map, m_l for the polyline-based georeferenced map) and the distances between each neighbor trajectory points n (noted as n_b on the base maps, n_p on the point-based georeferenced map, n_l on the polyline-based georeferenced map) are used for judging the accuracy and the stability of the positioning algorithms. For the results based on point georeferencing, the positioning error of one point is $e_1 = m_p - m_b$ referring to polylines, and $e_2 = n_p - n_b$ referring to the next neighbor trajectory points. For the results based on polyline georeferencing, the positioning error of one point is $e'_1 = m_l - m_b$ referring to polylines, and $e'_2 = n_l - n_b$ referring to the next neighbor trajectory points.

Figure 2.13 The distance from the trajectory point to the referencing road, and the distance between neighbor trajectory points

The values of e_1 and e'_1 are shown in Figure 2.14. The histogram of the errors is shown in Figure 2.15. As shown in Table 2.1, the average value of the errors and the standard deviation of the errors of the trajectory points on the polyline-based georeferenced map are smaller than those on the point-based georeferenced map. Similar results have been obtained for e_2 and e'_2. The values, histogram, and the average value and standard deviation of the errors are shown in Figure 2.16, Figure 2.17, and Table 2.2.

Figure 2.14 The errors referring to the distances to polylines

Figure 2.15 Histogram of the errors referring to the distances to polylines

Table 2.1 Average values and standard deviations of the errors referring to the distances to the roads.

	Point-based georeferencing	Polyline-based georeferencing
Average of errors (m)	2.457	-0.409
Standard Deviation of errors (m)	5.448	0.722

Figure 2.16 The errors referring to the distances between neighbor trajectory points

Figure 2.17 Histogram of the errors referring to the distances between neighbor trajectory points

Table 2.2 Average values and standard deviations of the errors referring to the distances between neighbor trajectory points

	Point-based georeferencing	Polyline-based georeferencing
Average of errors (m)	0.295	0.073
Standard Deviation of errors (m)	2.566	0.544

The statistics prove that polyline-based georeferencing achieve more accurate and stable positioning results than point-based georeferencing (Lu and Arikawa, 2013b).

Positioning errors on polyline-based georeferenced maps come from two aspects: map distortion and georeferencing errors.

Positioning Errors From Map Distortion

As shown in Figure 2.18, suppose all georeferencing polylines are correct; C_b is a spatial object on the base map; C_t is the corresponded object on the target map; C'_b is the calculated position from C_b; AB and $A'B'$ are the referencing polylines. Note the distance from C_b to AB as d, and note the map scales vertical to the polyline are s_v and s'_v on the base map and on the target map; the scales parallel to the polyline are s_p and s'_p on the base map and on the target map (suppose map scales are constant at the local area). Then the error distance between the calculated position C'_b and the object's position on the map image C_t is $e = d \cdot (\frac{s'_v}{s_v} - \frac{s'_p}{s_p})$. Note $k = \frac{s'_v}{s_v} - \frac{s'_p}{s_p}$, then we have $e = k \cdot d$. The positioning error is linearly correlated to the distance to the polyline.

(a) Objects on the base map **(b)** Objects on the target map

Figure 2.18 Positioning error is linearly correlated to the distance from the spatial object to the referencing polyline

Positioning Errors From Georeferencing Errors

Suppose the target map and the base maps have the same map projections, the errors of georeferencing have effects on positioning results in three aspects.

(1) Scale Error of Georeferences

As shown in Figure 2.19, the polyline $A'B'$ on the target map is shorter than the correct polyline AB, and note scale error $s = \frac{A'B'}{AB}$, C and C' are correct and incorrect positioning results, note the distance from C to AB as d, then the positioning error is $e_1 = (1 - s) \cdot d$.

Figure 2.19 Positioning error form scaling error of georeference

(2) Rotation Error of Georeferences

As shown in Figure 2.20, AB is correct polyline and $A'B'$ is the polyline with rotation error θ, C and C' are correct and incorrect positioning results, note the distance from C to AB as d, then the positioning error is $e_2 = 2 \cdot \sin\frac{\theta}{2} \cdot d$.

Figure 2.20 Positioning error form rotation error of georeference

(3) Translation Error of Georeferences

As shown in Figure 2.21, AB is correct polyline and $A'B'$ is the polyline with translation t, then the positioning error is $e_3 = t$.

Figure 2.21 Positioning error form translation error of georeference

Considering that short georeferences are vulnerable to scale error and rotation error caused by position inputting errors of the end points, it is suggested that too short polylines should be prevented when georeferencing map images.

One deficiency of using nearest polyline to calculate positions is that when the nearest polyline for calculation changes and the user's position is far from the polyline, there may be distinct jump of the user's trajectory, which affect positioning stability (Figure 2.22a). The thesis uses weighted average positioning to solve the problem. Firstly, using each polyline to calculate positions (noted as P_i) and the distance from the position to the corresponded polyline (noted as d_i), then weight each position inversely to the distance (noted as w_i), and the final positioning result (noted as $P = (x, y)$) can be calculated by Equation 7. The experiment results indicate that the weighted average positioning increases the positioning stability (Figure 2.22).

$$\begin{cases} x = \frac{\sum w_i \cdot x_i}{\sum w_i} \\ y = \frac{\sum w_i \cdot y_i}{\sum w_i} \end{cases} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (7)$$

The user's trajectory

(a) Positioning with nearest polyline **(b)** Weighted average positioning

Figure 2.22 Comparison of positioning through nearest polyline and weighted average positioning

2.7.2 Experiments on Direction Calculation

The north direction does not point to the same directions on a map image with distortions. In this research, experiments are carried on calculating image north directions with map images with different distortions.

First, an areal photo of the University of Tokyo Kashiwa Campus is used. The north direction of a point on the image is calculated by the nearest polyline. And the result is shown in Figure 2.23.

Then, the same experiment is done on a bird's-eye view areal photo, and the result is shown in Figure 2.24.

The results indicate a main factor of inconsistency of direction on a map image comes from the map distortion.

The rotation errors of the polylines for georeferencing also have effects on the map direction error. Note the rotation error of the polyline on the base maps as α and the rotation error of the polyline on the target map as β, then the error of the map north direction calculated by the georeference on the target map is $e = \beta - \alpha$. As mentioned in section 2.3.2, a short polyline is easy to have large rotation error and should be prevented.

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.23 Directions calculated by different polylines on areal photo

georeference

direction

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.24 Directions calculated by different polylines on bird's-eye view photo

2.7.3 Experiments on Map Overlaying

As shown in Figure 2.25, the same two maps are overlaid, and a 10 by 10 checkpoints matrix is used to sample errors of the map overlaying. A checkpoint can be referred by its row and column index (noted as $P(row, column)$), or by a linear index (noted as $P(10 \cdot row + column)$). The maps are overlaid with each point in the checkpoints matrix as focus points, and the distance between the corresponded checkpoints are calculated as map overlaying error at that point. Simulations are carried out with different georeferences on the two maps.

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.25 Check points on areal photo for simulations

First, the same polylines are used for georeferencing on the two maps (Figure 2.26), and the results show that the map overlaying error on every checkpoint is 0 regardless of the focus point (Figure 2.27). It proves the correctness of the map overlaying algorithm.

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.26 The same map with the same polylines for georeferencing to be overlaid

Checkpoint on the main map

Checkpoint on the background map

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.27 Map overlaying result with the same map and the same polylines for georeferencing

Then the same maps are overlaid with georeferences made by different polylines (Figure 2.28). The map overlaying results are shown in Table 2.3. The table records the focus point index (FP Index), overlaying error of the focus point (FP Err), the difference of map north on the two maps (ΔNorth),

the ratio of map scale calculated from the georeference on the two maps (Scale Ratio), the differences of the map image rotations (Δ Rotation), and the ratio of the different map sizes (Size Ratio). Figure 2.29 shows part of the results of the map overlaying based on different focus points.

The results show the fact that the rotation and scaling error of the map overlaying come from the relative errors of the georeferences on the two maps. Note the map north direction error on each map as e_{n_1} and e_{n_2}, and scaling error of georeferences on each map as e_{s_1} and e_{s_2}, then the map overlaying direction error is $e_{dir} = e_{n_2} - e_{n_1}$, and map overlaying scale error is $e_{scale} = \frac{e_{s_1}}{e_{s_2}}$. Because too short georeferencing polylines tend to have large rotation and scale error, maps overlaying calculated with short polylines tend to have a large direction and scale errors.

As for the map overlaying accuracy at the focus point, it depends on the positioning errors on each map. Note positioning errors at the focus point are $\overrightarrow{e_1}$ and $\overrightarrow{e_2}$ on the two maps, then the map overlaying error at the focus point is $\vec{e} = \overrightarrow{e_2} - \overrightarrow{e_1}$. As mentioned in Section 2.3.1, positioning error on a map decreases with the distance to the reference polyline decreasing. If the focus point is near both georeferences of the two maps, the possible max map overlaying error at the focus point will be small.

(a) Georeferences on the main map **(b)** Georeferences on the background map
(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.28 The same map with different polylines for georeferencing to be overlaid

Table 2.3 Map overlaying results

FP Index	FP Err (m)	ΔNorth (degree)	Scale Ratio	ΔRotation (degree)	Size Ratio
0	24.998	0.079	0.966	-0.079	1.035
1	22.097	0.079	0.966	-0.079	1.035
2	8.489	-0.743	1.018	0.743	0.982
3	9.233	-0.743	1.018	0.743	0.982
4	25.291	2.963	0.994	-2.963	1.006
5	10.811	-0.216	0.989	0.216	1.011
6	19.895	-0.394	0.965	0.394	1.037
7	10.928	0.266	1.016	-0.266	0.984
8	10.761	0.266	1.016	-0.266	0.984
9	13.633	-0.394	0.965	0.394	1.037
10	23.639	0.079	0.966	-0.079	1.035
11	20.591	0.079	0.966	-0.079	1.035
12	8.697	-0.743	1.018	0.743	0.982
13	9.064	-0.743	1.018	0.743	0.982
14	21.331	2.963	0.994	-2.963	1.006
15	11.056	-0.216	0.989	0.216	1.011
16	18.513	-0.394	0.965	0.394	1.037
17	35.940	1.758	0.951	-1.758	1.052

18	9.139	0.266	1.016	-0.266	0.984
19	11.803	-0.394	0.965	0.394	1.037
20	22.320	0.079	0.966	-0.079	1.035
21	19.393	0.079	0.966	-0.079	1.035
22	9.336	-0.743	1.018	0.743	0.982
23	9.509	-0.743	1.018	0.743	0.982
24	44.626	-0.008	0.989	0.008	1.011
25	11.363	-0.216	0.989	0.216	1.011
26	56.393	0.727	0.975	-0.727	1.025
27	22.989	-0.394	0.965	0.394	1.037
28	7.624	0.266	1.016	-0.266	0.984
29	10.010	-0.394	0.965	0.394	1.037
30	20.688	0.079	0.966	-0.079	1.035
31	18.458	0.079	0.966	-0.079	1.035
32	22.513	-0.145	0.991	0.145	1.009
33	10.595	-0.743	1.018	0.743	0.982
34	10.372	-0.743	1.018	0.743	0.982
35	11.731	-0.216	0.989	0.216	1.011
36	10.745	-0.216	0.989	0.216	1.011
37	23.161	-0.394	0.965	0.394	1.037
38	6.199	0.266	1.016	-0.266	0.984
39	8.027	-0.394	0.965	0.394	1.037
40	18.027	0.079	0.966	-0.079	1.035
41	17.052	0.079	0.966	-0.079	1.035
42	14.048	0.079	0.966	-0.079	1.035
43	11.496	-0.743	1.018	0.743	0.982
44	11.756	-0.743	1.018	0.743	0.982
45	12.170	-0.216	0.989	0.216	1.011
46	8.852	-0.216	0.989	0.216	1.011
47	21.850	-0.394	0.965	0.394	1.037
48	4.708	0.266	1.016	-0.266	0.984
49	6.329	-0.394	0.965	0.394	1.037
50	13.734	0.079	0.966	-0.079	1.035
51	12.804	0.079	0.966	-0.079	1.035
52	13.221	0.079	0.966	-0.079	1.035
53	9.584	-0.743	1.018	0.743	0.982
54	12.819	-0.743	1.018	0.743	0.982
55	12.668	-0.216	0.989	0.216	1.011
56	1.408	-0.216	0.989	0.216	1.011
57	16.197	-0.394	0.965	0.394	1.037
58	1.157	1.758	0.951	-1.758	1.052
59	8.767	-0.394	0.965	0.394	1.037
60	0.000	0.000	1.000	0.000	1.000
61	0.000	0.000	1.000	0.000	1.000
62	0.000	0.000	1.000	0.000	1.000
63	0.000	0.000	1.000	0.000	1.000
64	0.000	0.000	1.000	0.000	1.000
65	0.195	1.861	1.030	-1.861	0.970
66	0.000	0.000	1.000	0.000	1.000
67	0.000	0.000	1.000	0.000	1.000
68	0.000	0.000	1.000	0.000	1.000
69	7.075	-1.721	1.047	1.721	0.955
70	16.601	-1.461	0.972	1.461	1.029
71	1.303	-1.461	0.972	1.461	1.029
72	0.000	0.000	1.000	0.000	1.000
73	0.000	0.000	1.000	0.000	1.000
74	0.000	0.000	1.000	0.000	1.000
75	0.630	-0.840	0.982	0.840	1.018

76	0.000	0.000	1.000	0.000	1.000
77	0.000	0.000	1.000	0.000	1.000
78	0.000	0.000	1.000	0.000	1.000
79	0.000	0.000	1.000	0.000	1.000
80	7.146	0.114	0.985	-0.114	1.016
81	6.907	0.114	0.985	-0.114	1.016
82	4.790	-1.461	0.972	1.461	1.029
83	8.905	-0.399	0.992	0.399	1.008
84	6.524	-0.399	0.992	0.399	1.008
85	1.829	-0.840	0.982	0.840	1.018
86	17.794	-0.045	0.961	0.045	1.040
87	14.935	1.386	0.968	-1.386	1.033
88	11.399	1.136	1.010	-1.136	0.990
89	13.532	-2.021	1.035	2.021	0.966
90	3.835	0.114	0.985	-0.114	1.016
91	6.760	0.114	0.985	-0.114	1.016
92	6.353	0.495	0.993	-0.495	1.007
93	24.677	0.114	0.985	-0.114	1.016
94	12.827	-0.399	0.992	0.399	1.008
95	4.126	-1.054	1.005	1.054	0.995
96	25.330	-0.045	0.961	0.045	1.040
97	25.074	-0.045	0.961	0.045	1.040
98	15.984	1.136	1.010	-1.136	0.990
99	11.435	-2.021	1.035	2.021	0.966

(a) Maps overlaid based on $P(0,0)$

(b) Maps overlaid based on $P(0,9)$

(c) Maps overlaid based on $P(9,0)$

(d) Maps overlaid based on $P(9,9)$

(e) Maps overlaid based on $P(3,3)$

(f) Maps overlaid based on $P(3,6)$

(e) Maps overlaid based on $P(6,3)$

(f) Maps overlaid based on $P(6,6)$

Checkpoint on the main map

Checkpoint on the background map

(Areal photo provided by The University of Tokyo, Kashiwa Campus)

Figure 2.29 Map overlaying results of the same two maps with different polylines for georeferencing

2.7.4 Rules of Making Georeferences

According to the characteristics of polyline-based georeferencing, rules of making polylines for georeferences for accurate and stable positioning and map overlaying are summarized as follows.

(1) It is suggested to make polylines along suggested courses on the maps because positioning accuracy will decrease as the distance to the polyline increases. Figure 2.30 shows the differences of making georeferences along and off the course on the map, which indicates that georeferences along the course achieve better results when the user moves along the course.

(a) Georeferences along the course **(b)** Georeferences off the course

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.30 Comparison of polylines for georeferencing along and off the courses on maps

(2) Users should avoid too short polylines because as mentioned, short polylines are easy to have a large scale and rotation, which will cause errors in positioning, directing and map overlaying. Figure 2.31 shows the same maps georeferenced with too short polylines (georeferencing errors are intentionally added). Table 2.4 Figure 2.32 indicates obvious differences of map north directions and scales calculated by the polylines, and it results in obvious map overlaying errors.

(a) Map one **(b)** Map two

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.31 Too short polylines used in the same maps

Table 2.4 Map north directions calculated on two same map images with short polylines

Map	Map North (degree)	Scale (pixel/m)	ΔNorth (degree)	Scale Ratio
(a)	-10.9	3.23	23.8	0.63
(b)	12.9	2.03		

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.32 Overlaying of maps with too short polylines

(3) Users should avoid too long polylines. Long polylines are strong in resisting scale and rotation errors, but are weak in resisting map distortion changes, which results in obvious positioning errors at decision points along the georeferenced paths. Figure 2.33 shows the same maps georeferenced with too long polylines (georeferencing errors are intentionally added). Table 2.5 and Figure 2.34 show that long polylines resist the scale and rotation errors of georeferences, which contributes to stable and accurate map overlaying. Table 2.6 and Figure 2.35 indicate obvious positioning errors at sample points at sharp turnings and intersections along the polyline.

(a) Map one **(b)** Map two

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.33 Too long polylines used in the same maps

Table 2.5 Map north directions calculated on two same map images with long polylines

Map	Map North (degree)	Scale (pixel/m)	ΔNorth (degree)	Scale Ratio
a	1.64	2.31	-1.69	0.99
b	-0.05	2.28		

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.34 Map overlaying with long polylines

Sample point

Calculated point

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.35 Positioning results at sample points

Table 2.6 Positioning errors of sample points

Sample Point	Error (m)
1	34.0
2	16.4
3	4.1
4	22.7
5	9.7
6	18.8
Average	17.6

(4) Because of different purposes and distortions of different maps, it cannot give a suggested length for appropriate polylines. Users need to check and revise to find paths and lengths of polylines suitable for georeferencing a certain map. Figure 2.36 shows an example of a georeferenced map (noted as Map1) with 7 georeferences, which keeps a balance in the accuracy of map overlaying and positioning. The same map image is georeferenced with the same paths for map overlaying (noted as Map2). Figure 2.37 and Figure 2.38 show the map overlaying and positioning results, Table 2.7 shows the rotation and scale errors, and Table 2.8 shows the positioning errors at sample points. The results indicate that the georeferences avoid large map overlaying error and positioning errors.

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.36 An example of appropriate georeferencing

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.37 Map overlaying results

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 2.38 Positioning results at sample points

Table 2.7 Scaling and rotation errors of the georeferences

Georeference	Map1 North (degree)	Map2 North (degree)	ΔNorth (degree)	Map1 Scale (pixel/m)	Map2 Scale (pixel/m)	Scale Ratio
1	0.39	-0.4	-0.79	2.83	2.84	1.00
2	3.28	-2.77	-6.05	2.52	2.10	0.83
3	-3.53	-0.8	2.73	1.83	2.24	1.22
4	0.22	2.97	2.75	2.56	2.52	0.98
5	4.77	-3.53	-8.3	1.96	1.83	0.93
6	-2.97	0.45	3.42	2.10	2.56	1.22
7	-0.27	3.82	4.09	2.27	1.94	0.85

Table 2.8 Positioning errors of sample points

Sample Point	Error (m)
1	3.0
2	0.69
3	4.08
4	0.97
5	0.82
6	2.43
Average	2.00

2.8 Summary

This chapter describes the framework of map collaging, the content of which consists a hierarchy with three levels, that is, raw data, georeferenced maps and routes. Raw data are data without explicit geo-information and are the resources to build map collaging. Georeferenced maps are maps that are bundled with base map through georeferences, on which location-based services such as positioning

and directing can be provided. Routes are groups of georeferenced maps that are arranged to cooperate to share local knowledge.

Polylines are used as georeferences to connect analogue maps to the base maps in order to calculate positions and directions on the analogue maps and to overlay different analogue maps. The characteristics of polyline-based georeferencing are:

- It ensures stable and accurate positioning results along the polylines for georeferencing.
- A too long polyline cannot resist distortion changes on different parts of a map.
- A too short polyline tends to have distinct scale and rotation errors, which can cause errors of positioning, map directing, and map overlaying.

According to the characteristics of polyline-based georeferencing, rules for making map georeferences are summarized as follows:

- The end points of a polyline should be accurately corresponded to the points on the base maps.
- The directions of a polyline on the target map should be the same as the direction of the corresponded polyline on the base maps.
- Making polylines along recommended courses on analogue maps is suggested if available.
- Too long and too short polylines should be prevented.
- It is required to check and revise georeferences to adjust paths and lengths of polylines for georeferencing.

Chapter 3 Semi-Georeferencing on Map Collaging

In the previous chapter, polyline-based georeferencing is proposed to improve positioning accuracy, and is used for calculating directions and map overlaying for map collaging. However, georeferencing that directly connects target maps to the base maps has limitation in practices because sometimes users cannot find enough corresponded spatial objects for georeferencing. To solve the problem, the thesis proposes semi-georeferencing to build direct connections among analogue maps to enable positioning on old maps with little georeferences, and to increase accuracy of positioning and map overlaying.

3.1 Problems of Georeferencing

Georeferencing is the bridge to connect features on geometrically correct base maps and corresponded features on distorted analogue map images for positions, directions and map scales transferring between these two kinds of maps (Figure 3.1). With georeferencing, different analogue maps are directly connected to the base maps, forming a tree structure with depth of two (Figure 3.2). And relations among different analogue maps are indirectly connected through the base maps. For example, the map overlaying of two analogue maps is the result that both maps overlaid to the base maps.

Figure 3.1 One-hop connections between target maps and base maps

C: Geometrically correct map (usually the base maps)
D: distorted map (usually the analogue maps)

Figure 3.2 Relation among georeferenced maps

As mentioned in Chapter 2, positioning accuracy of georeferencing decreases as the distance to the spatial references increases. Positioning results at places that are far from the referencing objects on the maps have risks of inaccuracy and instability. One can use more polylines to control larger areas on the map images. However, in practices, sometimes it is difficult to directly find corresponded spatial objects for georeferencing, for example, it is difficult to georeference the old maps on which spatial objects have changed or disappeared. Figure 3.3 is a comparison between an areal photo of the current Kashiwanoha area and the base maps (Apple Maps). It can be found that the place used to be air base and farmlands, which do not exist any more. In this case, georeferences can hardly be made by directly matching spatial objects on the target map image with those on the base maps.

(a) Areal photo of Kashiwanoha area in 1948 **(b)** Base maps of Kashiwanoha area in 2013
(The areal photo of 1948 is provided by Geospatial Information Authority of Japan, and was originally taken by U.S. Army.)

Figure 3.3 Kashiwanoha area in 1948 and 2013

The limitation of direct georeferencing brings a problem of inadequate georeferences, which affects positioning and map overlaying accuracy. As shown in Figure 3.4, only one spatial reference is found on the areal photo of 1948 for georeferencing. The polyline is near the bottom part of the image, the positioning accuracy around middle and up part of the image cannot be ensured. For example, remains of areal fuel docks are recorded on the base maps and mapped to the areal photo of 1948. The results (Figure 3.5) indicate obvious positioning errors of the remains of the docks. (Four possible remains of the docks are recorded on the base maps, but their corresponding relations to the docks on the areal photos are not known.)

(The areal photo is provided by Geospatial Information Authority of Japan, and was originally taken by U.S. Army)

Figure 3.4 Only one polyline is used for georeferencing the areal photo of 1948

(The areal photo is provided by Geospatial Information Authority of Japan, and was originally taken by U.S. Army)

Figure 3.5 Positioning errors on the areal photo of 1948

The above example shows that practically it is sometimes difficult to make the georeferences directly between the target map image and the base maps, which affects the positioning and map overlaying results. In the next section, semi-georeferencing will be introduced to solve the problem.

3.2 Semi-georeferencing

Semi-georeferencing is the direct connections between two target map images (Figure 3.6). Semi-georeferencing enables direct position transferring and map overlaying of two target maps. Functionally, the concept of semi-georeferencing shares similarity with the concept of georeferencing and image registration, which are widely used for building 3D models (Thirion, 1994, 1996; Verhoeven et al., 2012; Reu et al., 2014; Koutsoudis et al., 2014), image orthogonalization (Goshtasby, 1986; Smith and Atkinson, 2001; Zitová and Flusser, 2003; Ladd et al. 2006; Bozzinia et al., 2012; Karel et al., 2013), and in the fields other than cartography and GIS, like the field of medical image process (Markelj et al., 2012; Li et al. 2015).

One significant difference of semi-georeferencing from the other similar concept lays in the purpose of the application of the concepts and the target users. Semi-georeferencing is proposed for ordinary people without special skills on digital map and image processing to edit local analogue maps to share their local knowledge for indicating users the characteristic of semi-georeferencing that it does not enable the position transfer between geographic coordinates and graphic coordinates, instead of applications that require high accuracy for professionalists, like spatial analyzing and surveying. Also,

image registration for professional applications focuses more on accuracy of calculation and sometimes sacrificed the cost of equipment and easiness of operations. Semi-georeferencing keeps a balance between the accuracy of calculation and the easiness of operations to enable more uses to edit map collaging content.

Figure 3.6 Semi-georeferencing structure with multi-hop connections between target and base maps

As shown in Table 3.1, mapping relations among geometrically correct maps can be made by map projections, and it is usually used in professional GIS, web and mobile mapping services. Georeferencing enables connections between distorted maps and geometrically correct maps, and it is applied in LBS with analogue map images. Semi-georeferencing builds connections directly among distorted maps, and it can increase the positioning and map overlaying accuracy on mapping services on distorted maps.

Table 3.1 Connections among different kinds of maps

Map types \ Map types	Geometrically correct map	Distorted map
Geometrically correct map	map projections photo orthorectifying	georeferencing
Distorted map	georeferencing	semi-georeferencing

With georeferencing and semi-georeferencing, the relations among maps change from a tree (figure 3.2) to a network (figure 3.7). A sequential of nodes that are used to connect two maps in a map relation graph is named as a *path*, noted as R. The geometrically correct base maps in the graph is noted as C, and distorted maps are noted as D. Without semi-georeferencing, a path to connect two distorted maps is $R = (D_i, C, D_j)$. With semi-georeferencing, a path to connect two distorted maps do not necessarily go through base maps, and can be noted as $R = (D_{m1}, D_{m2}, \dots, D_n)$. And a location on base map can be mapped to a distorted map through other distorted maps with a path like $R = (C, D_{m1}, D_{m2}, \dots, D_n)$.

Figure 3.7 Relation of maps with georeferencing and semi-georeferencing

Semi-georeferencing has three main functions: assisting to interpolate georeferences, increasing positioning accuracy, and increasing map overlaying accuracy.

3.2.1 Interpolate Georeferences with Semi-georeferences

Figure 3.8 shows semi-georeferencing results between areal photos of the year 1948, 1976, 1988, and 2004 around Kashiwanoha area (the blue lines and orange lines on the images). It can be found that some semi-georeferences are shared on parts of the map (the orange lines), while some semi-georeferences are shared by all the four maps (blue lines). The lines shared by all the maps can be connected to the base maps as georeferences by georeferencing the lines on most recent areal photo (2004). Through semi-georeferencing, more georeferences are found on the areal photo of 1948 and other areal photos, compared with the case of Figure 3.4.

(a) Areal photo of 1948 **(b)** Areal photo of 1976

(c) Areal photo of 1988 **(d)** Areal photo of 2004

(Same number refers to corresponded polylines on different maps. Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army)

Figure 3.8 Semi-georeferences on areal photos of 1948, 1976, 1988 and 2004. And georeferences interpolated with the help of semi-georeferences

3.2.2 Positioning with Semi-georeferences

The analogue map image that used as a base image for calculating positions on another map image is denoted as a *semi-base map*. The method to map a point from a semi-base map to a target map image is the same as the method to map a location from base maps to a point on a target map.

Without semi-georeferencing, a point on a map image can only be calculated directly from a location on base maps. With semi-georeferencing, a point on a map image can be calculated indirectly from point on other maps. Figure 3.9 illustrates the error propagation with semi-georeferencing. As positioning errors accumulate each time when mapping from one map to another. It needs to weight the edges with positioning error (Figure 3.10), and a shortest weighted path will achieve the best positioning result.

The weight of the edges in the maps relation graph is related to the location to be calculated. Thus the weighted graph has to be built each time when carrying out the calculation. In order to improve the efficiency of calculation, a maximum depth for searching the shortest weighted path can be set. Figure 3.11 shows the flow chart to calculate the position on a target map with semi-georeferencing.

Figure 3.9 Error propagation of semi-georeferencing

Figure 3.10 Weighted graph of map relations

Figure3.11 Flow chart of position calculating with semi-georeferencing

It is inefficient to calculate errors to weight the graph to search the best path for positioning. In practical use, distance from the position to the polylines for georeference or semi-georeference can be used to weight the graph edges to increase positioning efficiency.

Suppose the error accelerations with the distance to the polylines for georeferencing and semi-georeferencing are consistent, noted as a. Then the positioning error of a direct calculation path from base maps ($R_1 = (C, D_1)$) is $e = a \cdot d_1$, and the positioning error of an indirect calculation with semi-georeferencing ($R_2 = (C, D_2, D_1)$) is $e_s = a \cdot (d_2 + d_3)$. The positioning error is positively related to the total distance to reach a polyline for georeferencing. It is possible to use distances to weight the map relation graph.

Simulations are carried out to test the feasibility of positioning with semi-georeferencing. As shown in Figure 3.12, M1 and M2 are the same areal photos, and each has one georeference (the base map is noted as C), and there is a pair of corresponded polylines for semi-georeferencing connecting the two areal photos. Distances from the position to be calculated to the polylines are used to weight the map relation graph. Figure 3.13 and Table 3.2 show the positioning results of georeferencing and semi-georeferencing. The results show that generally the paths with smaller weights achieve more accurate positioning results. For sample point 8, the path with longer distance has smaller positioning error because of the different accelerations of the error increasing on the two maps resulted from different georeferencing errors.

Georeferences

Semi-georeferences

(a) Areal photo of 2014 (M1) **(b)** Areal photo of 2014 (M2)

(The areal photo is provided by Geospatial Information Authority of Japan)

Figure 3.12 Georeferences and semi-georeferences on same areal photo

Sample point

Georeferencing positioning result with path R=(C, M2)

Semi-georeferencing positioning result with path R=(C, M1, M2)

Georeferencing positioning error with path R=(C, M2)

Semi-georeferencing positioning error with path R=(C, M1, M2)

(The areal photo is provided by Geospatial Information Authority of Japan)

Figure 3.13 Positioning results of georeferencing and semi-georeferencing

Table 3.2 Positioning errors and paths distances of georeferencing and semi-georeferencing

Sample	Error1 (m)	Error2 (m)	Distance1 (m)	Distance2 (m)	E1/E2	D1/D2
1	89.78	11.69	1508.57	288.97	0.130	0.192
2	87.73	1.92	1412.09	158.39	0.022	0.112
3	100.43	1.88	1488.27	0.99	0.019	0.001
4	109.64	14.69	1435.16	141.03	0.134	0.098
5	127.61	34.2	1379.28	484.42	0.268	0.351
6	85.53	79.73	971.15	664.66	0.932	0.684
7	103.03	87.25	993.58	559.3	0.847	0.563
8	96.77	131.46	777.54	735.48	1.358	0.946
9	32.46	232.36	190	1384.69	7.158	7.288
10	45.41	287.17	238.66	2743.45	6.324	11.495

Error1: positioning error of georeferencing
Error2: positioning error of semi-georeferencing
Distance1: Weighted distance of path $R = (C, M2)$
Distance2: Weighted distance of path $R = (C, M1, M2)$
(* Smaller errors and path distance are noted in red color.)

3.2.3 Map Overlaying with Semi-georeferences

Figure 3.14 shows the map overlaying error on the focus point without semi-georeferencing. The focus point is calculated independently on two maps with errors of $\vec{e}_1$ and $\vec{e}_2$, and the map overlaying error on the point is $\vec{e} = \vec{e}_1 - \vec{e}_2$. Suppose the error accelerations with the distance to polylines for georeferencing are consistent on each map, and noted as a_1 and a_2 correspondently, then the value of the map overlaying error is in the range of $|\vec{e}| \in [|a_1 \cdot d_1 - a_2 \cdot d_2|, |a_1 \cdot d_1 + a_2 \cdot d_2|]$. Figure 3.15 shows the map overlaying error on the focus point by semi-georeferences. Note the error acceleration on the target map image based on the base semi-image as a_3, and the map overlaying error on the focus point is $e' = a_3 \cdot d_3$. Thus if semi-georeference can be found near a focus point, it will increase the map overlaying accuracy.

Figure 3.14 Map overlaying error without semi-georeferencing

Figure 3.15 Map overlaying error with semi-georeferencing

For map overlaying without semi-georeferencing, the result of map overlaying is the result of each map overlaid to the base map, and the order of map overlaying does not affect the final map overlaying result. While for map overlaying with semi-georeferencing, a map is overlaid directly with another map, and the order of map overlaying will affect the map overlaying result. In the case of Figure 3.16, note the areal photos of 1948, 1976, and 2004 as D1, D2, and D3. There is no semi-georeferences between D1 and D3, so it has to overlay D1 with D2 first, and then overlay D2 with D3. In the case of figure 3.17, there are semi-georeferences between each map, but the map overlaying accuracies are different with different map overlaying order. Note the error accelerations with the distance to polylines for semi-georeferencing on D3 base on D1, D2 based on D1, and D3 based on D2 as a_1, a_2 and a_3, then if directly overlaying D3 with D1 ($R = (D_1, D_3)$), the overlaying error on the focus point is $e_1 = a_1 \cdot d_1$. If first overlaying D2 with D1, and then overlaying D3 with D2, the overlaying error between D1 and D2 ($R = (D_1, D_2, D_3)$), is $e_2 = a_2 \cdot d_2 + a_3 \cdot d_3$. When distortions are consistent among maps, it is better to overlay maps to make final distance to the focus point shorter.

Similar to the case of positioning through semi-georeferencing, overlaying maps also follows a shortest weighted path. Figure 3.18 shows the flow chart to overlay a background map to a main map with semi-georeferences.

(a) Areal photo of 1948 (D_1) **(b)** Areal photo of 1976 (D_2) **(c)** Areal photo of 2004 (D_3)

(Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army.)

Figure 3.16 Maps overlaying order affected by relation graph

(a) Areal photo of 1948 (D_1) **(b)** Areal photo of 1976 (D_2) **(c)** Areal photo of 2004 (D_3)

(Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army.)

Figure 3.17 Maps overlaying accuracy affected by overlaying order

Figure 3.18 Flow chart of map overlaying with semi-georeferencing

As map overlaying errors accumulated when the paths get deep, in practical use, the above processes can be simplified. Firstly, find the polyline for semi-georeferencing that directly connect the main map and background map for map overlaying (whose path depth is two). If there are no such polyline, we use georeferences to overlay the two maps through the base maps (whose path depth is three). Figure 3.19 shows the simplified flow chart for map overlaying in practical use.

Figure 3.19 Simplified flow chart for map overlaying with semi-georeferencing

Simulations are carried out to test the map overlaying accuracies resulting from georeferencing and semi-georeferencing. The same areal photos of Kashiwanoha area taken in 2004 are used for simulating map overlaying. There are one pair of polyline for georeferencing and one pair for semi-georeferencing on each map (the same as the materials used in Section 3.2.2, Figure 3.12). 10 sample

points are used as focus points for map overlaying. The two maps are overlaid based on each focus point through georeferences and semi-georeferences. Figure 3.20 gives an example of the map overlaying based on the first focus point through georeferencing and semi-georeferencing. Table 3.3 shows the map overlaying results. It shows clearly that the map overlaying through semi-georeferences are more accurate than the map overlaying through georeferences.

(a) Map overlaying through georeferencing

(b) Map overlaying through semi-georeferencing
(The areal photo is provided by Geospatial Information Authority of Japan)

Figure 3.20 Comparison of map overlaying through georeferencing and semi-georeferencing

Table 3.3 Map overlaying errors at focus point through georeferencing and semi-georeferencing

Focus Point	Error1 (m)	Error2 (m)
1	95.88	1.86
2	76.70	1.54
3	90.70	0.00
4	104.09	5.38
5	138.01	3.64
6	108.86	8.17
7	135.42	7.36
8	169.92	6.60
9	254.51	2.40
10	328.64	3.18

Error1: map overlaying error at focus point through georeferencing
Error2: map overlaying error at focus point through semi-georeferencing

3.3 Case Study and Results

3.3.1 Background and Purpose of the Case Study

The method of semi-georeferencing is applied in an investigation of some war relics. During the Word War Ⅱ, the nowadays Kashiwanoha area was used as an air base of Japanese army, and in the east of the runway there were *L* shaped fuel docks which can be clearly recognized on the areal photo (Figure 3.21). There are some of the docks remain at present. The local history club wishes to find out which docks on the areal photo still remain.

(The areal photo is provided by Geospatial Information Authority of Japan, and was originally taken by U.S. Army.)

Figure 3.21 Fuel docks on areal photo of 1948

The exact places of the remains of the docks are investigated, and the locations of the remains are recorded with the GPS functions on smart phone (Figure 3.22). The areal photos of Kashiwanoha area taken in 1948, 1976, 1988 and 2004, as well as Apple Maps are used for the study. The positions of the

remains of the docks are calculated on each areal photo, and the positions on the areal photo of 1948 are mapped to the base map.

Figure 3.22 Recorded places of the remains of the docks on the base maps (Apple Maps)

3.3.2 Results without Semi-georeferencing

Without using semi-georeferencing, positions of the docks on the areal photo of 1948 are at first mapped to the base maps, and then mapped to other areal photos. Figure 3.23 shows the positions of the remains of the docks calculated from the base maps. Figure 3.24 shows the positions of the docks on the base maps calculated from the areal photo of 1948. The result shows that the positions of the docks calculated from the areal photo of 1948 and the positions of the remains calculated from the base maps do not match well on all the areal photos and on the base map. The distinct error mainly results from the long distance from the fuel docks to the polyline for georeferencing, especially on the areal photo of 1948 (Figure 3.25).

(a) Areal photo of 1948

(b) Areal photo of 1976

(c) Areal photo of 1988

(d) Areal photo of 2004

- Positions of original docks on the areal photo of 1948
- Positions of remains of docks calculated from the base maps

(Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army.)

Figure 3.23 Positioning results on areal photos

- Positions of original docks on the areal photo of 1948
- Positions of remains of docks calculated from the base maps

Figure 3.24 Positioning results on the base maps (Apple Maps)

(a) Areal photo of 1948

(b) Areal photo of 1976

(c) Areal photo of 1988

(d) Areal photo of 2004

(Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army.)

Figure 3.25 The polyline for georeferencing is far from the fuel docks

3.3.3 Results with semi-georeferencing

With semi-georeferencing, more corresponded spatial references can be found between the areal photo of 1948 and the base maps, including one referencing polyline near the docks (Figure 3.26). This referencing polyline is used to calculate the remains of docks on the areal photo of 1948, and locations of the docks on the base maps. The results are shown in Figure 3.27 and Figure 3.28.

(The areal photo is provided by Geospatial Information Authority of Japan,.and was originally taken by U.S. Army.)

Figure 3.26 Interpolated georeferences with one polyline near to the fuel docks

(The areal photo is provided by Geospatial Information Authority of Japan. The photo was originally taken by U.S. Army.)

Figure 3.27 Positions of remains of docks on the areal photo of 1948

- Positions of original docks on the areal photo of 1948
- Positions of remains of docks calculated from the base maps

Figure 3.28 Locations of docks on the base map (Apple Maps)

Positions of the original docks and remains of the docks on the areal photo of 1948 are first mapped to the areal photo of 2004 with georeferences, and then mapped to the areal photos of 1988 and 1976 with the polyline for semi-georeferencing that is near to the fuel docks (Figure 3.29). The positions of the docks on the areal photos are shown in Figure 3.30.

(a) Areal photo of 2004 **(b)** Areal photo of 1988 **(c)** Areal photo of 1976
(Areal photos are provided by Geospatial Information Authority of Japan. The photo of 1948 was originally taken by U.S. Army.)

Figure 3.29 Polylines for semi-georeferencing near to the fuel docks

(a) Kashiwanoha in 1976

(b) Kashiwanoha in 1988

(c) Kashiwanoha in 2004

- Positions of original docks on the areal photo of 1948
- Positions of remains of docks calculated from the base maps

(Areal photos are provided by Geospatial Information Authority of Japan.)

Figure 3.30 Positions of docks and remains of docks on areal photos

The results show that with semi-georeferencing, the positions of the original fuel docks on the areal photo of 1948 and the positions of the remains of the docks recorded in real places match much better. The results of the semi-referencing indicate that it is highly possible that the remains of the docks are the number 3, 4, 5 and 8 on the areal photo of 1948 (Figure 3.21).

3.4 Summary

Georeferencing is important for connecting analogue map images to the base maps for positioning and map overlaying. However, in practical use, it is difficult to make enough referencing polylines, especially on old maps.

Semi-georeferences, which directly connect target maps, are used to increase the positioning and map overlaying accuracy. Semi-georeferences between maps help to interpolate more georeferences on old maps. Besides, semi-georeferences allows positioning and map overlaying with one-hop connections among map images. Simulations show that semi-georeferencing contributes to improving the accuracy

of positioning and map overlaying. The case study of finding positions of remains of fuel docks of Kashiwa Air Base proves accurate and reliable result by using semi-georeferences.

Chapter 4 Continuity Management for Storytelling with Different Maps

The conventional web and mobile mapping services enable smooth transitions among a large amount of tiled maps (https://en.wikipedia.org/wiki/Tiled_web_map) with different scales and areas not to interrupt users' spatial browsing and learning. Most users may not be aware of using many tiled maps, and may consider a mapping service as one virtual map with characteristics of scaleless, seamless and endless. The number of tiled maps in a mapping service is huge, and all are designed to look coherent as one map and to be used as a base map and a mashup with various spatial data for general purposes. The tiled maps are generated by computers using computer generalization technology. The mapping service can cost low, but is about to miss the diversity and creativity of human's artworks from the role of maps.

Analogue maps like paper illustrated maps and map signboards created by human and graphic designers have been still more popular than web mapping in Japan if the purpose of a map is specialized such as tourism, walking tours and environmental education, particular in local community. The analogue maps are generally designed not to be used together with other analogue maps and not to be integrated with a GPS function. Map collaging proposed by this thesis is invented to solve mainly the restrictions of combining multiple special purposed analogue maps and integration of a GPS function. One of the difficulties of combining special purposed analogue maps comes from the variety of map representation such as scales, areas, directions, colors and so on. Naive dynamic collaging multiple analogue maps bears severe problems of discontinuity of transiting maps which will confuse users to appreciate maps and disturb their actions and imaginations. This chapter will establish new methods to solve the discontinuity problems of heterogeneous map collaging and to realize good user interfaces with keeping visual and cognitive *continuity* of it.

4.1 Discontinuities of Map Collaging

(1) Discontinuity of storytelling

The Chapter 2 and Chapter 3 have introduced methods to overlay different analogue maps. However, the map overlaying only provides access to the different local knowledge on different maps, but the knowledge on different maps are not connected or organized for efficient story narration. For example, without storytelling organization, the user's position may be shown on a background map rather than a proper main map when the user moves out of the current main map (Figure 4.1). Map switching among the maps designed for different scales brings the discontinuity between the map presentation scale and the map scale users expect for map reading. For example, in the case of Figure 4.2, the new main map is too small for reading if consistent maps scales are kept when switching maps.

(Map provided by Kashiwanoha Park)

Figure 4.1 Discontinuity of the user's position and the main map

(The left map provided by Kashiwa History Club; the right map provided by UT Kashiwa Campus)

Figure 4.2 Discontinuity of map scales suitable for reading

(2) Discontinuity of map overlaying

As mentioned, the map collaging combines maps based on focus point without geometric corrections on the map images. Places near the focus point can achieve high map overlaying accuracy, but places far from the focus point are under risks of large map overlaying errors. As shown in Figure 4.3, the adjacent roads near the focus point are combined accurately, but the corresponded roads intersections are not overlaid with high accuracy.

Another problem of focus point-based map overlaying is the unstable map overlaying results. Because map overlaying results are different with different focus point, map overlaying results become unstable when the focus point changes frequently (Figure 4.4).

(Maps provided by Kashiwanoha Park and Kashiwa History Club)

Figure 4.3 Example of discontinuity in focus point based map overlaying

(Maps provided by Kashiwanoha Park and Kashiwa History Club)

Figure 4.4 Example of instability of map overlaying with different focus points

(3) Discontinuity of POI icons

Another factor that causes discontinuity is POI settings of map collaging. Each map in map collaging has its own POI's. A POI on map collaging refers to a point registered on a map image, and an icon for previewing the POI content will be presented on the point. When the maps are combined, the POI's on different maps may conflict with each other. For example, if all POI's on each map are shown on map collaging, the POI's will be too crowded (figure 4.5a); if only POI's of the main map are shown, necessary information on background maps will be lost (figure 4.5b); if the same POI's on different

maps are shown on map collaging at the same time in different places (because of map overlaying errors), it will make users confused (figure 4.5c).

(a) All POI's shown

(b) Only POI's of the main map shown

(c) Conflicts of the same POI's
(Map provided by Kashiwa History Club)

Figure 4.5 Discontinuities in POI's settings of map collaging

(4) Discontinuity of map presentation

As shown in Figure 4.6, unlike seamless maps with the same presentation styles in conventional web mapping and mobile mapping, maps in map collaging have different presentation styles, clear borders, and different scales and alignments suitable for reading, which will make map collaging look discontinuous.

(Maps provided by Kashiwa History Club, UT Kashiwa Campus, Kashiwanoha Park and Konbukuroike Nature Park)

Figure 4.6 Map collaging with different styles of maps

(5) Discontinuity of map switching

Map switching in map collaging causes changes of map presentation styles and map topics. Besides, users are aware of obvious changes of the scale, location, and alignment on the main map. Different strategies of map changing bring different discontinuities. For example, in Figure 4.7(b), a user-centered map switching keeps the user' position unmoved on the screen before and after map switching, but the new main map is not in an upright alignment, and is too small to be read; in Figure 4.7(c), a map-centered map switching rotates the new map upright and scales to fit the screen size, but the user's location jumps distinctively on the screen.

(a) Before switching **(b)** User-centered switching **(c)** Map-centered switching
(Maps provided by Kashiwa History Club and UT Kashiwa Campus)

Figure 4.7 Switching main map of map collaging with different strategies

Map collaging using different maps has advantages of rich and diverse spatial information, which contributes to spatial storytelling, learning, and investigation. However, the use of heterogeneous maps brings problems of discontinuities. The discontinuities in map collaging need to be controlled so as to put into practical use. In the next session, the methods to manage different kinds of continuities of map collaging will be discussed.

The following sections will introduce methods to deal with the above problems of discontinuities in map collaging by using spatial triggers for automatic map switching, adjusting focus point for map overlaying, settings for POI's, visual effects of map collaging presentation and map switching.

4.2 Organizing Stories with Spatial Triggers

A spatial trigger in this thesis refers to a virtual spatial sensor to trigger map switching or information narration according to a user's position and moving trajectory. Polygon, polyline and point features are added on maps as spatial triggers to organize different stories on different maps with users' positions and moving trajectories.

4.2.1 Polygon and Polyline Triggers for Map Switching

Polygons and polylines are used as triggers for map switching. When a user crosses an edge (Lynch 1960) in the real world, such as entering or leaving a park, the system of map collaging should respond to the user's context change and switch the main map with adjusted map scale for presenting information of the new area the user enters. Polygon and polyline spatial triggers are used to realize automatic map switching in this case. A polyline or a polygon trigger is a polygon or a polyline feature on the base maps that is linked to different maps with an initial scale on each side of the trigger. The polygon or polyline triggers are usually set at the boundaries of different regions, and when a user moves across a trigger, the map linked to the side of the trigger that the user enters will be switched as the main map and presented in its initial scale (Figure 4.8). A side of a trigger can be left unlinked to any map. In this case, the main map will not be switched if the user goes to the side that is not linked to a map. In addition, a map's initial scale can be set flexible. In this case, when one map is switched as the main map, it will be presented as the same scale as the previous main map.

(Maps provided by Kashiwa History Club, UT Kashiwa Campus, Kashiwanoha Park, Konbukuroike Nature Park, and Geospatial Information Authority of Japan.)

Figure 4.8 Polygon triggers and polyline triggers that control map switches through the user's trajectory

In practical use, the GPS positioning results have errors. When users are walking along an edge without crossing it, the positioning error may misfire a trigger and cause unexpected map switches. To make the map switch stable, a buffer is added to the trigger, and the trigger will be trigged only when a user moves across the buffer (Figure 4.9). Besides, a simple animation is used during map switching to make the process smooth.

(Trajectory A will not fire the trigger; trajectory B will fire the trigger)

Figure 4.9 Spatial trigger with buffer

4.2.2 Point Triggers for Story Narration

Point triggers are points set on the maps with a buffer distance within which a preview of information of the point will be presented and relative knowledge will be automatically narrated. Usually, POI's on the maps work as point triggers so that the preview image of a POI will be presented and the audio introducing the POI will play automatically when users get close to the POI. Besides, relative distances on the screen, instead of absolute distance in the real world, are used as buffers for the point triggers, so that the buffer for firing the triggers can be adapted to the map scales. As shown in Figure 4.10, when a user zooms in the map, the distance to the POI on the screen gets larger and it will not fire the trigger; when the user zooms out, the distance gets smaller and it fires the trigger to present and narrate the information of the POI.

(a) Trigger not fired when zooming in **(b)** Trigger fired when zooming out (Map provided by Kashiwa History Club).

Figure 4.10 Distance on screen used as a buffer for point triggers

4.3 Focus Point Adjustment for Map Overlaying

The thesis proposes methods to dynamically adjust the focus point for map overlaying to avoid distinct map overlaying error on the screen, and uses representative focus points and polylines to increase stability of map overlaying results.

4.3.1 Dynamic Adjustment of Focus Point

Three kinds of focus points are used according to the user's interested places in different cases.

(1) The user's location

Current position is the point that is important for users. When appearing on the device screen, the user's position will be used as the focus point.

(2) The screen center

When users are browsing the map content on the device, their attentions are focused on the central part of the screen. If users browse maps that they are not on-site, the screen center will be used as focus point to overlay maps.

(3) The user's interested point

Apart from the above two default focus points for map overlaying, a user can also manually set focus point by double tapping his/her interested place on the screen.

The user's interested point has priority to be a focus point. If the user does not set a focus point, a default focus point will be set automatically according to the context whether the user's position is in or out of the screen. To ensure high overlaying results in the visible range, the focus point will be updated if the current focus point has been moved out of the screen.

4.3.2 Representative Focus Point and Polyline

Representative focus points and polylines are cognitively important spatial objects on the maps, such as important buildings and main roads, for stable map overlaying. It prevent unstable map overlaying caused by frequent changes of the focus point by overlaying maps based on the snapped point on the nearest representative point or polyline in the screen from the initial focus point mentioned above. It also ensures that important places on the maps will be overlaid with high accuracy. Figure 4.11 shows an example of comparison between maps overlaying directly on user's position and maps overlaying based on the snapped point on a representative polyline, which indicates that the latter results in accurate map overlaying of the main road.

(a) Map overlaying based on user's position **(b)** Map overlaying based on the representative polyline
(Maps provided by Kashiwanoha Park and Kashiwa History Club)

Figure 4.11 Comparison of maps overlaying directly on user's position and on the snapped point on the representative polyline

4.4 Setting for Compatible POI Icons

As mentioned, POI icons on different maps may conflict with each other if presented together on map collaging. Some POI's are specially designed for a thematic map and not suitable for showing on other maps; some POI's indicate important information that need to be shown all the time; some POI's are annotated on different maps which will confuse users if shown at the same time on map collaging.

To avoid the conflicts among POI's on different maps, POI's are divided into private POI's and public POI's; and POI's on different maps that refer to a same spatial object are grouped as exclusive POI's.

(1) Private POI's

Private POI's are the ones that will only be annotated and able to be triggered when they are on the main map. When private POI's are on background maps, they will neither be annotated on the map collaging, nor be triggered even if users are close to them.

(2) Public POI's

Public POI's are the ones that will be annotated on map collaging and are able to be triggered no matter when they are on the main map or the background maps.

(3) Exclusive POI's

The same POI's on different maps are grouped as a set of exclusive POI's. Usually POI's with the same title and close to each other can be grouped in an exclusive POI set. When one POI in an exclusive POI's set is annotated, other POI's in the set will not be annotated. And the POI on the main map has a higher priority to be annotated in an exclusive POI set than those on the background maps. Figure 4.12 shows the icons of POI's on map collaging.

The private and public POI's are set by map collaging content makers manually, while exclusive POI's can be grouped automatically.

(a) POI setting on the main map

(b) POI setting on the background map

(c) Icons of POI's on map collaging
(Maps provided by Geospatial Information Authority of Japan and Kashiwa History Club. The areal photo of 1948 was originally taken by U.S. Army).

Figure 4.12 Icons of public and private POI's on map collaging

4.5 Factors of Map Presentation and Map Switching Continuity Management

Combination with different styles of maps creates presentation discontinuities on the screen. Factors that may have effects on map collaging presentation and map switching continuities are summarized and to be tested under different map using context (noted as C) to find their combinations and values that reduce presentation discontinuities.

Different map using context requires different map presentation effects. Three types of context are classified based on whether the user is moving in the mapped area:

- General browsing ($C = 0$). Users generally browse the content of map collaging focusing on the whole maps instead of certain specific objects;

- On-site experiencing ($C = 1$). Users travel in the actual places to experience the local knowledge with local maps;
- Detailed comparing ($C = 2$). Users compare different maps to check relations of certain spatial objects on different maps in detail, for example, check whether two lines on different maps refer to the same road.

Factors that may affect presentation and map switching continuities are summarized below.

4.5.1 Factors Affecting Presentation Continuity

(1) The number of background maps (B)

The number of maps has direct effects on the presentation. It makes users feel messy if seeing too many different maps on screen, while too few maps are unable to present enough local knowledge.

As a map collaging should at least present one main map, the number of background maps determines the presentation effects of the map collaging. Three values of the number of background maps are tested:

- Show no background maps ($B = 0$);
- Show one background map ($B = 1$);
- Show all background maps ($B = 2$).

(2) Map transparency (Tp)

Another important factor is the transparency of the map images. Different transparencies create different presentation effects. An opaque map image is clear and attractive, while semitransparent map images provide comparison between overlaid areas.

It is inefficient to control transparencies of each map in map collaging. The thesis distinguishes the transparency of the main map and the background maps. Thus the main map will have its transparency value, while the other background maps share a same transparency value. Transparency with a high value is more opaque, while transparency with a low value is more transparent.

Three transparency strategies are tested (Figure 4.13):

- All maps have a high value of transparency ($Tp = 0$);
- High value transparency for the main map, and low value transparency for the background maps ($Tp = 1$);
- All maps have a low value of transparency ($Tp = 2$).

(a) Tp=0 **(b)** Tp=1 **(c)** Tp=2

(Maps provided by Kashiwa History Club, UT Kashiwa Campus, Kashiwanoha Park, Kashiwanoha Park and Geospatial Information Authority of Japan. The areal photo of 1948 was originally taken by U.S. Army.)

Figure 4.13 Map collaging with different map transparencies.

(3) Trajectory (Tj)

Trajectory can remind users of the places they have passed and can be recorded as personal stories. However, if only browsing maps, trajectories are sometimes obstructive. Tests are carried out to decide whether trajectory should be shown ($Tj = 1$) or not ($Tj = 0$).

(4) Automatically highlighted and narrated POI (H)

Automatically highlighted and narrated POI are supposed to attract users' attentions for storytelling. Tests are carried out to determine whether it should be automatically highlighted and narrated POI ($H = 1$) or not ($H = 0$).

(5) The user's position fixed (P)

Two ways of indicating the user's positing movements will be tested. One is to fix maps and move the position symbol ($P = 0$), and the other is to fix the position symbol on the screen (e.g. center point of the screen) and move maps ($P = 1$).

(6) Egocentric alignment of maps (E)

Egocentric map alignment, which keeps the direction of the map consistent to the directions of the devices, is widely used in many navigation systems. We will test it for map collaging whether it is good to keep maps egocentric all the time ($E = 1$) or not ($E = 0$).

4.5.2 Factors affecting Continuity during Map Switching

(1) Initial alignment (IA)

Initial alignment determines the new main map's direction after map switching. Four kinds of map alignments will be tested:

- Consistent alignment ($IA = 0$). It keeps the direction of maps unchanged before and after map switching;
- Geocentric alignment ($IA = 1$). It uses the earth as direction reference and the maps are drawn with the characteristic of north-up. Geocentric alignment is usually used for relatively small-scale maps, such as maps of countries, provinces, cities and so on. Besides, some local illustrated maps that cover relatively large areas use geocentric alignment (Figure 4.14(a));
- Egocentric alignment ($IA = 2$). It makes the directions on the map consistent to the directions of the devices, which makes it easy for users to distinguish directions and is often used in navigation systems (Figure 4.14(b));
- Map-centric alignment ($IA = 3$). Map-centric alignment is unique in the mapping services with analogue map images. It keeps the original directions of the main map on a device screen, which is natural for reading the analogue maps with map symbols and notations not rotated (Figure 4.14(c)).

(a) Geocentric alignment **(b)** Egocentric alignment **(c)** Map-centric alignment
(Maps provided by Kashiwa History Club, UT Kashiwa Campus and Kashiwanoha Park)

Figure 4.14 Different map alignments on map collaging

(2) Initial Size (S)

Initial size determines the new main map's size after map switching. Two kinds of initial size are tested:

- Constant size ($S = 0$). It keeps the map sizes unchanged before and after map switching;
- Predetermined size ($S = 1$). It resizes the new main map to the size set by the map collaging producer, and a default value is a size that fit the map image with the screen size.

(3) Transformation center (Tf)

Transformation center refers to the center point for map images rotation and scaling. Image pixels near the transformation center move shorter distances and slower, while those far from the transformation center move longer distances and faster. As a result, in the area near the transformation center, it will be more visually continuous during map rotation and map scaling. It is obvious that a transformation center should be on the screen. Under this prerequisite, three kinds of transformation center are tested:

- Map center: use the main map view center as the transformation center ($Tf = 0$);
- Screen center: use the device screen center as the transformation center ($Tf = 1$);
- User center: use the user's position on the screen as the transformation center ($Tf = 2$).

(4) Initial center (IC)

Initial center determines the target object to be moved to the screen center after map switching. Three kinds of initial center are tested:

- None initial center ($IC = 0$). It means that it will not adjust map positions after map switching;
- Center map ($IC = 1$). It will move the maps to make the new main map to the center of the screen;
- Center user ($IC = 2$). It will move the maps to make the user's position to the center of the screen.

(5) Animation effects (A)

Animation effects make the process of map switching smooth, and we will test users' preferences on map switching with animation effects ($A = 1$) and without animation effects ($A = 0$) are tested.

4.6 Experiments and Results

Experiments are carried out to find proper combinations and values of factors for reducing the discontinuities of map collaging presentation and map switching under different context.

Two kinds of experiments are carried out. One is using questionnaires to let users to choose their preferred settings from predetermined settings. The other is the experiment to analyze users' gazing point and map operations to summarize proper settings for map collaging.

4.6.1 Experiment with Questionnaires

Different factor combinations about the map collaging are designed, in each of which the value of the factors are fixed except for the variable factor to be tested. Table 4.1 shows the factor settings. The participants are asked to give their preferences to the variable factor.

For each setting, short demo videos are made to give examples of map collaging presentation, map switching, and simulated navigation with different factors and values. Volunteers participating in the experiment are required to watch groups of short videos and give their preferences to the combinations and values of different factors.

Table 4.1 Settings of the factor combinations in the experiment

No.	Variable	Constant
1	*Tp*	$C0$-$B2$-$Tj0$-$H0$-$P0$-$E0$-$IA0$-$S0$-$Tf1$-$IC0$-$A1$
2	*S*	$C0$-$B2$-$Tp1$-$Tj0$-$H0$-$P0$-$E0$-$IA0$-$Tf1$-$IC0$-$A1$
3	*A*	$C0$-$B2$-$Tp1$-$Tj0$-$H0$-$P0$-$E0$-$IA0$-$S0$-$Tf1$-$IC0$
4	*IA*	$C0$-$B2$-$Tp1$-$Tj0$-$H0$-$P0$-$E0$-$S1$-$Tf1$-$IC0$-$A1$
5	*Tj*	$C0$-$B2$-$Tp1$-$H0$-$P0$-$E0$-$IA0$-$S1$-$Tf1$-$IC0$-$A1$
6	*Tj*	$C1$-$B2$-$Tp1$-$H0$-$P0$-$E0$-$IA0$-$S1$-$Tf1$-$IC0$-$A1$
7	*IC*	$C1$-$B2$- $Tp1$-$Tj1$-$H0$-$P0$-$E0$-$IA0$-$S1$-$Tf1$-$A1$
8	($P0$-$E0$), ($P1$-$E0$), ($P1$-$E1$)	$C1$-$B2$-$Tp1$-$Tj1$-$H0$-$IA0$-$S1$-$Tf1$-$IC2$-$A1$
9	*IA*	$C1$-$B2$-$Tp1$-$Tj1$-$H0$-$P0$-$E0$-$S1$-$Tf1$-$IC1$-$A1$
10	*H*	$C1$-$B2$-$Tp1$-$Tj1$-$P0$-$E0$-$IA0$-$S1$-$Tf1$-$IC0$-$A1$
11	($B1$-$Tp0$), ($B1$-$Tp1$), ($B2$-$Tp1$)	$C2$-$Tj0$-$H0$-$P0$-$E0$-$IA0$-$S0$-$Tf1$-$IC0$-$A1$
12	*Tf*	$C0$-$B2$-$Tp1$-$Tj1$-$H0$-$P0$-$E0$-$IA0$-$S1$-$IC0$-$A1$
13	*B*	$C0$-$Tp1$-$Tj0$-$H0$-$P0$-$E0$-$IA3$-$S1$-$Tf1$-$IC1$-$A1$

Among all the 77 volunteer participants in the experiment, 42 (54.5%) are females and 35 (45.5%) are males; most participants (76.6%) are in their twenties, one is in his/her teens, and the others are above 30 years old; Figure 4.15 shows most participants are majored in liberal arts.

Figure 4.15 Backgrounds of participants.

From participants' answers, it is found that for some questions, participants show clear preference on certain settings (Figure 4.16(a)), while for the other questions, they do not (Figure 4.16(b)). From participants' comments, two reasons are found for the unclear preferences. For some factors, like the transparency of the map images, some participants hope that they can adjust the value beyond the given examples, which indicates that people's preferences vary on these factors. For the other factors, participants gave comments that they cannot tell the differences among different choices, which indicates that the factor is not sensitive for them.

(a) Answers of Question 3 **(b)** Answers of Question 12

Figure 4.16 Participants show different concerns and preferences on different factors.

According to the above findings, the factors are classified into three categories.

(1) Factors with common preferences

Factors with common preferences are the ones that users have common preferences on the value settings. Such factors will be fixed settings or changeable settings with default values that people commonly preferred. According to the participants' answers, the factors with common preferences and the preferred values are shown in Table 4.2.

Table 4.2 Factors with common preferences

Factor	Preferred value	Percentage (%)
S	1 ($C \neq 2$)	67.5
A	1	85.7
Tj	1 ($C = 1$)	74.0
E	0	88.0
H	1	74.0

(2) Factors with personal preferences

For factors with personal preferences, there is no certain value that is commonly preferred. Such factors will have changeable settings to be set by users. The default values are set as the value that is the most preferred by participants. The factors with personal preferences and their default values are shown in Table 4.3.

Table 4.3 Factors with personal preferences

Factors	Default value
B	1
Tp	1
IA	0
$P\ (C = 1)$	1
$Tj\ (C = 0)$	1

(3) User insensitive factors

User insensitive factors are the ones that users can hardly realize the differences in map presentation with different values of settings. As shown in Table 4.4, map transforming center (Tf) and initiate center (IC) are not sensitive to users, and they will be automatically adjusted according to map using context to avoid causing distinct discontinuities. Similar to factors with personal preferences, the user insensitive factors do not have a distinct major users' preferred value in all the samples, but when the samples are grouped, distinct preferences may be found. The samples are grouped to those under 30 years old and those above 30 years old, and the results show distinct preference of $Tf = 2$ in the group of above 30 years old (Figure 4.17). The preferred settings will be given higher priorities in automatic adjusting map presentation. For example, when $Tf = 2$ is given priority, if the user's position is on the screen, it will use the position, instead of screen center, as map transforming center for automatic map scaling and rotating. In the same way, $IC = 0$ is given priority in map switching

Table 4.4 User insensitive factors.

Factor	Value	Context
Tf	1	User's position out of screen
	2	User's position in the screen
IC	0	Main map in the screen
	1	Main map out of screen

Figure 4.17 Preferences results of samples grouped by age

Referring to the experiment results, principles of factors settings for map collaging presentation and map switching are summarized as follows:

- Animation effects and automatic narration of POI information are generally preferred by users, and should be default settings for map collaging.
- Users prefer that maps could be automatically scaled to the size that suitable for reading in the cases of map browsing and on-site experiencing.
- When comparing maps in detail, two maps should keep consistent positions, scales, and directions before and after map switching.

- Showing trajectory is generally preferred in the context of on-site experiencing. But in the case of detail comparing, trajectories are troublesome.
- Users are not sensitive to the different settings of map transforming center and initial center target after map switching. Map collaging can automatically adjust these two factors according to the user context.
- Other factors have varied preferences by different people and functions should be provided for people to set values of these factors.

A conclusion of detailed settings of each factor for map collaging presentation and map switching is shown in Table 4.5.

Table 4.5 Principles of map collaging presentation and map switching settings

Factors \ Context	$C = 0$	$C = 1$	$C = 2$
B	(1)	(1)	(1)
Tp	(1)	(1)	(1)
Tj	(1)	(1)	(0)
H	1	1	1
P	(0)	(0)	(0)
E	(0)	(0)	(0)
IA	(0)	(0)	(0)
S	1	1	0
Tf	*	*	*
IC	*	*	*
A	1	1	1

number: fixed settings
(number): user changeable settings with default value
* : automatically adjust settings based on context

Participants' feedbacks on whether they are willing to make map collaging content are collected. Figure 4.18 shows participants' wills on making map collaging content by themselves. The result shows that 41% of participants are interested in making map collaging contents by themselves. If classifying the participants by their ages, it can be found that for the 60 participants under 30 years old, 17 (28.8%) of them are willing to make map collaging contents. For the 17 participants above 30 years old, the result is 15 (88.2%). If classifying by their living areas, for 17 participants living around Kashiwanoha area, 13 of them (76.5%) are willing to make map collaging contents. The results indicate that generally, there are about two-fifth participants willing to make local map collaging by themselves. People above 30 years old are more positive in making the content than people under 30 years old, and local people are more positive than non-local people.

(a) All participants **(b)** participants above 30 **(c)** participants in Kashiwanoha local area

Figure 4.18 Participants who are willing to make map collaging content by themselves.

4.6.2 Experiment with Users' Gazing Points and Map Operations

As the web questionnaires cannot include all combinations and settings of the factors, experiments with users' gazing point on the maps and users' map operations are used for adjusting value settings for map collaging.

Map collaging content with six maps in Kashiwanoha area is used for the experiment. The scenes of general map browsing ($C = 0$) and navigation ($C = 1$) are tested. For the test for general map browsing, users are asked to browse the maps one by one. They can adjust map position, scale and direction during map browsing, and will manually switch maps when finished browsing one map. For the test for navigation, the map collaging application will play a simulated trajectory among the maps. The maps will automatically switched and the users can adjust the map position, scale and direction manually. Table 4.6 shows the factors settings for the tests. The equipment of eye tracker is used to record users' gazing point and map operations during map browsing.

Table 4.6 Settings for experiments with users' gazing points and map operations

Scenes	Settings
Map browsing	$C0$-$B2$-$Tp1$-$Tj0$-$H0$-$P0$-$E0$-$IA0$-$S0$-$Tf1$-$IC0$-$A1$
Navigating	$C1$-$B2$-$Tp1$-$Tj1$-$H0$-$P0$-$E0$-$IA0$-$S0$-$Tf1$-$IC0$-$A1$

Figure 4.19 shows the gazing point heat map during map switch and Figure 4.20 shows the statistic of user preferred map alignment. The experiment results show that users tend to focus on screen center during map switch in the context of general map browsing. User will firstly search around the screen center to find the new main map, and then move the new main map to the screen center with adjusted map scale and map-centric alignment.

In the context of navigation, users focus on the simulated self-position, and adjust map scales for easy reading. Users' trajectories are important spatial reference for map alignment during navigation. Consistent alignment ($IA = 0$) that keep user's trajectory stable during the whole navigation are most welcomed (40% of all the map switches). 23% map switches are egocentric ($E = 1$) that always make users heading up to the device. 12% map switches are initial egocentric that make map egocentric just after map switch ($IA = 2, E = 0$). The rest 25% are map-centric alignment ($IA = 3, E = 0$).

(a) General map browsing **(b)** Navigating

Figure 4.19 Heat maps of gazing point

(a) General map browsing **(b)** Navigating

Figure 4.20 Map alignment analysis according to users operations

According to the results, we summarize the main factors and their value settings for map-centered switching for general map browsing and user-centered switching for navigating (Table 4.7). Map-centered switching positions the new main map in the center of the screen ($IC = 1$), rotate it to map-centric alignment ($IA = 3$), and resize it to fit the screen size ($S = 1$). User-centered switching uses the user's position as map transformation center ($Tf = 2$), resize map scale ($S = 1$), and uses consistent alignment ($IA = 0$) and fixes user's position in the center of the screen ($P = 1$) as the default value, which users can adjust according to their preferences. Experiment results show that users' gazing point become more concentrative on the screen (Figure 4.21) and users' operations for adjusting maps for reading become fewer (Figure 4.22 and Figure 4.23) with the settings, which indicate that the settings contribute to continuous map collaging reading and operation for users.

As inconstant map positions, scales or map alignment, which changes the positions, size, and directions of corresponded spatial objects before and after map switching, add obstacles in comparing spatial objects on different maps, the thesis applies consistent position ($IC = 0$), scale ($S = 0$) and alignment ($IA = 0$) for the context of map comparing (Table 4.7).

Table 4.7 Settings of factors for map switching

Context	*P*	*IA*	*S*	*IC*
0	0	3	1	-
1	(1)	0	1	2
2	0	0	0	-

number: fixed settings
(number): user changeable settings with default value
- : any value is acceptable because it does not affect map switching visual effects in the corresponded context

(a) General map browsing **(b)** Navigating

Figure 4.21 Heat maps of gazing point with adjusted settings of factors

(a) Panning **(b)** Zooming **(c)** Rotating

Figure 4.22 Map operation times in the context of general map browsing

(a) Panning **(b)** Zooming **(c)** Rotating

Figure 4.23 Map operation times in the context of navigating

4.7 Summary

Map collaging, which combines different styles of maps to provide mapping services, enlarges mapping areas and enriches thematic information of single maps to tell local stories and knowledge. But the combination of different styles of maps has problems of discontinuities. This chapter proposed methods to reduce discontinuities of map collaging in storytelling with heterogeneous maps:

- Spatial triggers are used to connect knowledge to different maps to automatically present and narrate local knowledge on different maps to users;
- Dynamic adjustment of focus point is used to prevent distinct map overlaying errors and representative focus points and polylines are applied for stable map overlaying;
- POI's are classified into private POI's and public POI's by producers, and exclusive POI's sets will be generated automatically to control the density of POI icons on map collaging;
- A model for managing map collaging continuity is proposed by summarizing factors that affect the visual effects of map collaging presentation and map switching. The settings for values of the factors are determined according to experiments of web questionnaires and users' operations of map collaging.

Chapter 5 Implementation of Application Software

This chapter introduces the implementation of *MapCollaging* application, which operates on smartphones with Apple Inc.'s iOS system (above 8.0 version).

MapCollaging realizes the main functions introduced in the previous chapters, including position calculating with polyline-based georeferences, focus point based map overlaying, automatic map switching and information narrating, and so on, for local storytelling. Tools for making map collaging content are also implemented for people to participate in local knowledge sharing.

5.1 Application Structure

5.1.1 Data Structure

As shown in Figure 5.1, there are three hierarchies of data in the application: raw data, georeferenced map, and route.

Figure 5.1 *MapCollaging* data structure.

Raw data are images, texts and audios without explicit geo-information. In the application, raw data will store the title and path to the image, text or audio. The structure of raw data is shown in Table 5.1.

Table 5.1 Structure of raw data

Property	Type
title	String
dataPath	String

Georeferenced map is a map image georeferenced with polylines, on which POI's can be registered and LBS are provided. The structure of map is shown in Table 5.2.

Table 5.2 Structure of georeferenced map

Property	Type
ID	String
title	String
timeStamp	TimeStamp
imagePath	String
baseReferences	Array<BaseReference>
targetReferences	Array<TargetReference>
poiList	Array<POI>
minScale	Float
maxScale	Float

Route is a collage of multiple maps to provide services for a larger area and richer information than those on a single map. The structure of route is shown in Table 5.3.

Table 5.3 Structure of route

Property	Type
ID	String
title	String
maps	Array<Georeferenced Map>
triggers	Array<Trigger>
publicPOI's	Array<POI>

Other important objects and their data structure are as follows:

(1) Time Stamp

The structure of time stamp is shown in Table 5.4.

Table 5.4 Structure of time stamp

Property	Type
isTransactionTime	Bool
transactionTime	Date
startTime	Date
endTime	Date

(2) POI

The structure of POI is shown in Table 5.5.

Table 5.5 Structure of POI

Property	Type
ID	Int
title	String
timeStamp	TimeStamp
isPublic	Bool
positions	Array<Point>
keyWords	Array<String>
imagePaths	Array<String>
text	String
audioPath	String

(3) Polyline for Georeferencing on Base Maps

The structure of base reference is shown in Table 5.6.

Table 5.6 Structure of base reference

Property	Type
correspondedRefIndex	Int
shapeLocations	Array<Location>

(5) Polyline for Georeferencing and Semi-georeferencing on Target Map

The structure of target reference is shown in Table 5.7.

Table 5.7 Structure of target reference

Property	Type
correspondedRefIndex	Int
semiReferences	Array<Semi-referenc>
shapePoints	Array<Point>

(4) Semi-reference

The structure of semi-reference is shown in Table 5.8.

Table 5.8 Structure of semi-reference

Property	Type
correspondedMapID	String
correspondedRefIndex	Int

(6) Trigger

The structure of target reference is shown in Table 5.9.

Table 5.9 Structure of target reference

Property	Type
shapeLocations	Array<Location>
buffer	Float
mapID_side1	String
mapID_side2	String
initialScale_side1	Float
initialScale_side2	Float

5.1.2 Function Structure

MapCollaging integrates the editing functions with the browsing functions to make it convenient for users to make their own content. The function structure of the application is shown in Figure 5.2.

Figure 5.2 *MapCollaging* function structure.

5.2 Main Functions for Map Collaging Browsing

MapCollaging manages different maps with the functions of map switching, map transparency setting, and map visibility managing.

5.2.1 Map Switching

Despite the automatic map switching based on spatial triggers, *MapCollaging* provides three manual operations for map switching.

(1) Switching map by long tapping on the map image

The user can switch the main map of map collaging by long tapping on the map image of the map overlaying view (Figure 5.3). It is a direct way to switch map according to user's interests of the places. When multiple maps are overlaid at the tapped point, the main map will switch one by one in a loop from the upper layers to the lowers ones. It is suitable for comparing maps one by one, but is not efficient to find a certain map.

Map switching by long tapping is mainly designed for map comparing, thus the map positions, scales, and directions will keep consistent while switching maps.

(Maps provided by Kashiwa History Club and Kashiwanoha Park)

Figure 5.3 Map switching by long tapping on the map image

(2) Switching map with map list

When many maps are overlaid, it is not convenient to select a certain map by tapping on map overlaying view. In this case, the user can turn on the map managing panel (Figure 5.4) and switch the main map with the map list in it. This method is suitable for switching map by titles, which is also a quick and precise map switching with out trying many times by long tapping.

The selected main map will be scaled to fit the screen size, rotate to its upright direction and be put in the center of the screen, which is easy for map reading.

(Maps provided by Kashiwa History Club and Kashiwanoha Park)

Figure 5.4 Map switching with map list in the map managing panel

(3) Switching map with timeline

History is one of the main topics that are suitable for being presented by map collaging. Timeline panel is implemented for indexing maps and POI's in history (Figure 5.5). With the timeline, users can check timestamps of each map, and also switch the main map. It is fit for the case of finding a map for certain time in a series of historical maps.

Figure 5.5 Map switching through timeline.

5.2.2 Map Transparency Adjusting

Map transparency is important in map collaging presentation. A solid image of the main map is required for map browsing, while a semitransparent image of the main map is suitable for comparing different maps. *MapCollaging* provides two ways to adjust the maps' transparencies.

(1) Quick adjustment of main map transparency

As shown in Figure 5.6, by tapping the transparency quick adjusting button, the user can switch the transparency of the main map between the status of opaque and semitransparent. It provides a convenient way to compare two maps by quickly switching the main map to semitransparent.

(a) Opaque main map **(b)** Semitransparent main map

(Maps provided by Kashiwa History Club and Geospatial Information Authority of Japan. The areal photo of 1948 was originally taken by U.S. Army.)

Figure 5.6 Quick adjust of main map transparency

(2) Detailed adjustment of map transparency

As shown in Figure 5.7, in the settings view of MapCollaging, it provides two slide bars for adjusting transparencies of the main map and the background maps. Users can adjust the transparencies of the main map and the background maps according to their preferences.

Figure 5.7 Detailed adjustment of map transparency.

5.2.3 Map Shown/Hidden Status Managing

The number of background maps effects on map collaging presentation. Too many background maps may make it difficult for map browsing and inefficient for map switching. *MapCollaging* provides a function to show or hide certain map images to make the map collaging presentation clear.

As shown in Figure 5.8, the buttons attached to the map icons in the map list are the switches to show or hide the maps. Users can also show or hide all the maps (except the main map) by the two buttons at the right side of the map managing panel.

(Maps provided by Kashiwa History Club and Kashiwanoha Park)

Figure 5.8 Map shown/hidden status controlling

Apart from main functions introduced above, *MapCollaging* also provides functions, such as POI searching and viewing, trajectory managing, and so on to make it convenient for local storytelling. Details of these functions can be referred to in Appendix A.

5.3 Main Functions for Map Collaging Editing

To enable local people's participation in local knowledge sharing, tools to make map collaging content are developed, which include basic functions to make map georeferencing, annotate POI's, and set spatial triggers. Besides, assistant functions are developed to make the map georeferencing more efficient.

5.3.1 Map Georeferencing

To make map georeferencing, two main functions are needed: inputting polylines on the target map and the base maps, and bundling the corresponded polylines on the two kinds of maps.

Figure 5.9 shows the interfaces for editing georeferences on the target maps and the base maps. It takes three steps to add a polyline: (1) initiate a new polyline, (2) add shape points of the polyline, and (3) complete the polyline editing. Then, it takes two steps to bundle two corresponded polylines: (1) select

a polyline on the target map, (2) move to the base maps and select the corresponded polyline. Detailed instructions of making georeferences can be referred to in Appendix B.

(a) The target map (Provided by Kashiwa History Club) **(b)** The base maps (Apple Maps)

Figure 5.9 Functions for inputting and bundling polylines for making georeferences.

5.3.2 POI Setting

POI's can be annotated with multimedia of photos, texts, and audios, on the target maps with icons presenting the icons. Figure 5.10 shows the attributes for annotating a POI. A POI must have a title and at least one position, and can be enriched by information of a timestamp, keywords, text description, images and audio. A POI object can have more than one position, such as the POI's of convenient stores, public toilets and so on. The annotated POI's also act as point spatial triggers for POI information narrating. Detailed instructions for annotating POI's can be referred to in Appendix B.

(a) Setting POI attributes **(b)** Setting POI positions
(Map provided by Kashiwa History Club)

Figure 5.10 Interfaces for annotating POI's

5.3.3 Polyline/Polygon Trigger Setting

Two functions are necessary for setting polyline or polygon spatial triggers: inputting triggers shapes, and bundling triggers with maps.

Figure 5.11 shows the interfaces for setting triggers. The processes of inputting triggers are the same as those of inputting georeferences, and it takes three steps to bundle maps to a trigger: (1) select a trigger, (2) set the map for inside (for polygons) or left-side (for polylines) of the trigger, and (3) set the map for outside or right-side of the trigger. Detailed instructions of setting triggers can be referred to in Appendix B.

(a) Inputting and selecting triggers (Apple Maps) **(b)** Bundle a trigger with maps (The right map provided by Kashiwanoha Park)

Figure 5.11 Setting polyline and polygon triggers

5.3.4 Assistant Functions for Map Georeferencing

Four assistant functions are developed to make map georeferencing more efficient.

(1) Indicating roads on base maps by trajectories

The base maps are sometimes too general in local areas and lack of spatial objects for georeferencing. In this case, *MapCollaging* provides functions to record user's moving trajectories and present them on the base maps to indicate the roads (Figure 5.12).

(a) Analogue map **(b)** The base maps (standard) **(c)** The base maps (satellite)

(d) Georeferences with trajectories on the base maps
(Map (a) is Konbukuroike Nature Park map; the base maps are Apple Maps)

Figure 5.12 Add georeferences on the base maps with the help of trajectories

(2) Hints for unbundled georeferences

Since referencing polylines are inputted separately on the target map and on the base maps in different views, it is sometimes difficult to remember which references are inputted on the different maps, and find corresponded georeferences. To solve the problems, a function to provide hints for unbundled georeferences is developed.

As shown in Figure 5.13, the cyan lines are the hints for creating georeferences corresponded to the georeferences already inputted in another map, which are calculated based on the bundled georeferences. The hints on the target maps are corresponded to the polylines on the base maps that are not yet bundled, while the hints on the base maps indicate the unbundled polylines on the target map.

(a) The target map **(b)** The base map (Apple Maps)
(The areal photo is provided by Geospatial Information Authority of Japan)

Figure 5.13 Hints for unbundled georeferences

(3) Automatic polyline bundling

Automatic polyline bundling function is developed to increase the efficiency to make polyline georeferences (Figure 5.14). The user has to manually bundle at least one pair of corresponded polylines, and the application will automatically bundle other polylines by calculating end points of the polylines from the base maps to the target map, and comparing them with the end points of polylines on the target map. If the distance from an end point calculated from the base map to an end point originally on the target map is smaller than a buffer, the two end points are matched. If both end points are matched for two polylines, the two polylines are corresponded and automatically bundled. The application will recursively bundle the polylines until no more polylines can be bundled.

(a) Before automatic bundling **(b)** After automatic bundling
(Map provided by Kashiwanoha Park)

Figure 5.14 Automatic bundling corresponded polylines

(4) Guidance for map georeferencing

There are 12 steps of operations for making a georeference by the application including drawing polylines on the maps and bundling the polylines. It is difficult for beginners to remember all the processes to make georeferences independently. Guidance function is developed to make it easy for beginners and non-professional users to make georeferences (Figure 5.15). The application will present step-by-step guidance, and users follow the guidance to make georeferences by directly tapping the guidance.

(Map provided by Kashiwanoha Park)

Figure 5.15 The guidance function

More functions for map collaging editing can be referred in Appendix B.

5.4 Experiments and Results

User experiments are carried out to test the main functions of *MapCollaging* for map browsing and editing.

The processes of the experiments are as follows:

- Introduce *MapCollaging* and its main functions to users;
- Instruct users to use *MapCollaging* and complete some tasks;
- Record users' operations with a video camera and the log functions of *MapCollaging*;
- Get users' feedbacks with questionnaires.

The *MapCollaging* content for the experiment consists 8 maps of Kashiwanoha area: Kashiwanoha walking map, Kashiwanoha Park map, Konbukuroike Nature Park map, UT Kashiwa Campus map, and areal photos of Kashiwanoha area taken in 1948, 1976, 1988 and 2004. Ten volunteers (6 females and 4 males) have participated in the experiments for experiencing the browsing and editing functions of the application.

5.4.1 Experiments for Map Browsing Functions

According to the experiment processes, basic functions were introduced for browsing map collaging, and then the users were asked to complete the following tasks:

- Browse different maps in the Kashiwanoha area;
- Compare spatial objects between maps of different years;
- Check lifetimes of spatial objects;
- Experience a simulated walking around Kashiwanoha area.

After finishing the tasks, the users were asked to choose the functions that were impressive and easy to use, and functions that were confusing and difficult to use. The users also gave comments on the application freely.

Figure 5.16 shows users' impressions on the browsing part of the application. It shows that more than half users think it easy or very easy to use the application. Users say it is good to use multiple maps because they can find more information with multiple maps and learn the changes of an area by comparing different maps. Some users say they used to use different paper maps and Google Maps independently while travelling, and the application makes it convenient to use by combining all the maps together on the smartphone.

Those who think it hard to use the application complains that there are too many functions and it is difficult to operate the application without guidance.

Figure 5.17 shows users' impressions on specific tasks in using MapCollaging. It shows that the hardest operation is to compare spatial objects between two maps. Users say that it lacks references for comparing and hope illustrated graphs can be created as references to help compare objects on two maps. Tow users think it hard to use the timeline function because titles of maps and POI's are not noted on the timeline panel, which make it inconvenient to find a certain target. The users who think it hard to manage map visibility or transparencies say that there are not guidance for such settings and they are not sure what settings are suitable for browsing the map collaging contents.

According to users' comments, plans for revising the browsing part will focus on three aspects: providing guidance for operations, concise functions to make interface clear, and providing functions to help map comparing, for example adding illustrated graphs as references for comparing.

Figure 5.16 Users' impressions on the operation easiness of browsing part of MapCollaging.

Figure 5.17 Users' impressions on the operation easiness of specific tasks of browsing part.

5.4.2 Experiments for Map Editing Functions

The users were asked to finish the following tasks with *MapCollaging*:

- Add a new map and set its image;
- Make map georeferencing (under two different conditions: with and without hint and guidance functions);
- Annotate POI's on the map;
- Repeat the above steps to make a second map;
- Create a route and add the two maps to it.

After finishing the tasks, the users were asked to choose the tasks that they thought easy or difficult to finish, and the users' comment were collected.

Figure 5.18 shows users' impressions on the editing part of the application. It shows more than half users think it easy or very easy to edit map collaging content. Users say that it is good to provide the editing functions to enable creating map collaging content by themselves, and that they are interested to use the application for preparing travelling. A user mentions that she usually takes photos of map signboards at stations for local navigation, and she thinks it is convenient to use *MapCollaging* to collect map signboards and edit them for local guiding.

Figure 5.18 Users' impressions on the operation easiness of editing part of MapCollaging.

Some users also feel it hard to make map collaging content. Figure 5.19 shows users' impressions on specific operations map collaging editing. It indicates that drawing polylines, finding corresponded polylines, and bundling two polylines are the three functions that are difficult parts for users. It also shows that the assisting functions of hints and guidance make it easier for users to find corresponded polylines.

Figure 5.19 Users' impressions on the operation easiness of specific tasks of editing part.

5.5 Summary

This chapter introduces the implementation of *MapCollaging* application, which realizes the functions for local storytelling with multiple local analogue map images, and tools for local people to participate in making their own map collaging content.

The map browsing part of the application provides following main functions for local storytelling and experiencing:

- Local maps overlaying with indicating user's location and direction;
- Three ways of map switching for different situations that include map browsing (map switching through map list), spatial comparing (map switching by long tapping map image) and temporal comparing (map switching through timelines);
- Two ways of adjusting maps transparencies quickly or precisely;
- Showing or hiding certain maps;
- Taking memos, searching and viewing POI's, trajectory managing, and so on.

The map editing part provides the following main functions for making map collaging content:

- Adding and managing the three hierarchies of map collaging data: raw data, map, and route;
- Functions to input polylines and bundle corresponded polylines on the target map and the base maps for map georeferencing;
- Functions to set POI's on maps, and the icons will act as point triggers to narrate the POI information automatically according to the user's position;
- Functions to input polyline and polygon triggers and link maps to the triggers for automatic map switching;
- Assistant functions to improve the efficiency of inputting map georeferences, such as indicating roads on base maps by trajectories, hints for unbundled georeferences, automatic polyline bundling and step-by-step guidance for map georeferencing.

Results of the experiments indicate that *MapCollaging* is feasible for people to browse and edit map collaging content, and necessary to have assisting functions, such as hints and guidance, for people to make georeferencing.

Chapter 6 Fieldwork Experiments

In addition to the computer simulations and user tests in the laboratory, fieldwork tests were carried out to evaluate map collaging usability in real applications. Two fieldworks were carried out in different areas. One is the cooperation with local communities in Kashiwanoha and Hananoi areas to make map collaging content and application to represent the local knowledge of areas. The other is the cooperation with Shiroi City government and local communities for map collaging content making for Shiroi City by local users.

6.1 Map Collaging for Kashiwanoha and Hananoi

6.1.1 Background

Kashiwanoha and Hananoi areas are located in the north part of Kashiwa City, in which many important places are situated, such as Kashiwanoha Campus Station, Kashiwa Campus of the University of Tokyo, Kashiwa Campus of Chiba University, Kashiwanoha Park, Konbukuroike Nature Park and so on.

During the World War Ⅱ, the current Kashiwanoha area was the Kashiwa Airport of Japanese Army. Near the end of the war, a rocket plane named *Shusui* (秋水) was tested in the airfield. Some remains of the airfield can still be found at present, such as the trench for protecting airplanes and docks for storing fuel for Shusui.

After the war, Kashiwanoha and Hananoi areas have seen the changes including the ruin of the airport, the establishment of a golf course, the construction of Kashiwanoha Park, the abandon of the golf course (Mitsui Kashiwa Golf Course), the constructions of Kashiwa Campus of the University of Tokyo, the opening of Tsukuba Express and so on.

The task of the fieldwork is to create map collaging content to tell the historical stories of the areas.

6.1.2 Cooperation for Content Making

To collect materials for making content, the fieldwork is cooperated with local communities including Kashiwa Campus of the University of Tokyo, Kashiwa History Club, Kashiwanoha Park, Konbukuroike Nature Park, Urban Design Center Kashiwanoha (UDCK) and Kashiwa Goodwill Guide Association.

In the cooperation, the local communities were mainly responsible for providing information and materials, such as maps, photos, texts and so on, and they had chances of using the application software provided by us to give comments and suggestions for improvements. We were responsible for integrating the materials and make map collaging content, as well as revising the application software to respond to feedbacks from the users.

6.1.3 Results of the Fieldwork

The accomplishment of the fieldwork tests is an application for walking excursions named *KashiwaWalk*, which is created as an extension of *MapCollaging*. The KashiwaWalk v1.0 is published in Apple Inc.'s App Store. There is one walking route (コース 1: 柏の葉、花野井) containing 9 maps (Figures 6.1 and 6.2).

Figure 6.1 Screen shots of *KashiwaWalk* displaying one route with nine maps

(a) Map for visiting War Relics and walking around 柏の戦争遺跡＆散策マップ(柏の葉～花野井)

(b) Map of Kashiwa Campus, The University of Tokyo

(c) Map of Kashiwanoha Park

(d) Map of Konbukuroike Nature Park

(e) Map of Remains of the Kashiwa Airport

(f) Areal photo around Kashiwanoha in 2004

(g) Areal photo around Kashiwanoha in 1988

(h) Areal photo around Kashiwanoha in 1976

(i) Areal photo around Kashiwanoha in 1948
(Map and areal photos provided by Kashiwa History Club, UT Kashiwa Campus, Kashiwanoha Park, Konbukuroike Nature Park, and Geospatial Information Authority of Japan. The areal photo of 1948 was originally taken by U.S. Army.)

Figure 6.2 Maps used in *KashiwaWalk*

Map for Visiting War Relics and Walking Around in Kashiwa (from Kashiwanoha to Hananoi) (柏の戦争遺跡＆散策マップ(柏の葉～花野井)) is used as a default main map for walking tours. The maps of Kashiwanoha Park, Kashiwa Campus of the University of Tokyo, and Konbukuroike Nature Park are used for providing detailed information in each local area. A map of the remains of the Kashiwa Airport, and areal photos of Kashiwanoha area taken in 1948, 1976, 1988 and 2004 are used to present the changes of the areas in the recent history.

To organize the cue of the story, 9 triggers along a test trajectory are used to tell the story. Figure 6.3 and Table 6.1 show the distributions and attributes of the triggers. Triggers (3), (4) and (5) are used to show thematic local information. Triggers (1), (2) (6), (7), (8) and (9) are used for experiencing historical changes in the areas, for example, areal photo of 1948 will be presented near the remains of the main gate of the airport and the fuel docks.

Figure 6.3 Distributions of triggers (on Apple Maps)

Table 6.1 Attributes of the triggers

Trigger	Inside/left-side Map	Outside/right-side Map
(1)	(e)	(a)
(2)	(i)	(e)
(3)	(c)	(a)
(4)	(b)	(a)
(5)	(d)	(a)
(6)	(a)	(i)
(7)	(i)	(h)
(8)	(h)	(g)
(9)	(g)	(f)

(* The letters in the table are corresponded the maps shown in Figure 6.2)

The application is applied in the activities of the local communities. The application is applied in the walking tours held by Kashiwa History Club. Participant of the walking tour use the application to learn the history of Kashiwanoha area by the old photos about Kashiwa airport and the old areal photos of Kashiwanoha Area. The application is also applied in the investigation of the remains of the fuel docks of the Kashiwa Airport and successfully found the correspondent relation between the remained docks and the original docks on the old area photo (details can be referred to in Chapter 3).

6.1.4 Comments and Revises

The local communities had mainly positive impressions on the application software and gave their comments on it.

Representative positive comments are as below:

- It is convenient to experience the historical changes with the overlaying of historical areal photos.
- Automatic map switching and POI narrating are impressive as they are positively telling local stories with proper maps and information and do not need manual interactions.
- It is convenient to make notes with the memo function during real places investigations of historical spots for designing walking courses.
- The application is like a virtual museum for experiencing knowledge in real places.

Users also pointed out some deficiencies of the application and gave suggestions:

- It seems messy if all maps are shown at the same time;
- The Map for Visiting War Relics and Walking Around in Kashiwa (from Kashiwanoha to Hananoi) is not up-to-date (published in 2014) and some information needs to be updated;
- It will be good if bird's-eye view areal photos can be included.

The above comments from users are valuable for improving map collaging theory and application. Modifications and improvements have been made to meet users' expectations as follows.

Firstly, to ensure clear presentation of map collaging, experiments are carried out to optimize the number of background maps and transparency of background maps in different using contexts (discussed in Chapter 4), and the functions to control the shown/hidden status of certain maps are developed (introduced in Chapter 5).

Secondly, timelines are used to show the life cycles of the POI's and maps. For the maps that are out of date, the timelines can indicate the changes and provide up-to-date information. As shown in Figure 6.4, two POI icons with different timestamps are used to indicate the moving of UCDK from the east side of the station to the west side in 2014.

(Map provided by Kashiwa History Club)

Figure 6.4 POI's icons and timelines are used to indicate changes on maps

Thirdly, the application is updated to support bird's-eye view areal photo. As bird's-eye view areal photos have large distortions with inconsistent scales and north directions, semi-georeferences are applied to achieve stable overlaying of bird's-eye view areal photos to other maps. Figure 6.5 shows a bird's-eye view areal photo presented in map collaging.

(a) Bird's-eye view areal photo as main map **(b)** Bird's-eye view areal photo as background map
(Areal photos provided by The University of Tokyo, Kashiwa Campus)

Figure 6.5 Bird's-eye view areal photo of UT Kashiwa Campus in map collaging

6.2 User-created Map Collaging For Shiroi City

6.2.1 Background

Shiroi City is on the southeast of Kashiwa City, which has many historical shrines, temples, and cultural properties, such as Tomizuka Tomi Jinja Shrine, Raikou Ji Temple, Sairin Ji Temple, and so on. Besides, Shiroi City is famous for pear planting.

Map collaging content is created by users from Shiroi city to share the local knowledge.

6.2.2 Cooperation for Content Making

This fieldwork is cooperated with Cultural Affairs Division of Shiroi City Office and Kashiwa History Club.

In the cooperation, the local users from Shiroi City Office and Kashiwa History Club are responsible for collecting materials and making map collaging content with *MapCollaging*. And we are responsible for providing devices (iPad mini), giving technical instructions and improving the application according to users' comments.

There are two volunteers participating in making map collaging content. Participant A is a member of Kashiwa History Club who lives in Shiroi City. Participant B is a city officer majored in heritage archeology. Table 6.2 shows backgrounds of the participants.

Table 6.2 Backgrounds of volunteers

No.	Age	Mobile devices experiences	Experiences of using mobile mapping
A	70s	Feature phone	No
B	30s	Android & iPad devices	Yes

Three meetings are held to instruct the functions and operations of *MapCollaging*. The participants and content of the meetings are shown in Table 6.3.

Table 6.3 Instructions for making map collaging content

Date	Participants	Content
Apr. 4th	A	Experience walking with MapCollaging; General instructions for using MapCollaging
Apr. 8th	A, B	Instructions of edit functions; Making sample content
Apr. 12th	A	Instructions for making map georeferences
Apr. 19th	B	Solve user's problems

6.2.3 Results and Modifications

The participants plan to make map collaging content based on the guidebook of Shiroi Cultural Properties Walking Map, which contains 22 walking courses.

(1) Results of Participant A

By April 12th 2016 (8 days since first time using *MapCollaging*), Participant A had prepared 15 raw images and three raw texts for making content, but failed to make valid georeferenced maps or routes by himself. Participant A is unfamiliar with touch-screen devices like iPhone and iPad, and it is difficult for him to understand the ways of transferring data from PC to iPad. It was found that Participant A tended to press the iPad screen as pressing tangible buttons, which caused wrong operations. For example, Participant A pressed POI button too hard, which resulted in map panning operation. Another problem is misunderstanding of some concepts of map collaging. Participant A misused images of POI's as map images thus failed to make georeferenced maps (Figure 6.6).

Figure 6.6 Mistakes made by Participant A: map images are set as POI images.

Participant A was guided to make georeferences on at the third meeting on April 12th 2016 (Table 6.3). With the instructions, Participant A made one georeferenced map with 16 georeferences and 7 POI's (Figure 6.7).

(a) Georeferences **(b)** POI icons
(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 6.7 Georeferenced map made by Participant A under instructions

Test trajectories were made to check the georeferencing accuracy, and the result is shown in Figure 6.8. Obvious errors can be found in the circle area. The reason that caused the errors is an improper use of a place of interest, Enmeiji Temple, as a control point for building referencing polylines. Figure 6.9 shows that the Enmeiji Temple is not noted on the base maps for inputting geographic coordinates, and it is difficult to find the exact place on the base maps that is corresponded to the place on the target map. Meanwhile, the referencing polyline is relatively far from the designed walking course, thus amplifies the positioning errors.

(a) Test trajectory on base maps (Apple Maps) **(b)** Test trajectory on the target map (Shiroi Cultural Properties Walking Map, provided by Shiroi City Office)

Figure 6.8 Accuracy of positioning based on georeferences made by Participant A

(a) Standard mode of Apple Maps **(b)** Satellite mode of Apple Maps

Figure 6.9 Improper use of control point that is difficult to find on the base maps.

The above errors can be reduced by modifying the referencing polylines closer to the walking course. The revised referencing polylines and positioning results are shown in Figure 6.10. It can be found that the positioning results are more accurate after revising.

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 6.10 Revised referencing polylines and positioning results

(2) Results of Participant B

By April 19th 2016 (11 days since the first day using *MapCollaging*), participant B had appended 19 raw images and 10 raw audios, georeferenced 9 maps and made 6 routes (Figure 6.11). He had also taught one of his colleagues to make a georeferenced map with *MapCollaging*.

(a) Raw images **(b)** Raw audios

(c) Georeferenced maps **(d)** Routes

(The map 七次第二公園コース is made by Participant B's colleague; the first two routes are samples already in the application.)

Figure 6.11 Content made by Participant B

Figure 6.12 shows some typical georeferences made by Participant B. The characteristic of Participant B's georeferences is that he usually uses one side of the road, instead of the central line, for georeferencing. It ensures the accuracy when user is moving on the georeferenced side of the road, and is suitable for the cases that the width of the road cannot be ignored and the scale of the road width on the map is not consistent with the map scale. A test trajectory along the left side of the road is created, and the positioning results are presented in Figure 6.13. It can found that the densities of the trajectory points along different segments of the roads are different, which indicates an irregular distortion of the target map. The positioning results are generally good with most points located on the left side of the roads. However, errors can be found at two places. One is that the trajectory on the target map is not on the road at the beginning part. The reason is that this part is not georeferenced, and the positioning error increases obviously with map distortions. The other is that the trajectory points at the end part are located on the right side of the road. The reason is that the positions of the georeference polylines on the base maps are not accurate. When the base map is zoomed in, it can be found that the last referencing polyline on the base maps is not on road. To revise the georeferences, two referencing

polylines are added at the beginning part, and the positions of polylines are adjusted at the end part. The revises and results are shown in Figure 6.14, in which the positioning results improved at the start and end of the trajectory.

(a) Georeferences on the target map (Shiroi Cultural Properties Walking Map)

(b) Georeferences on base maps (Apple Maps)

(The left map provided by Shiroi City Office)

Figure 6.12 Georeferences made by participant B

(a) Test trajectory on base maps (Apple Maps)

(b) Test trajectory on target map (Shiroi Cultural Properties Walking Map)

(The right map provided by Shiroi City Office)

Figure 6.13 Positioning results of test trajectory

(a) Two georeferences added **(b)** Adjusted references **(c)** Revised positioning results
(a, c: Shiroi Cultural Properties Walking Map provided by Shiroi City Office; b: Apple Maps)

Figure 6.14 Revises of the georeferencing created by Participant B

Figure 6.15 shows the result of overlaying the same two maps georeferenced by Participant B and his colleague. It is obvious that the two maps are not well overlapped. Figure 6.16 shows the georeferences made by participant B and his colleague, in which two causes of the errors can be found. One is that Participant B uses one side of the roads and the corners of intersections for georeferencing. On distorted illustrated maps, the widths of the roads and sizes of the intersections are not presented in consistent scales, which brings errors of directions and scales to the referencing polylines. The other is that the colleague uses some polylines that are too short to prevent obvious errors of directions and scales. To solve the problem, the georeferences are revised by using the centerlines and intersection centers, and avoid short referencing polylines. Figure 6.17 shows that the maps are overlapped more accurately after modifying their georeferences.

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 6.15 Overlaying of the same two maps georeferenced by different users

(a) Participant B's georeferencing **(b)** The colleague's georeferencing
(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 6.16 Different georeferencing on the same map made by different users

(Shiroi Cultural Properties Walking Map provided by Shiroi City Office)

Figure 6.17 Maps overlaying after modifying their georeferences

From the fieldwork, two problems can be found in users' participation in making map collaging content.

One problem is that the touchscreen platforms like smartphones are not widely used by elderly people at present, which bring difficulties in operating the application. To solve this problem, tools for making map collaging content on conventional platforms like PC will be developed, which are supposed to be easier for elderly people.

The other is that users may not have enough knowledge and experiences to make accurate georeferences. To solve this problem, the principles for making georeferences (introduced in Chapter 2) are summarized to guide users to make appropriate map georeferences.

6.3 Summary

This chapter introduced two fieldworks for applying MapCollaging in actual use.

In the first fieldwork, different local communities cooperated and created an application *KashiwaWalk* for sharing knowledge of the Kashiwanoha and Hananoi areas, which are applied for local walking tour and history heritage investigation.

The second fieldwork shows feasibility of map collaging content making by local users. During the fieldwork, both participants show passions in making map collaging content. With application instructions, one participant (Participant A) can make map georeferences with guidance, and the other one (Participant B) is able to independently make map collaging content, and also teach others to make content. However, the participants still need instructions and practices to improve georeferencing accuracy.

According to users' comments, modifications are made for improving the map collaging, including semi-georeferences for overlaying bird's-eye view areal photos, map transparencies adjustment, map image visibility control, and so on.

In the second fieldwork we found problems of users' participation in making map collaging content, such as insufficient experiences for making accurate georeferences, and difficulties in operating smartphones. To solve the problems, map georeferencing rules are summarized to help users to make accurate georeferences (introduced in Chapter 2), and assisting functions, like hints and guidance functions, are developed (introduced in Chapter 5) for users to make map georeference easily.

Chapter 7 Conclusions and Future Work

7.1 Conclusions

This thesis proposed a framework of map collaging for sharing local knowledge. It is an innovative way to share local knowledge by mapping services on collaged local analogue map images.

In the field of cartography, map collaging provides a new way for mobile mapping services through multiple heterogeneous analogue maps, with accurate and stable positioning on distorted analogue maps, continuous map combination and map switching of heterogeneous maps, and user-friendly interfaces for multiple maps browsing and editing.

In the field of socio-cultural environmental studies, the new type of mapping services of map collaging has four main characteristics in contributing to the sharing of local knowledge for local development.

Firstly, it provides ubiquitous access to local knowledge. Materials that are stored in libraries and fixed on signboards are integrated on mobile devices to be conveniently used by common people.

Secondly, it provides on-site spatial learning and investigation. Imbedded with LBS, it enables users to experience knowledge on maps in real places. On-site spatial learning helps users to better understand knowledge being introduced, and investigate new knowledge by themselves.

Thirdly, it enables a spatial-aware knowledge narration. It organizes knowledge on different maps to tell logical stories and make local knowledge interesting and easy to understand. With spatial triggers, local knowledge can be narrated automatically at right places and be easily and efficiently conveyed to users along a trip positively by on-site storytelling, instead of being passively searched without storytelling or real-world experience.

Fourthly, it provides user-friendly tools for people to make content of map collaging. They can present easily their personal knowledge and experience as map collaging content to be shared by others. The framework enables local governments, communities and citizens to create the content at a low cost for a wide variety of people to share local knowledge effectively based on sophisticated spatial, visual and oral storytelling. The local knowledge shared by the users can be used by local governments and communities for heritage protection, tourism planning, facility management, and so on, for promoting local development.

To organize the fundamentals of map collaging, researches on the key issues have achieved the following results.

Polylines are applied for georeferencing analogue map images instead of points, and the polyline-based georeferencing ensures stable and accurate positioning results along georeferenced paths. A method of dynamic map overlaying based on a focus point is proposed to overlay multiple distorted local analogue map images without converting the original images into geometrically corrected normalization. It aims to keep the acceptable quality level for dynamic map overlaying around only a focus point or the current position with releasing risks of the exterior part far from the focus point into unacceptable quality level.

Conventional georeferencing of analogue maps are realized based on geometrically corrected normalized maps of the latest times. The restriction of using only the standard base maps causes the difficulty for finding common right and good reference positions among old analogue maps and the

standard base maps. *Semi-georeferencing*, which connects different analogue map images directly without the restriction of using the standard base maps, is proposed and realized. It allows users to find georeference positions and lines more efficiently and to control the accuracy of positioning and maps overlaying on the better quality level with a new method of generating virtual georeferencing relations based on the standard base maps from multiple semi-georeferencing relations based on non-standard maps.

Methods to ensure continuous map collaging presentation and storytelling are proposed and experimented. Spatial triggers are used to cue local knowledge for spatial storytelling, and a model of managing different factors for map collaging presentation and map switching is proposed for continuous combination and switching of heterogeneous maps.

An application, *MapCollaging*, is implemented based on theories of map collaging. User-friendly tools are implemented for map collaging browsing and editing. Assisting functions are developed to help users to make polyline georeferences.

Fieldwork experiments are carried out. In collaborations with local communities in Kashiwanoha and Hananoi areas of Kashiwa City in Chiba Prefecture, Japan, an iPhone application *KashiwaWalk* is developed for sharing knowledge of these areas. With collaboration with Shiroi City, experimental map collaging content is created by participants from Shiroi City office and local communities. The results of the fieldwork experiments indicate that map collaging is an attractive and efficient way for local knowledge sharing, and proves the feasibility of non-professional local people in making map collaging content for knowledge sharing.

7.2 Future Work

The research will continue to improve map collaging on the accuracy of LBS and easiness of operations, and apply the framework in wider areas for practical uses.

Firstly, the research will further improve the accuracy of positioning and map overlaying and design more smart functions for map georeferencing, for example, developing functions for automatically checking and optimizing georeferences made by users to increase the accuracy of positioning and map overlaying.

Secondly, now the application provides only offline services, which ensures the robust of map collaging content, but it is inconvenient to share the user-made content. In the future, the research will upgrade online services for uploading the user content conveniently. As the map collaging content may become much larger, methods to efficiently manage the big data of map collaging will be researched, as well as the methods for protecting copyrights and privacies during knowledge sharing.

Thirdly, currently there is only a small numbers of map collaging content and just a few users, which are not enough to support big data mining. In the future, with the online service of map collaging, it will be more convenient for communities and individuals to contribute to enriching map collaging content in different local areas. Based on the big data of local knowledge, analyses such as characteristics of local areas, numbers of visitors to areas, people's interested knowledge, relations between richness of local knowledge and the number of visitors, and so on, can be worked out to assist local development, and preserve local knowledge.

Fourthly, we will continue cooperating with the local communities to make more map collaging content, such as the content in Konbukuroike for nature education and the content of the designing of the future city of Kashiwa made by UDCK. Furthermore, we are going to extend the cooperation with other places, for example districts in Tokyo, to spread map collaging to wider uses.

With the further researches, map collaging is expected to be widely applied by more people participating in knowledge sharing to enrich the local knowledge, which will enable more people to enjoy local knowledge in real places for life-long education, and is benefit for activating local development.

Appendix A: MapCollaging Browsing Functions Instructions

A.1 Content List

(a) Route List **(b)** Map List

Figure A.1 Content List of *MapCollaging*

Figure A.1 shows the interfaces of content list:

① Go to editor button: go to editor part to edit content.

② Route/map switch: switch to browse route or map. Route provides location-based services (LBS) with multiple maps; map provides LBS with one map.

③ Route/map icon.

④ User location status flag:

user is in the route/map;

 user is out of the route/map.

⑤ Route/map title.

⑥ Number of the maps in a route.

⑦ Map topic

A.2 Map Browsing Interface

Figure A.2 shows the main interface for map browsing.

(Map provided by Kashiwa History Club)

Figure A.2 Interface for maps browsing

Components in the interface are as follows:

① Main map title

② Search bar

③ Map image

④ User's location

⑤ User's trajectory

⑥ Setting button

⑦ Compass

⑧ North arrow of the main map

⑨ Center user location button

⑩ Taking memo button

⑪ Map manage button

⑫ Timeline button

⑬ POI (Point of Interest) list button

⑭ Transparency quick adjusting button

⑮ Trajectory button

A.3 User Location and Direction

(Map provided by Kashiwa History Club)

Figure A.3 User location unit

As shown in Figure A.3, the three components that indicate users location and direction are as follows:

① User location

② Estimated error range

③ User direction

A.4 Taking Memo

Users can tap taking memo button (Figure A.2. ⑩) to take memos. A memo can include one text message, one audio clip and multiple photos. Figure A.4 shows the interface to take a memo.

Figure A.4 Take Memo

Components in the interface for taking memo are as follows:

① Show text view to edit the memo text

② Show audio tools to record and play the memo audio

③ Take photos for the memo

④ Delete the memo content

The memo icon will be shown at the place where the memo is taken on the maps. Tapping the icon can view and edit the memo.

A.5 Switching Main Map

The three ways of map switching are introduced in Section 5.2.1.

A.6 Timeline

Tapping timeline button (Figure A.2 ⑫) can show or hide timeline panel (Figure A.5).

Figure A.5 Timeline panel

Components in the timeline are as follows:

① Time labels

② Map story lifetime

③ POI story lifetime

④ Time indicator

⑤ End time of a POI

⑥ Start time of a POI

⑦ Undefined lifetime of a POI

Users can check the timestamps of maps and POI's with the timeline, and can also switch main map and view POI information from the timeline panel.

A.7 Map Transparency

Tapping the transparency quick adjusting button (Figure A.2 ⑭) can switch the status of main map image between opaque and semitransparent.

Users can adjust transparency of the main map and background maps specifically in settings (Figure A.2 ⑥).

A.8 Managing Trajectory

Tapping trajectory button (Figure A.2 ⑮) can show/hide current trajectory.

In the settings, users can set the time interval of trajectory recording and whether trajectory recording is enabled when the app is suspended (Figure A.2 ⑥).

Double tapping the trajectory button can manage the trajectory list (Figure A.6). Trajectories are sorted by time. Items with black font color are trajectories inside the route; items in gray are trajectories out of the route.

(a) GPS trajectory **(b)** Simulated test trajectory

Figure A.6 Trajectory list

Users can choose a trajectory and replay it (Figure A.7). Components in the trajectory replay panel are as follows:

① Trajectory replay panel

② Slow down button

③ Play/pause button

④ Speed up button

⑤ Speed indicator

⑥ Playing progress bar

⑦ Playing progress label

(Map provided by Kashiwa History Club)

Figure A.7 Replaying trajectory

A.9 Setting Focus Point of Map Overlaying

Map images are overlaid according to the focus point. Map overlaying accuracy is relatively higher around the collaging center, and may decrease as the distance to the collaging center increases.

The default collaging center is the user's position on the screen (when the user's position is inside the screen), or the center of the screen (when the user's position is out of the screen). The user can manually set the collaging center by double tapping his/her interested place on the screen.

The collaging center will be updated automatically once the previous collaging center moves out of the screen.

Appendix B: MapCollaging Editing Functions Instructions

B.1 Switching to Edit Mode

Tapping go to editor button (Figure A.1 ①) can switch to content editing interfaces (Figure B.1).

Figure B.1 Editor root view

Components in the interface are as follows:

① Go to browser button: switch to browsing content list view (Figure B.1).

② Go to route list

③ Go to map list

④ Go to raw data list

⑤ Settings button

B.2 Managing Raw Data

Tapping raw data item in editor root view (Figure B.1 ④) will show raw data list (Figure B.2).

Figure B.2 Raw data list

The components for managing raw data are as follows:

① Raw data items

② Raw data type switch

③ Add new item button

④ Swipe left to delete the item

There are two ways to add new raw data: importing from local files, and manual input.

(1) Importing local files

Step 1: Connect the iPhone with a computer, and drag data from the computer to the app's document through Apple Inc.'s iTunes (Figure B.3);

Step 2: Open the app and go to the raw data list. Tap add new item button (Figure B.2 ③), and choose *Import Local Files* (Figure B.4).

Step 3: Select data from the local files list (Figure B.5);

Step 4: Back to the raw data list view and the selected local data are added to the list.

Figure B.3 Importing data from a computer to the app

Figure B.4 Importing data from local files

Figure B.5 Selecting local data

(2) Inputting data Manually

Tap add new item button (Figure B.2 ③), and choose *Manually Input*;

Input data according to different data types.

- Image: take photos by camera, or choose photos from the album of the iPhone;
- Text: input with soft keyboard of the iPhone;
- Audio: record with audio panel (Figure B.6).

Change the file name from default if necessary.

Figure B.6 Audio recording view

Follows are the component in the audio panel:

① Data title

② Play/pause

③ Record/stop recording/stop playing

④ Audio progress bar

⑤ Audio progress label

B.3 Managing Maps

Map list view is shown in Figure B.7.

Figure B.7 Map list

There are three components in the view:

① Add new map button

② Map item

③ Edit map list button (deleting and reordering map items)

B.3.1 Adding and Editing Map

Tapping the add new map button (Figure B.7 ①) can add a new map; tapping the map item (Figure B.7 ②) can edit the map. The interface of adding/editing map is shown in Figure B.8.

Figure B.8 Map editing view

Components of the interface are listed as follows (items with red index number are required):

① Map title (required)

② Map topic

③ Time stamp

④ Keywords

⑤ Icon of the map

⑥ Georeferencing Unit (required)

⑦ Description

⑧ Cancel editing and back to map list

⑨ Save the map and back to map list

B.3.2 Map Georeferencing Unit

Tapping the image view or the edit button in georeferencing unit (Figure B.8 ⑥) will show four items for map georeferencing: map image (request), spatial references, POI's, and relative scale limits (Figure B.9).

Figure B.9 Items for map geocoding

Four components are contained in the map georeferencing unit:

① Map image (required)

② Spatial references

③ POI's

④ Relative scale limits

B.3.3 Setting Map Image

Choosing map image in the georeferencing unit (Figure B.9 ①) will show the editing map image view;

Tap + button to set the map image from the camera, the photo album of the iPhone, or the imported raw image data (Figure B.10);

Tap Done button to save the settings and back to the map editing view.

(Map provided by Kashiwa History Club)

Figure B.10 Setting map image view

B.3.4 Setting spatial references

Choosing spatial references in the georeferencing unit (Figure B.9 ②) will show the setting map image view (Figure B.11).

Polylines are used as spatial references for the map image georeferencing.

(Map provided by Kashiwa History Club)

Figure B.11 Setting spatial references view

The components in the interface for setting spatial references are listed as follows:

① Start/end inputting a new polyline

② Add a point the new polyline

③ Undo adding point

④ Cancel adding the new polyline

⑤ Select a polyline

⑥ Revert direction of the selected polyline

⑦ Match the selected polyline on base map

⑧ Delete the selected polyline

⑨ Save editing

⑩ Trajectory managing

⑪ Mark of the screen center, tap to add a point or select a polyline

⑫ Polyline spatial reference

⑬ Settings

⑭ Go to the base map spatial reference editing view (Apple Maps are used as the base map)

The processes of adding a new spatial reference are as follows:

Tap NewL (Figure B.11 ①) to start inputting a new polyline on the map image (Figure B.12a);

Tap AddPt or (Figure B.11②, ⑪) to add points of the polyline (move map to adjust the place to add a point at the screen center, Figure B.12b);

Tap EndL (Figure B.11 ①) to end adding the new polyline (Figure B.12c);

Tap BaseMap (Figure B.11 ⑬) to go to the base map editing view, and add the corresponding polyline on the base map (Figure B.12d);

Back to the setting spatial references view, tap Select or (Figure B.11 ⑤, ⑪) to select a polyline reference (Figure B.12e),

Tap Match (Figure B.11 ⑦) to the bundle base polyline view, and tap Select or to select corresponding polyline, and tap Done to confirm the bundle (Figure B.12f);

(a) Start adding new polyline **(b)** Add polyline points **(c)** End adding new polyline

(d) Add polyline on base map **(e)** Select polyline on image **(f)** Bundle polyline on base map

(Target map provided by Kashiwa History Club; the base maps are Apple Maps)

Figure B.12 Adding spatial references

Tips for making georeferences are as follows:

- Users can turn on trajectory with button and add marks with button in the base map to help adding polyline references on the base map;
- Users can choose base map mode among standard, satellite, and hybrid;
- Users can edit simulated trajectory on the base map by choose Trajectory at the top editing target segments, the way to input simulated trajectories is similar to inputting spatial reference polylines;
- Users can choose trajectories with trajectory managing button (Figure B.11 ⑩) in the setting trajectory view to check georeferencing results

B.3.5 Setting POI's

Choosing POI's in geocoding unit (Figure B.9 ③) will show the setting POI's view (Figure B.13).

(Map provided by Kashiwa History Club)

Figure B.13 Setting POI's view

The components of the view are listed as follows:

① Select POI button

② Edit POI button

③ Add POI button

④ Delete POI button

⑤ Save button

Adding/editing POI view is shown in Figure B.14.

Figure B.14 Adding/editing POI view

The followings list the components of the view to set POI's (items with red index are required):

① Title (required)

② Positions (required, details can be referred to in Figure B.15)

③ Time stamp

④ Keywords

⑤ Text (tap the text view to input manually; tap to choose text from the raw text list)

⑥ Images (tap 画像 to set POI images)

⑦ Audio (tap オーディオ to choose an audio from the raw audio list)

⑧ Cancel editing and back to setting POI's view

⑨ Save editing and back to setting POI's view

(Map provided by Kashiwa History Club)

Figure B.15 Setting POI positions

The component for setting POI positions are as follows:

① Select position button

② Add position button (a POI can have more than one position)

③ Add/modify position button

④ Delete position button

⑤ Relocate position button

B.3.6 Setting map scale range

Choosing relative scale limit in georeferencing unit (Figure B.9 ④) will show the setting map image scale limit view (Figure B.16).

Zoom in/out the map image, and use the setting buttons (Figure B.16 ①②③④) to set or cancel the map scale limits.

(Map provided by Kashiwa History Club)

Figure B.16 Setting map relative scale limits

The component of the view to set map scale ranges are as follows:

① Set maximum scale

② Cancel maximum scale

③ Set minimum scale

④ Cancel minimum scale

⑤ Setting status

⑥ Cancel editing and back to the map editing view

⑦ Save and back to the map editing view

B.4 Managing Routes

Route list view is shown in Figure B.17.

Figure B.17 Route list

The three components in the view are as follows:

① Add new route button

② Route items

③ Edit route list button (to delete and reorder route items)

(1) Adding and Editing a Route

Tap add new route button (Figure B.17 ①) to add a new route; tap a route item (Figure B.17 ②) to edit the route. The interface of adding/editing a route is shown in Figure B.18.

Figure B.18 Adding/editing route

Among the below components for adding and editing a route, the two with red indices are required:

① Title (required)

② Description (tap the text view to input manually; tap to choose text from raw text list)

③ Key words

④ Icon

⑤ Route map list (required)

⑥ Setting triggers

⑦ Cancel editing and back to route list

⑧ Save editing and back to route

(2) Managing Route Map List

Tapping Maps (Figure B.18 ⑤) will show route map list view to manage route map list (Figure B.19).

A route should contain at least one map in the map list.

Figure B.19 Managing route map list

The followings are the component in the view for managing routes.

① Add a map to the list

② Turn on/off the map list editing status

③ Remove a map from the list

④ Drag to reorder the maps in the list

(3) Setting Triggers

Triggers are used to automatically switch the main map of a route according to user's moving behavior.

Point triggers are set by annotating POI's, and the other two kinds of triggers can be set in this view: polyline triggers and polygon triggers. A polyline trigger will be triggered when the user moves across the polyline; and a polygon trigger will be triggered when the user enters or leaves the polygon.

Tapping Triggers (Figure B.20 ⑥) can set triggers for automatic map switching. Trigger setting view is shown in Figure B.20.

Figure B.20 Setting triggers (on Apple Maps)

The components for setting triggers are as follows:

① Start/end adding polyline trigger

② Start/end adding polygon trigger

③ Select trigger

④ Link trigger with maps

⑤ Delete trigger

⑥ Save edits

⑦ Cancel edit and back to route editing view

⑧ Save edit and back to route editing view

⑨ Add point/select trigger button

There are two main steps to set a trigger (create a polygon trigger as an example):

Steps to create the trigger shape:

- Tap (Figure B.20 ②) to start adding a polygon trigger;
- Tap (Figure B.20 ⑨) to add points to the trigger;
- Tap (Figure B.20 ②) to end inputting the polygon trigger.

Steps to link triggers with maps:

- Tap Select or (Figure B.20 ③⑨) to select a trigger;
- Tap Link (Figure B.20 ④) to show the link trigger view;
- Set map and scale (Figure B.21 ①③) for the area inside the trigger;
- Select Outside (Figure B.21 ⑥), and set map and scale for the area outside the trigger.
- Tap Done (Figure B.21 ⑧) to save and back to route edit view.

(Map provided by Kashiwanoha Park)

Figure B.21 Linking trigger with map

The components in the view are listed as follows:

① Set map: set the map in the certain side of the trigger. For example, Figure B.21 sets the map 柏の葉公園 as the map inside of the trigger, so when user moves in the trigger, 柏の葉公園 will be selected as the main map.

② Cancel map: cancel the map linked to the certain side of the trigger. If a certain side of a trigger is not linked with a map, the main map will not switch when it is triggered.

③ Set Scale: set the initial scale when the map is automatically selected as main map.

④ Cancel Scale: cancel the initial scale. Without explicit initial scale setting, new main map will be set to the same scale as that of the previous main map.

⑤ Scale status

⑥ Trigger side switch

⑦ Cancel edit and back to route edit view

⑧ Save edit and back to route edit view

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Publications

Published Papers

1. Ruochen Si and Masatoshi Arikawa (2016) Portable Map Signboard Collages on Smartphones Using Polyline Georeferences. The Cartographic Journal, 53 (1): 55 – 65.

Oral Presentations

1. Ruochen Si, Masatoshi Arikawa, Lu Min, Shimon Sugiura and Kazuhiko Nakamura (2015) Collecting, Sharing and Analyzing Map Signboards on Mobile and Web Mapping Services. 日本地図学会 2015 年定期大会. Tokyo, Japan, August 5 – 8.

2. Ruochen Si and Masatoshi Arikawa (2015) A FRAMEWORK OF COGNITIVE INDOOR NAVIGATION BASED ON CHARACTERISTICS OF INDOOR SPATIAL ENVIRONMENT. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-4/W5, 2015, Indoor-Outdoor Seamless Modelling, Mapping and Navigation. Tokyo, Japan, May 21–22.

3. Ruochen Si and Masatoshi Arikawa (2015) A Proposal for Evaluating and Designing Map Signboards through Physical and Spatial Features for City Communication. The International Symposium on Cartography in Internet and Ubiquitous Environments 2015. Tokyo, Japan, March 17 – 19.

4. Ruochen Si, Masatoshi Arikawa and Min Lu (2014) A Framework for Navigating with Map Signboards on Smartphones Using Basic and Advanced Image Geocoding Methods. 11th Symposium on Location-Based Services. Vienna, Austria. November 26 – 28.

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1. Ruochen Si and Masatoshi Arikawa (2016) Fast Prototype of Map Collaging on Smartphones. Japan Geoscience Union Meeting. Makuhari, Japan, May 22 – 26.

2. Ruochen Si and Masatoshi Arikawa (2015) Cognitive Features of Map Signboards for City Communications. Japan Geoscience Union Meeting. Makuhari, Japan, May 24 – 28.