博士論文（要約）
Doctoral Dissertation (Abridged)

Force Markers:
Embossed Fiducials for Recognizing Physical Objects on Pressure-sensitive Touch Surfaces

(Force Markers: 感圧式タッチセンサ面上に配した実物体認識のための凹凸基準マーカ**)**

韓　燦教

Changyo Han

Graduate School of Information Science and Technology

The University of Tokyo

Supervisor: Prof. Takeshi Naemura

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論文の内容の要旨

Title of Dissertation

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Name of Author

韓　燦教 (Changyo Han)

For modern personal computing devices, regardless of the size of the platform (from smartphones to interactive tabletop systems), multi-touch input has become the most popular input method: It provides much benefit since it accepts intuitive multi-touch gestures such as pinch, drag, or rotate. However, since the most touch input devices have flat and rigid surface, they lack of *graspable* experience that we are used to bring off in our daily lives. While tangible user interfaces, which have linkage between physical objects and digital information, can take place on interactive surfaces including multi-touch sensors to cope with such limitations.

In this dissertation, I discuss how interaction capabilities of the touch surfaces can be extended by placing recognizable physical objects on them. I especially focus on utilizing pressure-sensitive touch surfaces to integrate force-based interactions, which provides broader input modalities and interaction possibilities. To achieve such a system, I introduce several fiducial marker designs for the system to be aware of different objects on the surface. The major challenge of designing fiducial patterns for pressure imaging systems is that they have different physical characteristics compared to fiducials in camera-based systems. Throughout this thesis, I address and organize such problems, and propose several approaches to design fiducial markers for pressure-sensitive surfaces. The geometry of fiducials is distinguished by the objective of the applications, resulting in distinct marker designs.

The highlights of this thesis can be described as follows:

- I introduce a novel inventory management system, *BumpMarker*, which can identify the item, track the position, and monitor the weight change simultaneously by putting the items on pressure-sensitive shelves (Chapter 3).
- I demonstrate *ForceStamps*, a rapid prototyping platform for physical control interfaces, which uses 3D-printed circular fiducials. Users can make customized physical controls with combining various compliant materials with the markers, and arrange them on the touch surfaces to create a layout instantly (Chapter 4).
- Building upon ForceStamps, I further propose a modular tangible user interface, *PneuModule*, which forwards user input on tangible objects via pneumatic air pipes and inflatable pin arrays. The air pipes are spatially encoded inside the tangible object, allowing the surface to recognize the connection state of the extension modules, to accept continuous deformable inputs. (Chapter 5).

I also discuss the contribution of my dissertation from the view of tangible interaction, and I conclude with envisioning how force-based tangible interaction on touch surface can benefit user experience in broader domains.