TouchPair : Dynamic Analog-Digital Object Pairing for Tangible Interaction using 3D Point Cloud Data

Unseok Lee and Jiro Tanaka
Department of Computer Science
University of Tsukuba
Tsukuba, Ibaraki, Japan
{leeunseok, jiro}@iplab.cs.tsukuba.ac.jp

***Abstract*— Sensor-based pairing technology between digital objects for interactions are used widely (e.g., smart phone to Bluetooth headset). In addition, research about interactions between daily normal analog objects (e.g., a doll, Lego block) and digital objects has progressed and is also popular. However, such research can only involve interactions with pre-setup objects. The paired objects cannot be changed dynamically. In this paper, we propose a new analog-digital object pairing method by intuitive touch interactions using three-dimensional point cloud data. Several touch pairing methods are described in detail and paired objects are changed dynamically using the proposed method. In addition, a simple tangible interaction between two objects is described after pairing. Finally, we demonstrate the high recognition rate of the proposed method using experiments and describe our system's contribution.**

Keywords-dynamic pairing; point cloud; tangible interaction; 3d gesture;human computer interaction

I. INTRODUCTION

In everyday life, the touching action is natural and common. We touch objects to use them (e.g., a doll or toy to play, open a bottle cap for drinking). Touch interactions with digital devices have also become natural in recent years, because smart devices with touch screens and touch pads are now used widely.

Figure 1. Analog-Digital objects in everyday life

Simultaneously, in the field of human–computer interaction (HCI), research on interactions between physical objects and digital devices has progressed rapidly. A physical object is set as an input unit and the digital device is controlled by it. Such interactions are used widely and have become a 'natural' method. However, to use a physical object as an input unit, much effort and time is initially needed to set up sensors. Moreover, it takes time and effort to apply sensors again when changing the physical object as the input unit. In addition, the digital object is limited to a particular physical object. Thus, there is no 'natural' interaction between various objects. Regarding the input unit, research on methods for making a tangible object for which touch sensing is possible has progressed. For example, in the bowl project [2] , a simple media player in a bowl sits on a living room table and a range of physical objects can be placed within it. When an object is placed in the bowl, related media are played on the TV. The project used radio-frequency identification (RFID) sensors for tangible interactions. However, the system could not provide dynamic pairing between objects. The interactions and possible objects were also limited.

The "HandSense" [3] prototype used capacitive sensors for detecting when it was touched or held against a body part. It could determine whether a device was held in the left or right hand by measuring the capacitance on each side. Raphael [4] presented a method for prototyping grasp-sensitive surfaces using optical fibers. However, all of these examples require attaching sensors to the devices. This is unnatural in the real world. Also, the paired object cannot be changed dynamically.

In this paper, we propose a new method for dynamic pairing with tangible interactions between analog objects and digital objects in practical circumstances. This dynamic pairing is achieved through touch interactions. For example, one hand grasps a doll, an analog object. Then, the other hand grasps a smart phone, a digital object. The doll and smart phone are paired and prepared for tangible interactions. The system makes it possible to pair the doll with touch in three dimensions. The smart phone then shows feedback from interactions with the doll. We can change the paired objects dynamically. Figure 1 shows examples of pairing analog and digital objects in everyday life. Our pairing technique is based on three-dimensional(3D) point cloud data using two Kinect units. They capture and calibrate 3D point cloud data. Our system determines touch pairing and tangible interactions of the paired analog object, based on these calibrated data. In this way, the system can readily recognize what objects are touched and trace what objects are paired. In addition, we can recognize the touched position and movements of the objects. We present the results of tests of recognition rate for pairing using the proposed method.

The rest of this paper is organized as follows. Section 2 introduces related work on depth-based touch sensing and tangible interactions. We describe in detail the principles of the pairing method, the system specifications, and tangible interactions in section 3. We present details on the high recognition rate of our system in section 4. Finally, we describe our contribution and future work in section 5.

II. RELATED WORK

A. Depth-based Touch Sensing Technologies

In recent years, depth-based cameras and related technology have developed rapidly. Research on obtaining 3D data on objects using depth information has also progressed. The framework for 3D sensing using depth cameras has been improved markedly [5].

Florian et al. implemented tangible interactions using a depth camera and a 3D sensing framework [1]. They implemented touch detection and object interaction, supporting multi-touch and tangible interactions with arbitrary objects. They used images from a depth camera to determine whether a user's finger touched the object. However, they were unable to support 3D touching and dynamic pairing between objects for tangible interactions.

Andrew et al. used depth-sensing cameras to detect touch on a tabletop [7], using the camera to compare the current input depth image against a model of the touch surface. The interactive surface need not be instrumented in advance for the interaction and this approach allows touch sensing on non-flat surfaces. However, they only supported simple touch recognition and could not address touch in any direction with 3D objects.

B. Tangible Interactions with Analog Objects

"Digital Desktop" by Wellner et al. [8] was used in an early attempt to merge the physical and digital worlds. They implemented a digital working space on a physical desktop where physical paper served as an electronic document. The interaction with papers was by means of bare fingers. "Icon Sticker" [9], based on this idea, is similar. Icon Sticker is a paper representation of digital content. It consists of transferring icons from the computer screen to paper, so they can be handled in the real world and used to access digital content directly. An icon is first converted into a corresponding barcode, which is printed on a sticker. Then the sticker can be attached to a physical object. To access the icon, the user scans the barcode on the sticker with a barcode scanner. "Web Sticker" [10] uses barcodes to represent online information. It is similar to Icon Sticker, but instead of icons it manages Web bookmarks. They use a handheld device with a barcode-reading function to capture the input and display related information.

There were also attempts to improve tagging of physical objects for a more natural tangible interaction. Nishi et al. [11] registered real objects on a user's desktop based on a user indicating a region on the desk by making a snapshot gesture with four fingers. A color histogram was used to model the object and a pointing gesture was used to trigger the recognition. "Enhance Table" also uses a color histogram to model objects. However, the size is predefined and the system is limited to mobile phone recognition.

Although many previous tangible interaction studies have used physical objects for interactions, most of them are token-based approaches and provide only limited use of real objects. They do not support 3D object tracking or pairing for tangible interactions. Thus, to overcome this, we propose a robust 3D object-tracking method that detects touch in three dimensions. The system supports dynamic pairing between analog and digital objects, and makes analog objects accessible to touch anywhere.

III. TOUCHPAIR

A. Hardware and Software

Our system consists of two Microsoft Kinect sensors for Xbox 360 with stands. Two computers (Intel i7 2.4 Hz, 8 Gb RAM, and GeForce GTX 660M graphics card) are used to handle the 3D data. A desk and the pairing object for interaction are installed. The analog and digital objects are placed anywhere. The Kinect sensors are set at 80 cm from the desk. The computers are connected to each Kinect sensor, and the digital objects have wireless internet or Bluetooth connections with the computer, installed in the bottom of the desk (Fig. 2).

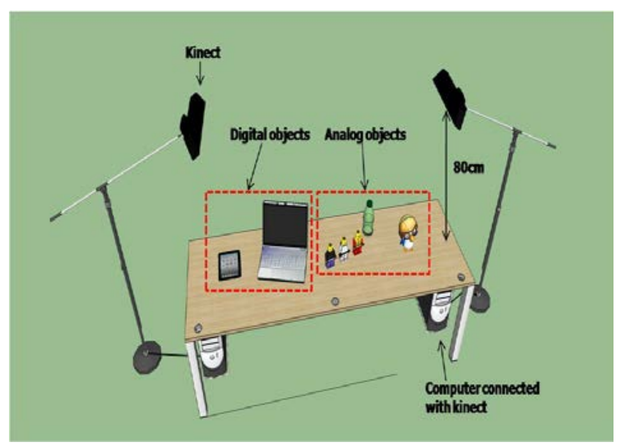

Figure 2. TouchPair System Configuration

Our system uses OpenFrameworks OpenNI [6] for the Kinect sensors and a point cloud method that provides example add-ons of frameworks. The system obtains 3D point cloud data and maps the RGB data to the point cloud. The movement of the points is based on pairing recognition. The proposed system was implemented on a Microsoft Windows 7 platform. The pairing recognition module was implemented in Visual Studio 2010 and OpenNI 1.5.4.

B. TouchPair Architecture

The entire system consists of three major modules(Fig. 3). The input data are obtained by the two Kinect sensors, on the left and right sides. The data are sent for processing. The process is detailed below.

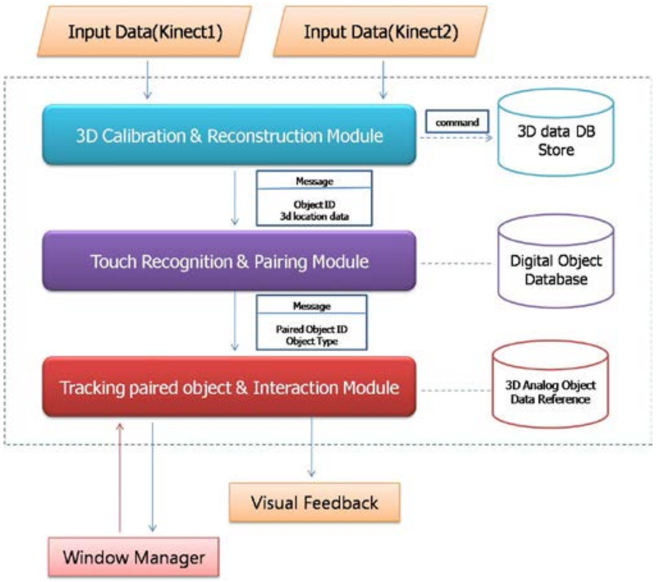

Figure 3. Diagram of TouchPair System Architecture

1) 3D calibration and reconstruction module: In this module, we calibrate depth data for each object, obtained from the two Kinect sensors. The system makes a 3D reconstruction using a point cloud library with calibrated data. The module commands store calibrated and reconstructed data in a database, which is then used by the touch-recognition module. After storage, the module sends messages to the touch-recognition and pairing module about object ID and object location using the 3D point cloud data.

2) Touch-recognition and pairing module: Touch is recognized in terms of the depth and position of the object and hands using 3D tracking. Using the previous depth information from the 3D reconstruction based on the point cloud, the system determines whether the hand touched the object, and if so, the position of the object. The system recognizes the time of touching between the user's 3D hand point cloud data and the object 3D point cloud data, then determines whether they are paired. A paired analog object's 3D point cloud data are stored and sent to the tracking module with information on the object type. We defined a limited objects database.

3) Module for tracking paired objects and interactions: After pairing, the system tracks the analog object based on saved 3D point cloud data. The paired digital object can be tracked; however, the paired objects do not commonly move. The paired analog object is tangible, based on 3D analog object data, from the 3D calibration and reconstruction module. We can make an interaction with the digital object in this module; the interaction is shown by visual feedback.

C. TouchPair Method using 3D Point Cloud Data

Our proposed method uses 3D point cloud processing of Kinect depth data. A point cloud itself is a set of data points in a coordinate system. We measured a large number of points on the surface of an object using OpenFramework [6].

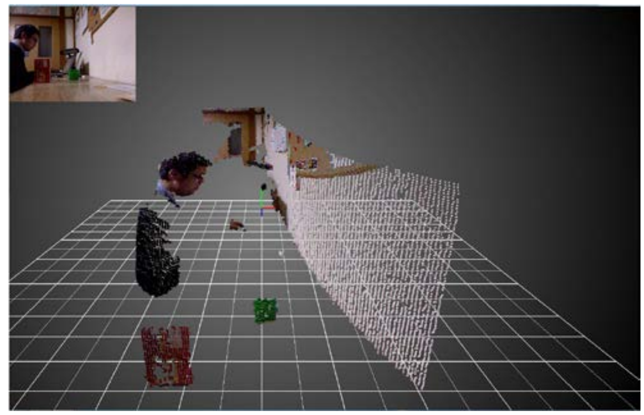

Figure 4. 3D Point Cloud Data

The system obtains RGB data from two Kinect sensors (Fig. 4) and assigns them to the depth area. However, all directions of the object cannot be reconstructed. Thus, we find the most appropriate location for the Kinects and position them so that they cover most of the experimental space.

1) Touch gesutre and recognition: Our touch pair system recognizes the touch actions of users' hands based on depth. The system calculates the depth of each point between a user's hand and the object by filtering closer data. The flow of recognition is as follows:

a) Calculation of all point depths: Calculate all points of the analog and digital objects and the user's hand on the table.

b) Determination of finger position: The system calculates the minimum and maximum depth of the finger by defined thresholds because we hold our fingers in specific ways when we touch something.

c) Determination of hand position: The system calculates the minimum and maximum depths of all fingers and the palm; from the front view, the system uses depth information from both sensors simultaneously.

d) Determination of grasping: Using depth data on users' hands and on objects collected from both sensors simultaneously, we found certain threshold values for recognizing the act of grasping.

2) Analog-digital object pairing: Our system performs time calculations between touched analog-digital objects versus touched object-object pairing. Implementation of object-object touching is shown in Figure 5c,d. When the system recognizes that the user wants to pair, the color is changed. The red color refers to the digital object and the analog object is blue. The recognized hand is shown in yellow using 3D point cloud data. The main steps are as follows.

 ISBN: 978-1-61208-325-4

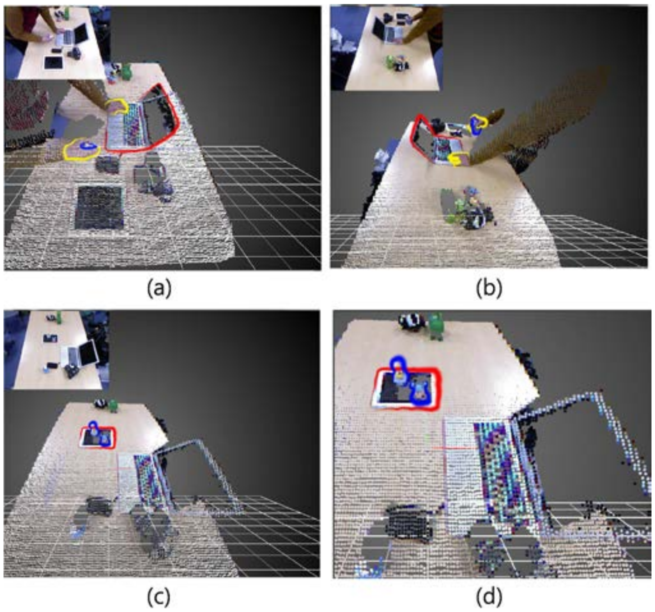

Figure 5. (a) Pairing gesture with hand touching to digital object and grasping analog object from right camera (b) Pairing gesture from left camera (c) Pairing by object-object touching, toy and smart pad are pairing (d) Detailed object-object pairing image

a) Time calculation: For pairing, the user maintains a touching posture for a few seconds after touching is recognized between the objects. The color is changed after the pairing.

b) Tracking a paired set: To track paired objects, the system calculates 3D point cloud data continuously, which are provided by the real-time reconstruction module (Fig. 3). The color of the tracked object is shown.

c) Changing a paired set: To change a paired object set, a pairing gesture is made for some time period. The user touches what he/she wants to pair. After a few seconds, performing the pairing gesture (Fig. 5) will change the pair set as indicated by the color feedback.

D. *Tangible Interactions*

After pairing objects, the system can be used in various tangible interactions. We designed a flight joystick using analog objects. Such a joystick can be used when playing a flight or gun game. Our system made a pairing between a notebook PC and a lotion bottle with a cap as a game controller. The game can be controlled by pushing the lotion bottle's cap (see Fig. 6b) and moving it. The movements can be recognized based on the cloud data for the object and the hand. We also designed a map controller with paired objects (see Figs. 5d and 6c). Our system tracks the two toys and the touched position; the map is moved to provide feedback.

Finally, we implemented a Windows Media Player controller with a paired green cube (see Fig. 6d). The system recognizes rotation of the cube's cap, then changes the volume as feedback. The application changes songs when the lotion bottle cap is pressed.

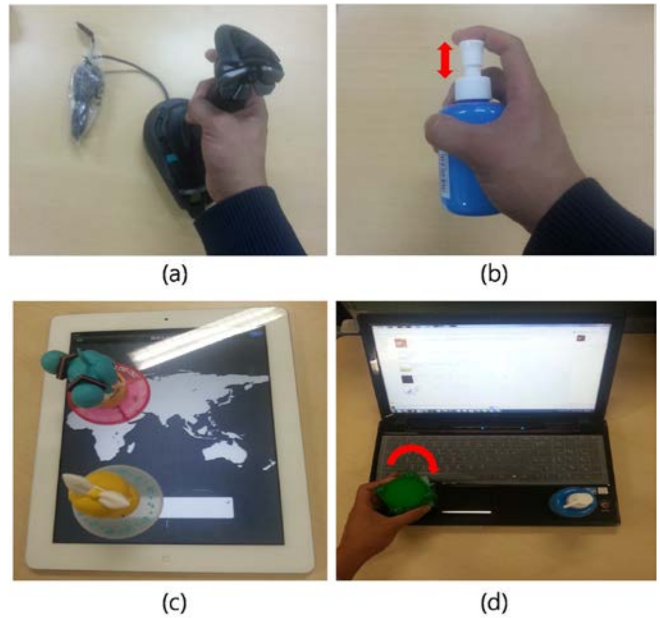

Figure 6. (a) Flight joystic controller (b) Paired analog object controller as flight joystic (c) Control the map by paired two toys (d) Control media player by paired green cube by rotation.

IV. EVALUATION

We evaluated the touch pair system focusing on recognition accuracy. We evaluated touch recognition while changing the analog and digital objects alternately. We also evaluated 3D object recognition and tracking to demonstrate the system's usability and robustness.

A. *Recognition Accuracy Experiment*

Four analog objects and three digital objects were used. We evaluated finger touching, hand touching, grasping, and object-object touching for each object. The experiments were performed on computers (Intel Core i7 CPU, 2.5 GHz, and 8.0 Gb RAM) using two Microsoft Kinect sensors for Xbox.

We performed the experiments with 10 volunteers. We explained each touch pairing method sufficiently. Then a volunteer performed four touching gestures to each object 100 times. We defined 3 s as the period for completing pairing via touching. When the system recognized a pairing, it showed color feedback. Touch recognition success alone was not counted. The participants were allowed to touch analog objects only with the finger and digital objects only with the hand. Table 1 shows the average pairing recognition success for the 10 volunteers.

Our proposed system showed >90% pairing recognition with the objects provided. We found that the average finger-based pairing recognition rate was higher than hand-based pairing. Finger pairing was recognized best when one or two fingers were used. Hand pairing requires checking whether the palm is touching. Thus, hand-based pairing recognition was less accurate than finger-based pairing. In addition, the success rate for touching a smart phone was lower than that for touching the other objects. This may have been because of the size of the object. Most adult hands are bigger than most smart phones. Thus, it becomes difficult for the system to find the positions of the finger and palm.

TABLE I. FINGER AND HAND TOUCH PAIRING RECOGNITION RESULT

Digital / Analog	Note PC		Smart Pad		Smart Phone	
	finger	*hand*	*finger*	*hand*	*finger*	*hand*
Toy	98.3	95.4	99.1	95.3	95.3	93.2
Black Doll	95.7	93.3	96.2	94	92.2	90.1
Green Cube	98.4	96.7	99.3	95.7	96	94
Pet Bottle	96.7	95.3	97.1	95.4	93	91

percentage of recognition rate(%)

Table 2 shows the results for other pairing methods, such as grasping and object-object pairing recognition. The experiments were performed in the same way as described in Table 1.

TABLE II. GRASPING AND OBJECT-OBJECT TOUCH PAIRING RECOGNITION RESULT

Digital / Analog	Note PC		Smart Pad		Smart Phone	
	grasp	*object*	*grasp*	*object*	*grasp*	*object*
Toy	91.4	94.3	89.1	98.1	87.3	94.2
Black Doll	85.4	95.4	85.1	97	85.2	91.1
Green Cube	91.2	96.2	90.1	96.7	87	96
Pet Bottle	90.1	97.1	90.2	97.4	88	94.3

percentage of recognition rate(%)

Grasping-based pairing recognition accuracy was >85% with the objects provided. This method uses point data from many directions. Generally, the front, side, and back surfaces of an object are touched when holding something with the hand. Thus, grasping has to be determined by analyzing the data from many directions. Thus, on the whole, the recognition rate was low. We also found that the recognition rate differed by object size and hardness. A plastic toy, green cube, and bottle are relatively hard. However, a doll is very soft. When the user touches or grasps a softer object, the system has difficulty determining touch depth. Thus, recognition accuracy was lowest for the doll among all objects provided. However, generally, the recognition rate was high.

B. Real-time 3D Object Tracking Accuracy

We evaluated object tracking after pairing. We moved analog objects during a 10 min experimental period (e.g., left-right, front-back).

Figure 7 shows the recognition accuracy for these tests. We obtained recognition rates of >80% for all objects. Because we used two Kinect sensors for real-time 3D object reconstruction and data comparisons, we obtained low error rates.

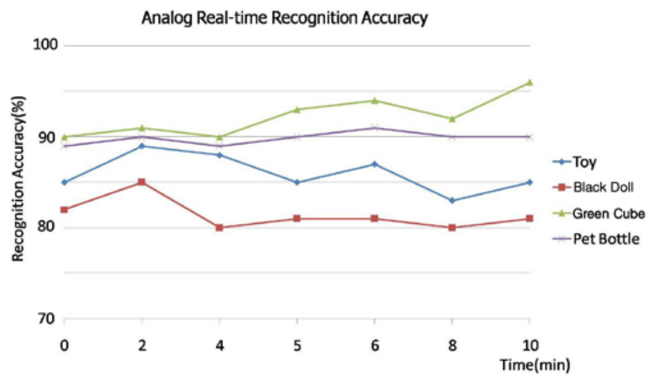

Figure 7. Analog Objects Recognition Accuracy

Figure 8 shows the recognition accuracy for three digital objects over 10 min. Smart phone recognition was <80% in around 4 min and 8 min after tracking. This is because the user was holding the smart phone with his/her hand. In particular, when we moved the smart phone with a front-back motion, the recognition rate decreased.

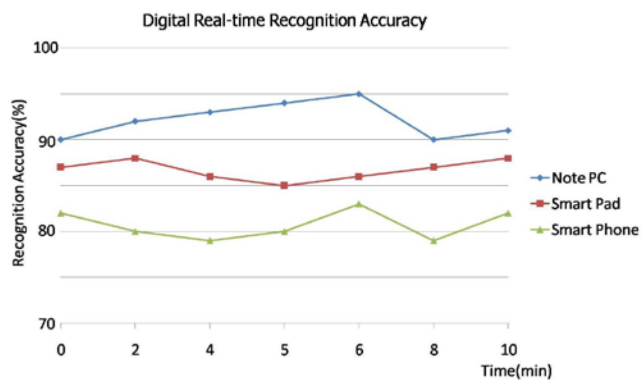

Figure 8. Digital Objects Recognition Accuracy

When the smart phone was near the user's body, the errors likely occurred because the smart phone "disappears" from the camera. However, we can overcome this problem by incorporating 3D data learning (obtained experimentally) into our system.

V. CONCLUSIONS AND FUTURE WORK

Our new dynamic analog-digital pairing method uses 3D point cloud data to assess tangible interactions dynamically. We used dynamic pairing based on finger and hand touching, grasping, and object-object touching. The accuracies were >90% for finger and hand touching and >85% for grasping and object-object touching. Almost the same results were obtained when we changed the locations of pairs dynamically. We obtained good real-time 3D object tracking results as well, despite using objects of different size, shape, and hardness.

The contributions of the present study can be summarized as follows. First, we have provided a new pairing method. Using this method to dynamically pair analog and digital objects, various tangible interactions can be achieved. Second, there is no additional device or sensor, so varied object recognition and pairing are possible. Third, we obtained good recognition rates and tracking results using the proposed method.

In future work, we expect to pair users and digital objects using this system. After pairing a user and a digital device, a digital object can be controlled by the user's gestures and motions. In addition, we expect to develop various tangible interaction applications based on our proposed system. For example, an augmented graphical support interface with a paired object using a projector or head-mounted display could be developed.

REFERENCES

[1] F. Klompmaker, K. Nebe, and A. Fast, "dSensingNI: a framework for advanced tangible interaction using a depth camera," TEI '12 Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction, pp, 217-224.

[2] E. S. Martinusseon, J. Knutsen, and T. Arnall, "Bowl: token-based media for children," DUX '07 Proceedings of the 2007 conference on Designing for User eXperiences, Nov. 2007, Article No. 17.

[3] R. Wimmer and S. Boring, "HandSense: discriminating different ways of grasping and holding a tangible user interace," in TEI '09 Proceedings of the 3rd International Conference on Tangible and Embedded Interaction, pp. 359–362.

[4] R. Wimmer, "FlyEye: Grasp-Sensitive Surfaces Using Optical Fiber," TEI '10 Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction, pp.245–248.

[5] OpenNI 3D sensing framework : Last visited on Nov, 2013. http://www.openni.org.

[6] openFrameworks : Last visited on Aug, 2013. http://www.openframeworks.cc.

[7] A. D. Wilson, "Using a depth camera as a touch sensor," ITS '10 ACM International Conference on Interactive Tabletops and Surfaces, pp 69-72.

[8] P. Wellner, ″The digitaldesk calculator: Tangible manipulation on a desk top display," in 4th annual ACM symposium on User interface software and technology UIST 1991, pp.27-33.

[9] I. Siio and Y. Mima, "Iconstickers: converting computer icons into real paper icon," in 8th International Conference on Human-Computer Interaction: Ergonomics and User Interfaces, pp. 271-275.

[10] P. Ljungstrand, J. Redstrom, and L. E. Holmquist, "Webstickers: using physical tokens to access, manage and share bookmarks to the web," in Designingaugmented reality environments DARE 2000, pp.23-31.

[11] T. Nishi, Y. Sato, and H. Koike, "Interactive object registration and recognition for augmented desk interface," in IFIP conference on human-computer interface Interact 2001, pp.240-246.