2005－UBI－8（59）
2005／6／10

Context based AR Interaction Table using Tangible Objects*

Youngmin Park and Woontack Woo

GIST U-VR Lab.
Gwangju 500-712, S.Korea
+82-(0)62-970-2226
{ypark, wwoo}@gist.ac.kr

ABSTRACT

Augmented Reality (AR) and Tangible User Interface (TUI) have been proven to provide intuition to human computer interface with richness of a tactile sense. Current implementations of the fields, however, have inherited 2D Graphical User Interface (GUI) scheme and worked as isolated systems. Consequently, the systems don't support an intuitive interface and limit fusibility of them. This paper presents an AR-based tangible interaction system for a table-top interaction environment which exploits user context. A projector under the table projects information or scenes onto the table to enhance user's interface. Two cameras on and under the table track tangible objects that are attached with ARToolKit markers and that are used as interaction tools. Furthermore, an augmentation display beside the table shows the real table which is combined with graphical objects. The augmentation is based on user context, and the system shares tracking information of the object as context through vr-UCAM [6]. Moreover, we also present a scheme to enhance the resolution of tracking information based on a tracking prediction using Kalman Filter. For the experiment, we have implemented a virtual world navigation system. The proposed system works as a common interface, therefore is applicable to a wide range of usages such as virtual reality and augmented reality applications.

***Keywords**:* Augmented Reality, Tangible User Interface, Context-aware, Virtual World Navigation

1. INTRODUCTION

Vision-based Augmented Reality extends users' perception of real world by augmenting virtual objects or information that users cannot directly recognize [1]. Tangible User Interface supports an intuitive interaction between human and computer by exploiting daily-life physical objects as a means of an interaction tool [2]. These concepts have the purpose on enhancing users' abilities to complete their work by reducing their attention on the interface itself. Recently, researchers try to combine both concepts to make an intuitive interface which gives humans' rich tactile sensation simultaneously [4].

Ishii et al. proposed Tangible Bits which exploits daily-life objects as an interaction tool to manipulate digital contents [2]. Rekimoto et al. developed an AR system which utilizes markers for tracking objects and a projector for displaying information on the table or wall. The system also supports information sharing among multiple devices [3]. In ARGroove, Poupyrev et al. controlled music by manipulating real records. It augments virtual objects on the records to display the control state [4]. TMCS is TUI system exploiting user context for personalized services and controlling multimedia contents with tangible objects [5].

Unfortunately, previous systems have not been designed to support multiple applications as a common interface system. Therefore, the systems are isolated [2][3][4]. And, without a proper feedback for users' activity except for final services, there is no way to find what is wrong under an interface failure [5]. Direct inheritance of GUI based interface manner has limited an intuition for novice users [3].

ARTable is motivated from the limitations of the previous AR and TUI systems. ARTable aims to support intuitive interaction and to work as a common interface for a variety of applications. Our daily-life physical objects can be intuitive interaction tools in ARTable. Moreover, it augments virtual information on the table and on the objects, which shows status of virtual interface space assumed to exist on the table. ARTable also makes use of vr-UCAM, which enables context sharing between various devices [6]. Therefore, user context is reflected onto the interaction, and object tracking information is shared with environmental devices in the form of context. Moreover, we present a scheme to enhance the resolution of tracking information based on the tracking prediction using Kalman

* This research is supported by Immersive Contents Research Center (ICRC) and GIST

Filter.

The proposed system has following advantages. First, it supports an intuitive interaction by combining Augmented Reality and Tangible User Interface concept. Second, it gives the personalized user interface based on user context. Last, through a resolution enhancing mechanism, object tracking information is shared in a form of context which gives potential to be used as a common interface.

This paper is organized as follows. In Section 2, we introduce system configuration of ARTable and the composition of each component including detail specifications. In Section 3, we present the result of our experiments with the usability test of ARTable applied to a virtual world navigation. Finally, we give a conclusion and remaining works, in Section 4.

2. ARTable

Fig. 1 illustrates software components of ARTable which consists of 4 key components; Calibration, Tracking, Table display, and Augmentation display. The Calibration is only for off-line step for a system setup and calculates transformation between two cameras on and under the table. The Tracking detects ARToolKit markers and calculates those poses into the enhanced resolution based on a prediction. The Table display and the Augmentation display are in charge of providing information to help users' interactions. Each component, except for Calibration, extends vr-Sensor and vr-Service of vr-UCAM. Therefore they share user context and objects tracking information with other devices.

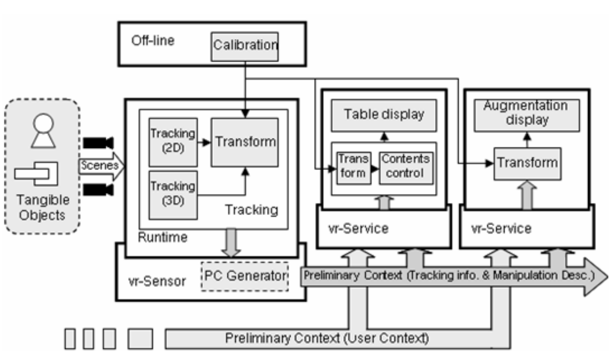


Figure 1 : Software components

Fig. 2 shows the practical system configuration. Under the table are a projector for a table display and a camera for tracking objects. The camera under the table is only used to track object's 2D position and 1D orientation. Under the table, lies a mirror to extend the line of sight of the projector and the camera. Beside the table the augmentation display shows virtual graphical models augmented on the scene of real table captured by the camera above the table. The upper camera is also used to track the 3D position and orientation of physical objects.

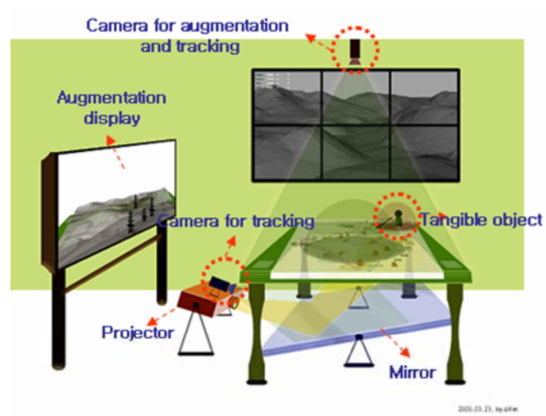


Figure 2 : System configuration

2.1 Calibration

The Calibration defines positional and rotational transformation matrices between two cameras and between each camera and the table. Since the scale of object tracking information is unknown, it is also required to define a normalization matrix to share the tracking information with other devices or applications. All of these processes are conducted during off-line.

The calibration process is as follows. First of all, the calibration needs two double-sided markers that have same but horizontally-flipped patterns on each side. Then, we place one of the markers (marker C_1) to be fit on the left-upper corner of the table surface. Another marker (marker C_2) is to be placed on the right-bottom corner of the table. In this way, the marker C_1 determines the table coordinate system. And, the distance between marker C_1 and C_2 is the table size used for a normalization.

Once the markers are placed on the table and both of them are visible through two cameras, we can calculate transformations between cameras and the table. Through a function of ARToolKit, the two markers are detected and the transformations between cameras and markers are available. T_{AC} is the transform from the upper camera to marker C_1. Likewise, T_{BC} is from the lower camera to marker C_2.

Then, T_{AO}, a transform between the upper camera and a tangible object, is transformed into the table coordinate system by the equation 1.

$$T_{AC}^{-1} T_{AO} = T'_{AO} \quad (1)$$

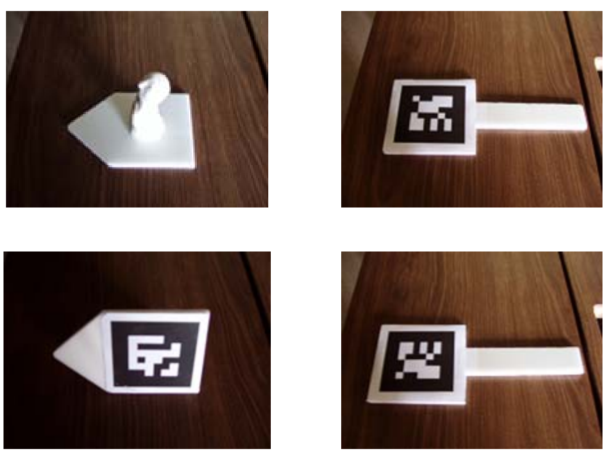
In the same way, the transform from the lower camera to a tangible object T_{BO} is transformed into the table coordinate system. The only difference of T'_{AO} and T'_{BO} is their opposite direction of the z-axis. Because the Z-value of T'_{BO} is not used, they are considered to be same.

$$T_{BC}{}^{-1}T_{BO} = T'_{BO} \tag{2}$$

Consequently, T'_{AO} obtains the position and the orientation of a tangible object in the table coordinate system. Since the table size is calculated from the distance between marker C_1 and marker C_2, the pose value can be normalized.

2.2 Tracking

Tangible objects are attached with ARToolKit markers to be tracked from two cameras; one above the table, the other under the table [8]. Fig. 3 illustrates examples of tangible objects. As shown in Fig. 3(a), a marker is attached on the bottom of a tangible object. In this case, only the lower camera can track the object, which limits the tracking information to be 2D position and 1D rotation. Nevertheless, the marker is not shown to the user and tracking does not fail even when the user occludes the object by hands. Therefore, it is possible to freely design the outer form of tangible objects. In case of 3(b) which attaches two markers on both sides of the object, the tracking is performed in a 3D space. In that case, however, the marker is revealed to the user and it restricts the outer form of objects to be partially planar.



(a) (b)

Figure 3 : Examples of tangible objects – the topside (upper) and the bottom side (lower) (a) an object for 2D tracking having free form (b) an object for 3D tracking

Tracking information of the object is refined to have dense resolution before it is shared with other devices using vr-UCAM. The resolution of tracking information is limited depending on the resolution of the camera. Contrarily, the requirement of applications using the tracking information is not known beforehand. Therefore, when the applications require high density resolution of tracking information, differences of tracking information between each frame amplifies. Finally, it is recognized as an error and it may obstruct a proper service.

Our scheme for increasing the resolution of tracking information is based on an interpolation between current tracking information and the predicted tracking information of next frame. Before a prediction, in order to remove a jittering, the extracted position is thresholded by a fixed value. Thus, if a new position of the marker is not different more than a threshold T from the previous, then it is considered as a jittering. Next step is to predict marker's movement using Kalman Filter [7]. By assuming a uniform acceleration of the markers' movement, the state of Kalman Filter is defines as equation 3.

$$x_t = \begin{bmatrix} \tau_t & \rho_t & \dfrac{d\tau_t}{dt_t} & \dfrac{d\rho_t}{dt_t} & \dfrac{\left(\dfrac{d\tau_t}{dt_t} - \dfrac{d\tau_{t-1}}{dt_{t-1}}\right)}{dt_t} & \dfrac{\left(\dfrac{d\rho_t}{dt_t} - \dfrac{d\rho_{t-1}}{dt_{t-1}}\right)}{dt_t} \end{bmatrix}^T \tag{3}$$

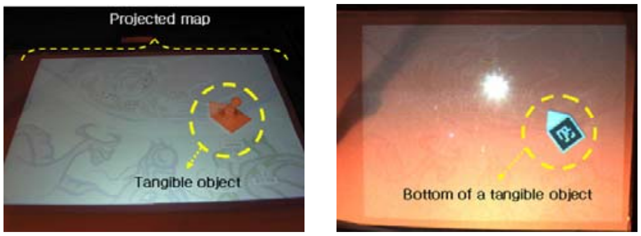
t is the time when the camera captured a scene. τ and ρ are the 3D position and rotation of the object respectively. On each frame, the marker is detected and next position and rotation of the marker is predicted. Until the camera captures the next frame, the detected and predicted values are used to generate N tracking information between them. The two values are linearly interpolated like (4). As an effect, the tracking information is increased N times in its resolution.

$$x_{t+\frac{n}{N}dt} = x_t + (x_{t+dt} - x_t)\frac{n}{N}dt \tag{4}$$

2.3 Table display & Augmentation display

The Table display presents the interface range in which the user can manipulate object and display the state of interaction space. As an example, when ARTable is used for a virtual world navigation, a 2D map of the virtual world is projected onto the table surface through the projector under the table. It helps the user to be aware of the user's position in the whole world. And the display can show dynamic visual effects according to user's object manipulation.

The table surface is so semi-transparent that the lower camera can see through the surface and the projector can display information on the surface simultaneously. Therefore, it is possible to detect markers attached on the bottom of tangible objects. Fig. 4 shows the table surface with a projector screen and a marker captured from the lower camera.

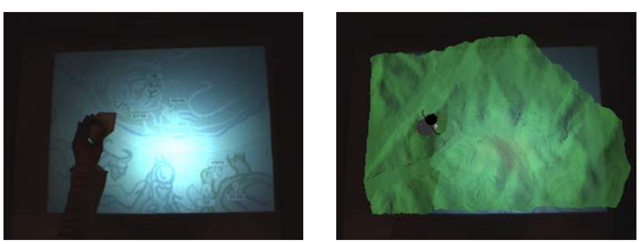


(a) (b)

Figure 4 : Table display (a) table surface on the table (b) the bottom the a tangible object seen through the lower camera

The Augmentation display overlays the whole interaction space which is assumed to exist virtually onto the real table. The upper camera captures the table surface with tangible objects and user's hands. Then, graphical objects are overlaied onto the scene to show what happens in the interaction space. The augmentation enables users to notice the objects' role in an interaction. When we apply ARTable to virtual world navigation, the field of VE is augmented on the table.

A camera pose required for augmentation is acquired in off-line during calibration step. Therefore, we don't use a special marker for an augmentation during runtime. Fig 5(a) shows the original scene of the upper camera and 5(b) shows graphical objects augmented on it.



(a) (b)

Figure 5 : Augmentation display (a) a scene of the upper camera (b) augmented graphical objects on the original scene; a field and a character

3. EXPERIMENTS

We have conducted an experiment to verify the effectiveness of ARTable by integrating with a virtual world navigation. The Augmentation display shows different models depending on user context. The Tracking module which extends the vr-Sensor generates a preliminary context with an object type, object tracking information, object manipulation information. Thus, the context is shared with other devices through vr-UCAM. Figure 6 illustrates the experimental setup; ARTable and a large back-projection screen for a virtual world.

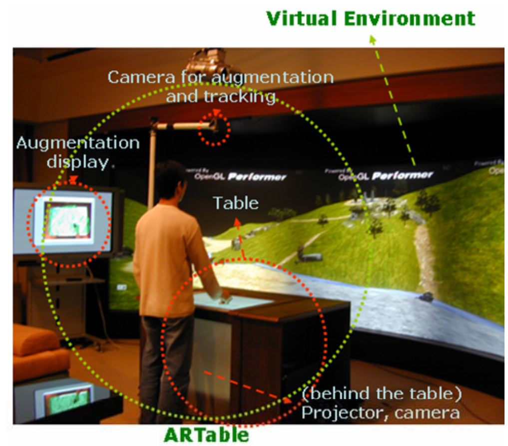


Figure 6 : Implemented system

We carried out a comparison between ARTable and a joystic, which are used for virtual world navigation based on the implemented system. Ten people attended the experiment, and they are only who have seen virtual environment applications but have not been tried it before. In order to evaluate the intuition of out system, we measured the time took for the participants to learn the usage of ARTable and a joystick. Then, the participants are ordered to move to a specific position of virtual world, and it is repeated 5 times. At the last, we asked the participants about overall satisfaction level. Each elements of table 1 show the results.

Table 1 : Comparison of ARTableand Joystick used for VE navigation – mean (standard deviation)

	ARTable	Joystick
Learning	32.4sec (8.8sec)	84.7sec (24.7sec)
Movement	10.4sec (7.1sec)	35sec (18.6sec)
Satisfactio n	76% (19.1%)	54% (11.4%)

Experimental results reveal that all of the participants could use ARTable without a prior knowledge and directions. In case of a joystick, in contrary, they seems to have difficulties in learrning the usage. After understanding how to handle them, the participants are ordered to move to a spefic position in the virtual world. By using ARTable, the participants could find the destination easily from the map projected on Table display. Considering a joystick, even though they knew how to control it, they could not move freely as they wanted. Furthermore, the map on the table surface acted as an indicator which prevents the users from being lost. However, when they are using a joystick, they losted in 12 trials of 50 times experiments, which caused the time exceed over 120 seconds. Hence, we excluded the cases which exceed 120 seconds from the statistics. On the other hand, ARTable has a defect, which couldn't recognize slight movements of objects. Some participants also pointed out that the current version support only 2D movement.

4. CONCLUSION AND FUTURE WORKS

This paper proposed an AR-based tangible interaction system named ARTable for a table-top interaction environment which exploits user context. By using daily-life physical objects as an interaction tool and displaying information helpful for interaction, ARTable provides intuitive interfaces. Furthermore, through vr-UCAM it is possible to exploit user context acquired from environmental devices and to share tracking information of the object. Based on the context sharing, the proposed system expands the fusibility various applications by working as a common user interface system. In our experiment, we verified that users easily perceive how to use the proposed system and that this system offers easy interface. Therefore, the proposed system has a wide range of its application such as virtual environment navigation, digital contents manipulation and an appliance control in a smart home environment. Further research issues include an investigation of a system configuration for a more intuitive interface and an accurate object tracking technique with a stable and robust result. And designing tangible objects for enhancing intuition is one of important issues. In addition, to make use full of the proposed system, various applications should be developed.

REFERENCES

[1] R. Azuma, "A Survey of Augmented Reality", Presence: Teleoperators and Virtual Environments 6, 4, pp.355~385, 1997

[2] H. Ishii, B. Ullmer, "Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms", in Proceedings of ACM CHI '97, pp. 234-241, Mar. 1997

[3] J. Rekimoto and M. Saitoh, "Augmented Surfaces: A Spatially Continuous Work Space for Hybrid Computing Environments", In Proceedings of CHI 1999, ACM Press, pp. 378-385, 1999

[4] I. Poupyrev, "Augmented Groove : Collaborative Jamming in Augmented Reality", ACM SIGGRAPH 2000 Conference Abstracts and Applications, pp. 77, 2000

[5] Sj.Oh and W.Woo, "Manipulating Multimedia Contents with Tangible Media Control System", International Conference on Entertainment Computin, Vol.3166, pp. 57-67, 2004

[6] Y.Lee, Sj.Oh, Y.Suh and W.Woo, "Developing vr-UCAM for Interaction on Distributed Virtual Environments", KHCI2005, pp. 507-512, 2005

[7] G. Welch and G. Bishop, "An introduction to the kalman filter". CS TR 95-041, UNC, 1995

[8] ARToolKit http://www.hitl.washington.edu/research/shared_space/download