TARBoard: Tangible Augmented Reality System for Table-top Game Environment*

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ABSTRACT

In this paper, we propose TARBoard which is a tangible augmented reality system designed for table-top game environment. The objective of TARBoard system is to let users fashion the board or card game in a more interactive and intuitive way. To achieve this goal, TARBoard adopt two features, augmented reality and tangible user interface. Augmented reality makes the game more realistic and interactive and tangible user interface enables users to interact with virtual objects in the game intuitively. TARBoard consists of a glass table, two cameras and a mirror. Markers are attached to the bottom of objects or cards used in a game. A camera is for tracking markers and the other camera is for augmenting virtual objects. The proposed system separates the tracking camera from the augmenting camera. The tracking camera tracks the image of markers reflected in the mirror below the glass table. The augmenting camera provides images where the virtual objects are augmented. As a result, TARBoard avoids occlusion problem in table-top augmented reality environment. In addition, TARBoard allows various types of objects to be used as tangible user interface, instead of cubes or flat panels which are frequently used in tangible augmented reality.

Categories and Subject Descriptors

K.8.0 [**Computing Milieux**]: Personal Computing - *General*

General Terms

Design

Keywords

Augmented reality, Tangible user interface, Table-top game environment.

1. INTRODUCTION

When augmented reality is combined with computer or video games, virtual world is brought out of a computer screen. Augmented reality can provide immersive feeling to users by augmenting virtual objects in real space. With increasing interest in augmented reality, there have been many researches about merging augmented reality with computer entertainment.

In Magicbook, users can interact with virtual objects augmented on markers by using tangible user interface [1]. ARGroove enables users to play music simply by picking and manipulating physical cards on a table without traditional music device [2]. ARQuake is a representative example of augmented reality application which applied augmented reality to the existing game. Users play the game Quake in real environment with a gun and HMD [3]. In AquaGuantlet, a mixed reality game for multiplayers, the players fight with invaders augmented in a room [4]. In Touch-Space, a user can interact with computers, physical objects, and other players in Touch-Space system [5]. AR bowling system combines augmented reality to sport game [6]. A user, wearing see-through HMDs, can interact with virtual objects by hand gestures.

However, previous systems use markers to augment virtual objects on the markers that exist somewhere in real environment. The virtual objects are augmented only when the markers are visible from users' viewpoint. Users can occlude markers by their bodies during interaction. Even when one player does not occlude markers in his or her view, he or she may occlude the others' views. In this case, users cannot see and interact with the virtual objects. Therefore, it is not desirable to attach markers for augmenting virtual objects in a board or card game, since users handle the objects or cards frequently during the game. In addition, the cards or board contain information, such as rules of the game, or figures used in the game. If we attach markers to augment virtual objects in the game environment, the markers hide necessary information. Thus, the markers disrupt the flow of games and users may feel inconvenience. For the more, the weakness of the conventional board or card games is that users need to visualize the situation in their mind during the game. Users read the instructions and characteristics of cards written on a card and play games with other users according to the rules. Thus, there is no additional feedback that makes the game more interesting and fascinating. Figure 1 shows the conventional card game environment.

Figure 1. Conventional card game environment

In this paper, we proposed TARBoard which is a tangible augmented reality system designed for table-top game environment. The objective of TARBoard is to let users enjoy games in a more interactive and intuitive way and to make games more realistic and immersive. To achieve these goals, TARBoard adopts two features and merges them with conventional card or board game environment. The first feature is augmented reality which pulls out digital contents to real world. Augmenting multimedia contents in an environment makes users feel that they are in the game. Thus, augmented reality supplements the lack of feedback in conventional card or board game environment. The other feature is tangible user interface. Tangible user interface allows users to interact with virtual objects and to play games without a keyboard and a mouse. The cards or objects of a game are used as tangible user interface in TARBoard.

TARBoard consists of a table made of glass, two cameras and a mirror. One camera is for tracking markers and the other is for virtual object augmentation. Markers are attached to bottom of objects or cards used in a game. The camera installed below the table tracks the markers of the objects on the table through glass. To enlarge the area viewed by tracking camera, we use a mirror. Thus, tracking camera sees the scene reflected in the mirror. The other camera provides images for virtual object augmentation. Users see the virtual objects augmented on the video stream from the camera. By calibrating both cameras, we augment virtual objects on the board or cards in table-top game environment. In TARBoard, users do not need to worry about occluding markers, since markers are hidden from users' views. Another advantage of our approach is that various types of tangible objects can be used as tangible user interface besides cubes or flat panels which are used frequently in tangible augmented reality applications. The concept of TARBoard system is shown in Figure 2.
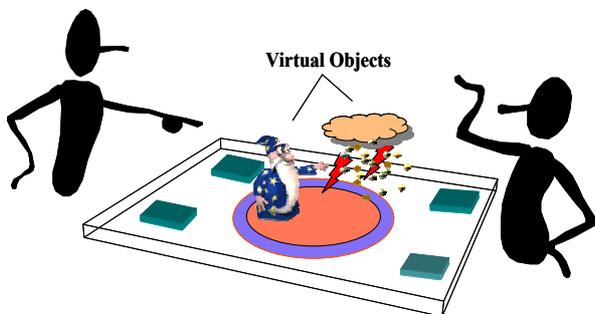

Figure 2. TARBoard system

This paper is organized as follows. In chapter 2, we explain the TARBoard system. We show our prototype implementation and experimental results in chapter 3 and provide conclusions in chapter 4.

2. TARBoard SYSTEM

2.1 Working Principle

TARBoard system has two processes, off-line and on-line process. In off-line process, the relative transformation between the tracking and augmenting camera is calculated. In on-line process, the tracking camera tracks the image of markers reflected in the mirror below the glass table. The position and orientation of the markers, seen from the tracking camera, are obtained. Then, the relative transformation which is pre-calculated in off-line process is applied to the position and orientation of the markers on the table. As a result, we obtain the position and orientation of the markers seen from the augmenting camera. By using this transformation, we augment virtual object on the video stream captured from the augmenting camera.
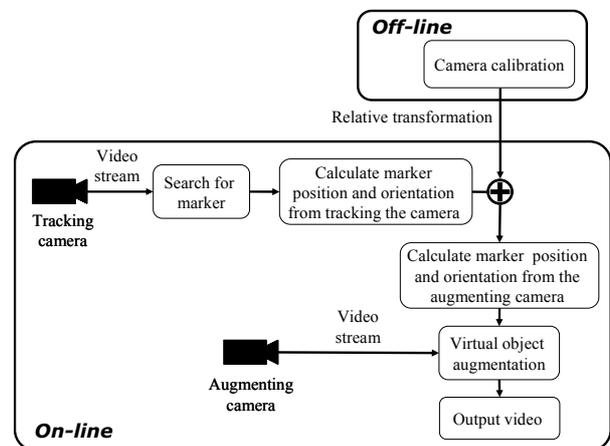

Figure 3. Work flow of TARBoard

2.2 Tracking Markers on Glass Table

In TARBoard, the camera tracking markers and the camera providing images on which virtual objects are augmented are separated. The tracking camera is installed below the glass table and tracks the markers on the table seen through the glass table. Markers are attached to the back side of cards and the bottom of objects used in a game. When objects or cards are placed on a table, the markers are hidden from users' views.

The region, covered by tracking camera, depends on the field of view of the tracking camera and the distance between the tracking camera and the glass table. If the tracking camera sees the table directly, the region is not large enough to play a game. If the field of view of the tracking camera is fixed, increasing the height of the table is one possible solution to enlarge the playable space. However, too high a table is not suitable for playing games and it makes users feel inconvenience. If the tracking camera has too wide field of view, the images obtained from it are distorted and markers are not tracked well. To cover the entire area of the table and to keep the height of the glass table reasonable, we place a mirror below the table to enlarge the game's playable space.

Tracking camera captures the image of the scene reflected in the mirror. Figure 4 shows the camera configuration of TARBoard.
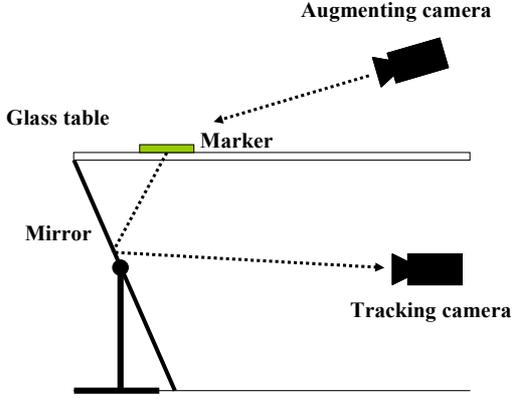

Figure 4. Tracking camera configuration

Figure 5 shows the geometrical analysis of the board game configuration. We put the origin of world coordinate system O below the mirror. In this configuration, the width of the area tracking camera can cover is calculated as follows.
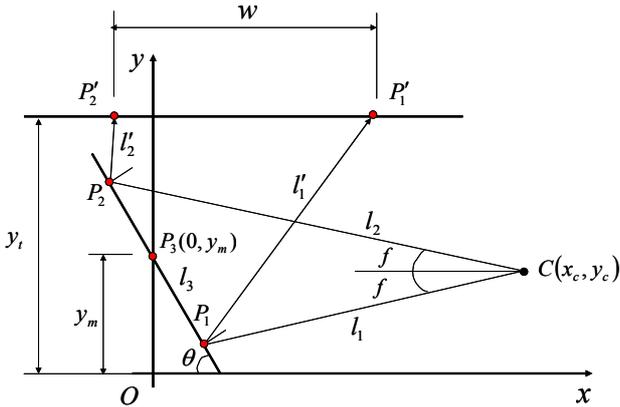

Figure 5. Geometrical analysis of tracking camera configuration

Let the camera center and the field of view of the tracking camera be $C(x_c, y_c)$ and $2f$, respectively. The mirror is tilted by angle θ with respect to x axis. We calculate the equations of the lines, l_1, l_2, and l_3, as shown in equation (1)

$$
\begin{aligned}
l_1: \quad & y = (x - x_c)\tan f + y_c \\
l_2: \quad & y = (x - x_c)\tan(\pi - f) + y_c \\
l_3: \quad & y = x\tan(\pi - \theta) + y_m
\end{aligned}
\tag{1}
$$

Then, $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ are obtained by calculating intersections of l_1, l_2 and l_3 in equation (2) and (3).

$$
\begin{aligned}
x_1 &= \frac{y_m - y_c + x_c \tan f}{\tan f + \tan \theta} \\
y_1 &= \frac{y_m - y_c + x_c \tan f}{\tan f + \tan \theta}\tan \theta + y_m
\end{aligned}
\tag{2}
$$

$$
\begin{aligned}
x_2 &= \frac{y_m - y_c - x_c \tan f}{\tan \theta - \tan f} \\
y_2 &= \frac{y_m - y_c - x_c \tan f}{\tan f - \tan \theta}\tan \theta + y_m
\end{aligned}
\tag{3}
$$

l'_1 and l'_2 are calculated using P_1 and P_2. From l'_1, l'_2 and $y = y_t$, we obtain the coordinates of $P'_1(x'_1, y'_1)$ and $P'_2(x'_2, y'_2)$. By calculating the intersections of $y = y_t$, l'_1 and l'_2. Equation (4) and (5) shows the line equations and obtained intersections.

$$
\begin{aligned}
l'_1: \quad & y = (x - x_1)\tan(\pi - 2\theta - f) + y_1 \\
l'_2: \quad & y = (x - x_2)\tan(\pi - 2\theta + f) + y_2
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
x'_1 &= \frac{1}{\tan(\pi - 2\theta - f)}(y_t - y_1) + x_1 \\
x'_2 &= \frac{1}{\tan(\pi - 2\theta + f)}(y_t - y_2) + x_2 \\
y'_1 &= y'_2 = y_t
\end{aligned}
\tag{5}
$$

The width of the area tracking camera can cover is expressed as the distance between P'_1 and P'_2, as shown in equation (6)

$$
w = \|P'_1 - P'_2\|
\tag{6}
$$

2.3 Virtual Object Augmentation

Augmenting camera provides the video stream where the virtual objects are augmented. Since the markers are tracked by the tracking camera below the table, we need to know the relative pose between two cameras to augment virtual objects on the augmenting camera's view. Figure 6 depicts camera calibration process. First, we measure the relative transformation between two cameras in an off-line. Then, we use the measured relative transformation matrix to calculate transformation matrix of the augmenting camera in run-time.
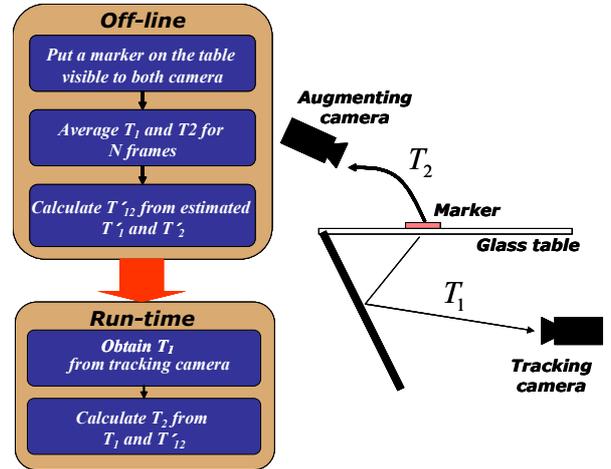

Figure 6. Camera calibration process

In the off-line process, we put a marker such that it is visible to both tracking and augmenting cameras. Then, we measure the transformations, T_1 and T_2, from world coordinates to the camera coordinates over N frames. Then, we obtain average of each transformation, T'_1 and T'_2 using the equation (7).

$$T_1' = \frac{1}{N}\sum_{i=1}^{N} T_{1i} \qquad T_2' = \frac{1}{N}\sum_{i=1}^{N} T_{2i} \tag{7}$$

where, T_{1i} and T_{2i} are transformations of the tracking and augmenting camera, respectively, in i^{th} frame.

As shown in equation (8), T_2 can be decomposed into the combination of T_1 and T_{12}.

$$T_2 = T_{12}T_1 \tag{8}$$

The relative transformation between the two cameras is calculated by using the equation (9).

$$T_{12}' = T_2'T_1'^{-1} \tag{9}$$

In run-time, we obtain T_1 from the tracking camera and calculate T_2 is calculated from equation (10).

$$T_2 = T_{12}'T_1 \tag{10}$$

Using T_2 calculated in equation (10), we augment virtual objects on the scene viewed by augmenting camera.

3. EXPERIMENTAL RESULT

3.1 Implementation

We implemented the prototype of TARBoard with following hardware and software. TARBoard is running on Xeon 3.0GHz CPU equipped with 2GB RAM and Quadro FX 3400 video adapter. We use two cameras which have IEEE1394 interface for tracking and augmentation. Both cameras captures images in 30 frames/sec and the size of an image is 320×240. The glass table has dimensions of 140cm×65cm×94cm (width×length×height). The distance between the tracking camera and the mirror is 120cm and the angle the mirror is tilted by is 55°. The mirror reflects entire area of the table. As software, we use OpenGL to render virtual objects, OpenCV [8] to process images from two cameras, and ARToolkit [7] to track markers and to obtain transformation matrix. Figure 7 shows the prototype implementation of TARBoard.

Figure 7. Prototype implementation of TARBoard

3.2 Game Play

We implemented a card battle game in current prototype of TARBoard. We assume that there are two players with their own cards. Each card represents a creature such as a dragon, a wolf, or a goblin. A creature has its own characteristics, such as health, power, and special skills etc. When two creatures fight, they attack each other in turn. Only one chance is given in a turn. The creature which runs out of health loses and is eliminated. The card of the lost creature is removed from the deck.

There is a figure of a creature on a card and a marker on the back side. The marker is tracked by the tracking camera and 3D model of a creature is augmented when the card is flipped. There are two types of areas on the glass table. One is called deck where users put their all cards upside down. A player cannot see the card processed by the other player. The other area is battle zone where the creatures fight. Figure 8 depicts the two areas.
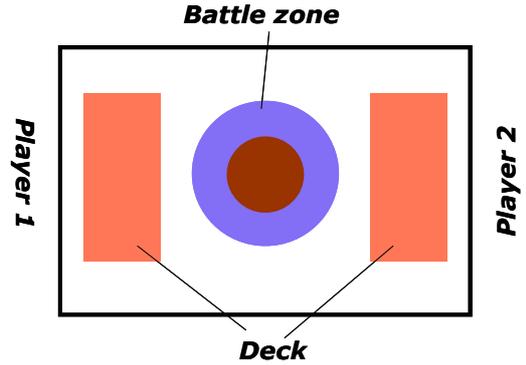

Figure 8. Game play environment

At first, an attacker turns over one of his cards and places it near the battle zone. The creature of the card is augmented on the battle zone. Then, the defender turns over one of his cards and places it near the battle zone to defeat the attacker's creature. Each user can attack only one time in a turn. The player loses the game if no more cards remain on his deck. Figure 9 shows the augmented creatures on the battle zone.

Figure 9. Creatures augmented on the battle zone

4. CONCLUSION AND FUTURE WORKS

In this paper, we propose TARBoard which is a tangible augmented reality system designed for table-top game environment. In TARBoard, virtual objects are augmented on the table and make the game more realistic and interactive. TARBoard adopt tangible user interface to enable users to interact with virtual objects in the game. For the convenience of game

players, the proposed system hides markers from users' views by separating the tracking camera and the augmenting camera. The markers are attached to the bottom of the objects or cards and tracked by the tracking camera installed below the table. Thus, we avoid occlusion problem in table-top augmented reality environment. It also allows various types of objects to be used as tangible user interface besides cubes or flat panels. There still remains several works to improve the current system. Firstly, there is no audio feedback in our current implementation. Since audio feedback can enhance realism of the game effectively, the 3D audio feedback will be implemented in a later version. Secondly, current system provides only one augmented view because the augmenting camera is fixed. To enable users to see virtual objects augmented in the environment anywhere, we are going to combine a tracker with the augmenting camera.

5. REFERENCES

[1] Billinghurst, M., Kato, H. and Poupyrev, I., "The MagicBook - Moving Seamlessly between Reality and Virtuality", Computer Graphics and Applications, 21(3), 2-4, 2001.

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

[3] Thomas, B., Close, B., Donoghue, J., Squires, J., De Bondi, P., Morris, M., and Piekarski, W., "ARQuake: An Outdoor/Indoor Augmented Reality First Person Application", 4th International Symposium on Wearable Computers, pp 139-146, 2000.

[4] H. Tamura, H. Yamamoto and A. Katayama, "Mixed reality: Future dreams seen at the border between real and virtual worlds", Computer Graphics and Applications, vol.21, no.6, pp.64-70. 2001.

[5] A. D. Cheok, X. Yang, Z. Ying, M. Billinghurst, H. Kato, "Touch-Space: Mixed Reality Game Space Based on Ubiquitous, Tangible, and Social Computing", Journal of Personal and Ubiquitous Computing, Volume 6, pp 430-442, 2002.

[6] Carsten Matysczok, Rafael Radkowski and Jan Berssenbruegge, "AR-Bowling: Immersive and Realistic Game Play in Real Environments Using Augmented Reality", ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, Singapore, 2004.

[7] ARToolkit. http://www.hitl.washington.edu/artoolkit/

[8] Open Computer Vision Library. http://www.intel.com/research/mrl/research/opencv/