Aero-Marker: Blimp-based Augmented Reality Marker

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Abstract
We describe an augmented reality (AR) marker that has both a virtual appearance and physical features. We integrate a blimp with an AR marker to overcome two problems found in conventional AR applications. One problem is mobility. While a conventional AR marker is generally paper-based and static, "Aero-Marker" floats in the air and moves toward the user. Thus, the relationship between the user and marker changes. The other problem is physicality. Unlike a paper-based marker, Aero-Marker has physical volume because it uses a physical blimp. Virtual information is overlaid on the entire surface of the blimp, like texture mapping in 3D computer graphics, making the virtual information tangible. Thus, the interaction between the user and marker changes.

Keywords
Augmented Reality, Marker-based AR, Aerotop, Blimp, Tangible User Interface, and Floating Interface

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces.

General Terms
Design, Human Factors

Introduction
To integrate the real and virtual worlds, 2D augmented reality (AR) markers have been developed. AR systems

recognize marker information (e.g., 3D position and unique ID) through a video camera and then overlays virtual information on the marker. Thus, users can see virtual information in the real world through the marker. Since AR markers are generally paper-based, the printed 2D code is simple to use. Using 2D codes is a suitable approach to producing AR applications for consumers because it is easy to generate and use the marker. Thus, it is useful for not only research projects but also products and consumer services like iPhone and Android applications. We easily predict that marker-based AR will continue to be developed in the future. However, conventional AR applications simply overlay virtual reality (VR) information on a marker in the real world. Its application thus has two limitations.

One limitation is that the relationship between the AR marker and user remains virtually the same since the AR marker is static. This means that users have to spot the AR marker, approach it, and capture its image with a camera device to initiate interaction, because the marker is designed to show virtual information in the real world. Also, the virtual information displayed by the marker depends on its position, so the information cannot move to an area where users cannot capture the marker. In case of considering characters in games, comics, and animated cartoons (e.g., humans, creatures, robots, and vehicles), they can move freely in the scene and sometimes fly in the air. In contrast, the movement of characters on an AR marker is inhibited for a simple reason. If users mainly capture and follow a character instead of the marker, the character disappears when the marker is out of camera range. There is a huge gap between AR and animated characters from the viewpoint of motion. Thus, in conventional marker-based AR applications, both the marker and virtual information are quite limited.

The other limitation is the reality of the virtual information since the AR marker does not have volume. The AR marker is basically flat, so the virtual information has no physical volume even if the information has 3D appearance. Users cannot touch the character directly, so they receive no feedback from the virtual object. For example, if a user feels familiar with a virtual character and tries to touch it, his or her fingers pass right through the character. Although the conventional approach can be used to easily represent flat and/or static information (e.g., pictures and text information), users cannot interact with 3D virtual information directly such as touching and throwing it. Although some markers have physical attributes, they are limited to expressing the volume of VR information. As a result, there is a huge gap between AR marker and virtual information. If an AR application provided physical feedback from virtual objects, it would make the connection between virtual and real more interesting and fun.

Therefore, we developed Aero-Marker for virtual and tangible AR applications. To overcome the limited mobility of an AR marker, we use a blimp to implement unique AR marker. The blimp enables the marker to move freely and fly in the air, so the relationship between user and marker is changed. For example, marker can approach users to initiate interaction, fly away from them, and chase them. To overcome the limitation of reality, we focused on a method for overlaying virtual information. Since the blimp size and shape can be freely designed, a wide variety of virtual character can be overlaid on the entire surface of the blimp like texture mapping in 3D computer graphics. A unique object that has a virtual appearance and physical features can be created, so the interaction between the marker and users is changed. For example, the blimp physically exists, so users can touch the blimp, throw, and hug the virtual object directly with feeling the volume.

For users of our system, capturing virtual object means capturing AR marker, and touching virtual object means touching AR marker. Thus, our approach based on mobility and physical features is useful for new types of entertainment and communication such as AR games and life-size VR gaming systems. Moreover, blimps are generally used as signage that can be viewed by many people at the same time. Since our marker is implemented as a blimp floating in the air, it is easy for people to find and share an AR marker and to obtain the virtual information.

In this paper, we describe our AR marker and the matrix system we designed for implementing it.

Contribution

Our contribution is to reduce the gap between the future vision of AR (e.g., comic books, animated cartoons, and science fiction movies) and conventional research. Advanced AR technologies have been introduced in such media. For example, in the cartoon *Dennō Coil* [1], real characters wearing special AR glasses can see virtual characters in the real world. This is similar to the conventional AR approach. However, they can touch the virtual characters while wearing the glasses. Thus, virtual monsters can chase and attack the real characters using their body and special weapons. This scenario exemplifies one of the goals in AR research, i.e., the virtual character has physical features and communicates with users who wear AR devices. In conventional marker-based AR applications, users get and feel no physical feedback from the virtual characters, and the virtual characters cannot move freely. We were particularly inspired by the concept of *Dennō Coil*, so our marker provides both physical features and mobility. The physical features enable users to touch virtual information, and the mobility enables virtual characters to approach users and initiate communication.

Our second contribution is to design new types of tangible markers. In our approach, the virtual information is overlaid on the entire surface of the blimp, so the blimp itself becomes an information node with a tangible feature. The blimp contains several sensors in order to detect and react to the user's actions such as touching the surface of the blimp and sensing the direction. Since the node is weightless even if it is large, users can easily lift, move, and throw it. Thus, new tangible markers can be designed with various sizes and shapes. In conventional approaches, tangible markers are designed as compactly as possible because larger ones are heavier. In our approach, large physical blimps can be easily designed because they are filled with helium and air. In addition, since the blimp can float in air, it can move toward a user with week power like wind. If the blimp moves toward a user only when the user needs it, then the user would make more effective use of the real space.

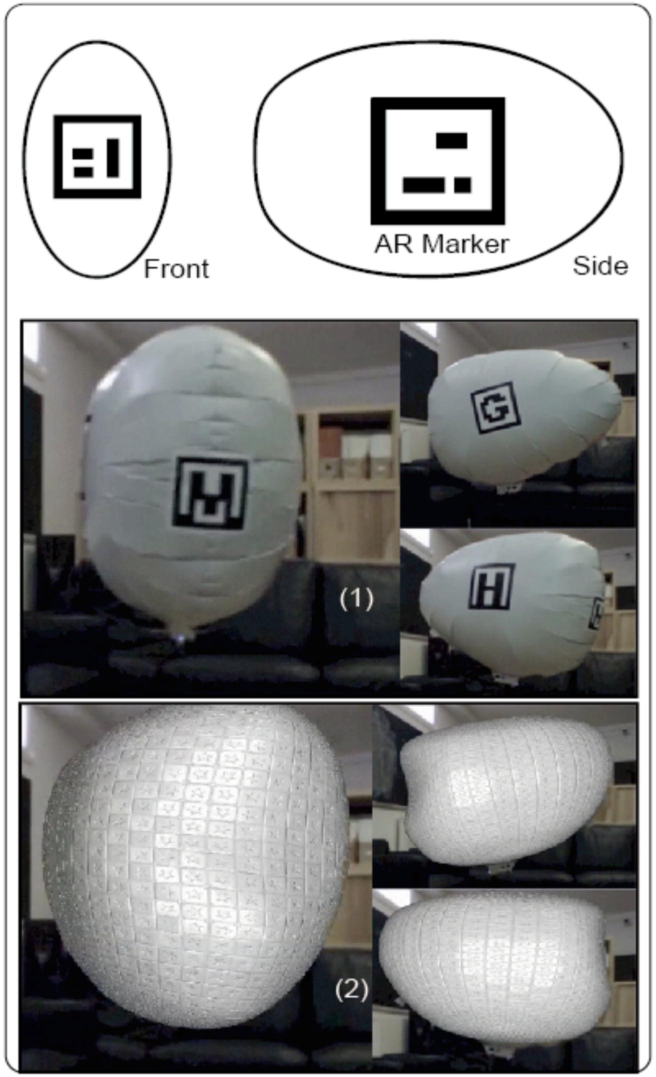

figure 1. Fixed Marker: Several AR markers are set onto the blimp surface (1). Virtual information is overlaid onto the entire blimp surface (2).

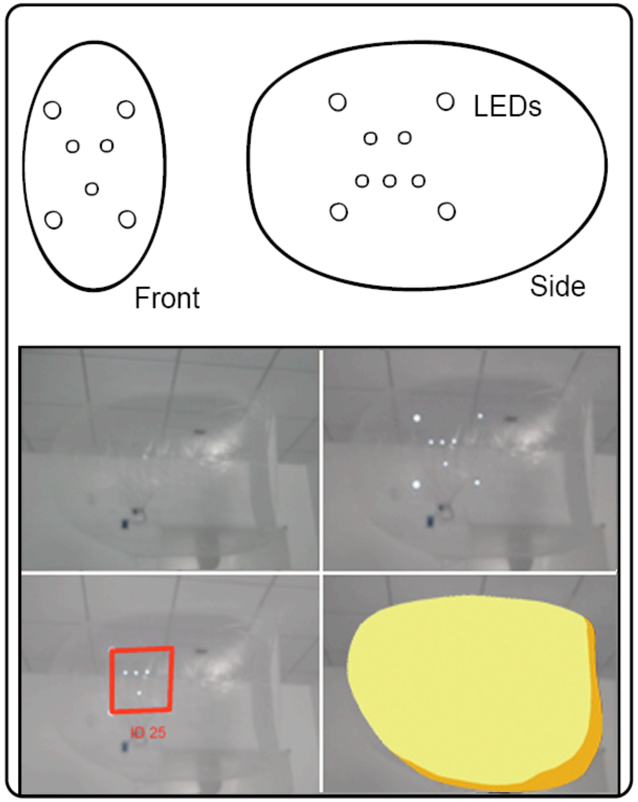

figure 2. Flexible Marker: LED is set onto the blimp surface as AR marker to realize virtual texture mapping.

Aero-Marker

We tested the following two approaches to implementing Aero-Marker: fixed approach and flexible approach. Fixed approach means that marker ID is fixed. Flexible approach means that computer server can change marker ID through the network. Although the materials of each implementation differ, the recognition process for detecting a marker in the real world is the same like Rekimoto [4].

With the fixed approach (Fig. 1), AR code or a line-dot pattern is painted onto the blimp's surface, making the surface an AR marker. We used black tape rather than paint to facilitate changing the pattern and size. The marker is basically the same as a conventional paper-based AR marker, which is very simple and does not require batteries.

With the flexible approach (Fig. 2), LEDs are used to create a marker. This is similar to conventional approaches like that of Matsushita et al. [5]. The use of LEDs to create the marker has several advantages. For example, the marker is almost independent of the light conditions, and since the marker emits light, it is usable in dark rooms. Also, the computer server an control on/off patterns of LEDs to change marker ID. Both approaches are simple and can be used to place several markers on one blimp. We set six AR markers, as follows: top, bottom, front, back, left side, and right side on the blimp surface.

As mentioned, the overlay of virtual information on the entire surface of the Aero-Marker blimp is similar to texture mapping in CG. Texture is used to make a polygon object more realistic in 3D CG. We use texture mapping to make virtual objects real and tangible. After the system recognizes the position and ID of an Aero-Marker (Fig. 1 (1)), it maps virtual texture onto a physical object (a blimp) (Fig. 1 (2)). As a result, a unique object is created that has a virtual appearance and physical features. Although the 3D object is the same, the use of different materials changes its appearance by using a wide variety of texture effects.

The Aero-Marker blimp has basically two main components, as follows: an envelope and a gondola (Fig. 3 (top)). The envelope enables the Aero-Marker blimp to float through the air. The envelope is made of vinyl chloride, so it will not burst if it is over inflated. Although it is difficult to express complex shapes by a blimp, it is easy to create simple objects like a stuffed toy. A motor that is contained in the gondola mainly moves the marker. The Aero-Marker blimp contains mobile processing units (MPUs, Arduino) that are connected to XBee modules for communication with the application server, and several sensors such as touch sensor (Fig. 3 (bottom)). Touching of the marker by the user is detected by means of the conductive threads on the marker surface, as with the Cloud Interface [2]. Aero-Marker sends the results for user touching to the server, causing the system to change the overlaid information and provide sound effects. To control blimp motion, the system provides automatic and manual modes like Floating Avatar [3]. To obtain the overlaid information, the user wears a head mounted display (HMD, Sony HMZ-T1) mounted on a video camera (PlayStation Eye). The video camera captures real-world images at 60 fps. The system recognizes the ID of an Aero-Marker on the basis of its AR marker, determines its position using imaging processes, and then transmits its virtual information to the HMD.

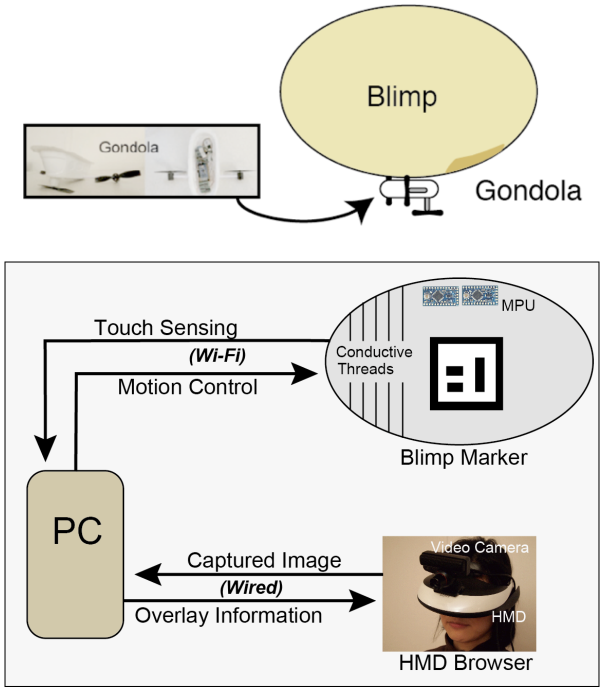

figure 3. System overview: Blimp envelope filled with helium provides lift. Gondola with propellers controls movement (top). Aero-Marker system comprises Aero-Marker blimp and HMD browser, which communicates through a network controlled by PC (bottom).

Discussion

Marker Mobility

We recorded the distance between the user and marker each time. Figure 4 shows a comparison between conventional AR marker and Aero-Marker. Through the demonstration, the distance varied greatly with our approach (Fig. 4 (top)), while it remained almost constant with the conventional approach (Fig. 4 (bottom)). We observed that users generally moved closer to the Aero-Marker to see it in more detail when they spotted it at a distance. Also, they went away from the marker to see the entire information. Some users stayed at the same place and watched the marker that is approachable to users. In contrast, users of the paper marker kept almost the same distance or manipulated the marker by their hand, since the marker was static.

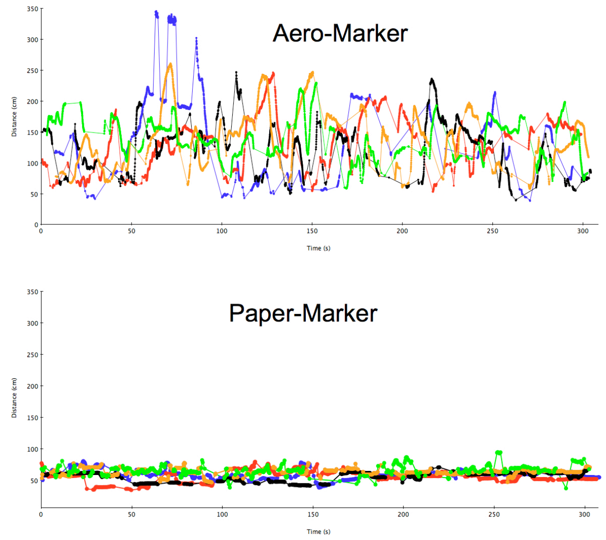

figure 4. Comparison between conventional AR marker and Aero-Marker: Distance between user and AR marker. We tested both Aero-Marker (top) and conventional AR marker (bottom).

In addition to determining the distance, we also observed user behavior. With our approach, the users' eyes always followed the blimp's movement. The virtual information was mapped onto the marker, so the virtual object was the same as following the blimp marker; therefore, the users at our demonstrations could always see the virtual information. Thus, users considered virtual information in our approach while they considered marker in the conventional approach.

Since Aero-Marker can move not only horizontally but also vertically, our approach can use space more effectively. In contrast, with the paper-based approach, users have to adjust themselves to the marker position and angle in order to see the virtual information because the virtual information disappears when the marker is out of camera range so that only the marker is in view.

Marker Physicality

We observed that all users touched the Aero-Marker blimp and changed its direction interactively. They commented that it felt like touching a stuffed animal because the marker on the blimp was soft. Since the envelope was made of a vinyl sheet and filled with helium, it felt safe and soft. Children especially enjoyed interacting with the virtual characters and objects directly. In contrast, users of the conventional paper-based markers initially enjoyed the interaction but later looked like they were bored because they mainly saw that the virtual object and the interaction was limited to simply pushing paper.

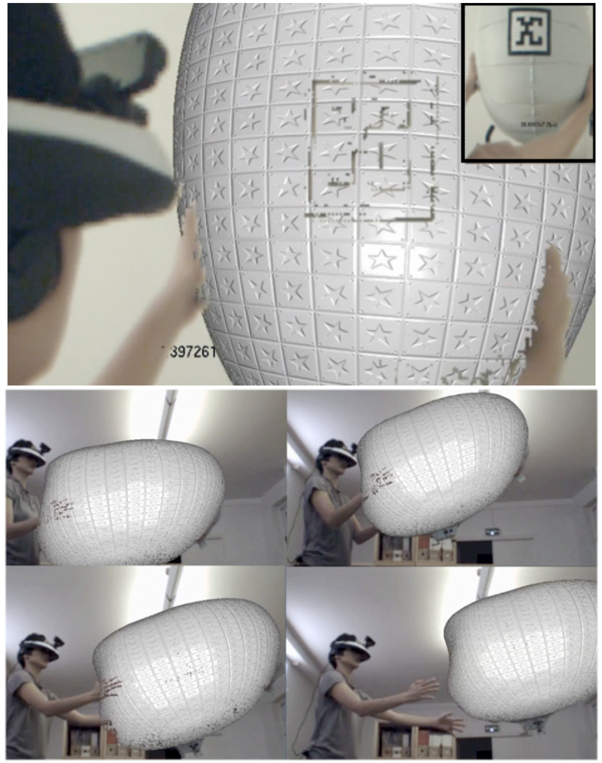

figure 4. Interaction with Aero-Marker: Aero-Marker physically exists so users can interact with virtual information.

As we mentioned in the previous section, our system provides unique interactions that conventional marker-based AR applications have not been supported. We received positive reactions about the physical features because our approach using virtual characters with physical features is unique. Here, we show some examples that we observed in our demonstrations to visitors.

As our Aero-Marker has physicality and weightless features, we observed users caught and threw virtual information (Fig. 4 (top)). We observed that some users enjoyed playing catch through the virtual object (Fig. 4 (bottom)). Aero-Marker contains touch sensors, so it changed the attribute when the user touched the surface. Thus, the user received both visual and physical feedback from the virtual character. Also, users hugged a virtual character directly.

We observed some collisions between people and the Aero-Marker. The markers moved freely and silently in the air, so they sometimes caused people to move backward a bit. However, the people interacted with the marker when they collided with one, observing it in detail and/or touching it. Thus, the collisions served as a trigger for users to communicate with the marker.

RELATED WORK

AR markers have been commonly used to integrate real and virtual worlds. Rekimoto et al. [4] introduced the use of practical 2D matrix code. The code contains a simple rectangle that is used to identify the position and a dot pattern inside the rectangle that is used to represent a unique ID.

Some research groups have focused on interaction, and several ways to make the marker interactive have been introduced into entertainment products. In Eye of Judgment [6] and SEGA WCCF [7], users set cards containing an AR marker in the game space. The users can move virtual information by manipulating the cards to change their formation. This type of interaction is very common in tabletop user interface research. Rekimoto and Ayatsuka proposed an extension of CyberCode [8], which is a product implementation of Rekimoto’s work. This Active CyberCode [9] has a variable part for direct manipulation using fingers. A user can control a virtual character or information invoked by a 2D code by "pushing" printed buttons. The variable part is recognized as an extended part of a code so that it costs almost the same as a normal CyberCode and is robust. AR Flavors [10] print the AR marker onto a cookie. Overlaying virtual information and generating virtual flavor enhance the user’s feeling that he or she is eating the simple cookie.

The dot patterns used to set the marker area and ID are simple, but the black and white pattern used can annoy users. Some researchers have focused on making the dot patterns invisible. Koike et al. [11] used polarization features to create an invisible marker. They also introduced applications such as a document lens and an image filter with their marker. However, they changed the basic material of the conventional marker design, so the interaction and application are almost the same. Nakazato et al. [12] used reflective paint to achieve an invisible AR marker. The painted area reflects infrared red (IR) light, enabling an IR camera to recognize the painted area containing the marker area and ID. Users can freely paint an invisible marker on a wall or ceiling, so unique ubiquitous computing applications are possible.

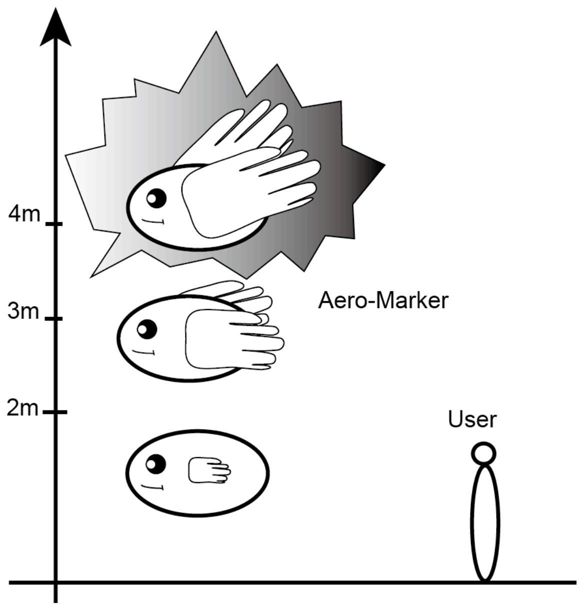

figure 5. Change of virtual object depending on height: The system uses virtual texture mapping less then 3m and adds extra effect and information more than 3m because users cannot touch the Aero-Marker

Future Work
Future work includes applying our system to entertainment and communication. The blimp's size and shape could be designed for application to life-size virtual reality gaming systems, for example. The number of Aero-Marker blimps could be increased to enable herds and shoals of creatures to be represented. Moreover, combining several AR approaches could enhance the demonstration space. The following three elements can be enhanced in the real world: floating markers, users, and static objects (e.g., columns, walls, and desks). To augment the users, we could use face recognition and overlay a virtual character's face onto the user's face. To augment the static environmental elements, marker-less AR technologies could be used. This would augment the entire demonstration space.

Changing the virtual information in accordance with the distance between the user and marker would enable more useful visualization because the marker floats in air. When the marker is far from people, the virtual information should be exaggerated to attract them such as by having a virtual bird spread his or her wings and by adding objects around the Aero-Marker blimp like particle effects. The system can change the appearance of virtual information depending on the height. For example, the system uses virtual texture mapping less then 3m and adds extra effect and information more than 3m because users cannot touch the Aero-Marker (Fig. 5).

CONCLUSION
We described our Aero-Marker for unique marker-based AR applications. The augmented reality (AR) marker we have developed has both a virtual appearance and a physical appearance. It is implemented using a blimp and has two advantages compared to conventional AR systems: mobility and physicality. Our blimp marker floats in the air and thus can move toward a potential user. Aero-Marker has physical volume because it is implemented using a physical blimp. Virtual information is overlaid on the entire surface of the blimp, making the virtual information tangible. Through early stage exploratory evaluation, we disclosed that our interface destined changes of the conventional maker-based AR paradigm.

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