Proceedings of Virtual Reality International Conference (VRIC 2011), 6-8 April 2011, Laval, France.
RICHIR Simon, SHIRAI Akihiko Editors. International conference organized by Laval Virtual.

InteractiveTop

An Entertainment System that Enhances the Experience of Playing with Tops

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Abstract—**We developed an entertainment system that enhances the experience of playing with tops by employing augmented reality technologies. A tabletop system tracks the positions and rotation speeds of multiple tops with a high-speed camera and displays audio and visual effects. A hand-held device, called an accelerator, enables virtual physical contact between the user and top by allowing the user to move and accelerate the top and obtain force feedback from the top. We propose a top battle game in which the player interacts directly with tops.**

Keywords- Tabletop; Spinning Top; High-speed Camera; Force Feedback; Augmented Reality

I. INTRODUCTION

Spinning tops have a long history around the world as a child's toy (Figure 1). As Eames et al. showed in their famous 1969 film *Tops*, tops have various shapes [1]. Although having differing shapes, tops as toys are simple, easy to use and allow people from different nations and of different generations to play together. A top is a simple toy, yet its behavior is unique when compared with the behaviors of other physical toys. Its attractive behavior is based on the gyroscopic effect acting within the top. We sense the force of the gyroscopic effect when touching or handling them. We consider that this experience helps children become aware of a basic phenomenon of physics.

In the present project, we extend these experiences with augmented reality technologies by providing visual, audio and force feedback. In the traditional use of tops, the user has physical contact with the top. They can apply an external force to the top with their hand and feel a torque. However, direct touching often has the unintended effect of moving the top, hence limiting continuous interaction between the user and top. In this work, we propose an entertainment system that allows the user to have direct prolonged interaction with a top, thereby extending the possibilities of traditional tops. Our system supports virtual physical contact between the user and top and augments the interaction with visual, audio and force feedback.

Figure 1. Traditional and contemporary Japanese tops.

II. CONCEPTS

The purpose of this research is to provide direct and continuous interaction between the user and top. We took two approaches.

First, we attempted to create feedback from the top to the user. The top has unique behavior based on the rotational energy provided by the user. In this work, we focus on three top behaviors: (1) on-axis rotation, (2) horizontal translation and (3) collisions between tops. These top behaviors are basic elements of traditional tops. We developed a system to augment these top behaviors and provide feedback to the user with visual and audio effects and force feedback.

Second, as the action from the user to the top, we allowed the user to control the top. We focused on real-time control of the position and rotation speed by the user. In the case of traditional tops, there are ways to control the top such as direct touching with the hand or using a special item such as a whip. These methods require special techniques and are a significant element of the fun of playing with tops. However, it is difficult for a beginner to control a top. We increased the controllability of the top to open up new possibilities of playing with tops.

On the basis of these concepts, we developed a prototype system that extends the possibilities of playing with tops. Our system comprises three components: (1) a top accelerator, (2) top stage and (3) top device. The top accelerator is a hand-held and compact device that moves and accelerates the top and generates force feedback. The top stage is a tabletop system that tracks multiple tops on the stage using polarized light emitted by infrared (IR) light-emitting diodes (LEDs) embedded within the top.

III. Technology

A. Multiple-top Tracking with a High-speed Camera

IR LEDs and a small battery are embedded within the top. The IR light is tracked by a high-speed camera under the stage. In addition, if the top rotates on the stage, the IR LEDs appear to blink on and off because of the action of a linear polarizer on the camera and another on the top (Figure 2). Our system calculates the positions and rotation speeds of multiple tops on the stage simultaneously by detecting and counting the high-frequency IR blinking using the high-speed camera and real-time image processing exceeding 750 fps. The positions and rotation speeds of the tops are converted to the parameters of a physics simulator running on a computer. This simulation result is used to overlay visual and audio effects and detect collisions between tops or between tops and virtual objects.

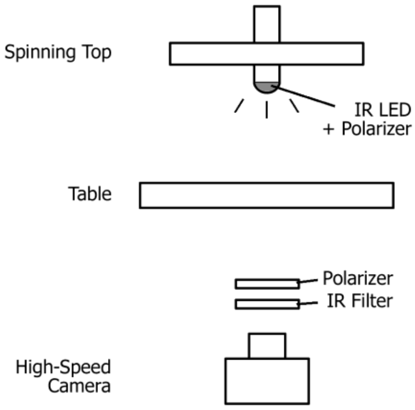

Figure 2. IR marker tracking system with a high-speed camera.

B. Top Acceleration

We developed an accelerator to increase the rotation speed of the top. This accelerator is compact and easy to use. The user increases the rotation speed of a top by positioning the accelerator 3 cm above the top without any physical contact (Figure 3). Furthermore, by moving the accelerator slowly toward the top, the user can position the top through a magnetic attraction between the accelerator and top. Thus, with the accelerator, the user controls the position and speed of a top.

Figure 3. User accelerating a top.

C. Force Feedback

The accelerator also provides force feedback to the user. The user receives vibration feedback based on the rotation speed of the top because of magnetic attraction and repulsion between the top and accelerator. This vibration provides the user with a feel for the acceleration of the top and helps the user keep an appropriate distance from the top.

A motor and small disk are embedded within the accelerator to create a gyroscopic force. The motor speed is controlled by a microcontroller within the accelerator in synchronization with the speed of the top. With the accelerator, the user's hand receives tactile feedback from the top.

IV. Implementation

Our system comprises three components: the top, the top accelerator and the stage.

A. Hardware of the Top

Figure 4 and Figure show the hardware configuration of the top. The top is made of ABS resin and an acrylic panel.

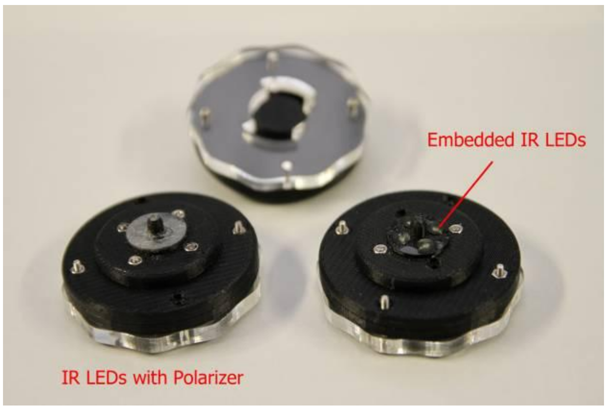

Figure 4. Tops made of ABS resin and an acrylic panel

The top is 6 cm in diameter and 2.5 cm in height, and weighs 45 g (including the weight of four small button batteries). Four neodymium magnets embedded on the upper side of the top interact with the accelerator. In addition, four IR LEDs with a linear polarizer are embedded in the bottom of the top around the axis (Figure 5). In this implementation, no microcontroller or special sensor such as an accelerometer is embedded within the top so as to reduce the size and weight.

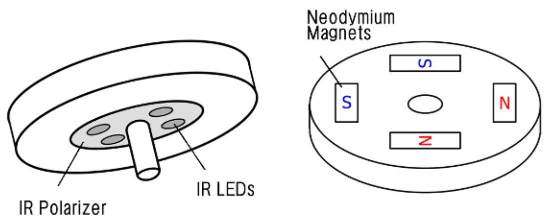

Figure 5. Four IR LEDs are covered with an IR linear polarizer (left). Two poles of the magnets are distributed around the axis of the top (right).

B. *Hardware of the Top Accelerator*

Figure 6 shows the hardware of the top accelerator. Figure 7 shows that the acceleration mechanism of the acceleration unit is basically the same as that of a brushless motor. If the accelerator detects the rotation of the top, it generates a magnetic force and accelerates the top. In this implementation, we use two coils to accelerate the top: a coil to detect top rotation and a coil to accelerate the top. If the top rotates under the accelerator, one pair of the magnets of the top and one coil of the accelerator allow an induction current to flow in a transistor. This current is amplified by the transistor and flows in the other coil, and as a result, a magnetic force is generated that accelerates the top. Using this mechanism, the accelerator can accelerate the top up to 2400 rpm.

Figure 6. The accelerator is composed of three units: an acceleration unit, a gyroscopic unit and an impact-force unit.

In the gyroscopic unit, one DC motor with a small disk-shaped weight generates a real gyroscopic force at the user's hand (Figure 6). The speed of the DC motor is controlled by a microcontroller, to control the power of the gyroscopic force synchronized with the real top speed. In addition, an electromagnetic solenoid generates a virtual impact force at the user's hand when the top collides with other tops.

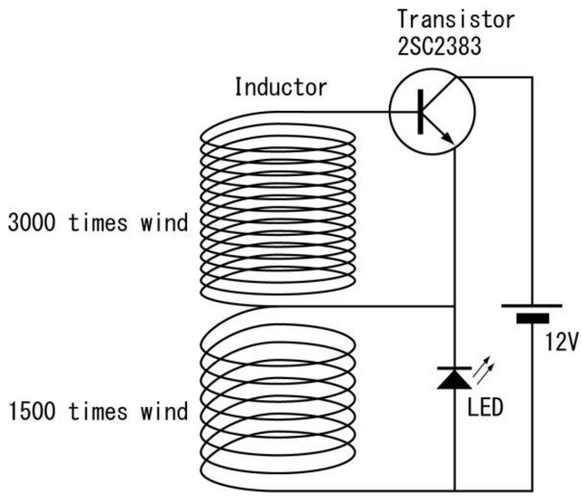

Figure 7. The top acceleration unit is composed of two types of electromagnetic inductors, a transistor and LEDs.

C. *Hardware of the Stage*

Figure the hardware configuration of the top stage. We employed an Imperx IPX-VGA210 high-speed camera with Asahi-Kasei WGF linear polarizer to capture polarized IR light from the tops, an EPSON EMP1710 visible-light projector to display application images and a personal computer (Core 2 Duo 3 GHz, 2 GB RAM, GeForce 9600GT). The stage surface is a flat or semispherical cast acrylic panel covered with an isotropic diffuser sheet.

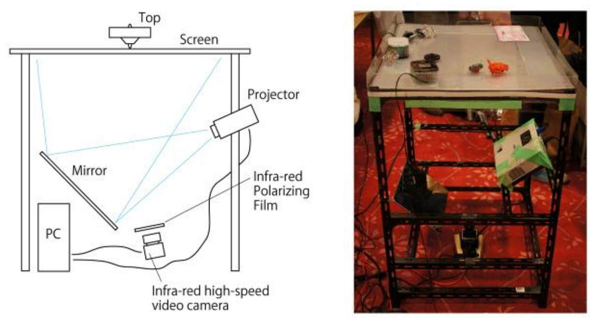

Figure 8. The stage comprises a personal computer, acrylic panel surface, high-speed camera and visible-light projector.

D. *Image Processing*

The image captured by the camera is binarized with a certain threshold to obtain high-intensity IR marker regions. Next, labeling is performed to calculate the centroid and luminance of each region. Since the frame rates of the image capture and processing exceed 750 fps, the displacement of a region over two frames is very small. Therefore, the region can be tracked by finding the nearest region in the previous frame. The luminance of the marker region changes depending on the angle of the top because of the IR polarizers on the top and camera. If the top spins 360 degrees, two IR blinks are detected. Luminance transition is recorded and counted to calculate the rotation speed of the top. Our system needs to capture at least five frames to detect a single blink of the marker; therefore, employing a capture rate of 750 fps, the system recognizes maximum rotation speeds of the top of about 4500 rpm.

V. APPLICATION

We developed a novel game application called the *Battle of Tops*, which is based on the traditional top battle game (Figure **Figure** 9). In this game, tops can be moved and accelerated freely with the player's accelerator. The maximum rotation speed is determined by the extent of a player's exertion, which is in turn determined by the number of button depressions on the accelerator or the heart rate measured by a heart rate meter within or external to the accelerator.

Figure 9. Two competitors playing the *Battle of Tops*.

VI. DISCUSSION

Our system recognizes the blinking of the polarized light from an IR LED to track the position, calculate the rotation speed and detect collision. The same IR blinking can be observed employing a polarized IR light source under the table and attaching a small retroreflective sticker with polarizer to the top, instead of embedding the IR LEDs and the battery inside the top. Applying this method, reflected polarized light is captured by the camera. This method simplifies the hardware of the top. In addition, this method can be applied to commercial tops (e.g., Takara-Tomy's *Beyblade* [9]) or traditional tops in many countries that cannot accommodate devices for tracking in our system.

We utilize the magnetic force between the magnets of the top and the coils of the accelerator to control the position of a top. However, in this implementation, the strength of the magnetic force is insufficient to move the top quickly. To allow the user to move a top more quickly, we may need additional magnets for the top and the accelerator to strengthen the attraction between them.

The accelerator is a hand-held device; however, it is too large for small children to use in one hand for a long time. To reduce the size and weight of the accelerator, we may reduce the size of the coil and introduce a cooling mechanism to allow a large current to flow through a small coil.

In this implementation, the user must start a top in a predetermined area on the stage to make a connection between their accelerator and top. To avoid this limitation, an identification signal can be sent from the top to the camera by the top's blinking IR LEDs when it starts rotating.

Becoming skilled at controlling a top is one of the fun elements of playing with tops. We would like to introduce advanced interaction techniques for an expert user. For example, the user can lift their spinning top upward from the stage and catch and hold it on their accelerator (Figure 10). They can then accelerate their top in their hand before dropping it onto the stage to strike other tops. We wish to introduce other advanced techniques of using the accelerator for which the top is on the stage or in mid-air.

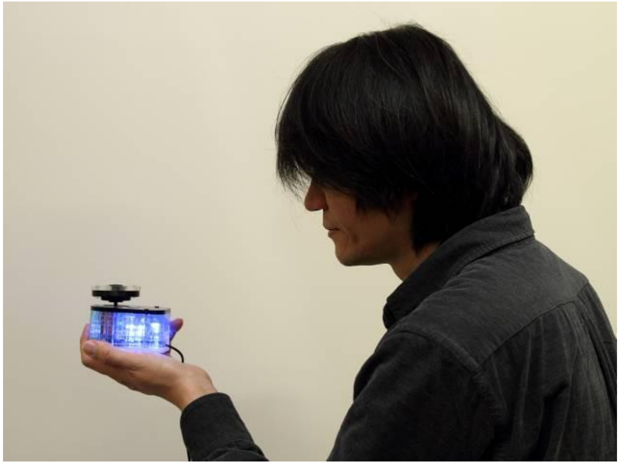

Figure 10. Advanced technique for the expert user: lifting the top from the stage and catching and accelerating it on the accelerator.

VII. RELATED WORK

Children today have access to many toys, including video games that are highly interactive and rich in terms of audio and visual stimulation. They have departed from using traditional toys that have less audio and visual feedback. To overcome this problem, many interactive systems have been developed to provide the user with rich audio-visual effects that overlay traditional toys and games. *PingPongPlus* [2] and *BouncingStar* [3] are entertainment systems that extend traditional ball-based sports with audio and visual effects by tracking the ball position or impact point in real time. *Augmented Coliseum* [4] is an entertainment system of augmented reality that augments a battle between remote-controlled robots in the real world with audio and visual effects.

In terms of works that have focused on the spinning top, *switch* developed an interactive media art device named "*Mawaru, Utsuru, Hirogaru*" that tracks the top with a video camera and displays visual effects around the top with a projector [6]. *MRSPINTOP* [5] from Laval Virtual ReVolution 2011 is a camera-based augmented reality entertainment system that observes the top with an overhead camera and overlays three-dimensional characters on the camera image. On the other hand, in the case of physical toys, especially the top, tactile sensation is a major element of the playing experience that is difficult to augment using only audio and visual effects. We developed a force feedback system to enable the user to feel the power of the top directly in their hand.

The gyroscopic effect has been used to provide haptic feedback to the user's hand. *Powerballs* [8] is a commercial hand-held exercise tool that consists of a free-spinning wheel. If a person holds the device and moves the wrist in a circular motion, the spinning wheel is accelerated and the wrist is exercised.

VIII. Conclusion and Future Work

We proposed a tabletop system and a hand-held device that enhance the experience of playing with tops. The tabletop system calculates the positions and rotation speeds of multiple tops and augments the playing field with visual and audio feedback. The hand-held device, called an accelerator, moves and accelerates the top and provides force feedback to the user to enable virtual physical contact between the user and top. We also proposed a novel top battle game in which the player interacts with tops directly; this game provides adults and children with the opportunity to learn the physics of well-known toys.

We employed a single-axis gyroscopic mechanism within an accelerator to generate a gyroscopic force that is conveyed to the user's hand so that they feel the spinning power of a top. We wish to introduce top attitude detection and three-axle gyroscopic force feedback such as for *GyroCube* [7] for the accelerator to present real-time torque feedback based on the attitude of the top.

In this implementation, there was no microcontroller or special sensor embedded within the top so as to reduce the size, weight and cost of the top and simplify the hardware to increase durability. However, such built-in devices may provide useful functionality, such as more accurate collision detection or top attitude detection. In addition, embedding an LED or small projector in the top provides display capabilities on/around the top. We are considering introducing these devices to expand application possibilities and increase the diversity of system hardware.

Furthermore, we plan to hide and embed the accelerator mechanism inside the table to enable the user to control a top without special devices. In this future system, natural input techniques such as touch sensing or vocal recognition will be used to control the top.

Finally, the current system provides force feedback to the hand via the accelerator. We are considering other feedback devices that provide feedback to the whole body.

Acknowledgments

We greatly appreciate helpful comments and suggestions made by Prof. Matoba and Prof. Nojima.

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