TAMA: Development of Trajectory Changeable Ball for Future Entertainment

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ABSTRACT
In this paper, we propose a ball interface "TAMA" (Trajectory chAnging, Motion bAll; "tama" means a ball in Japanese) that can change its own trajectory dynamically. Conventionally, it is impossible to go against the laws of physics. However, if the trajectory of the balls can be changed during flight, that virtually means balls can fly against physical laws. This should enhance the pleasure of ball-related games such as baseball, basketball, juggling, etc. In this research, we used the force of compressed gas from within the ball itself to change the ball trajectory. Previously, we developed the ball prototype equipped with a gas-jet unit. However, the primal prototype was too heavy to use in amusement. Additionally, there was no control of the timing of the jet and it was wired for power supply. In this paper, we introduce the latest prototype of TAMA, which trims the weight and adds new functionality. We discuss the feasibility of this system through experimentation in changing the ball's trajectory during downward flight.

Author Keywords
Ball; entertainment; motion sensing; jet pressure; sports.

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces: Interaction styles.

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INTRODUCTION
Digital technology has made our life convenient and comfortable. Recently many researchers have applied it into balls in order to make ball games more enjoyable and exciting [8, 19]. However, there are a few approaches that focused on the ball's actual motion. Considering variations of breaking balls and of feint techniques, clearly the ball's actual motion is one of the important factors for an enjoyment of ball games. Therefore, we have attempted to enhance an enjoyment of them by changing the ball's motion. Figure 1 is one of the images that shows our concept.

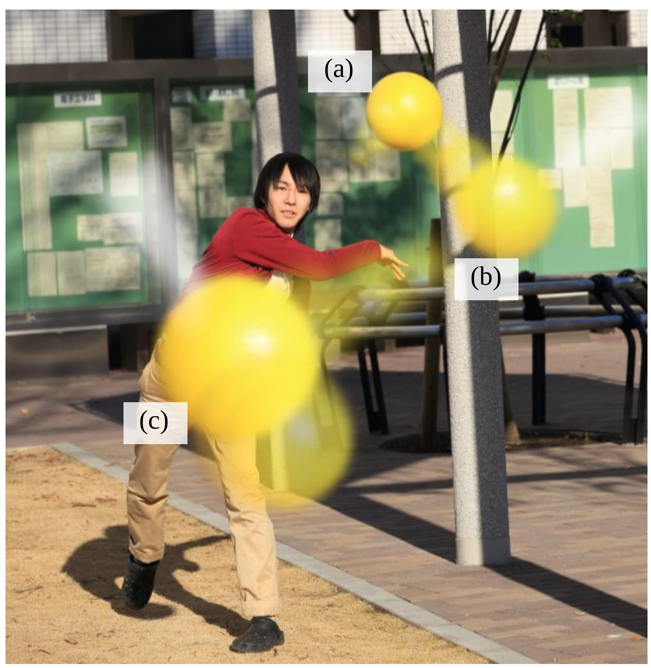

Figure 1. Concept of TAMA (Trajectory chAnging, Motion bAll), generating a special physical effect.

In the figure, a player is throwing a ball. (a) At first, the ball goes rightward. (b) But suddenly, the direction of the ball changes to leftward. (c) The direction of the ball changes to rightward again. Such unusual trajectory is often described in the world of digital games and animations, as a kind of “special effects”. However, it is quite difficult to generate such special effects in the real world.

In this study, we propose a ball with a gas-jet system that can change its trajectory “TAMA” (Trajectory chAnging, Motion bAll; “tama” means a ball in Japanese) [6]. The force that derived from the reaction of a jet of compressed gas can change the ball’s trajectory (such as Figure 2). Development of a ball that can control its own motion makes conventional sports and amusements more exciting and enjoyable. In this paper, we report the detail of the prototype systems and experimental results.

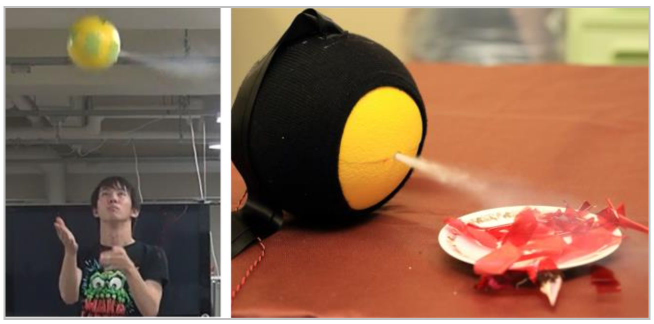

Figure 2. The ball ejecting compressed gas.

RELATED WORKS

Much research has been done to enhance an enjoyment of ball games by using various digital technologies. In this area, it can be categorized into three types of research. Applying digital technology to game fields, or to balls, or to both. Ishii et al. proposed an augmented table tennis by applying digital technology to game field. They added microphones to the ping-pong table to detect where the ball hit on the table. By using the proposed system, they succeeded in generating visual and acoustic effects to the game field based on the position of the ball [7, 20]. Mueller et al. have proposed the sports beyond the players' field. By using the screen projected the visual of the life-size opponent, they allowed the match of the table tennis or air hockey over a distance [11, 12]. BallCam! is a typical example of second research category, which applies digital technology into balls. BallCam! is capable of generating a stabilized point-of-view from a spinning ball with only one embedded camera [1, 10]. It is expected that we could vividly watch the video of the sport from the ball. Jeong et al. have developed a virtual catch ball system using SPIDAR-H, a kind of wire-based haptic display [9]. That system enables a person for doing catch ball with virtual characters. A ball is integrated with the SPIDAR-H so as to control ball’s physical status, such as speed, trajectory, which is necessary when the virtual character throws it. For third research category, the project "Bouncing Star" is a typical study. Izuta et al. developed a ball that includes various sensors and LEDs, as well as a special game field with a high-speed camera and a projector [8]. The ball and the game field can generate a certain visual effect, according to the motion of the ball. Sphero [18] is a ball that can change its motion on the ground via Smart Phones. The concept is quite similar but it could not change trajectory in the air, in spite of the fact that most ball-related sports games throw balls in the air. Nguyen et al. have developed a small, sphere-shaped satellite that could change its trajectory by using micro gas-jet[14]. However, the system is aimed to be used for satellites in the space, then the reaction force is quite weak to be used to change the trajectory of the conventional balls on the earth. Shootball by Sugano et al.[19] is a novel ball game that uses a camera-and-display-surrounded game field and a sensor-integrated ball. Cameras in the game field and a wireless shock sensor in the ball can detect the motion of the ball. Displays around the field shows goal areas or special area that has a certain function. Then players try to shoot those areas according to their game strategy with that sensor-integrated ball. As previous works show, developing a digitally integrated game field is one of the methods to enhance an enjoyment of ball games. However, that requires players to prepare such special game fields, which should reduce the chance to play. It should be a great benefit to ball game players that the game could be played anytime, anywhere. Then in this research, we focus on integrating digital technology into balls.

Up to now, many researchers have tried to apply digital technology to the balls. Such research can be largely grouped into two. The first group is integrating multiple sensors, including cameras, to make balls as a new kind of the sensing system. "PUYO-CON"[4] is ball-shaped input interface that can sense grasping situation. It has a soft body, so it can perceive direct touch and force with which it is held and how it is deformed under pressure while in use. GoalRef is the real-time ball tracking system using the wireless communication tip RedFIR. It helps the referees make the correct decisions on the goal in soccer [2]. 94FiFty is a sensors integrated basketball [1]. It can measure several information of playing such as bound counts, spin rate and so on. Players can develop skills rapidly by those information. Pfeil et al. presented a throwable panoramic camera using 36 mobile phone cameras. The ball-shape camera allowed capturing the complete panoramic image [16]. The second group is adding certain effects such as visual, auditory and motion to the balls. Rasamimanana et al. also added sensors to a ball, but added sound effects to the sport or game in response to activity [17]. There are few researches that focused on the ball’s motion. Halme et al. and Michaud et al. developed ball-shaped robots that can control the rolling motion [3, 11]. But these can control the motion only the ground.

As shown above, there is much research that have augmented the ball and sports. However, very few focus on motion of balls. When considering the variety of breaking balls in various conventional ball games, the trajectory of the ball should be one of the essential points that could affect an enjoyment of ball games. In our research, we develop a novel ball that focuses on its projectile motion during flight. Control of the ball motion through the air contributes to more exciting entertainment contents.

TRAJECTORY CHANGING BALL MOTION

In sports, ball trajectory is one of the most important elements. For example, in baseball, breaking balls generate interactive strategies between the pitcher and the batter. Thus, changeability of ball trajectory mid-flight contributes considerably to make various entertainments more enjoyable for not only players, but also the spectators. Dynamically motion-controllable ball enable us some new interactions to the ball. The following are such examples.

- Increasing varieties of breaking balls
- Controlling ball speed or flying distance
- Adjusting ball trajectory to goal or targets.

And we envision this system for use in the sport as a handicap or support of players' ability. In the match between players that have gaps of ability or one's physique (e.g. adults vs. children), using this system can bridge those gaps. In other words, a motion-controllable ball can realize sports where all players can compete all out.

Now, we suggested a sport application using the developed ball. In baseball, for example, it can make the match more exciting and tactical. This ball can change the vector of the motion. It allows new breaking balls (e.g. uprising, coming back) and controlling the ball speed or distance of flying. In a match between professional players, it improves the sophistication of the gamesmanship by expanding the varieties of gameplay. When it is a match between professional players and non-professional ones, this system could serve as a handicap. For example, it aids or disrupts the player's power by the controlling ball's speed and flying distance, and/or makes throwing some breaking balls easy. Handicaps affecting the game directly make the match very exciting without hampering play mechanics on either side. This system can enhance the enjoyment for all of players and audiences.

Moreover, this ball contributes to the creation of the new entertainment contents. If we can control the ball motion at will by equipping an input interface inside the ball, creation of new tactical sports or physical game that relies on player tactics can be expected.

PROTOTYPES OF TAMA

TAMA I

An early experimental system was equipped with a compressed gas-jet unit [6]. However, this was simple in structure with a mounted unit inside a hollow ball, so it was vulnerable to impact shock. So, for use in games, the material of the ball was changed to sponge to increase its impact resistance. This is the first prototype named "TAMA I".

System Configuration

This prototype consists of the gas tank (taken from a toy gun, Walther P99: MARUZEN), a servomotor (HSG-5084MG: Hitec Multiplex Japan) and an Arduino nano. These are placed within the sponge ball. The control of the gas jet was achieved by holding down a button which activates a connected servo-motor (Figure 3). This prototype's internal configuration and system of jet are shown in Figure 4. The weight of this prototype is 627g.

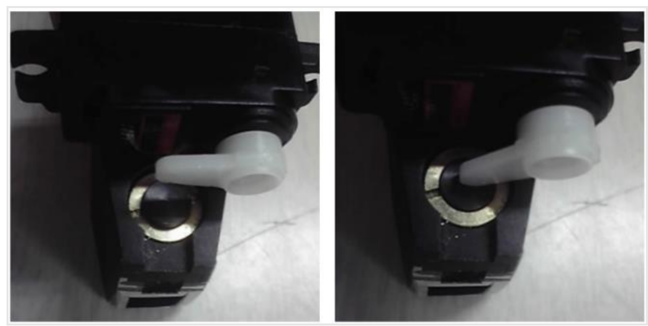

Figure 3. The gas ejection switch is controlled by the servo motor (Left: normal state, Right: ejection state)

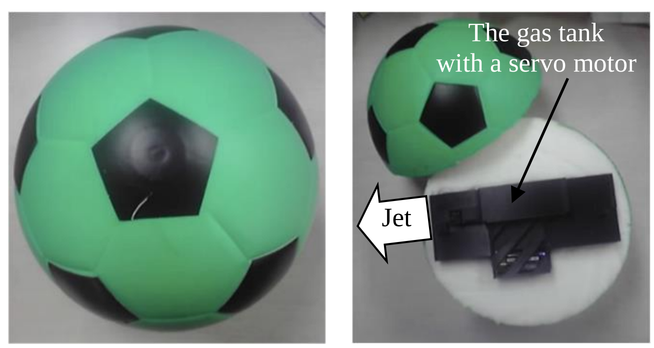

Figure 4. System configuration of TAMA I.

TAMA II

TAMA I had no function to control the jet timing, so these could not change the motion vector arbitrarily. In addition, TAMA I was heavy because of the rechargeable gas tank. It required to use lighter material. Therefore, we made a new prototype named TAMA II that has sensors to measure its own position. Improved points of this prototype are shown below.

- Detection of orientation, the prototype can control the jet timing based on it
- The gas - jet unit was downsized and weight was decreased by changing the system
- Controlling the quantity of ejected gas is enabled by controlling the duration of opening or closing the valve

System Configuration

TAMA II consists of an output component that ejects compressed gas and an input component that get information from sensors. An Arduino nano is equipped in the sponge ball, and ejection is controlled based on information from the input component. The output component consists of a compact inflator (MARUNI Industry) for bicycles, a CO_2 cartridge (BARBIERI) and a DC motor (SCL16-30: NAMIKI PRECISION JEWEL) to open or close the valve of the jet. The input component consists of a 6DoF IMU (SEN-10121: Sparkfun) and a potentiometer to measure the rotation of the motor to control the quantity of ejected gas. In addition, this ball can receive commands from the PC by the Bluetooth module. The total weight of this prototype is 378g, including16g consumable CO_2 cartridge.

We have succeeded in reducing the weight of 249g from TAMA I. Figure 5 shows the system configuration in the prototype.

BASIC FEATURES OF TAM I AND TAMA II

Table 1 shows the basic features of TAMA I and TAMA II. The Figure 6 shows the preliminary setup to measure the ejection force of the gas, simply putting a pressure sensor seat in front of the nozzle. In TAMA II, it was lighter than previous ones by installation of the new compressed CO_2 jet system but the jet pressure decreased. However, the most important requirement is to change the ball's trajectory. From this point of view, impulse-weight ratio should be the most important factor. As shown in Table 1, the ratio of TAMA II is higher than TAMA I. So from here, we will conduct further evaluation of TAMA II. Figure 7 shows the transition of the force of the ejection gas of the two prototypes.

Detailed evaluation of TAMA II

Ex1: Jet Test in Air and Sensing Ball Orientation

In this experiment, the prototype was set to eject the gas only a situation when the ball detected its free-fall and the angle of the jet nozzle to the horizontal plane was up to 30 degrees. At first, the ball was projected up to about 2 meters high. When it has met both of requirements of descent and direction, the compressed gas was ejected. We calculated its trajectory from values of the acceleration sensor in two conditions: the case that ejected and the case that did not. The result of the calculation and the value of sensors are shown in Figure 8 and Figure 9.

Data of Measurement	TAMA I	TAMA II
Weight [g]	627	**378**
Maximum Force [N]	13.24	6.80
Duration of Ejection [s]	1.4	1.4
Impulse [Ns]	6.93	5.14
Impulse-Weight Ratio [Ns/kg]	11.1	**13.6**

Table 1. Comparison data of two prototypes.

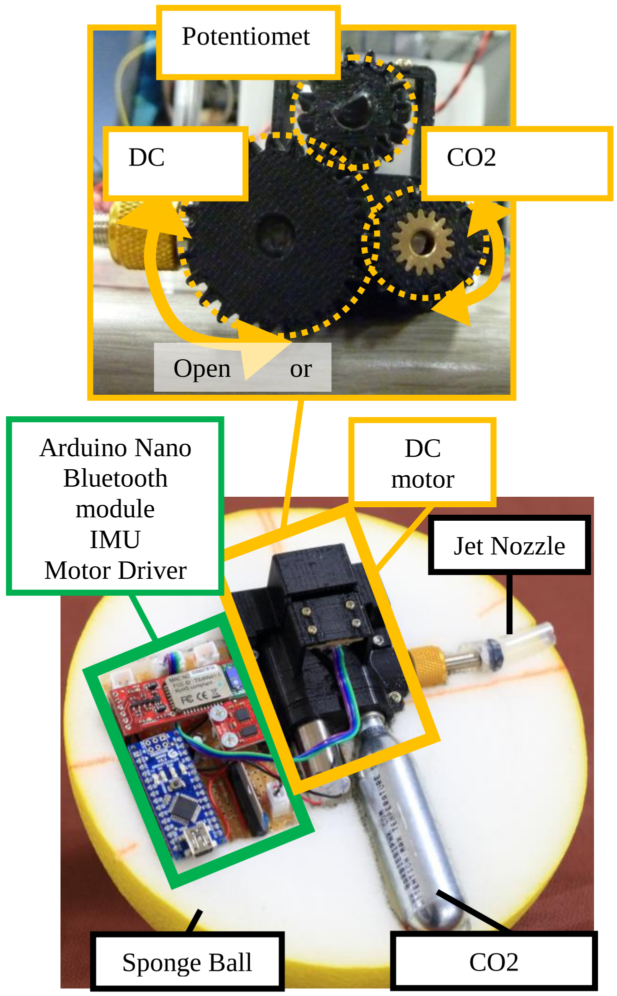

Figure 5. System configuration in TAMA II.

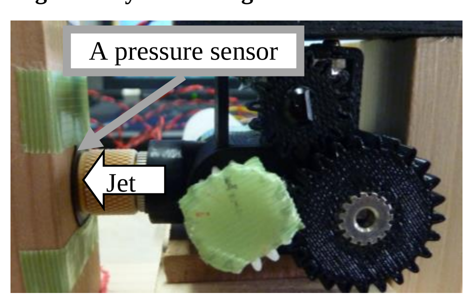

Figure 6. A preliminary setup to measure the force of the gas ejection

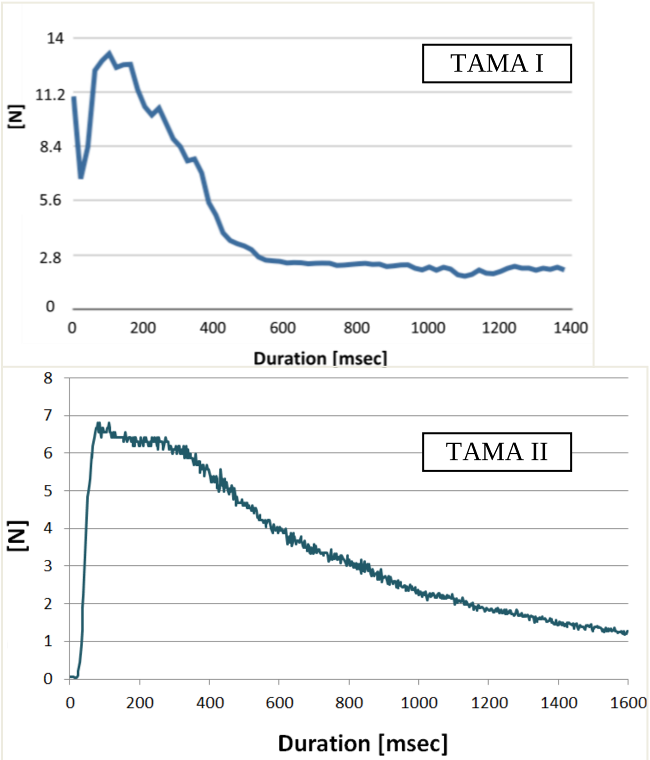

Figure 7. Ejection force transition.

Figure 8 shows the ball's trajectory from ascent to landing. A continuous line shows the trajectory with gas jet, and the dashed line shows the trajectory without gas jet. At the x-origin, the ball was tossed upwards. X-axis shows the absolute value of the horizontal displacement amount from the origin. Y-axis shows the height of the ball from the ground. It is evident that the gas jet had the ball changing the falling trajectory.

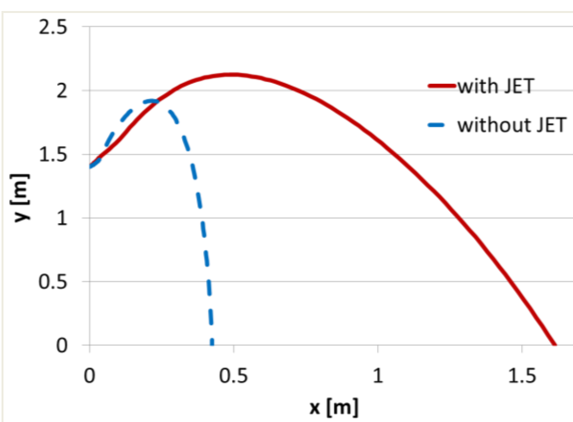

Figure 8. Amount of change of trajectory.

Figure 9 has three data curves that show the vertical acceleration, relative ball angle to the horizontal plane and the timing of the jet from the top. When the ball angle was less than 30 degrees and decreasing its acceleration was detected, compressed gas was ejected. It shows that the timing of the jet is controllable based on the information on its orientation.

In this experiment, the point of landing was displaced about 1.2 meters long by the gas jet. This proved the feasibility of this system.

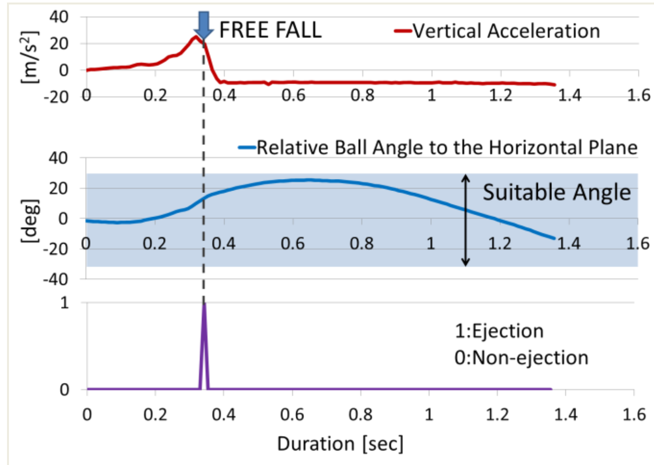

Figure 9. Sensing the angle and control the jet timing.

Ex2: Relationship between cycles of use of a cartridge and the force of the gas ejection

Changing a ball's trajectory requires enormous energy. In spite of the fact, the gas in the cartridge is quite limited. Then, we conduct an experiment to find relationship between cycles of use of a cartridge and the pressure force. In this experiment, we use a new CO2 cartridge. Then eject gas 4 times, each with a duration of 500 milliseconds. Between the cycles, we made an interval for about an hour to set the temperature of the cartridge back to normal. This is because, the cartridge becomes quite cold because of vaporizing heat after each ejection. That low temperature directly influences the pressure of the ejected gas.

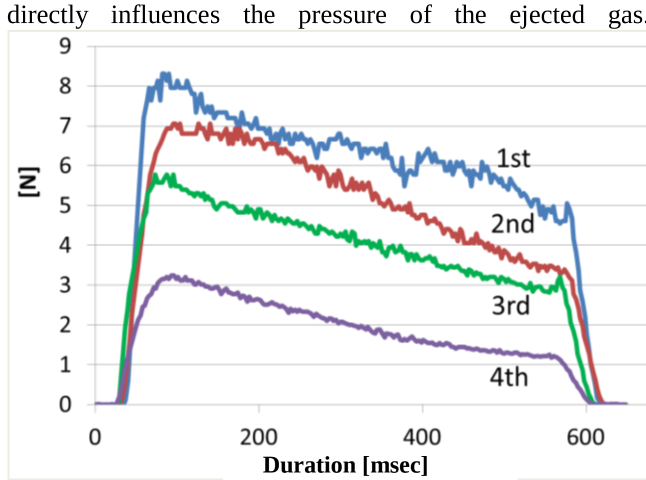

Figure 10. Relationship between cycles of use of a cartridge and the force of the gas ejection.

Figure 10 shows the result of the measurement. At second ejection, it was measured that relatively great pressure while it decreased from first. At third and fourth ejection, the pressure was very weak. Considering with actual throwing tests, it is expected that one cartridge can change the ball's trajectory only once or twice under these experimental conditions.

UNWIRE THE SYSTEM TOWARD ACTUAL APPLICATIONS

In the prototype shown above, it needs moderate electricity to open the valve. The required power was supplied via the wire from AC adapter. It is obvious that unwiring is quite valuable for ball type devices such as TAMA II. Using a battery as a power source is inevitable when considering an actual application. In the latest prototype, we have succeeded in completely unwiring it by equipping with lithium-polymer battery (3.7V, 1000mAh) and a power circuit. The total weight of the ball is 404g (including a CO_2 cartridge).

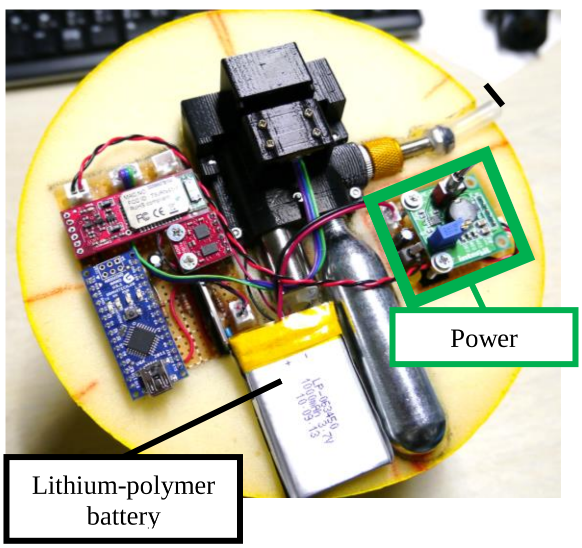

Figure 11. Unwired version of TAMA II

When changing the power source from an AC outlet to a battery, it often brings several problems such as weight and power. To change the trajectory of the ball, the valve of the CO_2 cartridge should be turned open fully and instantly to acquire enough thrust power. Then we performed an experiment to confirm the effect of changing power sources.

Effect of changing power source to the thrust power

Figure 12 shows a setup to measure the thrust power. The result is shown in Figure 13. The figure shows a relationship between time and thrust power. The blue dotted line indicates force transition when using AC as a power source. The red line indicates the same case when using a battery as a power source. From the result, by changing the power source from an AC outlet to a battery, the thrust power slightly decreased. This is because the lack of the power of the battery, it was unable to fully open the valve. However, the amount of decrease seems small. Then, we confirm the ability of changing the trajectory of the unwired version of TAMA II by actually throwing it up.

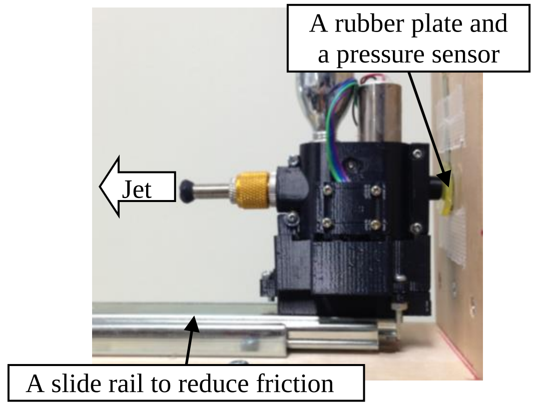

Figure 12. A setup to measure the thrust power.

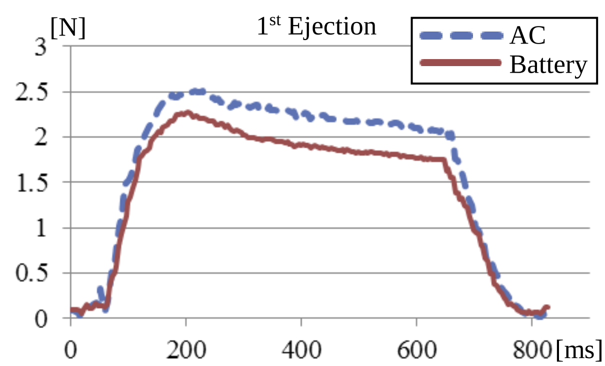

Figure 13. Thrust power transition.

Throwing up experiment

In this section, we performed a throwing up experiment to confirm that this prototype has enough potential to change its trajectory. We recorded the appearance of the change of the ball trajectory when the ball ejected at the peak position. Figure 14 is divided frame pictures captured from the video. The displacement between a circle around the ball and a center line shows the ball trajectory certainly changed by the gas jet. In spite of the increase of the weight, appearance of the change of the ball's trajectory compares favorably with wired version.

DISCUSSION

In this paper, we developed and improved the gas-jet ball prototypes. In the latest prototype, the weight of the ball is lighter, and jet efficiency is higher than in the previous prototype. The prototype cans sense its motion and attitude. It enabled the control of the timing of the jet without sending a command signal. The experiment showed that the jet system can change the trajectory of the ball mid-flight by sensing its orientation. This use of TAMA can imply a large addition of ball-related games.

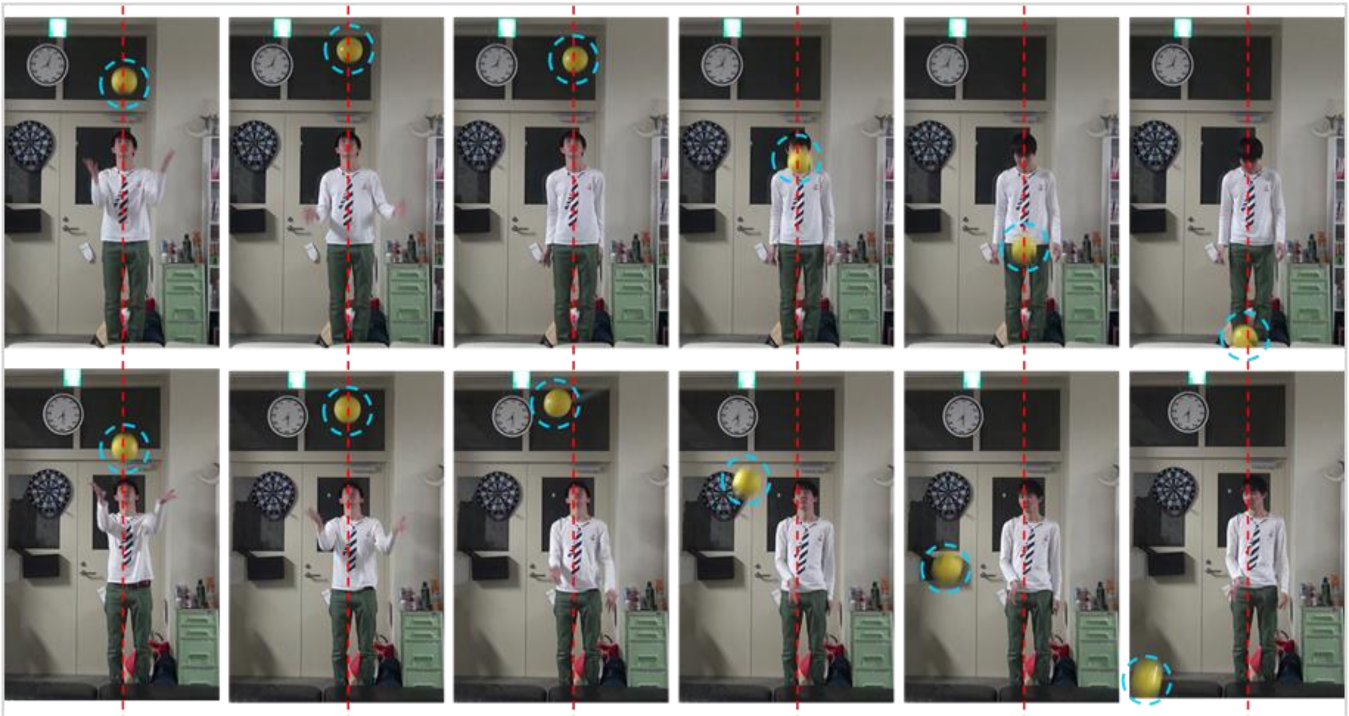

Figure 14. Appearance of the change of the ball trajectory (upward: a conventional ball, downward: the gas-jet ball).

In spite of the remarkable features of TAMA discussed above, current configuration has two big problems yet to be solved. One issue is pressure and temperature related problem. In this system, once the gas is ejected, the temperature of the tank becomes low due to loss of heat due to gas thermodynamics. This low temperature weakens the power of jet flow. Cartridges we currently use have capacity for two times of gas jets, if the temperature can be maintained after first gas jet. Currently, we solve this problem by exchanging CO2 cartridges after ejection every time, which is not cost effective. Another issue is related to the speed of ball's motion. Ideally, when ejecting gas to change its trajectory, the jet vector should be controllable. However, the direction of the jet nozzle in the current system changes during motion because the gas jet nozzle position is fixed. In spite of the fact, the current system is relatively slow when detecting orientation, thus cannot eject gas at an appropriate timing.

To provide novel entertainment property in ball-related games by using TAMA, several methods are considered. In this chapter, we will discuss three types of methods. The first one is, using TAMA as a kind of attractive special effects in games for prospectors. To discuss this, we assume the situation that the ball's trajectory change in an unusual way, triggered by players' command input such as special gestures. Such kind of special effects are often described in animations and cartoons, but have never occurred in the real world. Then, changing balls' trajectory itself has potential to be used for attraction for prospectors. Visual and acoustic special effects are also preferable for this purpose. The second is using TAMA for inducing game players to miss the handling of balls. If the ball's trajectory changes just before the player catches it, the player should miss catching the ball. This could be used for a kind of handicap. The experimental results show that total amount of change of the trajectory by using TAMA is enough to induce players to miss such handlings. To assure inducing such failure for players, faster trajectory change is preferred. Higher ejection pressure is one of the solution of this issue. However, the governmental law prohibits people who do not have an appropriate license to use cartridges with high pressure. The pressure of the CO2 cartridges which used in this system is almost near the limitation that allowed to be used by people who do not have the license. Therefore, instead of using higher pressure, increasing the number of cartridges is the affordable solution to increase the weight of flow. In addition, improving gas-ejection response should also be a solution for this issue. To comply with this demand, a faster valve that allows large amount of flow to earn enough reaction force is necessary. When achieved faster trajectory change, the trigger for the gas ejection should be considered. Current prototype systems use accelerometers to initiate gas ejection, which is relatively hard to control the timing of the gas ejection. Then, instead of the accelerometer, conventional Kinect-based, or camera-based gesture recognition systems should also be available for this purpose. In addition, our research member proposed a novel sensing system named PhotoelasticBall

[15] that could measure the magnitude and direction of applied force on the ball's surface. This PhotoelasticBall is aimed to detect slight hand gesture that is applied to the ball's surface. This means, when players catch a ball, they could input appropriate command before they throw the ball without looking the ball. This could help the player to control the timing of gas ejection without being known by other players around him. The third method to be discussed here is using TAMA for active assistance for players. In this case, precise trajectory control should be required. For example, gas ejection adjust the trajectory of the ball to be caught by a player, just before when the player almost fails to catch the ball. To comply with this issue, timing, direction and duration of gas ejection should be precisely controllable to navigate the flying ball to a certain place at a certain time to be caught by the player.

CONCLUSION

In this paper, we report developments of the ball that can change its trajectory. We introduced two prototypes and discussed their capabilities. The latest prototype is lighter and can sense its own orientation. Using a CO_2 gas-jet unit contributes to the system by making it smaller and lighter. At the same time, it has enough power for generating driving force. We succeeded in changing the free fall trajectory of the ball by ejecting the compressed gas. Also, we succeeded in the control of timing of jet based on the information from sensors on the ball. In the future, user tests will be conducted for evaluating the digitalization of ball-related games.

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