Petanko Roller: A VR System with a Rolling-Pin Haptic Interface for Entertainment

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Abstract. Most people will have experienced squishing clay and making it flat. The action of changing the shapes of real objects induces pleasant feelings or excitement. In this research, we propose a system, named Petanko Roller, which enables users to experience the sensation of rolling out any object in the real world with a rolling pin virtually. This system, by detecting the shapes of physical objects with a range camera, can represent haptic sensations of unevenness or friction of the objects, using modules for clunk mechanisms and brakes of a rolling-pin-based interface. Furthermore, by projecting images of the objects being squished on a tabletop display, it can also give optical feedback to users. In this paper, we discuss the system design, implementation, and behavior of users in exhibitions.

Keywords: Rolling Pin, VR Entertainment, Haptic Interface, Tangible Interface.

1 Introduction

When playing with clay, mixing cookie dough, or crushing cans, most people will have experienced squishing something and making it flat. Changing the shapes of real objects induces pleasant feelings or excitement. In cartoons or comics, we are often shown characters or physical objects being flattened by large objects. In contrast, in the real world, there are many objects that cannot be flattened because of their hardness, costliness, or uniqueness.

Under such backgrounds, we propose an entertainment system that can provide a virtual experience of flattening any physical objects including human's body by giving haptic and visual feedbacks. In this research, to realize such system, we mainly aimed to develop a novel interface that can represent textures and shapes of digital objects.

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In concrete, we propose an entertainment system which can represent both shape and texture of digital objects intuitively, named "Petanko Roller" (Fig. 1). To increase user's intuitiveness of interface, a technique to use daily tools as a metaphor for inducing specific action is often introduced in the field of human computer interface(HCI). As adapting this point of view for designing haptic interface, we used the metaphor of "rolling pin" which is a tool for rolling out cookie dough or clay. By moving a rolling-pin-based interface on a visual image on a tabletop display, the user can feel the unevenness and friction of the object according to the position of the device. Putting pressure on the digital object through the device stretches the object so that user feel the sensation of rolling out the object. It is also able to represent variety of haptic sensation such as hardness or texture of digital objects by adjusting the algorithm. Actuators for representing haptic sensations are all installed in the device, thus users are free from wearing particular device or other limitations.

In this paper, we describe the related work, the system design, and the feedbacks through exhibitions.

Fig. 1. Overview of Petanko Roller

2 Related Work

In resent years, in the field of HCI or VR, many systems have been proposed to provide rich and realistic experience to users by giving multi modal feedbacks other than visual or audio. Especially, interfaces which provide haptic sensation have been popular these days[10][12][5]. Such interfaces can dynamically represent shapes or textures of digital objects.

Among such researches, there are approaches that encourage intuitive interaction by using common tools or objects as metaphors. As for a major example of such interface in HCI, the metaDESK[11] utilizes physical objects as a computer interface under the concept of Tangible Bits[4][3]. There are also haptic interfaces proposed under such approaches. Virtual Chanbara[6] is a VR system that uses the inertial force of a spinning weight to enable users to feel Chanbara feedback. It can represent the reaction force when a player's sword hits virtual enemies. Funbrella[13] can record and replay rain with an umbrella-like interface that is composed of a vibration-giving mechanism based on a speaker and a microphone. Ikegami et al. proposed handy haptic feedback devices imitating daily tools such as a tweezer or a syringe named Tool Device[2]. Using the metaphor of everyday tools, they enable users to manipulate informations intuitively. The advantages of taking such approaches are that users can figure out how to use the device easily and also that it is easy to install various actuators or sensors in devices because they can have a certain size according to the tools used as metaphors. As basing on such approaches and focusing on a "rolling pin", we aim to develop an interface which represents the shape and resistance of digital objects with haptic and visual feedbacks.

One of the major feature of Petanko Roller is that it can represent the three dimensional shape of objects. Pin-displays [1][8] are similar purposed system for representing shapes. They physically represents the shape information by actuating arrayed pins up and down. Although pins are arrayed on tabletop device in such system, in our research it is the interface that includes linear actuated modules. It is able to represent the haptic sensation of rolling over objects with rolling pin by regulating the modules up and down according to the motion of the device. In the pin-display system, the size of the object which can be represented depends on the size of the display, but in our system, the size of the interface doesn't limit it, because of its unique system design.

Also there are related work on expressing hardness or texture of virtual objects. Claytric Surface[9] is a tangible display which can change the hardness of its surface by regulating internal particle density. The Haptic Touch Toolkit[7] can express the height and friction of virtual objects at single point, with a device which has an actuating rod and a brake. In contrast with these system, we propose a handheld sized interface which can represent 3D physical shape with clunk and brake modules placed in parallel.

3 Petanko Roller

3.1 Concept

As focusing on the pleasant feelings or excitement induced when changing the shapes of physical objects, we propose an entertainment system that user can virtually squish any object in real world as if they were clay. We developed a VR haptic system, named Petanko Roller, which user can experience flattening any physical object in the real world.

We describe the process of the user's experience in the system of Petanko Roller below (Fig. 2).

First, a user chooses an object in the real world that he/she wants to make flat. The system then captures the 3D shape of the object.

Secondly, by moving a rolling-pin-based device on the visual image on a tabletop display, the user can feel the unevenness and friction of the object. Putting pressure on the virtual object through the device stretches the object according to the force of the pressure and the motion of the device. With time, the object will be flat.

Thirdly, at the end, the user can keep a printout of the flat object that he/she rolled out as a souvenir.

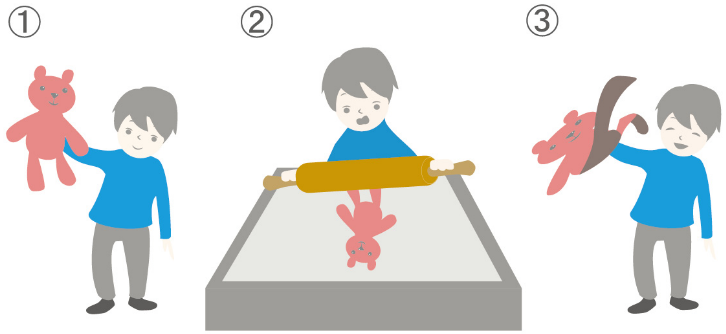


Fig. 2. Process of user experience

3.2 System Overview

The system of Petanko Roller consists of a rolling-pin-based haptic interface, a tabletop display, PC, Microsoft Kinect and a printer (Fig. 3). The system first detect the shape of an object using Kinect. The rolling-pin-based interface detects the pressure of users and provides haptic sensations of unevenness and friction of virtual objects. To provide the unevenness and the friction, servomotors and brakes are attached on tires. With a micro controller, the rolling-pin-based interface can communicate input and output data with PC. The tabletop display is composed with a projector to provide visual sensations and an infrared camera to recognize the motion of the rolling-pin-based interface by detecting the IR LED in it. Both of them are connected to PC to process input and output data, so that the system can provide both haptic and visual feedbacks according to detected users' action in real time. The printer is used for printing a flattened object as a piece of paper.

We describe the details of system design for each process and how they interact.

4 System Design

4.1 Detection of the Object

We implemented Kinect which is an infrared depth sensor for measuring the physical object's shape. Kinect is fixed approximately 100 cm above the tabletop display, in a downward direction (Fig. 4). On the basis of the range data acquired

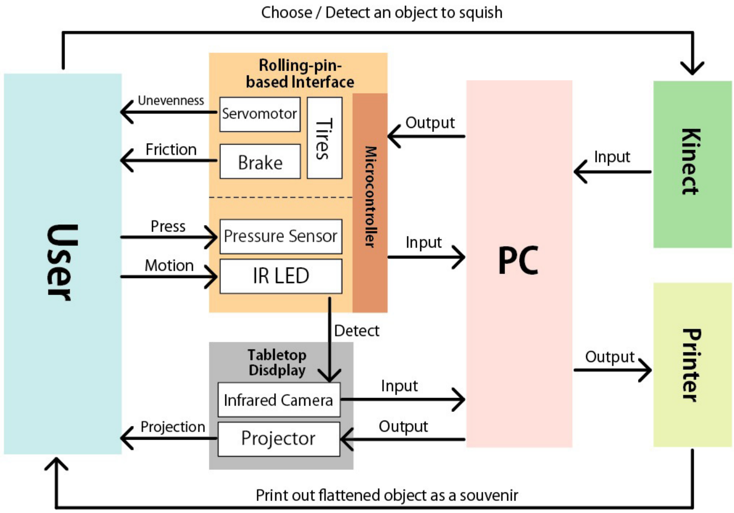


Fig. 3. Configuration of the system

from Kinect, shape data are generated and saved for PC processing. In the shape data, Each pixel's height datum is allocated from 0 to 255 by setting 0 as the top of the tabletop display and 255 as the highest part of the object. Kinect is preliminarily calibrated.

In addition, color image data clipped according to the height data are also saved at the same time(Fig. 5).

4.2 Rolling-Pin-Based Haptic Interface

We describe the rolling-pin-based interface that represents haptic sensations. As noted above, the rolling-pin-based interface represents the unevenness of the virtual objects and the frictional forces acting on them.

Fig. 6 shows the appearance and configuration of the device. In this device, tires and brakes are installed in parallel at the bottom, and clunk modules are connected to servomotors at the top. A pressure sensor is installed in each handle to detect the force of the pressure as Fig. 7 shows, and two IR LED modules are installed at the bottom for detecting the motion of the device.

When an actual rolling pin is rolled, each part of it bumps, according to the shape of the object. To represent such unevenness of virtual objects, in this system, each clunk module is actuated up and down, according to the relation between the digital object data and the position of the device(Fig. 8). Thus, users can perceive the overall shape of the objects by moving the interface.

When rolling a real rolling pin over an object, frictional forces act between the object and the rolling pin. To represent this, brakes are applied to the tires using servo motors. This mechanism is composed of a servo motor, a gear cut

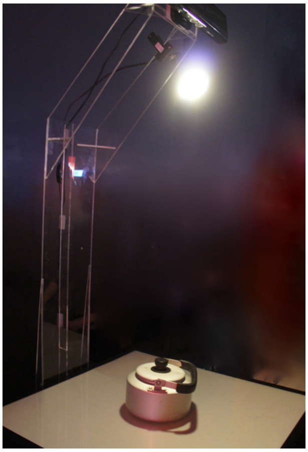


Fig. 4. Kinect detecting a physical object

Fig. 5. Generated image data and shape data using Kinect

on the cross, a brake plate, and two tires (Fig. 9). A gear cut is attached to the servo motor, so that it pushes the plate when the servo motor actuates. With this mechanism, users feel the friction between the tires and the plate as the friction of the virtual object. Also, as the tension of brake is adjustable, it can represent various kinds of material texture or changes in resistance according to the shape.

We implemented the device, which is 580 mm in length and 1.7 kg in weight, and has a handle of length 90 mm at each end (Fig. 6). Clunk modules are installed every 35 mm on the device. The device diameter, excluding the clunk modules, is 104 mm, and it can represent a maximum thickness range of 30 mm. We used servomotors as following: S11H/2BBMG/JR manufactured by GWS for the clunk module, and ZS-F135 by ZEBRA for the brakes. Each motor has torques of 7.6 [kgcm] and 1.6 [kgcm]. We used FSR402 by Interlink Electronics Inc. for the pressure sensors. The interface is connected to PC by wired from one end of the interface.

4.3 Tabletop Display

Next, we describe the tabletop display on which the rolling-pin-based device is used. In this system, the display gives visual feedback as projected images, and detects the position of the device on the display. Fig. 10 shows its overview. It consists of a projector, an infrared camera, a mirror, and a screen at the top. The projector is used to show images of the virtual objects on the screen. As the object becomes flatter, the projected image of the object also stretches with the software running on PC, so that users get feedback as both haptic and visual sensations.

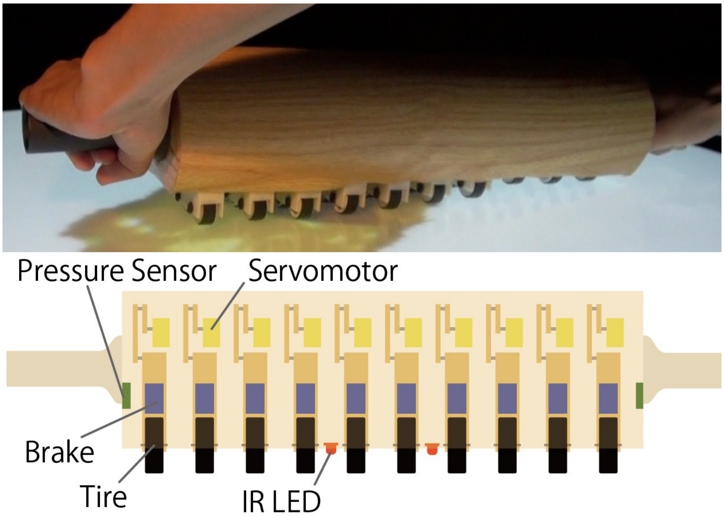


Fig. 6. The appearance and the internal composition of the interface

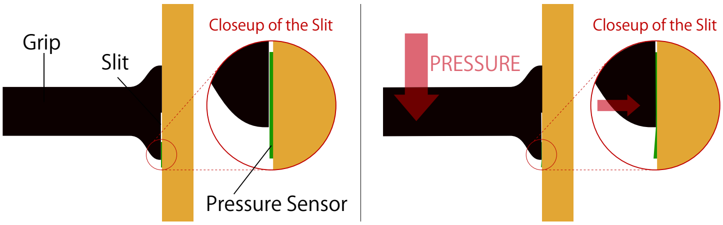


Fig. 7. Structure for pressure sensing

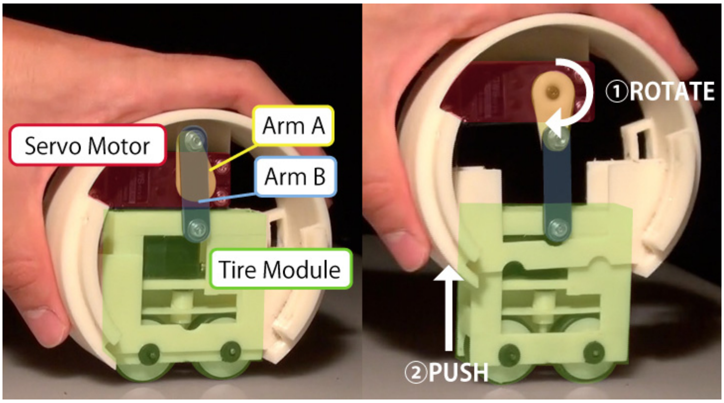


Fig. 8. Sectional view of Actuating the clunk module

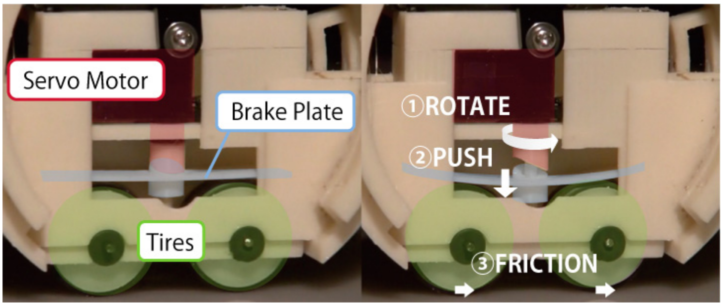


Fig. 9. Sectional view of Actuating the brake

Also, the infrared camera detects two IR LED modules installed at the bottom of the device, so it is able to regulate the clunk modules according to the position and the rotation of the device in real-time. Fig. 11 shows an example of the detected data and the calculated position of each module.

The tabletop display is 75 cm wide by 75 cm deep by 90 cm high.

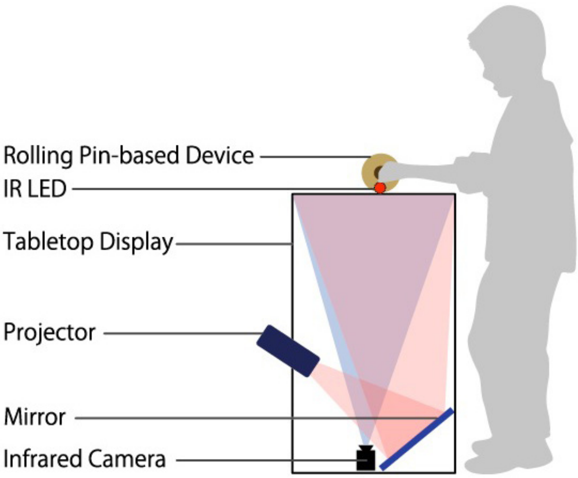


Fig. 10. Structure of the tabletop display

4.4 Software

We describe the software for representing the sensation of squishing doughy objects. This time, we developed simple original algorithms which do not use advanced physical simulations. There are 2 general phases for the software processing; one is processing for deforming object data and another is processing for providing haptic sensations. We describe each phase below.

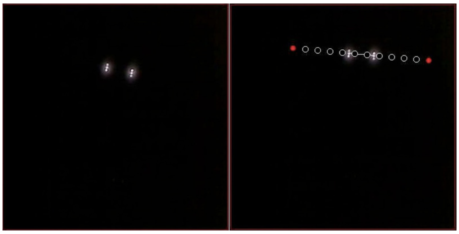


Fig. 11. Detected image of device using infrared camera

Processing for Deforming Object Data. For the processing of deforming object data, we converted the shape and image data generated using Kinect according to input data. As for the shape data, each pixel's height datum is allocated from 0 to 255 by setting 0 as the lowest part and 255 as the highest part of the object. Hence, we use a grayscale data for the shape data. The image data which is an overhead image of the object is saved in RGB image data.

As input data for processing changes in an objects shape, we used the position of the device, shape data, and the values from the pressure sensors in the handles.

For processing, the image and shape data are first divided into 60 x 60 grids (Fig. 12). When the values from the pressure sensors are higher than a specific threshold and the value of the height data of the virtual object with respect to the device position is higher than a specific threshold, each grid vertex is translated, according to the input data, so that it can represent the object being stretched. Specifically, each vertex is translated away from the device in a direction perpendicular to the axis connecting the end points of the device. The translation distance of each vertex D is represented by Eq. 1: L is the distance between the vertex and the device, P is the force value extracted by pressure sensor, H is the height data on each coordinate, and a is a positive constant. By adjusting the value of a, how the object stretches can be changed. The smaller value L is or the larger value P and H are, the larger translation distance D will be.

$$D = (aPH)/L \tag{1}$$

In the processing of objects being flattened, the system processes the shape data from 0 to 255 in real-time according to input data. Eq. 2 represents the concrete processing for height value for each pixel H: H_{prev} is the height value in last frame, H_{th} is a threshold that represents the the minimum value of height, D is the translation distance of the nearest vertex to each pixel, b is a positive constant. Regulating b changes the degree of the object being flat. The right side of the Fig. 12 shows the deforming process of shape data.

$$H = \begin{cases} H_{prev} - bD & (H_{prev} > H_{th}) \\ H_{prev} & (otherwise) \end{cases} \tag{2}$$

With these processing, when a user put force to the interface, the object data gradually stretches and flattens until it cannot stretch any further. Thus, the visual images of the flattened objects can be displayed with the projector.

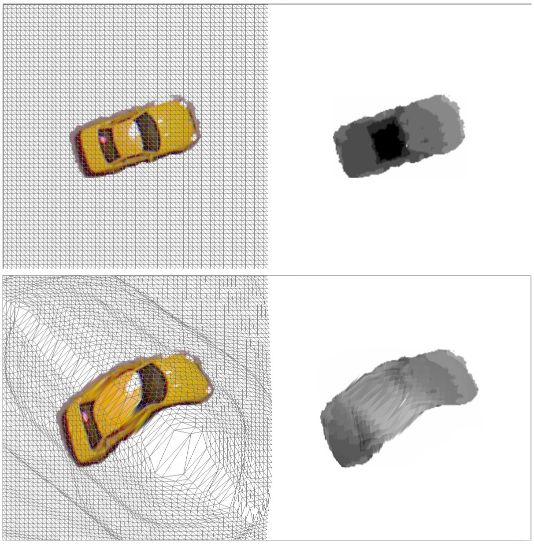


Fig. 12. Processing of the object data (Left: image data, Right: shape data)

Processing for Providing Haptic Sensations. Next, we describe the software processing for providing haptic sensations. As previously noted, the rolling-pin-based interface can represent 2 sensations; the unevenness and the friction. As for the unevenness each clunk modules in the interface actuates to express unevenness according to the coordinate height datum in the shape data. In concrete, the height data written in 0 to 255 are mapped into 0 to 3 cm for the clunk modules.

As for the friction, we used the change in shape data to represent the frictional force acting when the unevenness changes. For example, when a rolling pin moves up on a slope, user would feel the stronger frictional force. To represent such changes in friction, friction value F is represented by Eq. 3: H is the height value on the position of each clunk module, H_{ave} is the average height value in previous 10 frames. c represents the basis frictional force of virtual object and d is a coefficient of friction according to height data. By adjusting these positive constant values c and d, it can provide various textures of digital objects. We used these algorithms to represent haptic and visual sensations with a rolling-pin-based device and tabletop display in real-time.

$$F = \begin{cases} 0 & (H = 0) \\ c + (H - H_{ave})d & (H > 0) \end{cases} \tag{3}$$

5 Exhibitions and User Feedbacks

We demonstrated this system at exhibitions 8 times for general users both in Japan and overseas. In the exhibitions, we exhibited the entertainment system and approximately 1800 people experienced it in total. We describe the users' experiences, a survey, and the reactions and comments in exhibitions below.

5.1 Users' Experience in Exhibitions

At the beginning of users' experience, we tell them You can roll out any object with Petanko Roller. What do you want to roll out?, and ask them to choose an object to squish. For these demonstrations, we prepared sample objects: a toy car, a kettle, a doll, a sneaker, and so on. Objects brought by users can also be chosen.

In the initial phase of flattening the object, we tell users to move the device slowly, with little pressure, so that they can better check the reality of the haptic sensation of the virtual object. After that, we let them apply pressure to the virtual object through the device to flatten it. According to the pressure and motion of the device, the object is squished, and the process ends when the object becomes completely flat. At the end, at some exhibitions, we gave the user the flattened object as a piece of paper (card) as a souvenir (Fig. 13).

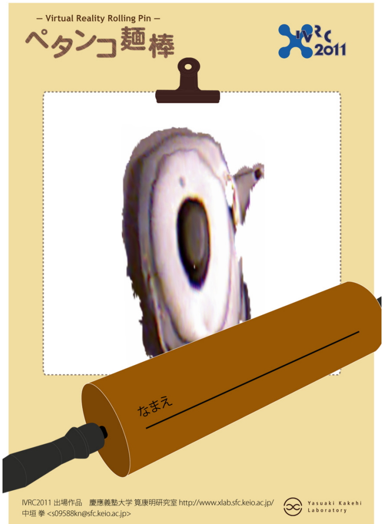


Fig. 13. An example of a printed card as a flattened object

5.2 Reactions and Comments in Exhibitions

Next, we describe the reactions and concrete comments of users at the exhibitions. Objects that are too hard to deform in the real world, such as the toy car or the kettle, were quite often chosen as the object to roll out. Users' personal objects, not only bags or cameras but also body parts of themselves or an accompanying person, were often chosen. When human's body were chosen, we let users to lay their upper body on the table top display in the detecting phase.

At the stage of checking the reality of haptic sensations, many users were surprised when the device actuated at the moment it was placed over the image. Moreover, many users commented, The sensation of rolling out objects was pleasant. In particular, when body parts such as faces were chosen, we could see users enjoying the visual changes, as if their facial expressions were changing as they squashed them. Also, some people commented that they felt special sensation or emotion when squishing themselves or accompanying person.

However, some users commented, “It was hard to feel the haptic sensations,” when the detected objects were too small, or when the object was not very uneven. One reason for this could be that the system is unable to detect small unevennesses with the distance resolution of Kinect. In addition, there were some cases of poor object measurement because the infrared rays emitted from Kinect were reflected by, or went through, objects with a reflecting surface or some degree of transparency. Also, there were difficulties for children such as less power to squish or short arms to reach at the back of tabletop display, especially seen at some exhibitions which has many children for visitors. However, we could see many children enjoying squishing object together with the help of their parents (Fig. 14).

Fig. 14. A child and a parent enjoying Petanko Roller together

We also conducted a survey in the form of a questionnaire to collect users' comments in an exhibition named “Ishikawa Dream Future Festival 2011.” There were 99 questionees answered. Each participant was asked to answer their impression through the experience as below.

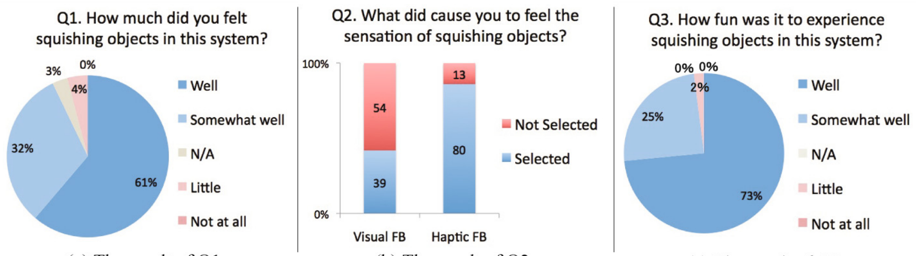
- $Q1$ How much did you felt squishing objects in this system? (1=Not at all, 2=Little, 3=N/A, 4=Somewhat well, 5=Well.)
- $Q2$ What did cause you to feel the sensation of squishing objects? (Visual Feedback, Haptic Feedback, Unknown, Others) [multiple answers allowed]

– $Q3$ How fun was it to experience squishing objects in this system? (1=Not at all, 2=Little, 3=N/A, 4=Somewhat well, 5=Well.)

As for the result, toward $Q1$, our result came out to an average of 4.51 and variance of 1.06 (Fig. 15 (a)). This indicates that most participants understood the intention of the work and they actually felt it.

In addition, as asking 93 participants, who answered more than 4 in $Q1$, to answer the reason in $Q2$, we got the result of 44% chose visual feedbacks, 86% chose haptic feedbacks, 1% chose unknown, and no one chose others (Fig. 15 (b)). This result prove that haptic sensation using the interface was primary factor to express squishing objects. The visual feedbacks provided by projector also had effects in some extent for representing it.

Besides, for the result of $Q3$ which asked participants for the satisfaction of the experience, the an average was 4.7 and the variance was 0.34 (Fig. 15 (c)). From this outcome, it can be said that the experience provided in the system have high entertainment rate.



(a) The result of Q1. (b) The result of Q2. (c) The result of Q3.

Fig. 15. The result of the questionnaire

6 Conclusions

In this paper, we proposed an entertainment system for flattening any physical object in real world using rolling-pin-based interface. The interface we developed can represent both shapes and textures of digital objects by clunk modules and brake for the tires. Through exhibiting the system, we found that the experience of squishing objects provided by this system is realistic and enjoyable to some extent.

Future research could consider using advanced physical simulations in the algorithm, to obtain greater realism. Representing various kinds of materials other than clay, by adjusting the algorithm and device design could be another subject. To enhance the haptic sensations, several ways of upgrading the device design could be considered: installing vibration speakers, increasing the maximum value of the thickness range for the clunk mechanism, or downsizing the device.

In addition, the previously noted problem of errors in object measurement using Kinect need to be solved. We are thinking of increasing the precision by introducing a high-resolution camera with Kinect, or upgrading the image-processing algorithm.

In future work, we will propose other applications using this interface. Examples are applications for representing information that is difficult to interpret visually, such as the representation of altitudes on maps, or applications that include game elements as entertainment content. We will also propose to apply this interface for computer aided design (CAD) softwares, which enable users to manipulate shape of digital objects intuitively and provide the shape and texture of the object as haptic feedbacks interactively at the same time.

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