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Garden Aqua: Tangible user interface study using levitation

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Abstract

Garden Aqua is a tangible user interface (TUI) that interacts with several balls floating over a water stream. Water is pumped up from the nozzles of several water pumps, and the ball floats above the water stream as a medium. The motion sensor at the top of the Garden Aqua detects the user's hand gesture, and the sensor allows the user to change the position of the ball and adjust the height of the water stream in real time. To apply Garden Aqua system to application works, we have created the Tone Matrix which composes a music of symphonious harmony using a user's hand position and motion. And it was exhibited at Siggraph Asia 2013. In addition, we analyzed the elements of TUI framework of two representative studies and Tone Matrix. Tone Matrix has most elements of TUI. The partially contained haptic direct manipulation element can be supplemented by an intuitive gesture control using motion sensors. It is expected that this study helps carry out further studies on TUI in practice and by analyzing TUI elements.

Keywords: Tangible user interface, TUI, Levitation, Ambient display, 3D interface, Image processing.

1 Introduction

In recent years, studies on Tangible User Interface (TUI) are constantly evolving. Different with the while existing Graphic User Interface (GUI) which deals with digital information such as a keyboard, a mouse and a monitor. TUI uses the abundant human sense of sight, hearing, touch, and body to connect the digital world with the physical world through actual interaction such as tactile manipulation and physical expression [1]. Users can interact with the digital world by combining with digital information through media of ordinary objects such like sound, light, air and water that are made up of atoms in the real world. It is considered as the main difference with the existing graphic interface [2].

Many studies on tangible interface have been carried out to embody its prototype and to develop the new system so far, however, their interactions with physical objects have been mostly performed on a two-dimensional surface. In the study by Jinha Lee and Tobias Alrøe, it was determined that the physical interaction with a user is feasible on a three-dimensional space through a levitation using various media as going beyond the boundary that the interaction is feasible only on a two-dimensional space [3,4].

In this study, the medium for the levitation of Garden Aqua system is water (Figure 1). Water is a substance that we interact frequently in our daily lives. Water fountains have been set up for public arts and entertainment from ancient times, and they have been created in various shapes from differences of the

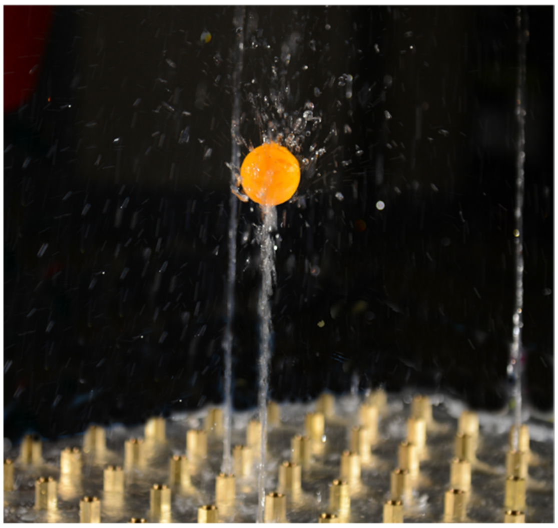


Figure 1 Levitation of Garden Aqua system using water as a medium

height or forms of the water streams. Garden Aqua system is a new type of TUI system that blends physical objects and digital virtual information in a 3-dimensional space. This system uses water stream to control the height of the water stream and the movement of levitating balls. In order to develop Garden Aqua system, it needs to design 5 elements as follows. Ball levitation using water, vertical height control, hand tracking, lighting system and 3-D calibration are essentially required. Accordingly, we present Garden Aqua system, which is a 3D TUI system using water levitation. And we produced a Tone

Matrix, which is a work designed by Garden Aqua system. The purpose of this study is to construct a research method of 3D TUI system through a series of processes for design, production and analysis by displaying the manufactured tone matrix and analyzing it according to TUI framework elements.

2 Background

2.1 Tangible user interface

Tangible User Interface (TUI) enables to embody an interface that is impossible for computer to express by itself as connecting digital environment to physical environment [5]. TUI provides an interface for specific application using a real physical form while Graphic User Interface (GUI) means an interface by a number of tools composed of pixels of a screen. That is, TUI can provide an interface that exactly match up with a user's physical environment while GUI should take unnecessary works to match to lots of interfaces [2].

Hornecker (2006) suggested the Framework of TUI [6]. As shown in (Table 1), the TUI Framework is classified into 4 categories; Tangible Manipulation, Spatial Interaction, Embodied Facilitation and Expressive Representation. The first category, Tangible Manipulation, is for smooth operability and reaction of the interface, i.e., how much a user express the tangible interaction physically. The second category, Spatial Interaction, is for applied tangible interaction in a real space and for movement of the interaction in the space. The third category, Embodied Facilitation, is for how much the material and spatial compositions of the product have an influence on users (or gallery)'s collective behavior. The last category, Expressive Representation, is for the expression and comprehension levels of elements and digital representation used in TUI. It was emphasized that the representation results induced from actions applied in practice should be connected smoothly and definitely connect.

2.2 Levitation

A well-known work on levitation is the "ZeroN" (Figure2a). Using magnetic levitation, which has been studied for a long time, the object has been floated in the air, and the object has been further developed to change the magnitude of the magnetic field according to the position of the object. In addition, by reading the depth value of an object through an infrared camera, a user can read the position of the object in a three-dimensional space as well as a two-dimensional plane by moving the object within the magnetic field. Through this two technology, a natural moving in the air was enabled not influenced by gravity. ZeroN also can be applied in several ways. It changed the simulation of physical phenomenon that only possible in the virtual world to the type as possible in the real world. Or through ZeroN system, it can be provided physical layout of buildings at architectural field and manipulate the essential components such as lighting and camera at the same time. That was impossible in the existing real-type interface system.

Another study of aerial support is "Aerial Tunes" (Figure2b). As the author stated, “In Aerial Tunes we expect the magic of the floating balls to be intriguing as much as the people interacting with the installation for the people watching it”. Aerial Tunes system is a more artistic and magical expression than technical expression.

Aerial Tunes consists of six cubes and bubble balls. Each cube includes a sensor that checks for distance and movement, and a

Table 1 TUI framework

Category	Element	Contents
Tangible Manipulation	Haptic Direct Manipulation	Can users grab, feel and move the 'important elements’?
	Lightweight Interaction	Can users proceed in small, experimental steps? Is there rapid feedback during interacting?
	Isomorph Effects	How easy is it to understand the relation between actions and their effects?
Spatial Interaction	Inhabited Space	Do people and objects meet? Is it a meaningful place?
	Configurable Materials	Can we configure the space at all and appropriate it by doing so?
	Non-fragmented Visibility	Can everybody see what’s happening and follow the visual references?
	Full Body Interaction	Can you use your whole body?
	Performative Action	Can you communicate something through your body movement while doing what you do?
Embodied Facilitation	Embodied Contraints	Does the physical set-up lead users to collaborate by subtly constraining their behavior?
	Multiple Access Points	Can all users see what is going on and get their hands on the central objects of interest?
	Tailored Representations	Does the representation build on users’ experience?
Expressive representation	Representational Significance	Are representations meaningful and of long-lasting importance?
	Externalization	Can users think and talk with or through objects, using them as props to act with?
	Perceived Coupling	Is there a clear link between what you do and what happens?

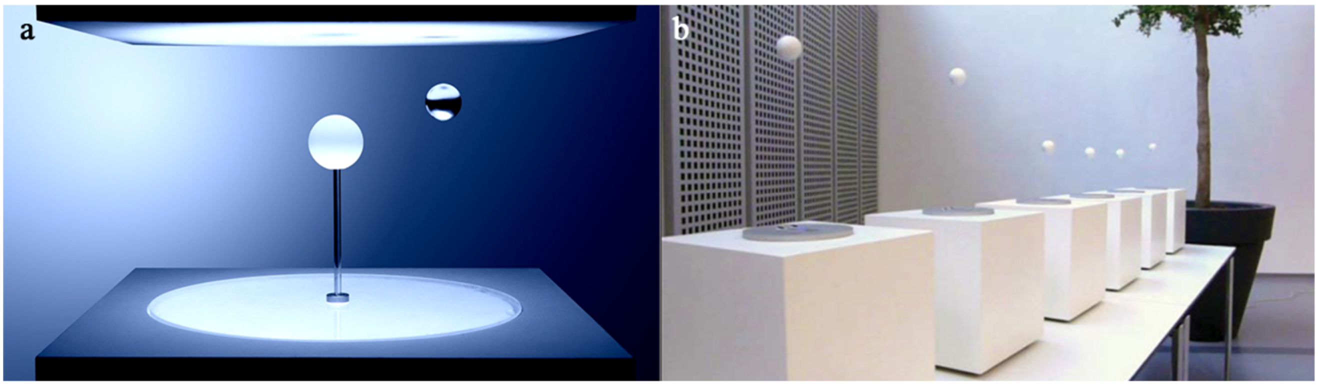


Figure 2 (a) ZeroN, (b) Aerial Tunes

blower that can wind vertically. The wind from the underlying blower caused the ball to float in the air. The sawn is produced and reproduced according to the height and position of the ball. The six boxes used the same algorithm, but the sound being played is mixed into a stereo soundscape in accordance to the (in the audio software predefined) physical position of the cube in relation to the speakers. This makes the soundscape seem more spacious to the audience.) Aerial Tunes made abstract mood by using the inspired sound from a wind bell and Tibetan songs.

2.3 Tone matrix

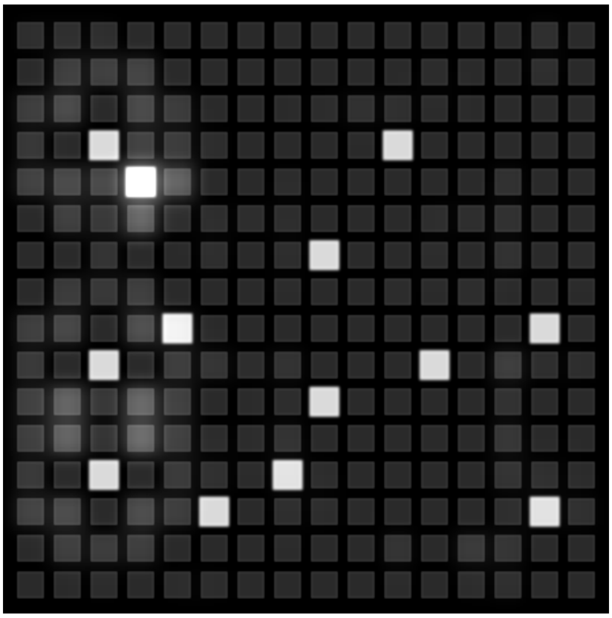


Figure 3 Tone Matrix

Tone Matrix is a tool for creating harmonious music with simple user interaction (Figure 3). There are 256 cells of 16 cells on X-axis for time and 16 cells on Y-axis for scale. Through a mouse, a user can produce music as turning each cell on or off. The music is played as follows; a cell focused on X-axis moves one cell from the left to the right. When arrived at the end of X-axis, the cell returns to the initial point and moves from the left to the right again. If the X value of the cell is focused on, and if the cell is turned on, the corresponding note is played. If a user selects several cells, the corresponding notes with the cells are played repeatedly along the X-axis. If harmonious notes on Y-axis are arranged differently although the same cells on X-axis are selected, finally beautiful music can be produced.

3 Design

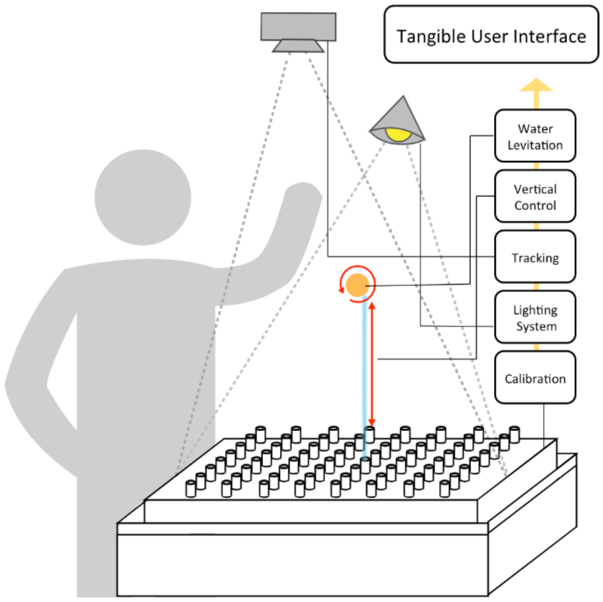


Figure 4 Design of Garden Aqua

Garden Aqua system uses water as a levitation medium, so it is necessary to put the lower section of the device in water. Each pump motor of the lower section sucks up water, and the sucked water takes the shape of each water streams, then be shoot up. A depth camera installed downward from the upper side of the Garden Aqua is installed to recognize the user's hand, thereby changing the height of the water stream. This allows the user to place the ball in any part of the space, recognize the hand with a depth camera, automatically draw the water, and place the ball on the water stream. The lighting system also illuminates each ball and stream to make them more visible. The design method is illustrated in (Figure 4).

3.1 Levitation

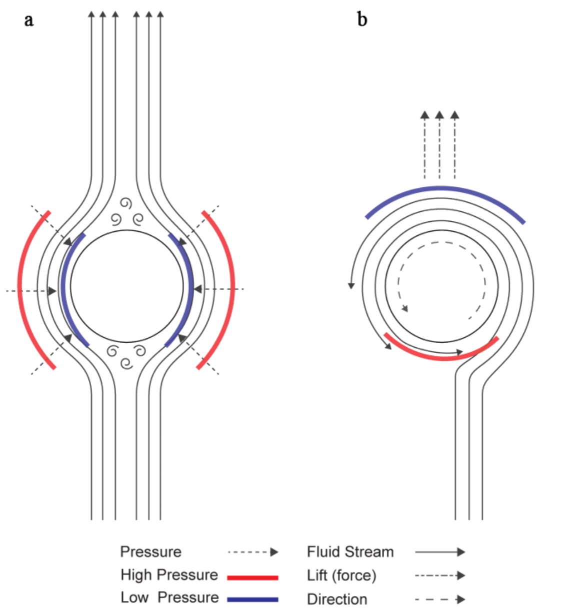


Figure 5 Principle of levitation

As shown in (Figure 5), when the user puts the ball on the water stream in the same direction, the ball keeps going up and down on the water stream, and does not fall down, and keeps its position continuously. This is because the pressure of the moving fluid (water) is greater than the pressure of the stationary gas (air). As you can see in (Figure 5a), the water is passing on both sides of the ball. This phenomenon is likewise because the pressure of the outer water moving forward is stronger than the pressure of the air between the ball and the water, so that the ball does not fall out and the ball stops moving inside the moving water.

The phenomenon shown in (Figure 5b) is a phenomenon applying the phenomenon shown in (Figure 5a). The levitation phenomenon is applied to a ball on a single stream. When the water rises up the ball, the outside air is applied with a weak pressure, and at the same time strong water pressure is applied to the water coming down the ball, causing the ball to continually circulate in one place due to the difference in pressure. In addition, due to the surface tension of the water, the sphere always rotates in the same direction, and the fluid velocity at the upper and lower sides is changed to generate lift.

$$L = \frac{1}{2}\rho V^2 AC$$

L : Lift Force

ρ : Fluid density

V : Stream velocity

A : Area of sphere

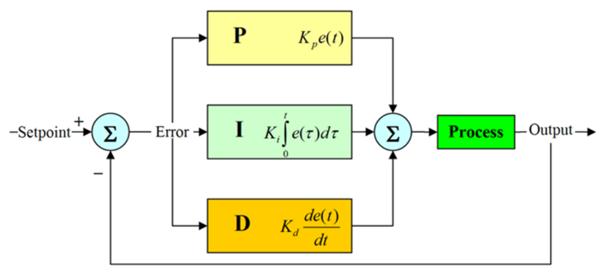
C : Lift coefficient

Figure 6 Formula of lift force

As shown in (Figure 5), lift becomes stronger as fluid density, fluid velocity, and contact area increase.

3.2 Vertical height control

The ball should be used that has enough mass can be levitate. The mass is inversely proportional to acceleration when given the force (F=mA). In Garden Aqua, this formula is to be used also. In other words, when the ball receives levitate force(F) then receives acceleration(A) to float in the air. This acceleration(A) is inversely proportional to the mass of the ball, so, even if the pressures of the water stream are the same, the lighter mass can given the more acceleration caused by levitate force, the higher the height of the ball's floating.



$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

Defining u(t) as the controller output, the final form of th PID algorithm is :

K_p : Proportional gain, a tuning parameter
K_i : Integral gain, a tuning parameter
K_d : Derivative gain, a tuning parameter
e : Error = SP - PV
t : Time or instantaneous time (the present)
τ : Variable of integration; takes on values from time 0 to the present t.

Figure 7 Formula of PID algirithm

The height of the water stream can be changed by control of water pressure that can be controlled directly by pump motor. At this time, the formula of PID Algorithm such as (Figure 7) is applied.

3.3 Hand tracking and light system

When a user tries to place a ball on a water stream coming from a nozzle installed at the bottom of the Garden Aqua, the water stream of the nozzle is automatically raised to a suitable position. Then the user can intuitively put the ball on the water stream of the desired height easily. It allows to recognize the position and the shape of the user's hand and to control the water stream by processing images using a depth camera installed on the top of Garden Aqua.

The processing images using a depth camera is the followings; as shown in (Figure 8), images are input into the camera in real time. In the image frame including the hand, objects except the hand are extracted in the image through Adjustment Threshold. The extracted hand shape is determined by Contour tracking, and then calculate to which nozzle is subject. And then, the spurting nozzle and the height and the pressure of the water stream are calculated from the height of the nozzle and the depth observed by the depth camera, and finally, the water stream is spouted from the nozzle.

A light system is installed on Garden Aqua. To let the user check user's hand position, the system plays a role to show the hand's position through light. By regulating colors and positions of the light differently, the light is projected upon different water streams to express various data on streams of water.

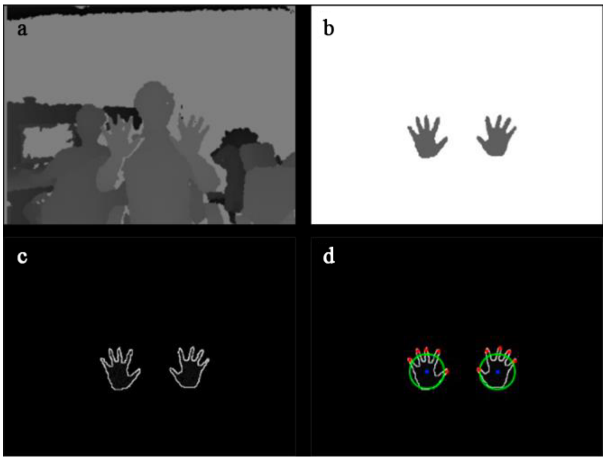


Figure 8 Hand tracking and light system (a) Gray-scale image of real world. (b) Extraction through adjustment threshold (c) Contour tracing (d) Segmentation of hands

3.4 3-Dimension calibration

Some problems on precision may be caused to apply to image data after calculating the data themselves from a lens of one depth camera. In particular, the errors are slightly different depending on the position of the lens. This phenomenon is able to be solved by calibration (Figure 9). Two points having exact distances (80cm, 150cm) are placed by arranging checked patterns of black and white colors on each position, and then the distances are measured. Calibrate the obtained values of x-, y- and z-axes by multiplying by the calibration value. And, calibrate the pump motors by height test for each pump because they have pressure difference by product.

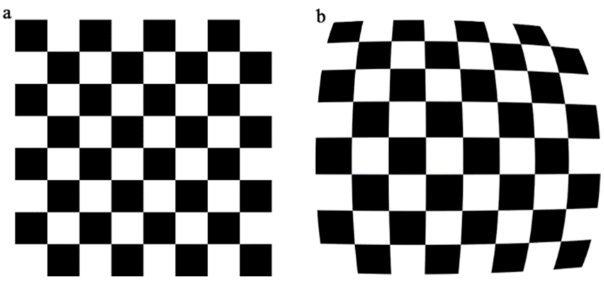


Figure 9 (a) Calibration completed (b) Calibration required

4 User interaction

4.1 Positioning of balls

For Garden Aqua, balls are put on jets of water. A user holds the ball above one of several nozzles after choosing the corresponding ball, and then a water stream is automatically shot slightly below to the height of the ball, and the user puts the ball upon the water stream. Not only one ball but balls as many as the number of total nozzles can be put on water streams at the same time, and only one ball can be put on one cell. Balls should be placed as controlling it properly.

4.2 Controlling of height of water jet

A ball on a water stream is stopped in its place as levitating. In Garden Aqua, the pressure of the water streams is controlled by using this principle. The ball on the water stream can be moved vertically up and down by fine control of the pressure. The pressure of the water stream is regulated by height and position of the user's hand. The user puts his/her hand on the water stream on where a ball is levitated. Then, the distance between the user's hand and the water stream is calculated by a depth camera. When the user's hand is somewhat gone up higher than the height of the water stream, the height of the water stream gets higher as heightening the water pressure. On the contrary, when the user's hand is somewhat gone down lower than the height of the water stream, the height of the water jet gets lower as lowering the water pressure. Accordingly, the height of the ball levitating on the water stream can be naturally regulated as the height of the water stream is regulated.

5 Application of Garden aqua: Tone Matrix

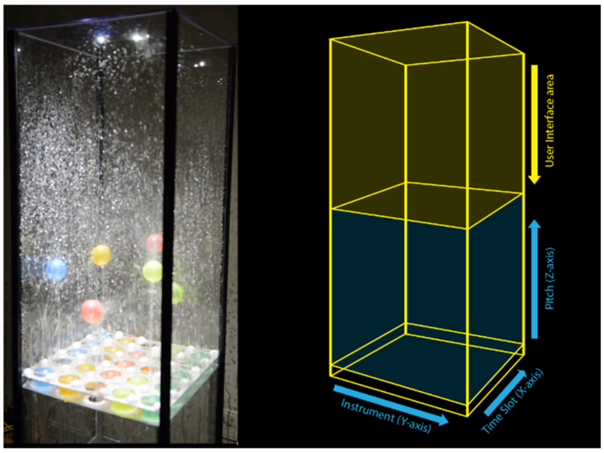


Figure 10 Tone Matrix structure

In this study, we make an application work applying the existing Garden Aqua system. In existing Tone matrix work, the music played changes as the X, Y positions of the cell change. As shown in (Figure 10), one more dimension was added to Tone Matrix applying Garden Aqua than the existing work. The X-axis is a time axis like the existing work. Repeatedly moving from left to right in the X-axis, plays the sound of the cells of the X positions being focused. On the other hand, the Y-axis and the Z-axis mean the type of instrument and the pitch of the sound, unlike existing works. When the Y position is changed, the musical instrument type of the music to be played is changed. Depending on the Y position, it is selected as one of a total of 8 instruments (flute, trumpet, violin, cello, harp, marimba, piano and organ). And, when the position in the Z axis increases, the pitch of the sound of the corresponding cell increases. So, by using various instruments and various pitch, more variety of music can be made. The operation method of Garden Aqua Tone Matrix is as the following.

Tone Matrix has 36 cells, 6 for X-axis and 6 for Y-axis, and each cell has a motor pump and a nozzle. A ball is located on every cell. A user makes a motion recognition equipment (Kinect) read the user's hand motion. The equipment is installed on the top of Tone Matrix. A lighting system is also installed on the top of Tone Matrix. The light system illuminates corresponding cells to the position of the user's hand in real time whenever the user moves user's hand.

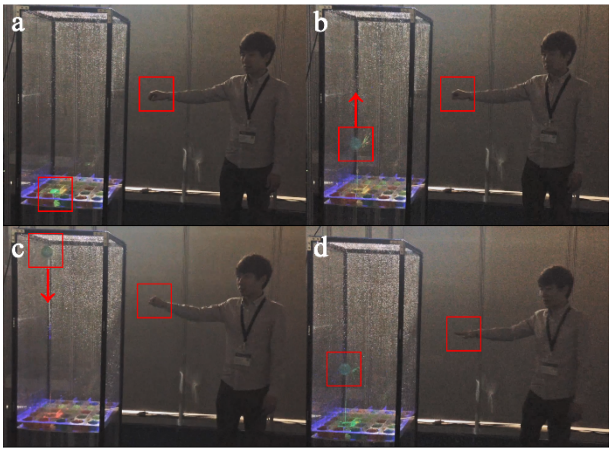


Figure 11 User input gestures for Tone Matrix (a) Select (b) Upward (c) Downward (d) Deselect

The user can use 4 gestures as Tone Matrix inputs. The first input is a gesture that selects a cell (Figure 11a). When the user motions to pick a ball with user's fingers on the corresponding cell, the cell is chosen, and the light system on the top illuminates the cell continuously. When the cell is chosen, the user can control the height of the water stream above the selected cell. Second input is a gesture to raise user's hand (Figure 11b). When the user put user's hand up on the chosen cell, the pressure of the water jet strengthens, and the ball is gone up to the height of the user's hand. As the ball height increases, the pitch of the sound of the cell increases. Third input is a hand gesture down (Figure 11c). When the user put user's hand down on the chosen cell, the pressure of the water jet weakens, and the ball is gone down to the height of the user's hand. Contrary to the second input gesture, the lower the height of the ball, the lower the pitch of the sound in that cell. The last input is a gesture that deselects the cell (Figure 11d). When the user motions to unpick a ball as unfolding user's fingers, the ball is stopped in the position. At the same time, music is produced by matching the corresponding sequences, notes and instruments through position values of X, Y and Z-axes of the ball depending on the method of producing music of the above mentioned Tone Matrix. The user can produce lots of music as controlling many balls.

6 Discussion

We produced Tone Matrix among application methods utilizing Garden Aqua system in practice. This product was selected for Emerging Technologies in Siggraph Asia 2013, and it was exhibited to let many users use for 3 days. We checked whether this product is accorded with TUI elements by using 4 elements of TUI Framework suggested by Hornecker (2006). In addition, we examined the difference between two representative studies using levitation by checking and comparing them. We marked ○ if the product exactly embodies TUI elements, △ if partially embodies them, or × if not embodies them. The following (Table 2) shows embodiment of TUI elements by product.

Table 2 Embodiment of TUI elements by product

Category	Element	Tone Matrix	ZeroN	Aerial Tunes
Tangible manipulation	Haptic Direct Manipulation	△	○	○
	Lightweight Interaction	○	○	○
	Isomorph Effects	○	○	○
Spatial interaction	Inhabited Space	○	○	○
	Configurable Materials	○	○	△
	Non-fragmented Visibility	○	○	○
	Full Body Interaction	△	△	△
	Performative Action	○	○	△
Embodied facilitation	Embodied Constraints	○	○	○
	Multiple Access Points	○	○	○
	Tailored Representations	○	○	○
Expressive representation	Representational Significance	○	○	○
	Externalization	○	○	○
	Perceived Coupling	○	○	○

All of three products embodied most elements, however, they partially embodied for several elements. In Haptic Direct Manipulation of Tangible Manipulation, Tone Matrix has limits that a user can control balls indirectly. But it's because the real working parts and the controlled parts were separated in order to agreeably control Garden Aqua using water. The motion sensor located at the top out of the product catches intuitive gestures of a user's hand, and balls located in the product move instantly. Therefore, it may be considered as a complement of the direct control elements. In Full Body Interaction of Spatial Interaction, all products are partially embodied. All of the three products are able to be controlled by hand and arm, but not by whole body. In particular, Zero N has more limits. In Performative Action, Tone Matrix is able to apply hand's motion to the product by tracking the motion in real time, while the others partially apply to the systems.

7 Conclusion

Many studies on TUI have been carried out until recently, and lots of interfaces could be emerged by these studies. This study on the levitation by 3D TUI has been carried out by various media from the several existing studies. In this study, the levitation was realized by using water as the medium, and a 3D TUI, the Garden Aqua system, was produced.

To produce TUI of Garden Aqua, the levitation was designed using difference in water pressure by each height of balls floating on water jets. And, the vertical heights of the balls and the water jets were controlled by regulating pressures of the water jets spurting from nozzles of water pumps. In addition, we applied a user's commands as being input through the hand-tracking technique in real time in order to provide the feedback to the user in real time, and we showed the relevant feedback to the user through the lighting system. Finally, it enabled to exactly control without any distortion through a 3-D calibration process. By the above designs, the simple and intuitive TUI interaction was enabled so that Garden Aqua system and the user can select locations of the balls and control heights of the water jets.

In addition, we produced Tone Matrix, an application of Garden Aqua system, and exhibited it in Siggraph Asia. Accordingly, we analyzed elements by Framework of TUI together with two representative products embodying Tone Matrix and levitation TUI. As the result, most elements were embodied in three products, however, several elements were required to be filled up. Additional studies will be carried out on the elements necessary to be complemented as the result of the analysis of this study. And we try to contribute to the relevant TUI studies by producing and analyzing various products using Garden Aqua system.

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