Granular Material Display: Information Presentation System using Two Layers of Granular Material and Speakers

Satoshi Nakanishi*, Shumpei Akahoshi†, Mitsunori Matsushita‡,
Graduate School of Informatics, Kansai University, Osaka, Japan
Email: {*k209555, †k854371,‡t080164}@kansai-u.ac.jp,

***Abstract*—In this paper, we propose a method of presenting information by manipulating granular material that are placed on two layers. In recent years, substantial displays, which are displays that present information by manipulating some form of material have been gaining traction in the research community. As these displays utilize materials found in nature, they are capable of blending in with the surrounding environment. To create a novel substantial display, we propose a substantial display that utilizes granular material and speakers. In the proposed system, two types of granular material with different colors and sizes are placed on two layers. By emitting sound waves from a speaker installed under the lower layer, the granular material on the lower layer rises to the upper layer and creates a pattern as the color of the granular material on each layer is different. To determine the optimal parameters, we examined four different granular material and varied the sound wave frequency. Finally, we implemented a system that allows users to emit sound waves at any arbitrary position on the canvas with two layers of granular material.**

***Index Terms*—Frequencies of Sound Waves, Substantial Display, Information Presentation**

I. Introduction

Currently, we have access to various types of information and numerous ways in which this information is being presented. In recent years, display devices have gained increased usage with the mass adoption of smartphones, televisions, and personal computers. In addition, display devices without light emission such as displays that present information by manipulating substances have been developed as well. In this paper, we classify these displays as substantial displays. Substantial displays operate by manipulating substances resulting in a pattern that appears either by the reflection of visible light or the change in shape of the substance. This mechanism can intuitively present information in the real world using materials that are found around us [1]. As substantial displays can blend in with the surrounding environment due to the characteristic of the granular material, they are used in fields such as media art and advertising. The types of substantial display currently being used, however, are limited. In this paper, we propose a new substantial display that makes a novel expression. To blend in with the surrounding environment, it is preferable to use materials that we are familiar with while implementing the substantial display. As such, our system uses granular material to implement the substantial display. Granular material such as sand is not only common, but an abundantly available material. For example, it is commonly found at sandboxes at parks and beaches. Furthermore, sand has been used as a medium to present information such as sand painting and in the hourglass.

II. Related Work

Malte *et al.* proposed a tabletop interface called *Madgets* that manipulates objects placed on a plane using multiple electromagnets [2]. In this system, by applying magnetic force as an external force, it is possible to move an object to the position on a plane that is touched by the user.

Hirayama *et al.* implemented the *Shaboned Display* which uses soap bubbles that expands and contracts to simulate pixels of a screen [3]. Furthermore, they proposed a method to detect the bursting of soap bubbles as input representing changes in the surrounding environment. Using that method, they implemented the *Shaboned Chirne*, an acoustic device that generates different sounds depending on which bubbles bursts.

Leithinger *et al.* implemented a three-dimensional desktop display called *Relief* which operates based on controlling the vertical movement on aluminum pins [4]. As this display is a three-dimensional representation, the user can intuitively understand models such as terrain.

Pixie dust of Ochiai *et al.* is a system that manipulates objects using sound waves [5]. It can float in the air and move objects to an arbitrary position in the three-dimensional space by creating a standing wave with ultrasonic speakers.

Ketsuro-Graffiti of Tsujimoto *et al.* is a display that utilizes a natural occurring process called water condensation [6]. In this system, the creation of dew condensation is controlled by changing the temperature of the mirror surface using a Peltier device.

MOSS-xels of Kimura *et al.* is a system that presents information by using moss blocks to simulate pixels of a screen [7]. In this system, it utilizes the fact that the leaves of moss are closed in a dry state and opened in a wet state to represent a pixel. To adjust the humidity condition, a pump and a fan is installed on the back of the moss block.

inFORM is a display that expresses a three-dimensional shape by adjusting the vertical movement of pins in plastic rods [8]. This system can recognize three-dimensional objects such as human hands using a camera and reproduce the movement. It is possible to change the position and orientation

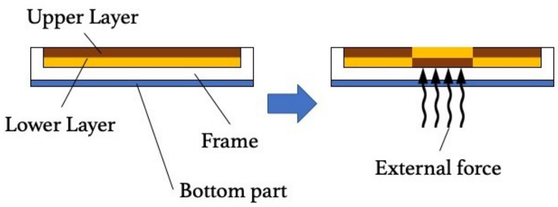


Fig. 1. Proposal

of objects placed on plastic pins. Furthermore, by projecting different colors using a projector, it is possible to express three-dimensional graphs.

Bellies Wave is a display that is based on rubber material and utilizes the characteristics of rubber that changes color when stretched to simulate a pixel [9]. The pixel representation is varied by feeding air to two layers of rubber films with different colors resulting in expansion and shrinkage.

III. Proposal

In this paper, we propose a method to express shades using granular material. As shown in Fig.1, two kinds of granular material with different colors and sizes are arranged in two layers. By applying external force under the lower layer, the arrangement of the granular material is changed. As a result, a pattern appears on the upper layer as the colors of these granular material are different. We propose two methods of applying external force under the frame as illustrated in Fig.1, namely magnetic force and sound waves.

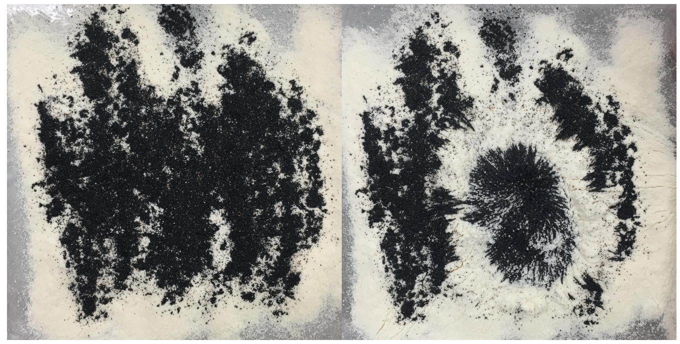
The details of each method are described below.

A. Method using magnetic force

In this method, we use iron sand and granular material not affected by magnetic force. First, the granular material not affected by magnetic force is placed in the lower layer, and iron sand is placed in the upper layer. By positioning a magnet close to the granular material on the lower layer, thus attracting the movement of the iron sand from the upper layer, we would like to study if patterns are able to be formed on the upper layer due to the color difference of these granular material.

B. Method using sound waves

In this method, we use two kinds of granular material that are different in color and size. First, the granular material with smaller grain size is placed on the lower layer, and the one with larger grain size is placed on the upper layer. By applying sound waves from a speaker installed under the lower layer, the granular material on the lower layer rises to the upper layer. We would like to study if patterns are able to be formed on the upper layer due to the color difference of these granular material.



before after

Fig. 2. Magnetic force

IV. Experiments to study impact of different external forces

We conducted experiments to examine the suitability of either external forces for our proposed system. To conduct the experiments, we first built the frame of the prototype with plastic material with the width and height of 120 mm × 120 mm and thickness of 5 mm on each side. Next, in order to construct the surface for placing granular material, a material that allows for easy transmission of the external force was pasted to the bottom of the frame as external force is applied from under the system.

A. Experiments of the method using magnetic force

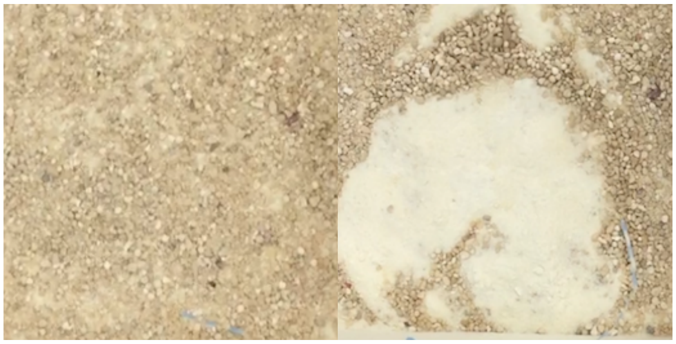
The experiment was conducted to examine whether magnetic force is suitable as the external force of our proposed method. In this experiment, granular flour was placed as a granular material not affected by magnetic force on the lower layer, and iron sand was arranged on the upper layer. A polyethylene film was pasted to the bottom of the frame. We experimented by varying the distance of a magnet to the bottom of the system.

The results of the experiment is shown in Fig. 2. The iron sand placed on the upper layer was attracted to the magnet, however only a small amount of iron sand gathered at the position where the magnet was positioned. The initial thought that the iron sand would gather below flour placed in the lower layer did not occur. From this result, it can be concluded that using magnetic force as the external force is not suitable for our proposed method.

B. Experiments of the method by sound waves

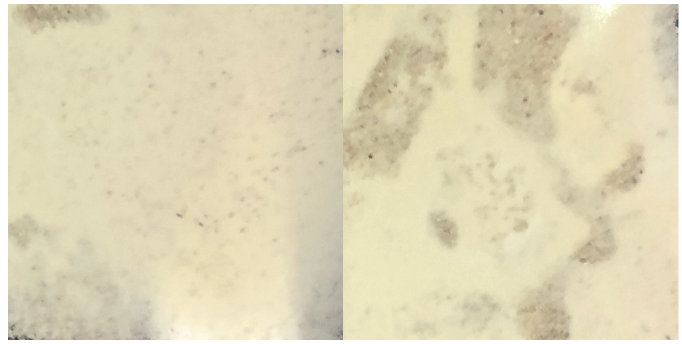
The experiment was conducted to examine whether sound waves are suitable as the external force of our proposed method.

In this experiment, lighter flour was placed on the lower layer, and brown sand was arranged in the upper layer. A polyethylene film was pasted to the bottom of the frame. A speaker connected to the PC was installed at the bottom, and sound waves of various frequencies were emitted. In this experiment, two types of speakers were used. In addition, the



before after

Fig. 3. Sound waves force(surface)



before after

Fig. 4. Sound waves force(bottom side)

test data of visual programming language, PureData[1] was used as the sound source.

The details of the experiment were described below.

1) When using parametric speaker: This experiment was conducted using parametric speakers to apply force only to a specific point of the system. Parametric speakers are acoustic devices with sharp directivity using ultrasound. Due to this characteristic, it is assumed that it would be suitable for manipulating the granular material. In this experiment, a commercially available parametric speaker making kit (Tristate Ltd.[2]) was used and it was found to be incapable of manipulating the placed granular material. It is assumed that the cause of this was due to a weak sound wave output from the parametric speaker.

2) When using USB speaker for PC: To output stronger sound waves, we used a commercially available USB speaker for PC (Acer Inc.[3] MS 1238US), and experimented again. The result of this experiment is shown in Fig. 3 and 4. By applying sound waves, the lighter granular material on the lower layer rises to the upper layer resulting in a pattern due to the color difference. Based on this result, it can be concluded that sound waves from a USB speaker for PC were suitable as the external force for our proposed method.

In addition, it was confirmed that the movement of the granular material changed depending on the frequency of the sound wave to be output.

V. Selection of granular material and bottom frame

A. Selection of granular material

Experiments were conducted to select two kinds of granular material used for our proposed method. In these experiments, materials that are found in nature were used to implement substantial displays that are able to blend in with the surrounding environment. We conducted experiments using four different granular material, namely (A) granular flour, (B) flour (C) brown sand, (D) green sand (see Fig. 5). The flour labeled as (A) is granular and the size of the grain is smaller than the flour labeled as (B). Also, the brown sand labeled as (C) is different in that the size of the grain is smaller than the sand labeled as (D). In addition, the colors of (A) and (B) granular material are both white, and there is no notable color difference. Therefore, excluding the combination of (A) and (B), experiments were conducted using all other combinations of the four types of granular material. As described in the previous section, we used a frame made of plastic material with width and height of 120 mm × 120 mm and thickness of 5 mm on each side. A polyethylene was pasted to the bottom of the frame. For the sound source, the test data of visual programming language, PureData was used. Various frequencies were output from the speaker MS1238US. The mass of each granular material was 18.5 g which can cover the 120 mm × 120 mm area of the frame. Then, with a camera fixed directly above, the conditions of the frame before and after applying sound waves were photographed and the lightness of the image was compared. For the image to capture the result after applying the sound wave, we took the photograph only after stopping the output of the sound wave when the movement of the granular material was no longer noticeable. For the brightness measurement, we used the histogram tool of image editing software, GIMP[4]. Brightness is expressed on a scale of 256 steps from 0 to 255, with brighter colors having a higher value. Furthermore, in order to accurately measure lightness, experiments were conducted while keeping the settings and location of the camera constant.

The before and after results of the experiment are shown in Table I, while the measured lightness difference is shown in Table II. In the combination of (A) and (C), the powders in the lower layer rose to the upper layer. Similarly, for the combination of (A) and (D), it was found that the granular material in the lower layer rose to the upper layer in the same way. However, due to the color difference of the material, it was found that the difference in brightness was greater when (A) and (C) were combined. Although there was movement of the granular material with combination of (B) and (C) or (D), when compared with the combination of (A) and (C)

[1]http://puredatajapan.info/ (2019/02/08)
[2]http://www.tristate.ne.jp/ (2019/02/08)
[3]https://www.acer.com/ac/ja/JP/content/home (2019/02/08)
[4]https://www.gimp.org/ (2019/02/08)

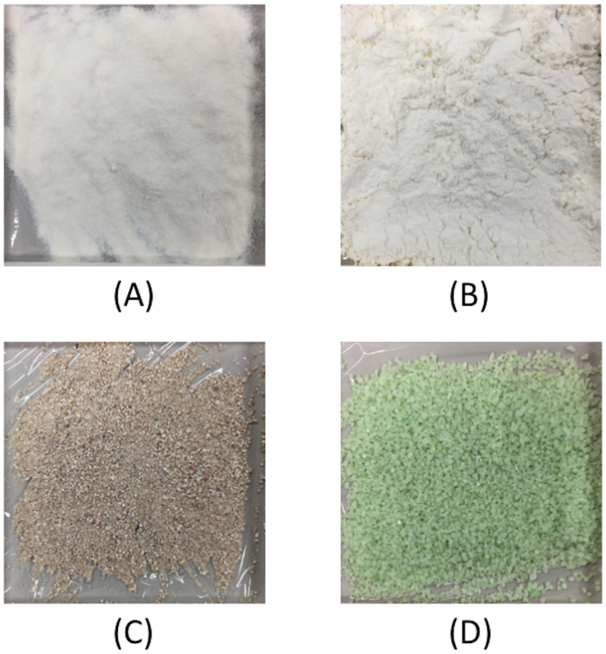


Fig. 5. Color of each material

or (D), it is noted that the area where the pattern appears is small. Meanwhile, with the combination of (C) and (D), the movement of both granular material that was more pronounced was observed. When comparing the images for before and after sound waves were applied however, the brightness difference is small. Based on these results, it was concluded that the combination of (A) and (C) is the most suitable combination of materials for our proposed method.

Therefore, in our proposed system, granular material (A), granular flour is used as the lower layer while granular material (C), brown sand is used as the upper layer.

B. Selection of the bottom frame

The bottom frame for our proposed method plays the role of transmitting sound waves emitted by the speaker to the granular material. For the purpose of selecting a material that is suitable for the bottom frame, we compared a polyethylene film which is a thin and made of soft material with a plastic plate which is rigid and has a thickness of about 0.7 mm. The result when using a plastic plate at the bottom is shown in Fig. 6 while the result of the difference in brightness before and after applying sound waves for each material is shown in Table III.

By comparing Fig. 3 and Fig. 6, it was found that when the plastic plate was used for the bottom frame, the movement of the granular material was smaller when compared with the bottom frame using the polyethylene film. Based on Table III, it was found that when the polyethylene film was used, the lightness difference was large.

Consequently, for our proposed method, a polyethylene film was deemed suitable for the bottom frame.

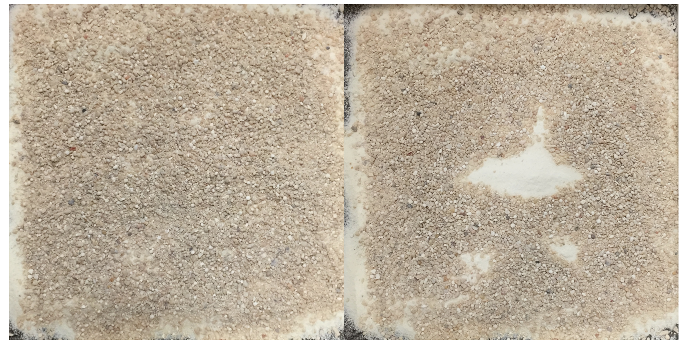


Fig. 6. Material selection at the bottom

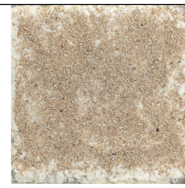
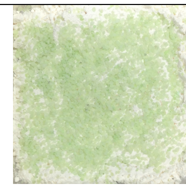
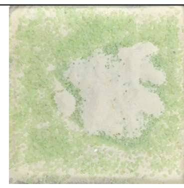
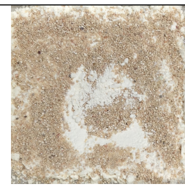
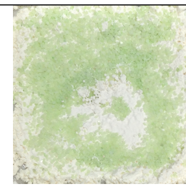
VI. EXPERIMENT TO STUDY IMPACT OF DIFFERENT FREQUENCIES

In the experiments conducted in section IV and V, it was confirmed that the movement of the granular material differs with each frequency. Based on this, we investigated which frequencies were suitable to operate with the two types of granular material used for the proposed method. Experiments were conducted to investigate frequencies that were able to manipulate the lower layer containing granular material used for our proposed method. For the results shown in section V, the proposed method was implemented by having granular flour on the lower layer, brown sand on the upper layer, and polyethylene film pasted at the bottom. As in section V, we used the frame made of a plastic material with the width and height of 120 mm × 120 mm and thickness of 5 mm on each side. For the sound source, the test data of visual programming language, PureData was used. Various frequencies were output from the speaker MS1238US. The mass of each granular material used was 18.5 g which can cover the 120 mm × 120 mm area of the bottom frame. Then, with a camera fixed directly above, the conditions before and after applying sound waves were photographed and the lightness of the images were compared. For the brightness measurement, we used the histogram tool of GIMP. Furthermore, in order to accurately measure lightness, experiments were conducted while keeping the setting and location of the camera constant.

First, the experiment was conducted with sound waves in the frequency band from 100 to 500 Hz in 100 Hz increments. Fig. 7 shows an example of the state before the sound wave was applied and the state after the sound wave was applied at each frequency. When applying sound waves at frequencies of 100 Hz, 200 Hz, and 300 Hz, the movement of the granular material was large, and a pattern was observable on the upper layer. No patterns, however, were observed at 400 Hz and 500 Hz. Based on this result, it was found that the frequency band that is suitable with the combination of granular material used was 200 to 300 Hz.

Next, we repeated the same experiment however this time with sound waves in the frequency band of 200 to 300 Hz in 20 Hz increments. The resulting state at that time is shown

TABLE I
SELECTION OF GRANULAR MATERIAL

	(A) and (C)	(A) and (D)	(B) and (C)	(B) and (D)	(C) and (D)
before					
after					

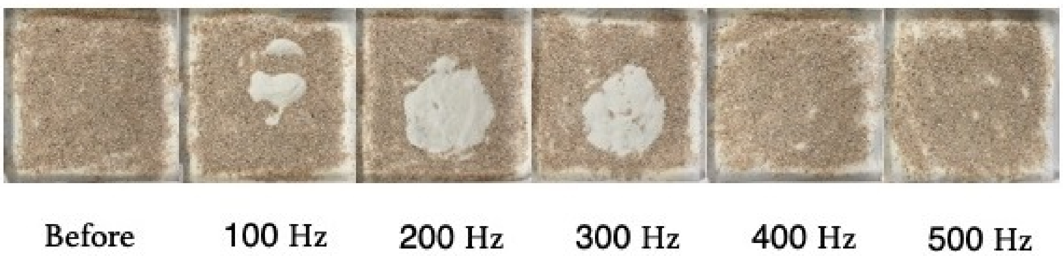


Fig. 7. Experimental results with frequency increments of 100 Hz

TABLE II
LIGHTNESS DIFFERENCE FOR EACH MATERIAL COMBINATION

		Lower layer		
		(A)	(B)	(C)
Upper layer	(C)	7.0	2.9	—
	(D)	0.5	2.1	1.7

TABLE III
THE LIGHTNESS DIFFERENCE FOR EACH MATERIAL ON THE BOTTOM

	Lightness difference
Polyethylene film	7.0
Plastic board	1.9

in Fig. 8 and the brightness as measured by GIMP is shown in Table IV. To investigate whether the pattern appeared on the entire upper layer, Fig. 8 and Table IV includes the case where only flour was spread over the entire frame. Comparing the lightness difference when only flour was used with the lightness difference when different frequencies were applied, it was found that a pattern appeared in 20 to 30% of the whole area.

In this experiment, we compared the image before any sound wave was applied and the image where the sound wave was stopped when the movement of granular material was no longer noticeable. The time at which the movement of the granular material was no longer noticeable varies with frequency however. Table V shows the time it took to reach the point where the movement of granular material was not observable for sound waves in the frequency band from 200 to 300 Hz. Based on Fig. 8, it can be noted that the average brightness is highest at 300 Hz while taking the longest time to reach the point where there was no further movement (see Table V). There was a difference of 41 seconds between 220 Hz, which had the shortest time for a pattern to appear, and 300 Hz, which had the longest time. To implement the substantial display, it was concluded that frequency selection should be done based on the particular use case because the movement of the granular material is dependent on the frequency of sound waves.

Furthermore, it was observed that the area where the pattern appeared was about 60 mm in diameter and located near the center of the speaker. Based on this finding, it was concluded

Fig. 8. Experimental result with frequency increments of 20 Hz

TABLE IV
LIGHTNESS DIFFERENCE AND CONTRAST RATIO

	Average lightness	Lightness difference	Contrast ratio
before	163.8	—	—
200Hz	171.9	8.1	0.953
220Hz	172.7	8.9	0.948
240Hz	173.8	10	0.942
260Hz	172.4	8.6	0.950
280Hz	172.1	8.3	0.952
300Hz	177.5	13.7	0.923
Flour only	200.8	37	0.816

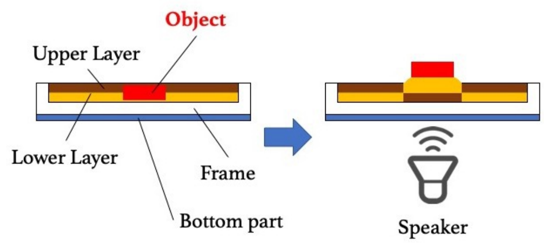


Fig. 9. Mechanism of the content

TABLE V
SOUND WAVE EXPOSURE TIME AT EACH FREQUENCY

Frequency（Hz）	200	220	240	260	280	300
Time（s）	27	14	26	34	37	55

that the area where the pattern appears in our proposed method depends on the performance of the speaker.

In summary, it is noted that the frequency of the sound wave influences two aspects of our proposed method, namely the area where the pattern appears and the time it takes for the pattern to appear.

VII. Overview of results

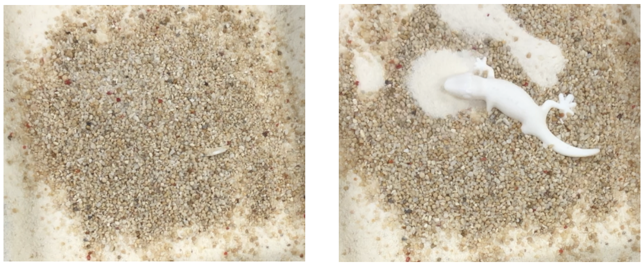
In section IV, we conducted experiments to determine which of the two external forces would be suitable for our proposed method. It was concluded that the method using magnetic force as the external force was not suitable while the method using the sound wave as the external force was able to display a pattern. When using sound wave as the external source however, it was found that parametric speakers did not result in any observable pattern while the USB speakers for PCs was capable of emitting a louder sound output and consequently was able to produce a pattern. As such, speaker performance can be classified as one of the important factors for our proposed method.

In section V, we analyzed the suitability of various granular material for our proposed method that uses sound wave as the external source and the material for the bottom frame that would allow the transmission of sound waves. Based on this experiment, it was found that granular flour and brown sand was suitable for the lower and upper layer respectively. With regards to the material for the bottom frame, we compared two different materials, one of which is thicker and harder than the other. It was observed that the polyethylene film which is made of a thin and soft material is suitable for the bottom frame.

In section VI, we conducted experiments to study the effects of different sound waves on our proposed method. It was found that granular material can be manipulated by applying sound waves in the frequency band of 200 to 300 Hz when the configuration consists of placing granular flour in the lower layer, brown sand in the upper layer, and polyethylene film at the bottom frame. Additionally, in the frequency band of 200 to 300 Hz, it was found that the speed of the granular material movement in forming a pattern varies depending on the selected frequency. Therefore, it is necessary to select suitable the frequency based on the type of content that needs to be presented on the substantial display.

VIII. Content example

In our proposed method, we manipulate the movement of the granular material in the lower layer by applying sound waves and consequently, the granular material in the lower layer would rise to the upper layer and form various patterns depending on configuration.



before after

Fig. 10. Content example

This mechanism is shown in Fig. 9. First, an object is buried between the granular material on the lower and upper layer. Next, when sound waves are applied from a speaker installed under the lower layer, the object and lower granular material would rise to the upper layer and appear on the surface (see Fig. 10).

This content consists of the frame, the bottom frame, the speaker, and two kinds of granular material. We constructed the canvas by pasting a polyethylene film to the bottom of the frame. On the canvas, two types of granular material are placed on two layers. Based on the results of experiments carried out so far, we had granular flour placed on the lower layer and brown sand on the upper layer. The speaker installed at the bottom is Vp210[5] that can produce a loud volume even though it is small in size. With frequency of the sound waves from the speaker at 220 Hz, the granular material can be manipulated in a short time. Also, from the experimental results, the area where the pattern appears is only near the center of the speaker.

Therefore, we implemented a system that can move the location of speaker and made it possible to manipulate the granular material to any arbitrary position. In order to move the speaker to an arbitrary position, a CNC rail was installed to the bottom of the canvas (see Fig. 11). By rotating the stepper motor of the CNC rail and having the belt interlocked, this would make it possible to move the installed speaker freely on the X and Y axis. The user can then move the speaker by pressing a button on the controller.

IX. Perspective

After manipulating the substance with an external source to present the information on the substantial display, it would also be necessary to restore it to the original state. In our proposed method however, it cannot be restored to its original state once a pattern has been formed. For this reason, in order to switch the presented information, we will propose a method of returning to the original state based on a phenomenon called *Brazil nut effect*. *Brazil nut effect* is a phenomenon where larger particles come to the surface when particles of different sizes are shaken [10]. In the future, we will implement a system that utilizes this phenomenon such as by shaking the entire canvas to restore it to the original state.

[5] http://www.acouve.co.jp/product/pd_vp2.html (2019/02/09)

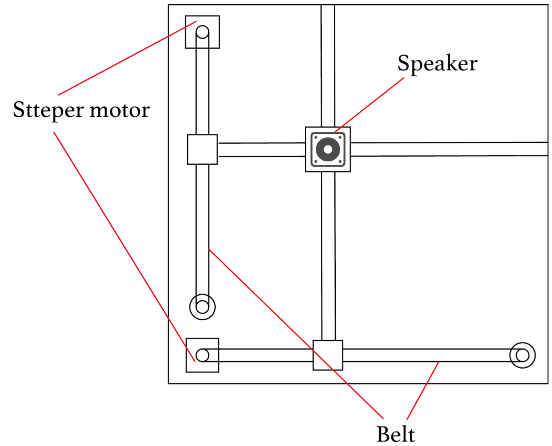


Fig. 11. CNC rail map

X. Conclusion

In this paper, we proposed a method of presenting information by manipulating granular material. In order to implement this system, we examined the suitability of various materials and manipulation method. We also produced content in the form of a pattern using the proposed method. In the future, we will consider a method to restore the entire canvas to the original state.

References

[1] Poupyrev, I., Nashida, T. and Okabe, M.: Actuation and tangible user interfaces: the Vaucanson duck, robots, and shape displays, *Proceedings of the 1st international conference on Tangible and embedded interaction*, pp. 205–212 (2007).

[2] Malte, W., Florian, S., Simon, J. and Jan, B.: Madgets: Actuating Widgets on Interactive Tabletops, *Proceedings of the 23nd Annual Association for Computing Machinery Symposium on User Interface Software and Technology*, pp. 293–302 (2010).

[3] Hirayama, S. and Kakehi, Y.: Shaboned display: an interactive substantial display using soap bubbles, *ACM SIGGRAPH 2010 Emerging Technologies*, No. 21 (2010).

[4] Leithinger, D. and Ishii, H.: Relief: A Scalable Actuated Shape Display, *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, pp. 221–222 (2010).

[5] Ochiai, Y., Hoshi, T. and Rekimoto, J.: Pixie dust: graphics generated by levitated and animated objects in computational acoustic-potential field, *Association for Computing Machinery Transactions on Graphics*, Vol. 33, No. 4, Association for Computing Machinery (2014).

[6] Tsujimoto, Y., Itoh, Y. and Onoye, T.: Ketsuro-Graffiti: an Interactive Display with Water Condensation, *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces*, pp. 49–55 (2016).

[7] Kimura, T. and Kakehi, Y.: MOSS-xels: Slow Changing Pixels Using the Shape of Racomitrium Canescens, *ACM SIGGRAPH 2014 Posters* (ACM, ed.), No. 20 (2014).

[8] Follmer, S., Leithinger, D., Olwal, A., Hogge, A. and Ishii, H.: inFORM: Dynamic Physical Affordances and Constraints through Shape and Object Actuation, *Proceedings of the 26th annual ACM symposium on User interface software and technology*, pp. 417–426 (2013).

[9] Nojiri, F. and Kakehi, Y.: BelliesWave: Color and Shape Changing Pixels Using Bilayer Rubber Membranes, *ACM SIGGRAPH 2014 Posters*, No. 17 (2014).

[10] Rosato, A., Strandburg, K., Prinz, F. and Swendsen, R.: Why the Brazil Nuts are on Top: Size Segregation of Particulate Matter by Shaking, *Physical review letters*, Vol. 58, No. 10, pp. 1038–1040 (1987).