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Contents

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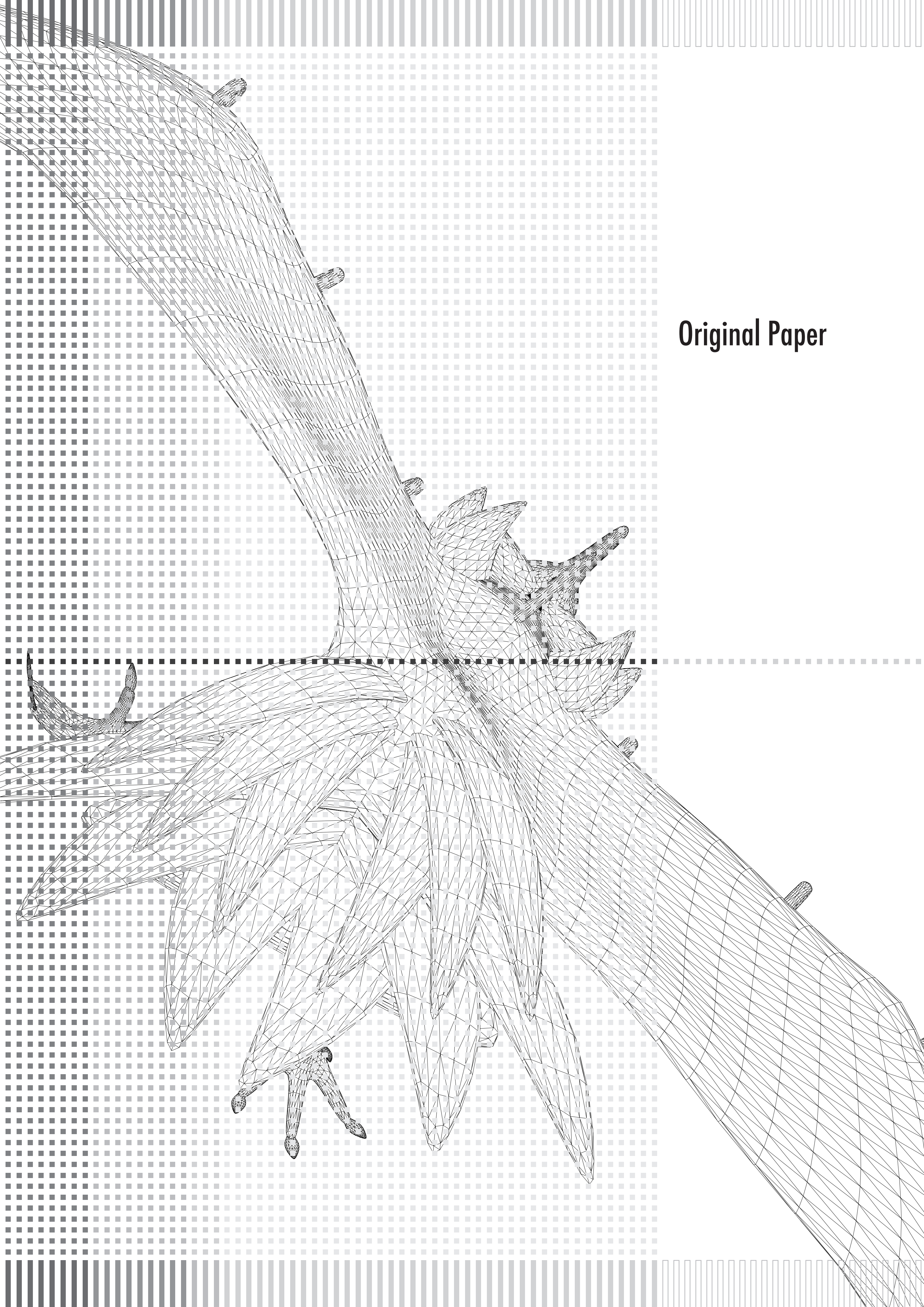

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STICK TRACK: a System Generating Musical Score for Drums Indicating the Hitting Hand

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Abstract
On playing drums, it is important to master the correct stroking order. Drummers are required to learn the drum rudiment to play drums efficiently. Generally, musical scores for drums do not have the annotation that indicates which hand drummers use to stroke each drum, left or right. Although drum teachers handwrite such annotation on the musical score, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically. In this research, we proposed a musical score generating system that indicates the hitting hand to stroke each drum. Our proposed *STICK TRACK* recognizes the hitting hand on the basis of the data of a gyro sensor that are embedded in the drum sticks and MIDI message from an electronic drum. We constructed the prototype system and evaluated its effectiveness.

Keywords: Drum, Musical score, Learning support, Motion recognition

1 Introduction

On playing drums, it is important to master the correct stroking order. For example, when the drummer plays the phrase like Figure 1 red square, there are cases that he/she strokes floor tom with a right hand not to cross his/her hands. In this way, there are the stroking orders to play efficiently. Therefore, drummers should learn the information that indicates which hand they use to stroke each drum(referred to as "hitting hand" in this paper) on each phrase. As the previous method to learn the hitting hand, there is the learning method to learn a phrase repeatedly by watching the professional performance. However, in this method, it takes much time to learn the hitting hand because the stroking motion of playing drums is so fast. Also, drum teachers handwrite annotation like the hitting hand on the musical score. As another method, they use the application generating musical score like DAW (Digital Audio Workstation) to indicate the hitting hand. On the other hand, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically.

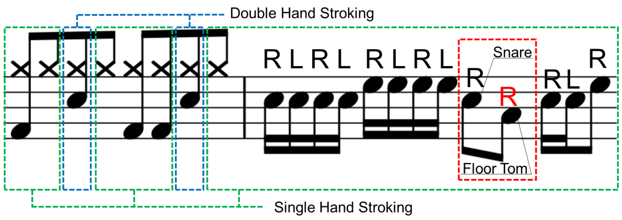

Figure 1 Musical score for drum performance

Therefore, in this research, we construct *STICK TRACK* for generating the musical score that indicates the hitting hand for drum performance. *STICK TRACK* recognizes the hitting hand on the basis of the data of a gyro sensor that is embedded in the drum sticks and MIDI message from an electronic drum. *STICK TRACK* generates musical score that indicates the hitting hand automatically using recognition data. Additionally, the system records information about the hitting hand by using MIDI message.

The remainder of this paper is organized as follows. Section 2 explains the related work. Section 3 describes the design of *STICK TRACK*, and Section 4 explains the implementation of a prototype system. Section 5 describes the evaluative experiment. Finally, Section 6 gives conclusions and outlines future work.

2 Related Work

On playing the drums, there have been proposed a variety of learning support systems. YAMAHA Song Beats[1] and Roland V-drums Friend Jam [2] are the applications for learning the drums. A user can learn the drums with watching the electronic musical score and the video of professional drummers. However, it is difficult for the user to understand the hitting hand because the stroking motion of playing drums is so fast. Additionally, these applications cannot indicate the hitting hand. Thus, there is not the system that generates the musical score indicating the hitting hand on playing drums automatically.

There are the systems to recognize the motion of players and indicate the performance information on the musical score. Antoniadis et al.[3] developed the system that generates a piano score indicating the gesture information of a pianist, such as fingering and hand position by using the camera and acceleration sensors. However, the indicating information on the score is too complex for the learner to understand that information correctly. Weyde et al.[4] also proposed the learning method for the violinists by using the camera. While they use the system [5] that indicates violinists the motion of their arms as the wave data visually, this system does not assume to generate the musical score.

Sawa et al. [6] proposed the real-time fingering detection system for contrabass by integrating camera image and musical rules. Takegawa et al. [7] also developed the system that detects fingering for piano by camera and color makers and adds fingering information to the musical score. While these systems are not assumed applying drum performance, we consider that generating the musical score that indicates performance information by recognition motion can be applied to play drums. In this research, we aim to develop the system for drums that generates musical score indicating the hitting hand by recognition of stroking motion in real-time.

Also, there is a variety of the methods to recognize the performance information on drum performance. AeroDrums[8] translates the stroking information into MIDI message by using the camera. This application is not assumed to recognize the hitting hand and generate musical score indicating it. Bouenard et al. [9] also analyzed the stroking gestures on percussion performance by motion capture. However, the recognition using the camera and motion capture is inconvenient for drummers to set up the devices and calibrate the motion. It is difficult to use this application on actual performance like a live show because the lighting prevents this application from recognizing the motion correctly. While the DAW applications like Logic Pro X[10] that translates the sound source of the drums into MIDI message also have been developed, the generated musical score cannot indicate the hitting hand. Van Rooyen et al. [11] proposed the system that recognizes the hitting point of drum head by audio data. Although using audio data useful to recognize the timing of stroking, it is difficult to specify the hitting hand on actual performance.

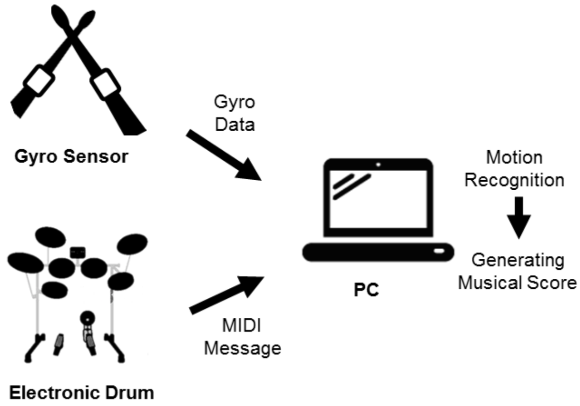

Figure 2 System structure

3 Design

We designed *STICK TRACK* from the following policies:

(1) Usage in actual performance: We assume that this system will be used for not only practicing but also actual performance, such as live show. In general, although the stroking motion on drums is recognized by the camera, this method cannot apply in actual performance due to the lighting. Our system applies the gyro sensor to recognize the stroking motion correctly in such environment.

(2) Real-time recording performance information: The proposed system records the performance information to review them in practicing and actual performance in real-time. We aim that the proposed system is used as the learning support for confirming the characteristics of the hitting hand and the mistaken point after a performance.

3.1 System structure

Figure 2 shows a system structure of the proposed system. This system consists of two drumsticks equipped with a gyro sensor, an electronic drum, a PC, and a MIDI sound generator. The sensor data are sent to the PC by Bluetooth communication. While a drummer plays an electronic drum with the proposed drumsticks, the system generates the musical score indicating the hitting hand. The proposed system recognizes the timing and the instrument that a drummer stroked by gyro data and MIDI message from an electronic drum. Using two information, the system recognizes the hitting hand and the instrument that the drummer stroked. Finally, the system generates the musical score indicating the hitting hand.

3.2 Recognition method of the hitting hand

Figure 3 shows the flow of recognition the hitting hand. The system recognizes whether the drummer stroked the drum by MIDI message at first. Secondly, the proposed system recognizes two stroking patterns. One of them is the stroking that the drummer

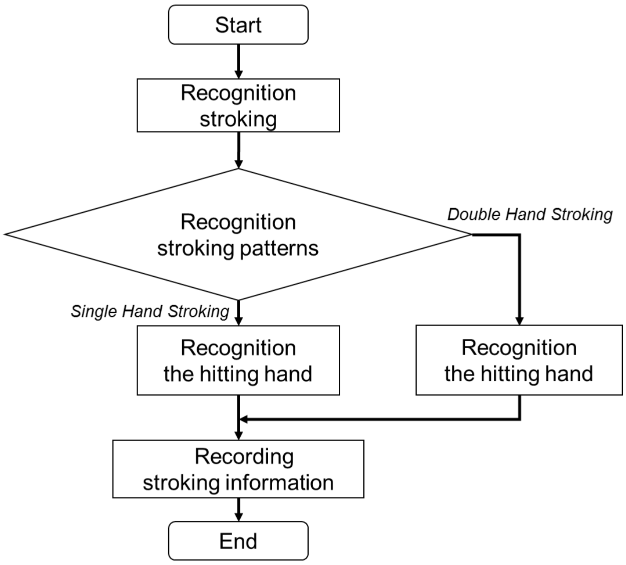

Figure 3 The flow of recognition the hitting hand

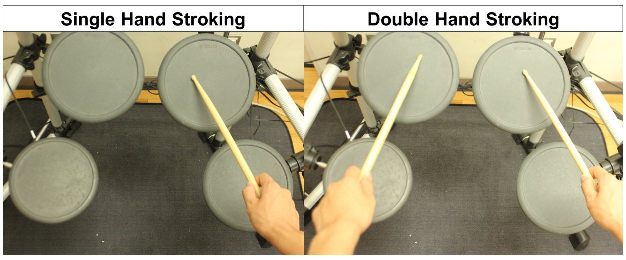

Figure 4 Stroking patterns

strokes a drum with only one hand (referred to as *Single Hand Stroking* in this paper) as shown in the left of Figure 4, and the other is the stroking that he/she strokes drums with both hands (referred to as *Double Hand Stroking* in this paper) at the same time as shown in the right of Figure 4. The system recognizes which pattern he/she stroked the drum with *Single Hand Stroking* or *Double Hand Stroking*. On each stroking pattern, the methods to recognize the hitting hand are different. The system recognizes the hitting hand in accordance with each method. Finally, after recognition the hitting hand on each method, the system records information of the hitting hand and generates the musical score.

3.2.1 Recognition of stroking patterns

The proposed system recognizes *Single Hand Stroking* and *Double Hand Stroking* on the basis of time interval that the system receives MIDI messages. Figure 5 shows the timing that two MIDI messages ($\mathrm{MidiOut}_1$, $\mathrm{MidiOut}_2$) were sent. The proposed system sets a threshold value to recognize the stroking pattern. For example, a threshold value is set 25ms. If time interval (Δt_{12}) between $\mathrm{MidiOut}_1$ and $\mathrm{MidiOut}_2$ is shorter than 25ms, the system recognizes the stroking as *Double Hand Stroking*. After recognizing stroking pattern, the proposed system starts to recognize the hitting hand. Recognition methods on each pattern are shown as follows.

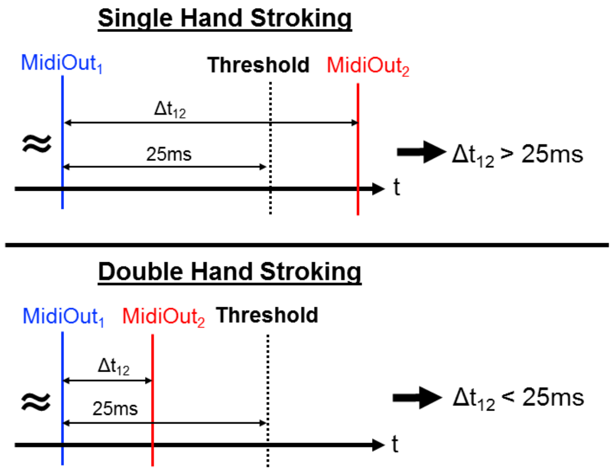

Figure 5 Recognition of stroking patterns

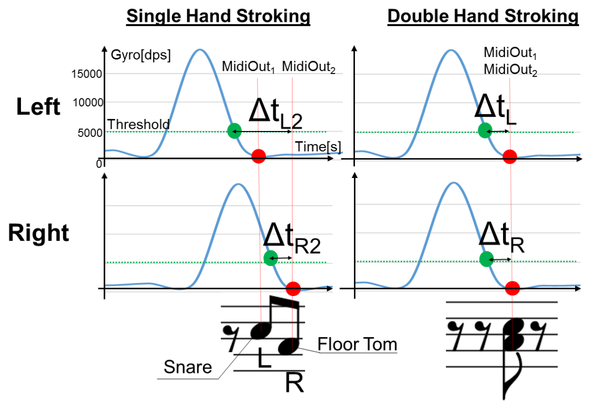

Figure 6 Gyro data of stroking

3.2.2 Recognition of Single Hand Stroking

The system recognizes the time when the drummer stroked drums by 1-dimensional gyro data. The left of Figure 6 shows the waves of gyro data when the drummer strokes the drum with each hand. Positive values arise when he/she brings his/her arm down to stroke. As shown in Figure 6 red line, when the value is "0" after the gyro data reaches a maximum value, it is considered that the drumstick hit a drumhead. Therefore, in this moment, MIDI messages are sent to PC. In this system, to prevent false recognition when the drummer does not stroke, a threshold value is set to prevent false recognition. The system recognizes the hitting hand by a time interval between the time when the gyro data went down a threshold value and the time when MIDI message was sent. The left of Figure 6 shows the waves of gyro data when the drummer actually stroked snare drum with a left hand and floor tom with a right hand. Compared the time receiving $\mathrm{MidiOut}_2$ with the time when each gyro data went down a threshold value, the time interval on hitting with a right hand (Δt_{R2}) is shorter than the time interval on hitting with a left hand (Δt_{L2}). Therefore, it is recognized that $\mathrm{MidiOut}_2$ was sent by stroking with a right hand.

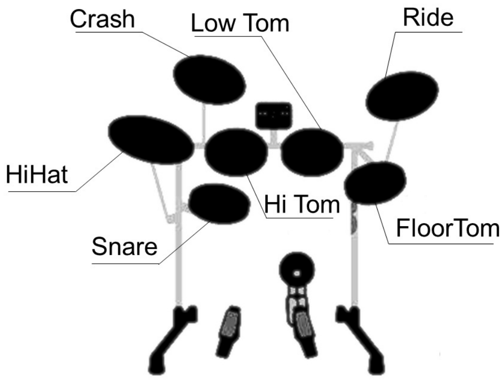

Figure 7 Drum set

Table 1 Results of applying rules

	Combination	Result	
		L	R
Rule1	Snare-Floor Tom	Snare	Floor Tom
	Hi Tom-Low Tom	Hi Tom	Low Tom
	Crash-Ride	Crash	Ride
Rule2	Snare-Low Tom	Snare	Low Tom
	Snare-Ride	Snare	Ride
	Hi Tom-Ride	Hi Tom	Ride
	Hi Tom-Floor Tom	Hi Tom	Floor Tom
	Crash-Floor Tom	Crash	Floor Tom
	Crash-Low Tom	Crash	Low Tom
Rule3	Hihat-Snare	Snare	Hihat

However, in this method, the system cannot recognize correctly in the case that the drummer strokes the drums with both hands at the same time. The details on the recognition method for *Double Hand Stroking* are as follows.

3.2.3 Recognition of Double Hand Stroking

On *Double Hand Stroking*, both MIDI messages are sent at the same time. The gyro data of each hand also goes down a threshold value at the same time. Therefore, as shown in the right of Figure 6, on *Double Hand Stroking*, the time interval between each hand has no much difference ($\Delta t_L \fallingdotseq \Delta t_R$). Thus, it is difficult to recognize the hitting hand on *Double Hand Stroking* by the method of *Single Hand Stroking*. Then, to recognize the hitting hand the proposed system uses the rules that are defined by the features of drum performance, the layout of drum set and the characteristics of playing a variety of phrases. We define the following 3 rules on *Double Hand Stroking* to recognize the hitting hand.

Rule1: Each hand does not cross if each instrument is set up at the same height.

In this paper, we assume using a general drum set as shown in Figure 7. In this case, the combinations that each instrument is set up at the same height are snare-floor tom, hi tom-low tom, and crash-ride. In general, the drummer does not stroke these instruments with his/her hands crossed. Therefore, when the drummer strokes these combinations, the system recognizes that he/she strokes an instrument on the left side with a left hand and he/she does on the right side with a right hand. For example, in the case of stroking snare and floor tom at the same time, it is recognized that he/she strokes snare with a left hand and floor tom with a right hand. Table 1 shows the results of recognition when the drummer strokes each combination.

Rule2: Each hand and instrument are at the same side if each instrument is set up at the different height.

On *Double Hand Stroking*, if both instruments are set up on different height, the drummer does not cross his/her hands to stroke each instrument. However, in the case that horizontal position of each instrument has not much difference, it is not adapted this rule. Additionally, because hihat is stroked to keep the beat and he/she cross their hand frequently, it is also not adapted this rule. As shown in Table 1, for example, in case of stroking snare and ride at the same, it is recognized that he/she strokes snare with a left hand and ride with a right hand.

Rule3: Each hand crosses on playing 8 beat pattern using hihat.

In general, when the drummer strokes hihat and plays 8-beat pattern, each hand crosses. Therefore, the drummer who is right-handed strokes hihat with a right hand and does snare with a left hand. In this paper, although the system does not recognize the beat pattern, we assume that the drummer strokes hihat and snare at the same time on playing 8 beat pattern. Additionally, on playing 16 beat pattern, the system can recognize the hitting hand by the method of *Single Hand Stroking* because the drummer does not stroke hihat and snare at the same time.

3.3 Recording information of the hitting hand

The system records information about the hitting hand by using MIDI message. This method is based on the reason that recording performance information as MIDI format has a possibility adapted in a variety of DAW applications. Information about the hitting hand is included as the value of *panpot* inside MIDI message as follows.

Left hand The value of *panpot*: 0
Right hand The value of *panpot*: 127
Both hands The value of *panpot*: 64

For example, when the drummer strokes the drum with left hand, the value of *panpot* is adjusted "0". Also, when the drummer should stroke a drum with a left hand, they can listen drum sound from left side by recording the value of *panpot*. Therefore, the adjustment *panpot* also helps him/her indicate the hitting hand as an auditory feedback.

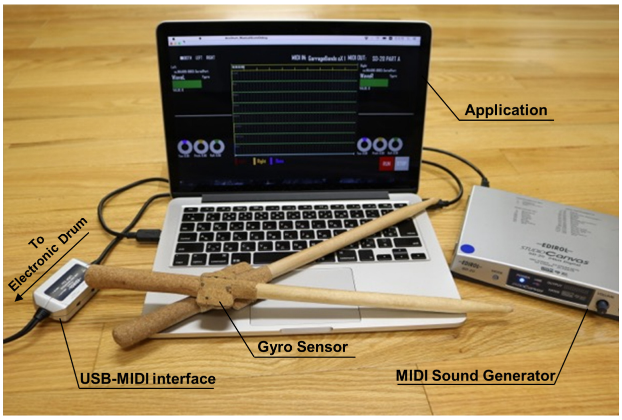

Figure 8 A prototype of the proposed system

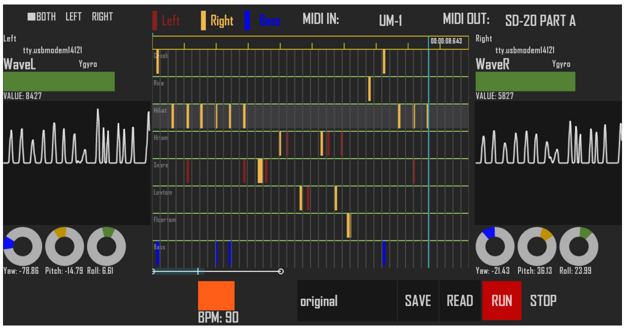

Figure 9 Screenshot of our application

4 Implementation

We implemented a prototype. As shown in Figure 8, a prototype consists of two drum sticks, PC and MIDI sound generator. A drum stick is attached a gyro sensor Wireless Technology WAA-010. We attached a gyro sensor to not drummer's wrist but drum stick because gyro data changes largely. Also, a gyro sensor is attached to the middle of the drum stick, so as not to hit drums. We used Roland SD-20 as a MIDI sound generator. We connected an electronic drum and PC by using Roland UM-1 as a USB-MIDI interface. An electronic drum is YAMAHA DTXPLORER. We implemented a prototype system on OS X v10.10 using Xcode 8.0.

Figure 9 shows a screenshot of the application for the prototype. A user can confirm the gyro data and set MIDI input and output device, and a threshold of gyro on the application. The center of Figure 9 shows the musical score that is generated on the basis of gyro data and MIDI message. The musical score indicates the stroking information on each drum and the colors of note on each sequence in the center of Figure 9 indicate the hitting hand. The red note describes that drummer stroke with a right hand, the yellow note describes left hand. The blue note describes using a bass drum.

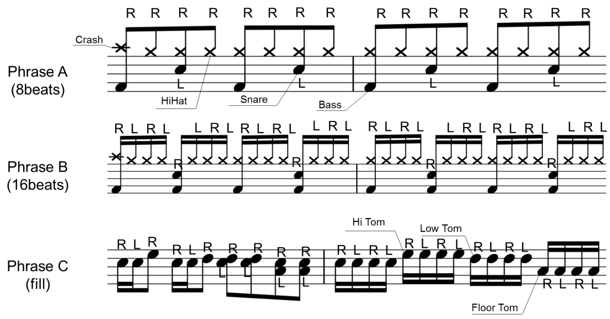

Figure 10 Trial phrases

Table 2 The recognition ratio [%]

Phrase		A		B		C	
BPM		90	120	90	120	90	120
Subject	I	100	96.3	100	100	98.5	99.2
	II	96.3	98.1	99.7	100	100	100
	III	99.4	97.5	100	99.4	99.6	98.5
	IV	99.4	96.9	99.4	99.1	99.2	98.8
Mean		98.8	97.2	99.8	99.6	99.3	99.1
		98.0		99.7		99.2	

5 Evaluation

We conducted two evaluative experiments to investigate the effectiveness of the proposed system. As one experiment, we investigated the recognition accuracy of the proposed system. The other is the investigation of the effectiveness on the performance when the learner uses the proposed system.

5.1 Recognition accuracy

Experimental method

We investigated the recognition ratio of the proposed system. In this evaluation, we used 3 phrases shown in Figure 10 as trial phrases. Tempos are 90 and 120bpm (beats per minute). The subjects studied each phrase with each tempo for 10 times. Trial phrases were composed of two measures. As shown in Figure 10, on Phrase A subjects play 8 beat pattern, on Phrase B they play 16 beat pattern, and on Phrase C they play a fill (a short musical passage). The subjects play each trial phrase in accordance with indicating of the hitting hand on the musical score shown in Figure 10. Four male and one female university students took part in this evaluation. All subjects have more than two years of drum experience. All of them were right handed. In this evaluation, a threshold value of gyro to start recognition was set 3000dps (degree per second). Also, a threshold value of time interval to recognize the stroking pattern was set 25ms. Before investigating the recognition ratio, the subjects practiced the trial phrases for 10 minutes with the proposed drum sticks.

Results and discussion

Table 2 shows the recognition ratio of each subject stroking each phrase. The recognition ratio shown in Table 2 is calculated on

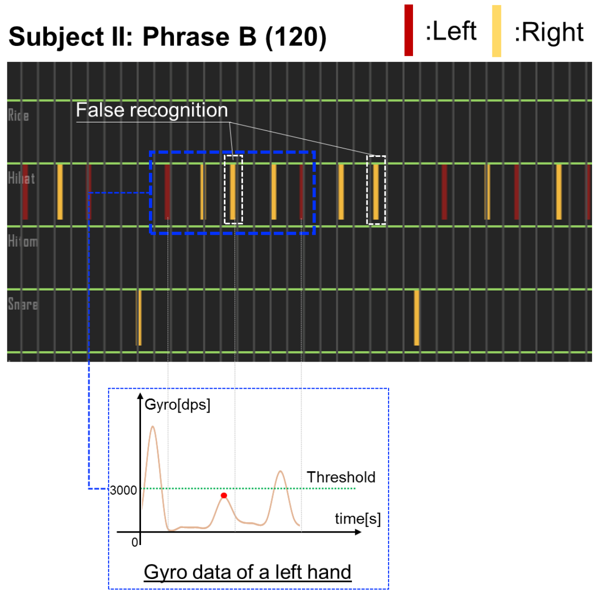

Figure 11 False recognition on performance

the basis of false recognition. False recognition describes that the system did not recognize the hitting hand correctly. As shown in Table 2, the recognition ratio was more than 95% in all patterns. On *Double Hand Stroking*, there was not false recognition. On the other hand, there were false recognition when subjects played Phrase B and Phrase C. Figure 11 shows false recognition when Subject II played phrase B with 120bpm. Actually, in Figure 11 white square, Subject II stroked hihat with a left hand. However, the proposed system recognized that the hitting hand was a right hand falsely. As shown in the bottom half of Figure 11, gyro data in this moment was lower than a threshold value. Therefore, the proposed system did not start to recognize the stroking. As a result, this false recognition arose because the system could not compare time interval between each hand. To prevent these false recognition, it is necessary to adjust a threshold value that enables to recognize weak stroking.

5.2 Effectiveness on the performance

Experimental method

We investigated the effectiveness on the performance in case that the learner uses the musical score indicating the hitting hand. In this evaluation, we compare the performance quality between the usage of the proposed score and the conventional score. While the proposed score includes the indication of the hitting hand, the conventional score does not include it. The subjects play a trial phrase shown in Figure 12. Tempo is 120bpm. Three male university students took part in this evaluation. All subjects have one to three years of drum experience.

Firstly, the subjects learn the phrase with the conventional score shown in the upper half of Figure 12 for five minutes. During this learning, each subject learns the phrase in their own way of the hitting hand. After learning, we recorded their performance with DAW application and the camera.

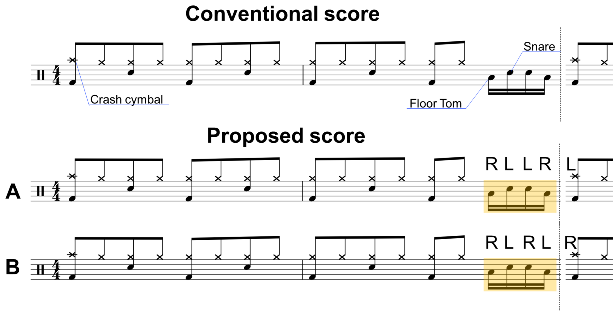

Figure 12 Trial phrases

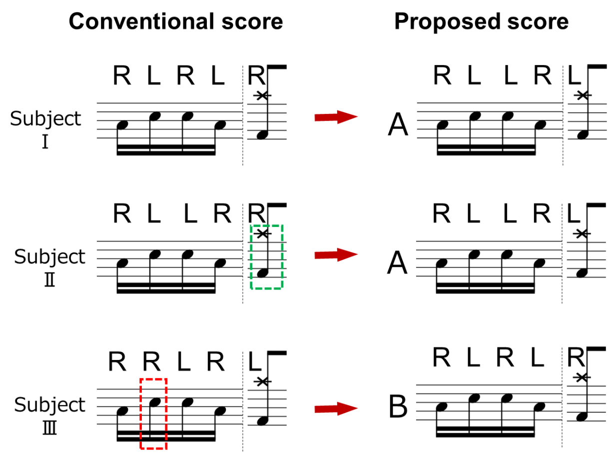

Figure 13 Stroking order of each subject

Nextly, the subjects learn the same phrase with the proposed score shown in the bottom of Figure 12 for five minutes. The proposed score indicates two ways of hitting hand. These scores are generated on the basis of the stroking order that four professional drummers set. All professional drummers have experienced drums more than 15 years. The subject can choose the way of the hitting hand from them and learn the phrase, if the hitting hand in the learning with a conventional score is different from the proposed score. After this learning, we also recorded the performance of subjects. We compare the performance quality between the proposed score and the conventional score.

Results and discussion

Figure 13 shows the stroking order when each subject actually played the phrase with a conventional score. The stroking orders of Subject II and Subject III are different from the proposed score. Two subjects chose the proposed score as shown in Figure 13. Also, Subject I learned the proposed score A.

Firstly, we discuss the effectiveness of stroking timing. In conventional learning, Subject II could not stroke crash cymbal with the correct timing. He had a tendency that he stroked the point shown in the green square of Figure 13 later. He could not move his right hand from floor tom to crash cymbal with keeping tempo, because he stroked the drums with a right hand in a row. In a case of using the proposed score A, he could keep tempo because they use each hand alternately. As these results, the subjects could prevent the failures on their performance by using the musical score indicating the hitting hand.

Nextly, we describe the effectiveness of stroking strength. In conventional learning, Subject Ⅲ had a tendency that he stroked the point shown in the red square of Figure 13 weakly. This factor is considered that he stroked the drums with a right hand in a row and second stroking was weak. On the other hand, when the subject learns the phrase with the proposed score B again, he could stroke them in the same strength.

However, subjects sometimes dropped the drum sticks and stroked a false instrument with the proposed scores. This reason arose because they played with the hitting hand that they had not used on usual performance. Thus, while the proposed system could improve their performance quality, the subjects are required to get used to the hitting hand. On the usage of the proposed system, we need to collect a variety ways of the hitting hand on each phrase by professional drummers. What the learners find the hitting way that they prefer from them is considered as the efficient usage of the proposed system. Therefore, we need to make the library that a variety ways of the hitting hand are recorded by using the proposed system.

6 Conclusions

In this research, we constructed *STICK TRACK* for generating musical score that indicates the hitting hand for drum performance and described the construction of a prototype system. *STICK TRACK* recognizes the hitting hand on the basis of the data of a gyro sensor that are embedded in the drum sticks and MIDI message from an electronic drum. A prototype system generates a musical score that indicates the hitting hand. The results of an experiment demonstrated that our system enabled generating the musical score effectively. Also, the proposed score could indicate the learner the correct stroking order and improve their performance.

For future work, to improve the objectivity of the effectiveness, we plan to evaluate the system with more complex phrases and with more subjects. We also need to investigate the usability of the soft application in the proposed system. Additionally, we plan to implement the plug-in software that is applied in a variety of DAW applications. Furthermore, the drummers of a variety of genre use our system and it is required to extract the characteristics of the hitting hand between genre.

Acknowledgments

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Sidestep and Sneak peek: spatial actions in augmented reality games

ARSurface - Dynamic Spatial Augmented Reality for Tangible Interface

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Abstract

We propose a novel concept of game, which allows players to experience tangible interaction with the virtual world of digital games by mixing motorised scenery with dynamic projection mapping.

A specific hardware - which includes a controllable platform, on where players can setup customised polygonal shaped scenery to play games projected onto its surfaces, and a single, or a pair, of focus free laser pico-projectors pointed toward the platform direction - is proposed as a game console able to run this experiment. The controllable platform orientation is synchronised with the game play in a way the moving physical scenery and the projected virtual contents are constantly aligned. By designing 3-dimensional (3D) animations, which are rendered and projected in accordance with the physical surface orientations, we were able to enhance the illusion of depth toward these planar projection during the game play, while giving the chance for our flattened 2-dimensional (2D) main character to make use of all directions which surrounds him.

The use of projection mapping is justified since we intent to exploit the characteristics of projected 2D light onto 3D objects in order to extend digital games means of expressions. In this paper we discuss about spatial actions, which are actions players can perform at physical object creases. When synchronised with motor movements, these actions extend the sense of volume in relation to the game character providing a tangible connection between players and digital content. We also discuss about the technical aspects regarding the development of this project and its application as a tangible game design tool.

Keywords: game design, tangible interface, projection, mixed reality

1 Introduction

The term Augmented Reality (AR) refers to the possibility of extending our perceived reality (real world) by adding computer-generated imagery to complete or replace physical objects we see. This mixed reality can be exploited in many ways, whether by making use of head-mounted or hand-held devices, resulting in individual AR experiences, or by overlaying, displaying or projecting virtual contents on the surface of physical objects, resulting in a collective AR experience [1]. Spatial Augmented Reality (SAR, also known as projection mapping) is a current trend on developing all sorts of mixed reality interfaces from artwork installations, experimental movies or games [2,3,4]. The use of projectors makes it possible to add new layer of virtual contents displayed on physical objects. Because of this characteristic, SAR can be easily associated with tangible user interface as a method to translate between shared virtuality and reality.

Interaction with spatially augmented objects is however, in many cases, limited to a setup where objects and projectors remain static in relation to each other or present some lack of mobility. Our research is motivated by exploiting techniques capable of producing adhesive SAR to be laid on top of non-static objects. Here we discuss about the piece of hardware developed in order to run our experiment with spatial scenes (Figure 1) and point out these actions characteristics.

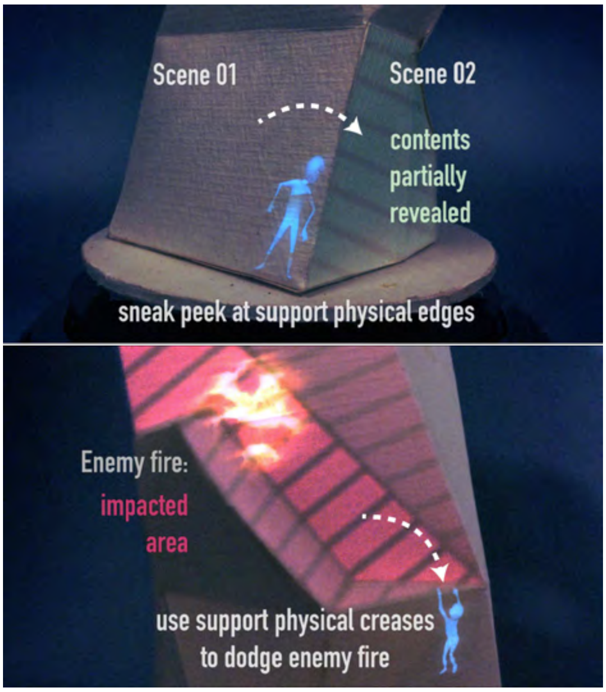

Figure 1 - Spatial actions are performed on physical creases mixing support object movement synchronised with animation designed to enhance the sense of depth in the projected scene.

Figure 2 - Dynamic SAR interactions designed for moving supports depend on image sensors to detect target object movements before updating contents to be projected. (a) Side by Side hand-held camera-projector device. (b) Reflective IR markers detected by cameras, used on Project Omote, (c) Scanning the environment with Microsoft Kinect sensor in RoomAlive project.

2 Related work

Most of the digital game experiences designed to have tangible interfaces using SAR are somehow based on tabletop game plays, in such way players can manipulate physical props like mini-figures or cards [5,6], having the projectors fixed above a table. As example, researches and commercial products such as Microsoft PlayAnywhere [7], and Lampix [8] seems to be aligned with this setup.

Other setups that allow projection to be expressed on 3-dimensional objects or surfaces with or without any degree of freedom are also available:

• ARmy [9] is a tabletop military strategy game where players can use primitive-shaped blocks to build up their own board before the game starts. A camera positioned above the board detects the blocks distribution to calculate the game dynamics. During the game play the board remains static while mini-figures are manipulated directly by players, thus updating the game instructions.

• RoomAlive [10] is a concept of immersive gameplay in which the player's room is 3-dimensionally scanned, allowing the system to make use of each physical surface to be part of a SAR experience game. During the game play the previously scanned surfaces remains static while the players' bodies movements update the game framework.

• SideBySide [11] proposes a portable device, which embeds an IR camera in a portable projector. Working similarly as a flashlight, which projects virtual information directly on planar objects. The player can freely move this hand-held device and project contents on apparently any dull surface. The contents are updated accordingly to the device orientation and readings from the IR camera (when using IR markers).

Projecting virtual contents onto moving objects requires the system to be aware of what content and how this content must be projected (Figure 2). The basic framework for this kind of applications relies on how the player's interaction over the target objected is detected by image sensors, and how fast and efficient the system reads data from these sensors to extract relevant information necessary to update the contents to be projected.

Other than limiting the target objects to be moved in a slow manner, running sophisticated computing vision subroutines in real time can overload graphic processors. This affects the application main routine, reducing interaction performance. Consequently this compromises the projection alignment with the target support, vanishing the illusion necessary to create convincing mixed reality. An alternative would require a extremely high-rate frame rate camera-projector module (above the average 60 fps) [12] connected to a system capable of running both computing vision subroutine and game play.

Instead, in our experiment we are working in the opposite direction, having the player to control the system which in its turn mechanically controls the physical object (Figure 3). This technique has the advantage of eliminating computing vision subroutines, thus having the processors dedicated to the generation of virtual imagery to be projected. Also, because the motor spins accordingly to known constants, it is possible to rotate it at any speed supported by the hardware (±10 to 100 RPM) without having the virtual projection to be misaligned with the physical object support.

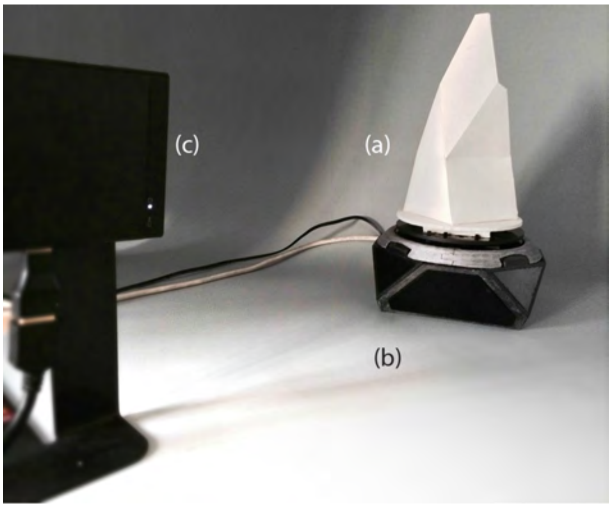

Figure 3 - An (a) physical object lays on top of (b) a controllable platform-hardware placed in front of a (c) free-focus laser projector. Projector and hardware connected to PC. Composition proposed as game console for this experiment.

3 Hardware and software development

3.1 Hardware

Originally, the physical object used as game stage can have as many degrees of freedom as the number of motors or actuators connected to the system. At this very stage, hardware and software are under development in order to facilitate its evaluation, while the main procedures runs satisfactorily. We present the hardware including only one degree of freedom, as a turntable platform connected to a 200 steps/revolution stepper motor which is driven by a microcontroller subjected to PC commands. The system can recognise the angle of this turntable to project onto the support object accordingly. When hardware is turned on it will run a self-alignment procedure so the its rotor will start at origin.

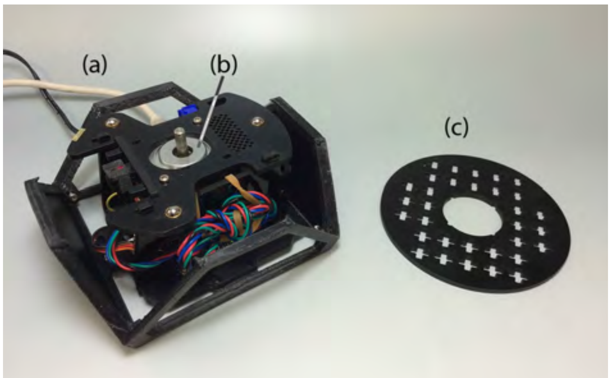

Figure 4 - Hardware is connected to a PC by (a) serial cable, which controls (b) a stepper motor. A support object is fixed on (c) a perforated disc mounted on top of the hardware.

The turntable platform is stabilised by 3 bearing balls located bellow its disc contact points. In addition, the platform disc is perforated in a pattern, which allows the posterior fixation of objects (Figure 4). Physical objects used as support for projection can be made of paper, or 3D printed, having its surface made dull for better illumination. Pico-projectors are portable devices designed to project contents during more casual situations. Their lenses field of view are not so wide and the brightness and contrast they offer are limited, since they use different source of light in comparison to desktop projectors, such as LED or Laser. The choice of using a laser projector is due to its focus free characteristic, perfect for the case where the distance between projector lens and projected surface isn't a constant. Also, the lenses characteristics of these projectors allows small details to be observed with satisfactory resolution on the nearly projected surfaces.

3.2 Software

Developed in Processing IDE [13], it consists of three basic modules, which are able to run a projector-calibration tool, an interface to the microcontroller, and the game play. Projector calibration is made every time a new support is changed or when projector or turntable changes their position in relation to each other. The motor control sends data to the hardware depending on game instructions. These data are degrees of rotation the motor is set to perform and revolution speed. Motor control can also read if hardware has completed its self-calibration procedure in order to setting up rotor at origin. The game play runs a basic physics class capable or allowing the player to move the game main character along the scenes. The game is composed by a sequence of planes, designed and mapped to each polygonal surface found on the physical object. When the player moves through the game, the motor is instructed to rotate accordingly. In this scenario, motor can run smoothly, following the character position, or revealing next scenes abruptly if this is the intention of the stage design.

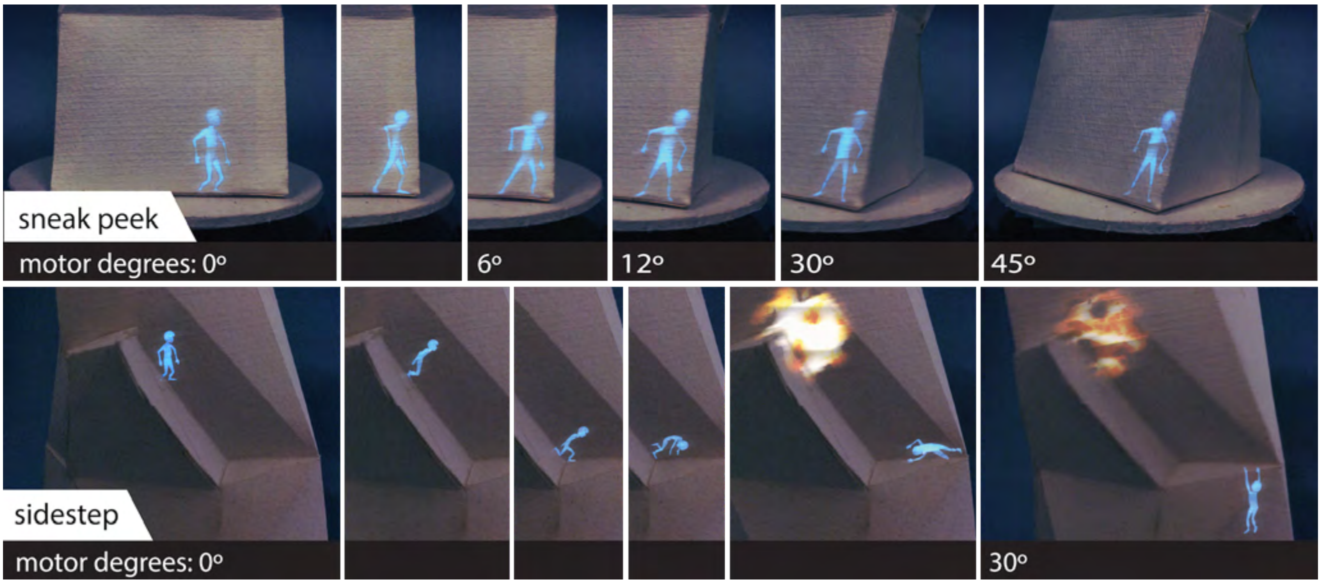

Figure 5 - Spatial actions designed for the turntable platform hardware. Animation plays aligned with the rotation of object support enhancing the illusion of depth.

4 Spatial actions

We suggest two spatial actions, which can be performed by the game main character in order to enhance the perception of 3D space or depth in SAR interactions. Spatial actions are designed to combine digital animation and physical object movement in such way players have the illusion of volume coming from the projected surfaces. These actions are provided by making use of the physical creases found on the support object and giving to it an opportunity to serve as attributes in the game such as places the game character specifically can use to perform spatial actions, as seen in Figure 5.

To follow with the explanation about spatial actions, we would like to highlight two spatial actions of them, which are used in our application: Sneak peek and Sidestep.

4.1 Sneak peek

Sneak peek actions take places on vertically oriented creases representing a wall corner from where the avatar can "spy" contents on its adjacent polygons in stealth mode. The crease angle between polygons must be physically constructed to make possible such kind of action inside the game. As a default value, if the crease angle between adjacent polygons are greater than 60°, the system will accept sneak peek action on this location. By performing this command, players can anticipate what is coming on next game scenes and get ready for a duel or reward, or even finding another path to go in order to avoid that area of the game.

4.2 Sidestep

Sidestep actions allows a runway manoeuvre to dodge enemy fire or seek temporary refuge. In a traditional 2D platform game, player would block or try to escape from enemy's fire while being trapped on a 2D coordinate system. In a first person shooter game, players can also dodge left or right from enemy's fire by hiding behind walls or door frames. In our game, we experiment a hybrid dimensional action, allowing a 2D character to make use of the physical geometry of the object onto where it is being projected. The sidestep action can be performed in spots where crease angle found on support object allows this kind of interaction between animation and support object. That is, when adjacent faces are not flat. Sidestep action is designed for vertical or horizontal creases, but subjected to the game design basic rules.

4.3 Other actions to be developed

There are other actions that can be applied to the game in order to explore the geometry and solid properties of the physical object. As example, the use of tunnels or holes, proposed on the game as means to transport the character from a place to another, can bring the discussion about how hollow the physical object can be, and how the use projection mapping can influence our perception toward the characteristics of the object as we know.

5 Projection and other technical aspects

5.1 Projector calibration

The projector calibration is a procedure used for solving the projector projection matrix. Specially for dynamic projection mapping, that is to say, when the spatial relationship between projector and illuminated object are constantly changing, this matrix is a key element for ensuring the precise alignment between projected virtual content and physical surfaces. The matrix contains information about the projector intrinsic and extrinsic parameters, such as the projector field of view, the projector screen size, the projector center position and orientation, among others. These parameters are stored in the form of a 4 x 3 matrix which are used to convert a 3D point in the virtual world to its correspondent 2D position on the

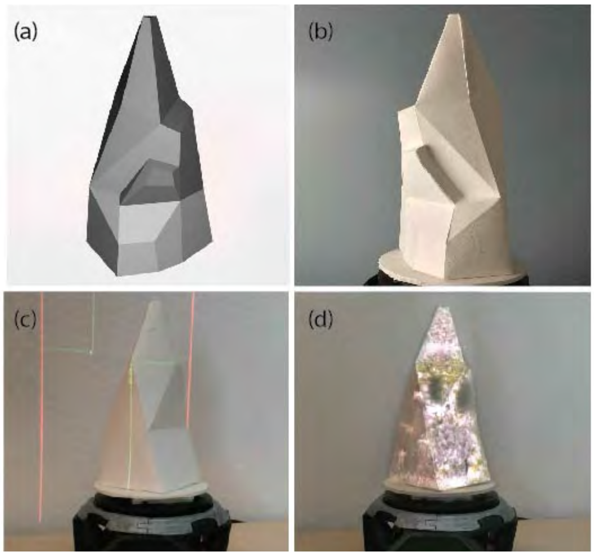

Figure 6 - a) 3D model representation of the physical object (b) used as base for projection; c) Crossed cursor projected on object for projector calibration setup; d) Virtual contents projected onto the physical object after calibration.

projector projection plane. Thus, every fragment existing in our game application has its 3D coordinates multiplied by the projector projection matrix in order to display correctly on top of their correspondent planes in the physical support object.

We have developed a tool in order to calibrate the projectors used in our application. The calibration process basically compares a physical object to its equivalent 3D virtual model (Figure 6 a and b). We have adopted a calibration method based on the single-camera calibration method suggested by Richard Radke [14]. This method requires the user to arbitrarily chose six non-coplanar vertices stored in a desired sequence. Having the physical object completely covered by the projection frame, the user can use a mouse cursor. to click over the previously determined vertices in the same sequence as those have been stored (Figure 6 c). Next, the system has enough information from the collected correspondent points to solve the projection matrix and project contents (Figure 6 d). The projector is said to be calibrated as long as the projector and physical object remains in place. Ideally, projector and the object platform should be fixed on the same base to avoid recalibration in case projector must be relocated.

5.2 Dynamic projection mapping

So far, the projection calibration can provide us relative accuracy for mapping physical objects in order to have them prepared for projections. However, similar results could be easily achieved using geometric distortion correction [15], that is, manually (e.g. using a mouse cursor) adjusting the image plane by dragging its corners until it gets visually aligned to the surface of the object one wants to project onto.

In order to have dynamic projection mapping we need to keep track of the physical object position and orientation after calibration process is performed so the system can automatically recalibrate the projector on the fly. As mentioned before, the current system developed for our game

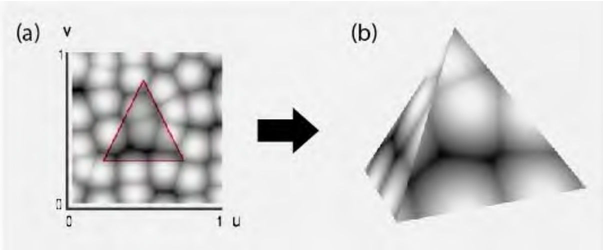

Figure 7- a) bitmap texture with a triangle representation of the 3D model (b) faces. b) 3D model having its faces textured by the selected portion of bitmap in (a).

application does not rely on any sensor, such as cameras, in order to track and retrieve information of the physical object being used as support for the projection. However, since the object is manipulated by user via system instructions, the system always knows where the physical object is positioned, preserving the calibration results as expected. A similar experiment [16] was conducted by the artist Cyril Diagne, having a physical object spinning at a controlled speed, which allowed the system to be aware of how to perform the projection mapping as expected.

5.3 Projection and game objects layers structure

In 3D applications, the process where users load bitmaps to be used as texture on the top of 3D models and set up how these planar images should match the geometry of the model is known as UV mapping (Figure 7). In such applications, U and V are the standard coordinates representing the axes X and Y within a face. Since 3D models can have very complex geometry, mapping each face individually to a portion of the bitmap texture can be very laborious. These applications usually provide tools to make the mapping process less complicated. By projecting the texture on the 3D geometry, users can associate many polygons to match the texture as desired. By choosing the right UV projection method, the modeller can have a good starting point to continue refining the texture on the model.

As with the UV mapping processes available on 3D applications, physically projecting 2D graphics on the surface of physical objects results in a certain level of distortions that should be handled somehow. The most well-known distortion related to projectors occurs when the projection surface is tilted in relation the projector itself, causing a rectangular image to display as a trapezoid. This scenario is almost inevitable for projection mapping setups where artists wants to project multiple images on complex objects having different angles and distances between their faces, requiring a equally complex technique to overcome this condition.

In the case of our application, bitmap texture used on the background, which are intended to be flat, can be projected within a certain amount of distortions using a basic setup where each face projects its correspondent portion of the bitmap multiplied by the projection matrix. However, the same cannot be applied to moving or interactive objects within the game. As seen in figure 8, projecting objects which are manipulated by player (e.g. characters) or perform some animation inside the game, will flatten with the background if we follow the same UV projection method used until now. This issue becomes more visible when projection takes place while the character or animated objects stands next to the edge between two adjacent planes, thus being projected on both planes at the same time (Figure 8 b and d).

We have opted to display these interactive objects in a foreground layer, using a different technic, so these objects can have their volume and lively characteristics preserved. In addition, the objects displayed in the foreground feels like detached from the background.

In order to make it possible to combine different projection methods to support mapping game objects, including collision surfaces such as floors, walls, and interactive characters or items, with the physical object geometry, we have developed a structure containing different layers, some hidden, for system and design evaluation, and some are rendered, as seen in Figure 9. For simplicity, we are presenting a 3D cube model as a physical support object to explain the structure of the layers and how they are setup individually.

Important to mention that, one of the main concepts of this project is to provide some sort of tangible game design interface, allowing a game to exist in multiple ways, slightly changing its complexity in accordance with the geometrical characteristics of the physical object the player decides to project the game onto. However, many of the processes discussed in the following subtopics, related to the game layer configuration, are setup manually, representing a limitation for using or designing complex geometry to be used in our project during this early development stage.

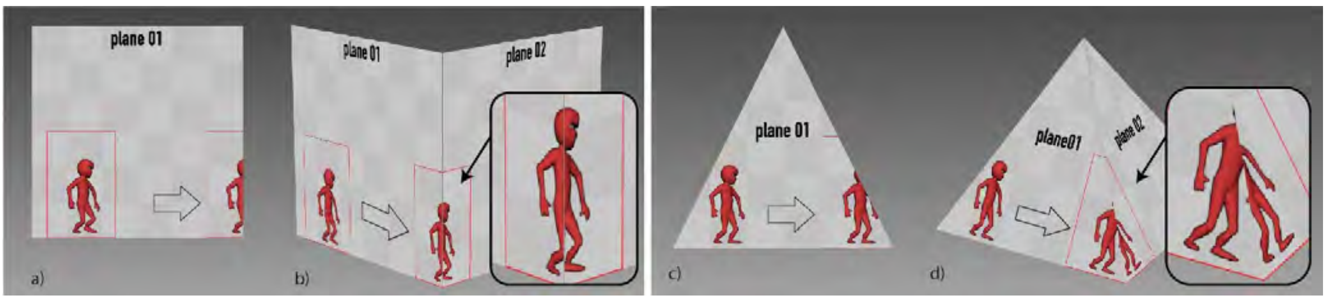

Figure 8 - a) Game character contained inside game map layer is moving to the edge its current plane. Seeing from the perspective of the player, character seems to be flattened against the plane, and its appearance becomes strangely distorted when the character is being projected on between two adjacent planes at the same time (b). The same problem is aggrieved when adjacent planes share edges non-perpendicular to the plane base (floor) (c and d).

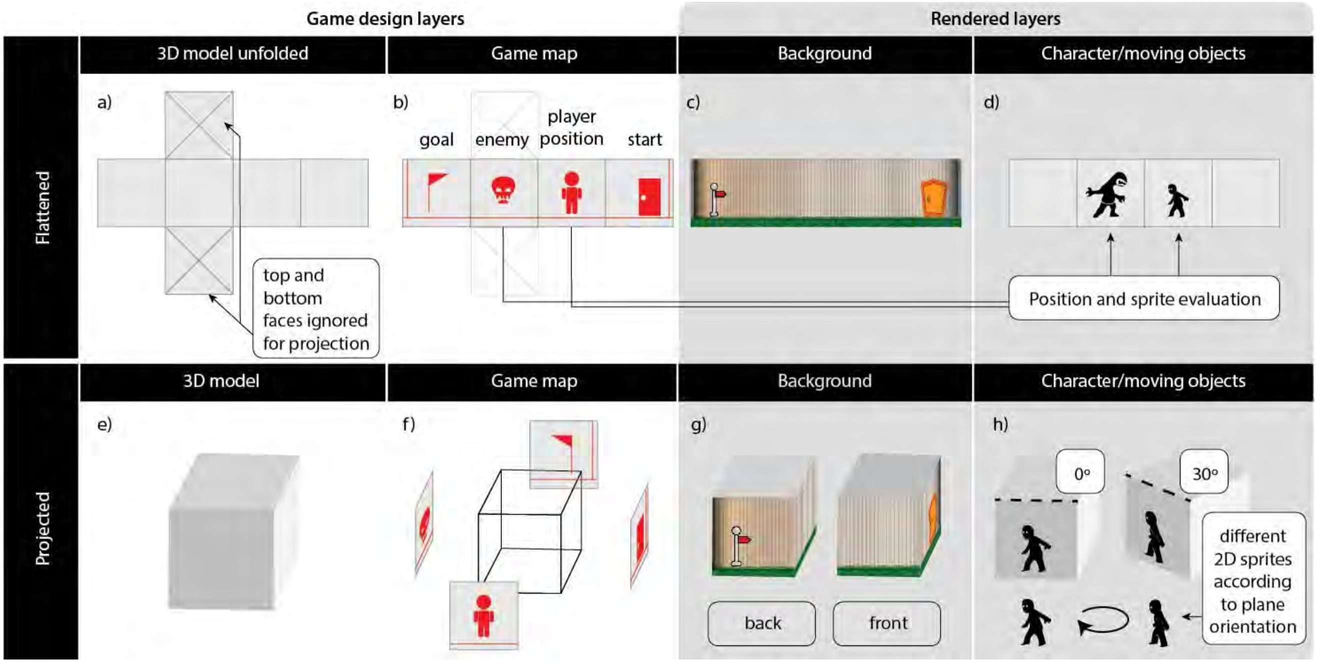

Figure 9- Game layers structure overview. a) 3D model unfolded, b) Game map (stage design) based on model unfolded layout, c) background texture bitmap, d) characters displaying on foreground after retrieving their position from game map, e) 3D model, representation of the physical object, f) Game map split and positioned according to 3D model planes, g) background texture applied/ projected on the 3D model, h) sprites display according to plane orientation in relation to the projector center.

5.3.1 Physical object and plane conversion

As explained earlier, 3D applications offers some tools used to facilitate the process of unfolding 3D geometry into a plane and mapping each polygon face to a portion of a bitmaps texture. Figure 10 - a shows a some possible way (Cylinder UV projection) of unfolding the 3D model used on our application. Projection unfolding methods don't take into account every single face of the model, but instead their relative position to the UV projection plane. All the faces visible from this plane are flatten, losing on dimension, resulting in distortions that might need some attention. A cylinder projection includes UV projection planes around the object and sew the view of each plane into one single plane that can be displayed on some UV editor window. On the other hand, the paper sheet unfolding method is not resulting of a projection analyses. Instead, this method maps each face to a plane individually, preserving their corners angles and their connection, whenever possible, to their adjacent faces. Also, all the edges are kept in proportion to each other (Figure 10 - b). Although the main purpose of using this unfolding method is to create a printable version of the 3D model, so it can be built as a physical object later, we have adopted this as a UV map layout to be used on converting the game map layer to the correspondent faces on the physical object because proportions remains undistorted. This way we can make sure that if a character on the game (virtual) moves 10 units to the left, the same applies to the physical model.

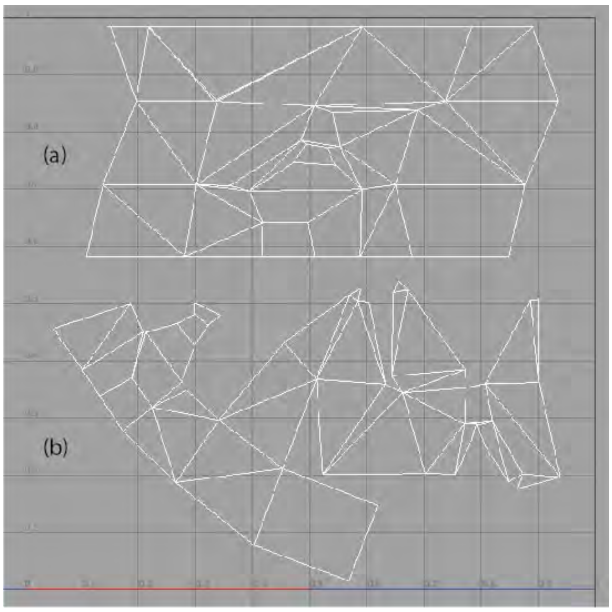

Figure 10 - a) Cylinder UV projection (generally provided by 3D applications) and b) the paper sheet unfolding method, used for building paper craft folding models.

5.3.2 Game map layer

This layer is used to design the game (stage) map, including collision surfaces which defines stage routes and goals. In addition, collectable items, tunnels and challenges spots for the game play can be decided on this layer. We have developed a tool which allows the creation of these game objects having the physical object planar map (defined in the previous step) used as a layout. See Figure 9 (b and f). By simply drawing lines and dragging them with the cursor, we can setup the basic collision surfaces like floors and walls for a stage design (Figure 11 - a). After the game map is decided, each fragment relative to a model plane is subsequently

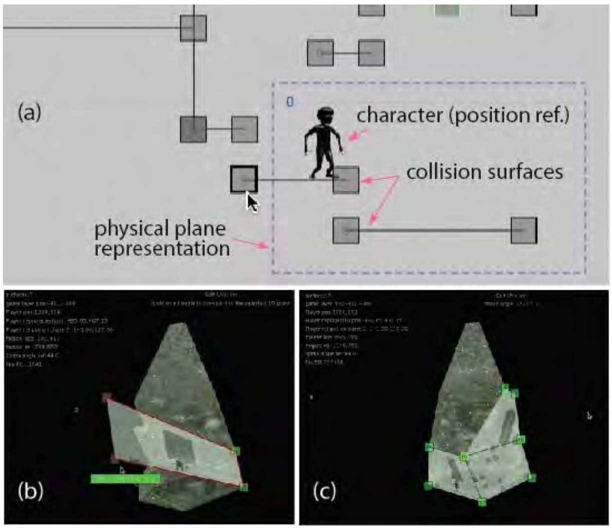

Figure 11 - a) Some game objects such as collision objects (floor, walls) are being designed inside the limits of the plane, represented by dashed lines. Every portion of the game map contained inside this plane representation becomes a game map fragment, later attached on the 3D model correspondent faces, as seen in (b) and (c).

connected to its 3D respective faces as seen in figure 11 (b and c). Because of this step, we can track the position of the moving objects, including the main character (manipulated by players) in relation to the 3D model center. This transform information is used later to render characters and other dynamic objects on top of the background layer, and will be detailed on the respective subtopic.

5.3.3 Background layer

The background layer is nothing but a bitmap texture designed to be mapped to the 3D object. Since the game map layer is not visible during the projection, the background texture is aimed to reinforce the game layout, including visual indications of floors, walls, holes and obstacles on their respective positions. Because of this dependency existing between the background and the game map layer, we have used the later as a reference to draw textures and other elements, on an external graphics editor application, and exported a bitmap image, used in our experiment.

This bitmap image is intended to be projected on the physical object the same way as it displays on the 3D model. Thus, after we have mapped the 3D model using traditional techniques for 3D texturing (on an external application), we were then able to retrieved the UV coordinates contained in each vertex of the 3D model and finally convert these coordinates to be used on the projector plane. As a result, we could project each 3D face to its correspondent surface on the physical model.

Currently, the background texture used in our application is flat and includes no bump (relief) nor other sublayer rendering instructions. We believe this texture layer can evolve to incorporate additional sublayers, such as normal or parallax mapping, causing a more interesting sense of perspective for the player during the game play.

5.3.4 Characters and moving/animated objects layer

This corresponds to the topmost layer where objects are animated or manipulated by user input commands. Objects contained in this layer render using a different technique than that used on the background layer. The reason is that having these “floating” objects dependent on the UV coordinate for each static face, would cause them to look flattened. In addition, when the animated object swipes from a plane to its adjacent plane it could be clipped out (Figure 8). A simple solution for this issue was to project the objects laying on this layer over the background separately. This way we make sure the object is always projected in alignment with players’ point of view (projector center). Let us take the example of the main character to broaden the scope of this technique.

All the actions (animation) performed by the main character are condensed in a single bitmap file as shown below, in Figure 12. This sprite sheet contains all frames used for the animation correspondent to each action of the main character.

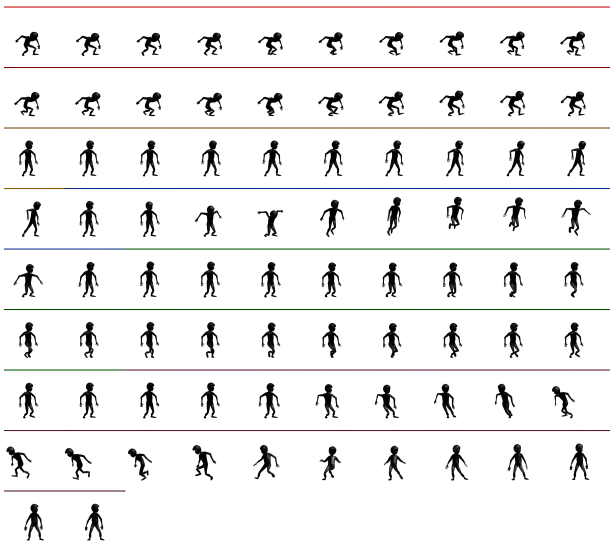

Figure 12 - Main character action sprite sheet for 0º plane orientation. Every coloured line represents an action performed by players during the game.

During the game play, the character is controlled by the player and its position is updated inside the game map layer, where character’s collisions against the game objects is evaluated. In order to extract the character position from the game map, we need to perform some transform operations. After identifying which plane is holding the character, we transform the 2D position of the character inside the game map to its 3D position on that specific plane - on the 3D model. We offset this point position to the 3D model center and finally multiply the result to the projector projection matrix in order to have the character correctly projected on the physical model.

We still need to be aware the projection is being performed at an angle, incurring in the so called keystone effect, which might cause the character to display more or less tilted. But because we have access to the orientation of each plane in the 3D model we are able correct this distortion by multiplying the character texture corners to the projector matrix, thus interpolate the result for each pixel within that area.

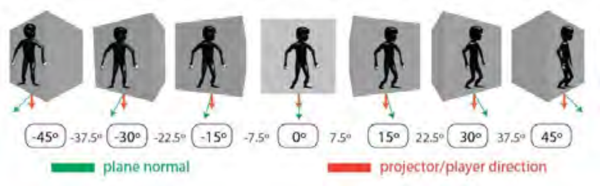

Figure 13 - same sprite frame from main character displayed according to a different sprite sheet set.

Finally, we add a sense of volume to the character and distance from the background by rendering the character according to the difference of the plane normal where character stands and the projector center direction, as observed in Figure 13. The red arrow represents a vector from the center of the plane to the projector/player direction, while the green arrow represents the face normal direction. We have prepared 13 sets of sprites contained all animation frames (see Figure 12), from different views: -45° to 45°, within intervals of 7.5°, corresponded to the motor minimum interval a game command will allow the motor to spin. The system will display the character's action from one of these sets, by considering the motor current angle, the projector center and the character position.

The projection method described in this subtopic intentionally distorts the object being projected to satisfy the player's unique point of view. Because of this arbitrariness, it is possible that some of the projected objects, including characters, might result in visual limitations (e.g. perspective distortions) for viewers situated somehow distant from the projector center.

6 Conclusion and future work

We have introduced spatial actions to be performed in digital games projected onto 3-dimensional moving support object with the goal of mixing this sort of interaction with tangible interface for games. Traditionally, game consoles embeds a CPU able to load data from external removable media and process it in real time according to the player's commands. The same game can be played, *"as is"*, in any compatible console. Instead, we propose the concept where the same game can vary infinitely according to the physical environment where it is projected onto. This concept of game can be developed bearing in mind to run a set of constant rules, such as the game objectives, challenges, story, characters, all previously defined by the game developer. At the same time, all these rules can be distorted by the physical surface onto where game is decided to be played. We envision a moment where this sort of hardware and software would be available for game designers and players so they could produce creative customised contents to be shared among other players. For the next steps, we are aiming to produce a more solid and standalone concept for hardware, including a self-calibration step, improving the game engine and game design tools, including procedural methods to build up the game layout randomly if desired and intuitive methods for 3D scan support objects.

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Practical Study of Open Sharing at Yamaguchi Center for Arts and Media [YCAM]

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Abstract
Yamaguchi Center for Arts and Media [YCAM] (herein after "YCAM") is an art center focused on media technology. It produces artwork incorporating media technology, develops media technology, archives related information, and provides education. YCAM has open shared its works from some of its projects. To "open share" means to publish a work so that a third party can utilize it freely within certain conditions. In this paper, the introduction of open sharing at YCAM and the practice of implementing open sharing will be described and discussed.

Keywords: intellectual property, open sharing, creation process, media technology, art

1 Introduction

1.1 Open Sharing

We define open sharing as the practice of publishing works and allowing a third party to use these works freely within certain conditions. This permission is based on so-called "IP rights" such as copyrights or patent rights. The conditions can be defined by licenses or terms of use (e.g., Creative Commons License). Designing and practicing open sharing are considered to be part of legal design ("legal design" means designing laws, contracts or rights by citizens or users; it works like lubricating oil, driving society [1]).

Open sharing can increase creativity. As a result, it leads to the creation of new expressions and helps to solve various problems. In this paper "Creativity" means: 1) a factor that encourages creation, 2) a factor that increases quality and quantity, and 3) the implementability of creation, leading to new ideas and works.

When we translate this word to English, we considered the word "Open Publication" that is used in MIT Open Course Ware. However it sounds only for contents like Movies, Sounds, Text. By the way, we also Software or Hardware and so on. So we decided to define a new word "Open Sharing" to cover them.

1.2 Current Situation of Creation and Open Sharing

After the growth of the Internet, there was much discussion about how society was going to change. This discussion went beyond the increase in chance contact between people who were strangers and beyond the activation of intercommunication. It was expected that new, valuable, and synergetic effects would be created through the fusion of different fields. On the other hand, there was concern that conflicts would occur [2][3].

Creation activities came to be affected by the same developmental issues that took place in other fields. In this paper, "creation" means to make a new idea or work. The development of an information structure that includes not only a high-speed network or high performance devices, but also an information sharing service, leads to the formation of an online community that works as a hub. As a result of this development, people who had not collaborated together in the past came to collaborate and open share their works. Open shared works provide further creation. Various developments in technology, new expressions, solutions of problems, and new content are produced through this creation cycle [4][5]. There is "a framework of creation with collaboration and open sharing via the Internet."

Additionally, opportunities were increased for people to gather in real-life places and conduct intercommunication and creation. For example, in the 1990s, the "workshop" method was expanded rapidly and has now become common especially in Japan. Through "workshops," it is possible to convey technology and ideas effectively and create personal connections. Additionally, events for concentrated creation in a specialized field (e.g., a hackathon) have also come to be held more often [6]. We term this "a framework of creation where people gather physically."

These two frameworks cannot be divided, but are in a complementary relationship and have an affinity for each other. Zachary Lieberman, who is an advocate for "DIWO (Do it with Others)," says that in an online community, a network of personal connections strongly affects collaborative development with open sharing[7]. This means that it is important to combine the two frameworks into one. In this kind of situation, open sharing of works is significantly effective.

When we examine the current situation of creation from another perspective, we can see that the movement in which general citizens perform creation has spread and has become more socially important. This movement is called the "Democratization of Manufacturing." For example, the number of exhibitors in and visitors to Maker Faire and Mini Maker Faire increased by 24 times between 2006 and 2013 [8]. Additionally, in 2012, the Obama Administration initiated a four-year program designed to establish workshops with digital fabrication equipment such as 3D printers and laser cutters in 1000 schools. This movement will further progress this trend [9].

In the background of this change, new cultures of or thoughts about creation exist and affect the change. For example, the "culture of personal fabrication" progresses with personal self-motivation and creativity as its engine, and "the spread of machine tools" and "the exchange and sharing of creation-based knowledge" as its wheels [10]. The FabLab structure, which is a framework of creation, actualizes the culture of personal fabrication. Open design, with which creators allow third parties to utilize, distribute, derive their work and provide new derivatives of their work freely, is another example. It is claimed that this changes the structure of design practice [1].

There are other variable practices of creation present in the background (e.g., Linux). It can be said that these practices have a common point in that the open sharing of works is included in the process.

Open sharing can be used not only in public or non-profit operations but also in business operations. It is significantly present in business circles and is known as the "freemium model" [11]. In the manufacturing industry, there were over 300 fare-paying open hardware products by the end of 2011. The value of the performance of these products exceeds 50 million dollars [9].

Therefore, open sharing is an important element in the current situation of collective creativity.

1.3 Related Case

Case examples of open sharing that are related to the media technology on which YCAM focuses include "openFrameworks" or "Pure Data" in relation to software and "Arduino" or "the EyeWriter" in relation to hardware. "EYEBEAM" and "Public Lab" are open sharing cases that pertain to an organization.

The EyeWriter is an open source eye-tracking system. Third parties have added new functions to the technology and used their own modified versions of it [12][13][14], while other third parties have begun new projects inspired by it [15]. The EyeWriter project was included in TIME magazine's "The 50 Best Inventions of 2010," the Design Museum's "Brit Insurance's Designs of the Year" in 2010, and received the Prix Ars Electronica (Golden Nica), the 2010 FutureEverything Award, and more. At the presentation of the Prix Ars Electronica, the product was commended as "an ongoing, open-source, collaborative research effort" that provides encouragement to ALS patients [16]. A member of staff from YCAM InterLab joined the development team of the EyeWriter 2.0.

EYEBEAM is a nonprofit art and technology center established in 1997 [17]. It holds four exhibitions and 40 workshops every year. In EYEBEAM Creative Residencies, an artist or an engineer outside EYEBEAM develops creative open source technology as a fellow or a resident. This can be thought of as a research and development project that is prepared for open sharing and run by an organization. Public Lab is an example of a nonprofit organization addressing social issues, which open shares hardware and sells its works [18]. However, their processes of open sharing or tools for open sharing have not been published.

1.4 YCAM InterLab

Yamaguchi Center for Arts and Media [YCAM] is an art center focused on media technology. It operates around a central axis defined by the pursuit of new artistic expression incorporating media technology. For example, it produces artwork incorporating media technology, develops media technology, hosts a variety of events, archives related information, and provides education.

YCAM InterLab is a research and development team that was created in 2003 when YCAM was established. It also functions as a hub of personal connections. InterLab has continuously executed collaborative research and development with various artists and engineers. As a result, InterLab began to function as a hub for intercommunication between people related to media technology and art. In addition to gaining a synergetic effect with InterLab in research and development, collaborators can expand their network of personal connections through this hub. InterLab also expanded its network through building connections with collaborators.

In other words, InterLab already had "a framework of creation where people gather physically." Therefore, it had an affinity for "a framework of creation with collaboration and open sharing via the Internet" and was ready for open sharing.

2 Implementation and Purpose of Open Sharing in YCAM

2.1 Consideration of Implementation

In order to implement open sharing in YCAM, we first considered and defined criteria for open sharing. The criteria is "if open sharing matches 1) operational policy and 2) the goal and circumstance of each project, then go for open sharing." This criteria could be utilized by other operational bodies.

We checked the consistency of open sharing with YCAM's operational policy. Yamaguchi city government made an ordinance to establish YCAM. The ordinance defines YCAM's mission, that is operational policy, as follows:

1.creation and promotion of culture and art,
2.support for citizens to conduct autonomous cultural activity,
3.education utilizing information technology,
4.research utilizing information technology,
5.archiving and providing documents and information,

etc.

The effects of open sharing include spreading work, boosting new creation, helping education, boosting R&D, archiving properly and increasing presence.

If YCAM's works were open shared so that citizens could utilize them, it is possible that the works would be spread and utilized more (including in the fields of art and education) and thus, new creation would be boosted (this complies with missions 1 and 2). Additionally, this could increase the presence of the art center through publicity and enhance the center's function as a hub. Increasing the center's presence can help to execute various missions (this complies with missions 1-5).

Open sharing leads to proper archiving, including the accumulation of technology and activities (this complies with mission 5). Quality enhancement (e.g., versatility, which is a part of increasing creativity) and an increase in motivation can be expected through postulating open sharing at the beginning of the project [19]. Open shared works can help other new projects, which can boost R&D (this complies with mission 4). When participants in a participatory project experience open sharing or open shared works are used beneficially in the project, education related to media technology or open sharing is advanced (this complies with mission 3).

In summary, open sharing was introduced at YCAM because the effects of open sharing match YCAM's operational policy. The particular use of open sharing depends on the goal and circumstances of each project.

2.2 Goal

As mentioned above, open sharing can increase creativity and lead to the creation of new expressions and solutions for problems. If the effects of open sharing in the operation (mentioned above) function properly, the result of open sharing should contribute to operational policy. This means that for an operating body, the initial goals of open sharing are that its effects are actualized (and this works in the same manner for other operational bodies). Therefore, the goals of open sharing conducted by YCAM are as follows:

1)	Spread Work and Boost New Creation
2)	Archive Properly
3)	Boost R&D
4)	Help Education
5)	Increase Presence

3 Methods

In some YCAM projects, works were open shared in consideration of the goal and circumstances of each project including the nature of work, cost-effectiveness, etc.

In order to execute open sharing, we developed a procedural model and tools required for open sharing and studied related issues. Each is executed in parallel and interacts with the other; for example, a tool is updated through its use in projects, and projects are executed effectively by using a tool.

These perceptions and knowledge, which are gained through the development of procedures and tools, are also utilized in the conception or implementation of projects.

Additionally, we open shared the tools and results of the study so that third parties could use them to open share works by themselves. This could lead the third party to improve its creativity and enhance its projects.

3.1 Process Model of Creation with Open Sharing

We designed a procedural model of creation that includes open sharing. It is based on a PDCA cycle (figure 1) [20], developed to befit open sharing and match a creation process. In this model, the creation process has steps such as [Pre-Production: Plan, Production: Do, Post-Production: Do, Reviewing: Check, Updating: Action]. The elements that are needed for open sharing are included in each step. With this model, we developed tools for effective open sharing and considered related issues.

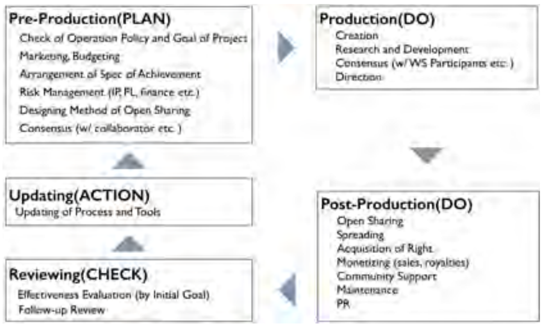


Figure 1 Process Model of Creation with Open Sharing

3.2 Study in IP Risks and Countermeasures

Studying patent risks and countermeasures is related to "Risk Management" in the model. To explore the IP risks that practitioners who engage in open sharing face, we began our study by researching patent risks in open sharing practices, and then explored the proper countermeasures required to avoid these risks [21]. This section of the study is published on the website as a paper so that it can be used by third parties.

3.3 Legal Tools

Legal tools (Contract Form for Joint Research and Development, Consent Forms for Participatory Project) were developed and utilized to properly and efficiently execute open sharing projects.

These works (the contract form and consent forms) are the result of a collaborative project with Tasuku Mizuno, an attorney at law.

1) GRP Contract Form

The Contract Form for Joint Research and Development is related to "Designing Methods of Open Sharing" and "Consensus" in the model. We have developed a GRP Contract Form, which is designed with the aim of implementing Joint Research and Development with the open sharing of the work [22].

The goals of the GRP Contract Form are: 1) to open share work properly, avoiding dangers (i.e., that nobody can use the work after project has been completed), and 2) to increase creativity. These goals are achieved through designing a production framework that includes open sharing, by having a framework in common beforehand, and by coordinating agendas and tasks.

This contract form relates to projects that meet the following conditions: 1) an organization such as an art center or research institute invites a collaborator such as an artist, an engineer or a researcher, 2) joint research and development is performed, and 3) the work is open shared in order to lead to further deriving and development.

It is designed to be used by a host that is similar to the organization mentioned above, and an invited collaborator. It aims to increase creativity in research and development by clarifying elements that should be configured and processes that should be executed, and through strengthening confidential relationships and motivation.

A user evaluation of the GRP Contract Form was conducted in order to increase creativity and the things needed for open sharing [19]. The result of the evaluation suggests that worked well for creativity and executing open sharing.

Additionally, for participatory projects that were executed at YCAM, we developed a consent form with the aim of properly open sharing the works created by participants and of increasing creativity.

2) Consent Form for Open Sharing Works made in "YCAM Summer School"

In 2013, YCAM hosted the "YCAM Summer School" series of workshops, focusing on media technology and personal fabrication, which were open to all citizens. This consent form was created and applied in order to enable the workshop host to open share the works created by participants in the workshops based on the Creative Commons License, according to each participant's intention. The form itself is again open shared (currently only in Japanese) and may be used by other workshop hosts.

3) Consent Form for Open Sharing "games" made in "Think Things"

In 2015, YCAM hosted "Think Things ― An ecosystem of 'things' and 'games,'" a participatory exhibition focusing on the driving force of games that generate new opportunities for learning and creation. Participants create new "games" and record it in "ASOLOG," which is a paper for recording "games" in the venue. ASOLOG made by participants was open shared with the public at the venue and on the website (http://asolog.ycam.jp/) with the participants' consent. It aims to create new "games" with "games" registered with ASOLOG previously.

This consent form was created and applied in order to open share "ASOLOG" based on the CC0 or Creative Commons License to create further deriving and development of "games." The form itself is also open shared to the public (currently only in Japanese) and may be used by other hosts.

4) Consent Form for "2015 YCAM Sports Hackathon"

YCAM has conducted the "YCAM Sports Research Project" since 2015. The 2015 YCAM Sports Hackathon was held as a part of this project. New sports created by participants in the event were played in "Yamaguchi Future Sports Day." Documents that describe the new sports created in the event were open shared on the website.

The "Consent Form for 2015 YCAM Sports Hackathon" was developed for participants of 2015 YCAM Sports Hackathon.

This consent form is based on the "IAMAS/makeathon agreement" that is open shared by IAMAS. The goal of this consent form includes 1) to explain the concept of the event, 2) to improve creation 3) to place the consent form as a part of facilitation 4) to experience open sharing. It is characterized by explaining the concept of the event, showing that the idea is public domain, sharing rights of work with the participants and host, enabling the open sharing of the work, and setting up credit for publication.

3.4 Guidelines for Open Sharing

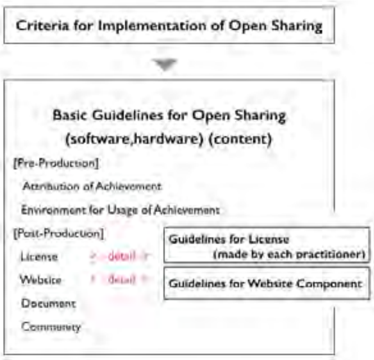


Figure 2 Framework of Guidelines for Open Sharing

The guidelines for open sharing is related to "Designing Methods of Open Sharing" and is designed to cover all parts of the model. Using case studies, we discussed efficient methods for and the important points of open sharing. Then, we developed guidelines for its practice and established the principles of open sharing works [23]. This "Guidelines for Open Sharing" consists of "Criteria for Implementation of Open Sharing" (this is described in 2.1), "Basic Guidelines for Open Sharing," and "Guidelines for Website Component" (Figure 2).

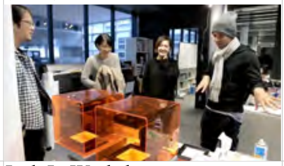
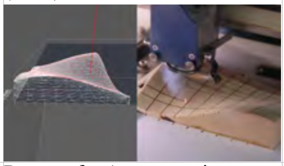
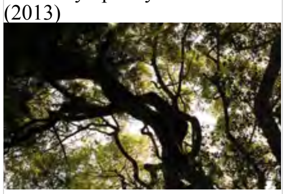
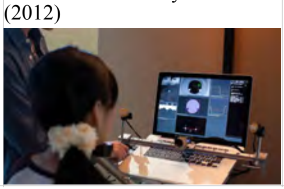
The guidelines for open sharing is practical, but it is not versatile enough. To solve this problem, we are preparing an update that will arrange the composition into two parts, "Principles" and "Practical Manual."

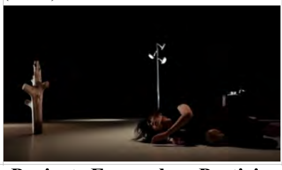
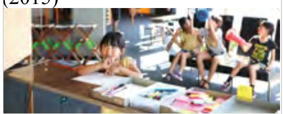
4 Result

YCAM has open shared its works of projects such as media technology, content, workshop, and document (Table 1) [24]. In each project, consideration was given to ensure matching of open sharing and the goal and circumstances (described in 2.1). The circumstances include characteristic features of the works, so that when a project involved more than one work, each work was considered for adoption of open sharing.

The outline of each case is shown on the website from the point of view of the work, license, and case of use.

Table 1 Practice of Open Sharing in YCAM (-2016.3)
(Projects and Open Shared Works)

A. Projects Focused on Developer-Generated Work		
1	Open Yeast Protocols (2016) 	Document of experimental protocol w/ Creative Commons License BY-SA
2	Guest Research Project vol.3 (2015) 	(in preparation)
3	Jack In Workshop (2015) 	(in preparation)
4	ofxEpilog (2014) 	Software to control laser cutter w/ GPL v3.0
5	Reactor for Awareness in Motion (RAM) (2013-2015) 	Software of coding toolkit to create environments for dancers w/ Apache License 2.0, GPL Hardware of motion capture system w/ Creative Commons License BY-SA
6	Forest Symphony (2013) 	Drawing of Dubstrate(pdf) w/ Creative Commons License BY-SA Drawing of Dubstrate(Gerber Format File) w/ Creative Commons License BY-SA Parts List w/ Creative Commons License BY-SA Software to control Hardware(Arduino Sketch) w/ Apache License 2.0 Software to handle Biometric Data(Sample code for oF and Processing) w/ Apache License 2.0 Biometric Data from trees w/ CC0
7	Guest Research Project vol.2 (2012) 	Software of time line tool w/ Apache License 2.0
8	How to Make the EyeWriter 2.0 (2012) 	Document of assembling instructions w/ Creative Commons License BY-SA

9	Guest Research Project vol.1 (2011) 	Software for projection mapping w/ MIT License
10	Choreography filmed: 5days of movement (2011) 	Movie of dance performance w/ Creative Commons License BY-NC-SA
B. Projects Focused on Participant-Generated Work		
1	2015 YCAM Sports Hackathon (2015) 	Document of new sports w/ Creative Commons License BY-SA
2	Think Things (2015) 	Document of new games (ASOLOG) w/ CC0
3	YCAM Summer School (2013) 	Movie, Graphic, Drawing, 3D Modeling Data, Modulobe Data w/ Creative Commons License (depends)
C. Legal Tools		
1	Consent Form for "2015 YCAM Sports Hackathon" (2015) 	Consent Form for participatory project w/ Creative Commons License BY-SA
2	Consent Form for Open Sharing "games" made in "Think Things" (2015) 	Consent Form for participatory project w/ Creative Commons License BY-SA
3	Consent Form for Open Sharing Works made in "YCAM Summer School" (2013) 	Consent Form for participatory project w/ Creative Commons License BY-SA
4	GRP Contract Form (2013) 	Contract Form for collaborative project w/ Creative Commons License BY-SA

(Images are from YCAM's website.)

5 Discussion

5.1 Achievement of Goals

The results of the practice are discussed below with regard to each goal.

1) Spread Work and Boost New Creation

In some projects, YCAM's open shared works were expressly utilized (A6,7,910). They were not only employed for experimental use, but also for the creation of new artwork. One case was acclaimed by leading competition in the field [25]. It is believed that the open shared works have been spread and boosted new creation.

Open shared documents from YCAM (including legal tools) were not explicitly used on the Internet. On the other hand, Tasuku Mizuno, who is one of the core members of the GRP Contract Form production team, mentioned that the GRP Contract Form considerably affected some projects, for example, 1) successive projects by Shigeru Kobayashi that open share contract forms including the "IAMAS/makeathon agreement" and 2) "HACKberry," which is an open-source project producing a myoelectrically-controlled artificial arm by exiii. The GRP Contract Form was spread outside of YCAM, even outside of the media art field, and it is thought that it helped new creation.

2) Archive Properly

Each work is open shared on each project's website. The works are not only published, but are also combined with other documents for users such as the introduction of the projects, manuals, or samples. This increases the possibility of use of these works by third parties, and helps to properly archive the works and knowledge related to the projects.

3) Boost R&D

As a result of open sharing, not only has the creativity of third parties who utilize the work been enhanced as mentioned above, but also the creativity of creators who make the original work [19]. The user evaluation of the GRP Contract Form (mentioned in 3.3) showed that using the form has a beneficial effect because it leads to a "sense of safety, as it is possible to utilize the work after the end of the project" and an "increase and maintenance of motivation through confirming the implementation of open sharing." According to users' comments, an increase in motivation to improve quality is caused by the fact that the work will be made available to third parties and that reuse is guaranteed. This means that open sharing has a beneficial effect on enhancing R&D.

4) Help Education

In some participatory projects, participants open shared their own works and created new works by utilizing others' works.They are strongly related to the activity of YCAM education team, especially from the point of view of education that promotes learning the idea of open sharing and experience it.

The YCAM Summer School (B3) offered a series of workshops focusing on media technology that were open to all citizens. The works made by the participants in the YCAM Summer School were open shared with the participants' consent. Each participant who created a movie and soundtrack not only published his/her work but also made the decision to apply a public license (Creative Commons License) to it (Movie Creation: 8 w/CCL:7; Sound Creation: 4 w/CCL:2; Modulobe: w/CCL:51).

In Think Things (B2), participants created (a) new personal "games" through their experience, including "Play," "Create," and "Share." The created "games" were published at the venue and on the website (like art pieces that are exhibited in museums). Participants could not only create an idea from scratch but also withdraw the ASOLOG (record of "games") created by others and arrange it to create new "games." In a period of about 60 days, 730 ASOLOG were created and open shared.

At the 2015 YCAM Sports Hackathon (B1), around the core concept of "developlay," an expression coined to refer to a combination of "development" and "play," the participants developed new types of sports which engaged both the brain and body. Ten documents of created sports were open shared.

Workshops were held where participants used open shared works (A2,5,7,9). This system is effective for education because the works were archived properly and were able to be utilized after the event by the participants.

The participants could learn about open sharing through experiencing open sharing. In addition, the consent forms were utilized for legal considerations and they enriched participants' understanding of open sharing (B1,2,3). This means that we can utilize consent forms as tools for facilitating open sharing.

5) Increase Presence

Widely advertising a center's unique and beneficial activities has the effect of increasing its presence. YCAM's open sharing activities sometimes appear in media articles. Although the number of such cases is small, the main topic of such articles is open sharing [1][26][27]. Many cases take up open sharing as a topic when YCAM's activities receive recognition or they are introduced to the public [28][29][30][31]. Additionally, open sharing is considered helpful in increasing affinity and ensuring the smooth dissemination of information, which in turn leads to an increase of the presence of the operating body (YCAM).

Regarding YCAM's function as a hub that can create new networks of personal connections, it is mainly determined by 1) the personal, outward-looking activities of people who are involved in the project, 2) the impact of the project, 3) the usability and availability of the work, and 4) the management that aims to spread the project. Additionally, open sharing indirectly contributes to enhancing the center's hub function through participatory projects, utilizing the open shared works (including workshops), ease of access to the open shared works, the affinity caused by open sharing, and the connection to the open source community.

The workshops utilizing open shared works (mentioned above) are a case in point (on a face-to-face basis). The participants worked together at these workshops and made new connections. It was reported that some teams that were created during the workshop continued their activities even after the workshop had ended(A5).

In another case of participatory projects (B2), the participants created new games based on others' games. This is another example of people being connected via a medium (ASOLOG in this project).

There are more than ten cases in which third parties who saw "How to Make the EyeWriter 2.0" contacted YCAM. Some of them inquired about the details of how to build it (and some of them did), while others suggested a collaboration with YCAM. These third parties are a diversity of people like designers, welfare participants, and so on.

Some works are open shared on GitHub and connect with the open source community through relationships on the Internet. In A7 and A9, openFrameworks, an open source software (toolkit for creative coding), was utilized for development, and the works were open shared. This led to the convening of the 2013 openFrameworks Developer Conference at YCAM as a hub for intercommunication. It also encouraged popular creators in the open source community to come to YCAM from distant places at another time.

Through open sharing, these activities enhanced the creation of new connections among people who did not previously know each other or YCAM, and thus increased the center's function as a hub. Of course, open sharing also plays an important role in increasing the center's public presence.

5.2 Problems and Future Research

5.2.1 Problems

The works of some projects were not expressly used by third parties. Third parties utilized open shared works of the other projects to create something new. However, we have not had possession of a tracing system that would allow us to properly track this. Tracing is important not only for evaluating the effects of the activity, but also for making connections between third parties and YCAM. While it is difficult to trace the spread of works, it may be important to consider using a tracing system or providing some incentive for third parties to report their own usage. Sustaining community support and maintenance are also problems that remain to be solved.

In participatory projects, user evaluation of open sharing has not yet been conducted. Evaluations that include users' points of view are needed to understand the effect on participants' creativity.

5.2.2 Future Research

1) Share Know How

We open shared the tools and results of the study presented in chapter 3. The guidelines for open sharing is practical but could be relatively less versatile (as mentioned in 3.4). We hope to make a guidebook to summarize our expertise that is more accessible to the public. Through these activities, we want to share and spread experience and knowledge gained through these practices, which can be called the meta-design of open sharing.

2) Update

Because the cycle of technology or methods in the field of media technology moves rapidly, it is often necessary to consider and absorb new elements (e.g. bioware). Legal elements like licenses are on a level with this cycle. It is necessary to update our works related to open sharing by introducing new discussions on a constant basis.

3) Combine Open Operation and Exclusive Operation

It is thought that the choice and combination of open operation and exclusive operation will be more important and significant in IP management. We want to utilize our study for education to acquire this kind of ability. Additionally, we want to take in an operation combined with open sharing and exclusive operation that is effective for increasing creativity (e.g., Arduino).

4) Considering a New Framework

YCAM has practiced two kinds of frameworks: "a framework of creation with collaboration and open sharing via the Internet" and "a framework of creation where people gather physically." We have attempted to expand collaborative networks by increasing face-to-face connection and online connection in conjunction with the two frameworks. For example, RAM Summer Camp 2014 was a workshop/ hackathon that was run in a learning-camp style at YCAM and covered the subject of open shared works on the website. Increasing the synergetic effect of the two frameworks is a future issue.

5) Effective Utilization of Open Shared Works

LabACT vol. 1 "The EyeWriter" was a project that produced new art works using the EyeWriter, which is a piece of open-source hardware as mentioned above. It was held in YCAM in 2011 with two artists, exonemo and Semitra. LabACT vol. 2, "Eye-Tracking Informatics," was developed and created together with the artist Seiko Mikami. "How to Make the EyeWriter 2.0," which is mentioned above, and the "Eye2Eye" workshop are also a part of the works of this project.

In this project, we utilized the open shared work, gave it a new perspective and technology, intensively produced new expressions, and created a new value for the work. Research into process and production methods that utilize open shared works effectively will become more important with the increase in open shared works.

6 Conclusion

We have set up open sharing practices at the art center, made tools for open sharing, and considered related issues. We practiced open sharing and discussed how it worked. The discussions supposed open sharing worked to achieve its goal. On the other hand, some problems were also discovered. We wish to conduct further research and practice in order to address these newfound problems and challenges.

We thank YCAM's legal advisor, Tasuku Mizuno (an attorney at law, City Lights Law Office, Arts and Law, Creative Commons Japan), who has given us valuable advice and collaborated with us to progress open sharing.

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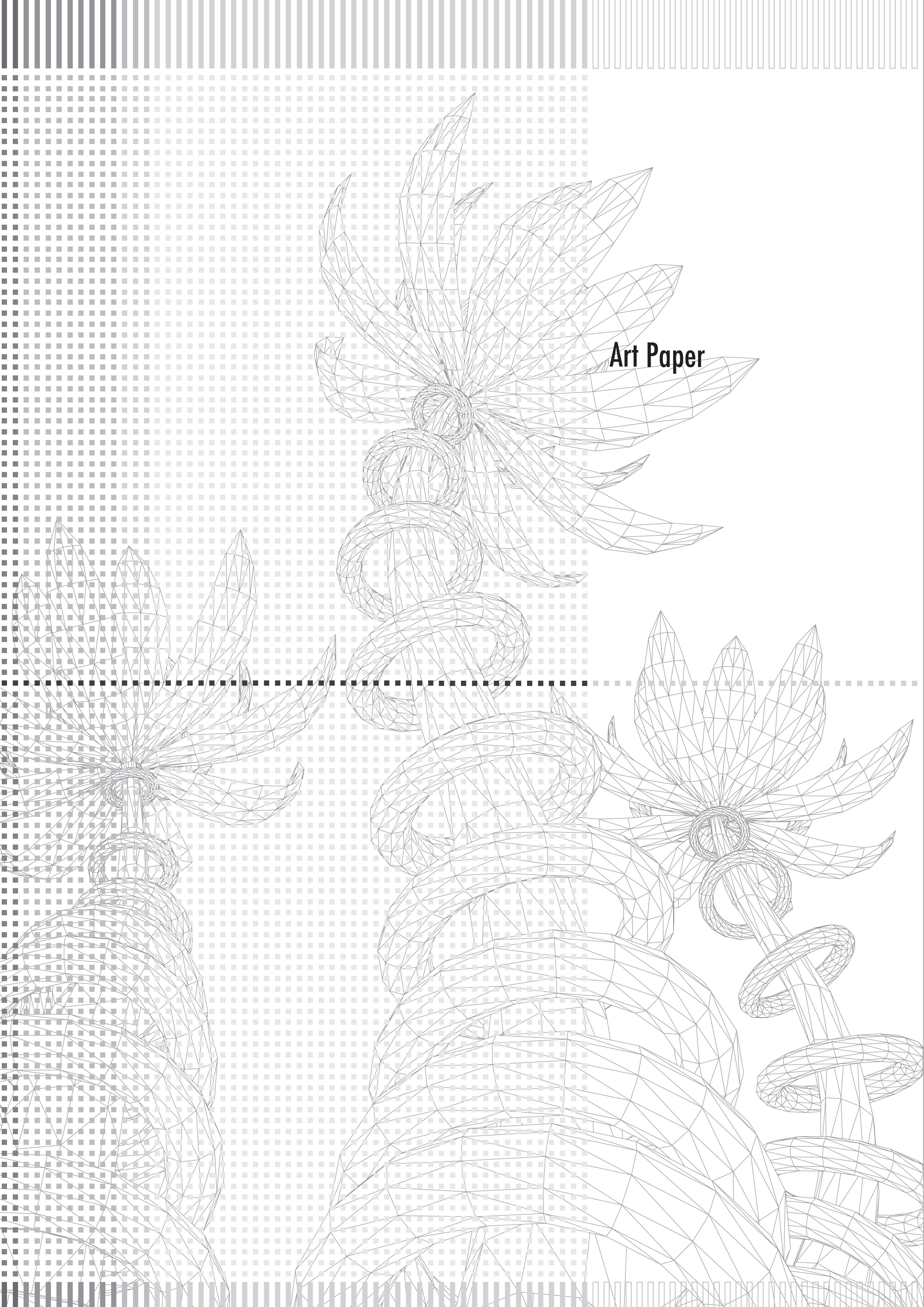
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Medallions

3D-printed Wall Plaques Featuring Procedurally-generated Ornate Shapes

Abstract
“Medallions” is comprised of a series of wall plaques featuring ornate shapes. In this work, each medallion was procedurally generated, and 3D-printed. This project is an attempt at translation from traditional ornamentation to a modern algorithmic art by using a combination of a procedural approach in Computer Generated Imagery (CGI) and the rapidly expanding field of 3D-printing technology. As an element of the medallions, we used 2D metaballs, which are a kind of modeling method in CGI. A drawing algorithm of the metaballs was modified and optimized to generate complicated ornate patterns. Also, regular-polygonal shapes were used for the process of density calculation of each metaball. However, a generated 2D pattern cannot be converted into a 3D model directly because there is an inconsistency that lines with convex information overlap each other in the intersection points on the 2D pattern. To solve the issue, we used an algorithm that an accurate peak height level is calculated at each pixel; the algorithm enables us to generate lines without overlaps. In this way, generated patterns were converted into 3D models, and then the models were 3D-printed finally. The finished artworks were displayed at several art exhibitions, and gained a certain reputation.

Keywords: 3D Printer, Metaball, Ornament

1. Artist Statement

Producing decorative ornaments is time- and energy-intensive because it usually involves complicated motifs. Therefore, ornaments have tended to be removed from contemporary designs along with the modernization of manufacturing after the industrial revolution[1]. However, it is pointed out that the world of traditional manufacturing may change drastically because 3D-printing technology has been growing rapidly in the past several years[2]. By using the technology, it may become possible exquisite designs which have been difficult and costly in traditional manufacturing. This characteristic seems to also be beneficial in the field of formative arts, especially decorative ornaments.

Also, a procedural approach, which is a technique to produce CGI based on an algorithm, may also be useful for generating ornate shapes efficiently. Procedural techniques have been used mainly to simulate natural objects and natural phenomena that are too complicated to be drawn or animated by artists. However, applications of the approach to artificial entities including decorative ornaments increased gradually in recent years[3]. As CGI becomes increasingly indispensable for feature films and video games, it is said that various artificial entities are desirable to be generated procedurally. For example, Whitehead[4] notes that there is room for further research on a procedural approach for generating decorative ornaments to save production costs, especially for numerous video games set in the medieval period. Considering these situations, it appears that a combination of 3D-printing and procedural approach could be beneficial in the field of decorative ornaments.

Incidentally, as an artist, the author has produced some algorithmic art animations; ornaments were featured in some of the works[5]. We think that one of the attractions of procedural techniques is mesmerized details which are difficult with hand drawing. This characteristic is also applicable in the field of ornaments. This project is an attempt of materializing such a beauty found in procedural approach as a tangible artwork in the real world. Based on these viewpoints, a combination of 3D-printing and a procedural approach was applied in this project to produce wall plaques.

2. Related works

Unlike fine arts, which are based on the artist's sensitivity, most decorative arts are based on highly standardized patterns. They usually have distinct formative rules, and they have been developed and sophisticated according to these rules. Decorative arts can be widely classified from primitive geometric patterns, to exquisite ornaments that consist of realistic motifs. As long as formative rules in ornaments, such as repetition, symmetry, and rhythm, are clear, we can extract rules from some decorative styles, and translate them into a computer algorithm.

Although few research cases deal with a procedural approach for designing decorative ornaments, some previous works pertain to the early years of CGI. For instance, Alexander[6] described a FORTRAN program for generating the 17 plane symmetry patterns. However, most research studies from that time focused on simple geometric patterns or tiling patterns. As applications of CGI expanded in the 1980s and 1990s, advanced representations of ornaments emerged gradually. A popular topic in this field is the guilloche, an ornate motif consisting of woven ribbon. Guilloches are widely observed in various traditional Western designs such as Celtic, medieval Russian and Armenian ornaments. Kaplan et al.[7] attempted to construct an algorithm for generating woven ornaments called "Celtic knots" in an enclosed 2D space. Islamic patterns are relatively popular in procedural generation because a clear geometric rule is applicable in their production. C. S. Kaplan et al.[8] attempted to draw the Islamic star pattern using an exquisite tiling configuration. Another study focused on floral patterns, which are present in medieval Western illuminated manuscripts. Most floral patterns in illuminated manuscripts are filled with repeated motifs based on a complicated iteration rule. Wong et al.[9] proposed a drawing method called "adaptive clip art" to fill an enclosed 2D space with floral ornaments. By changing the rule of stem branching and the type of floral motif, this method can be employed to represent various floral patterns in enclosed spaces. The abovementioned works, however, have focused exclusively on planar decorative patterns, and very few attempts have been made at procedural generation of 3D or semi-3D ornaments, such as reliefs, wall plaques, moldings, and grilles. Havemann et al.[10] attempted to generate Gothic style ornaments using Generative Modeling Language (GML). However, their approach covers a limited number of simple motifs, such as arches and a rosette, and it is impossible to generate complicated tracery patterns from the late Gothic period. The author attempted to generate more realistic Gothic ornaments by use of a motif oriented algorithm[11].

Unlike the abovementioned related works, this project does not intend to simulate historical styles of traditional ornaments; rather, it attempts to generate "ornament-like" shapes efficiently.

3. Medallions

This project focused on characteristics found in carvings such as architectural elements in Western traditional ornaments; it was attempted to construct an algorithm based on the characteristics. One of the popular motifs in Western architectural ornaments is a "medallion." It is a circular object with a geometrical or floral motif based on a rule of rotational symmetry, and it has been widely seen in various styles of decoration, from ancient to modern (Fig. 1). It is also called a "rosette" when this type of ornament is used in furniture decoration. Although expressions of medallions vary based on the number of symmetrical axes and the type of motifs, they usually consist of relief-like elements whose cross section has an acute angle. On the basis of this characteristic, construction of a procedural algorithm that generates complicated medallion-like objects was attempted.

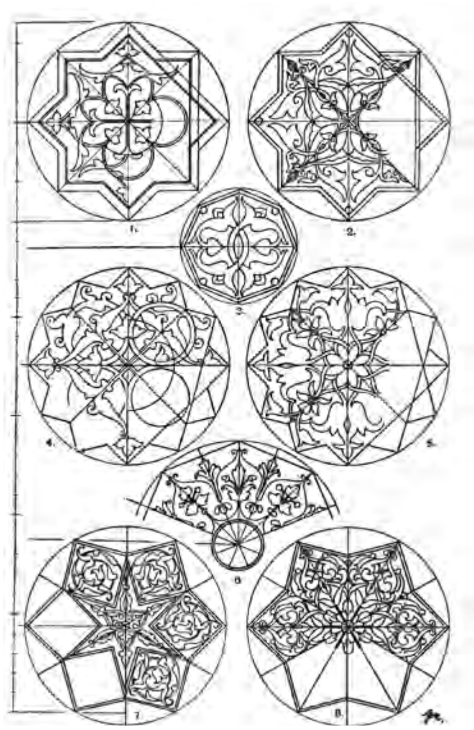


Figure 1 Examples ofmedallions in traditional ornaments
Meyer, Franz S., *Handbook of Ornament*, Dover Publications, 1957

4. Algorithm

Here, an algorithm that is based on medallions' morphological characteristics is constructed. It is desirable for the algorithm to be able to generate various patterns by changing parameters. On the basis of the requirement, this project used a metaball as an element of a medallion. Specifically, we used an algorithm called "stepwise threshold detection[12]." This method can generate more complicated shapes than the regular metaballs; it seems suitable for representing decorative patterns, which are the focus of this project.

4-1. Metaballs

A metaball, a kind of implicit surface, is a modeling technique for representing a smooth curved shape by using density distributions defined in a space[13]. Since it can generate a smooth organic shape whose metaballs merge into each other, like mercury, this technique has been used to represent the human body, animals, and amorphous shapes such as water drops. However, it has been often said that use of metaballs is an unsuitable technique to represent artificial objects such as manufactured products because it is difficult for metaballs to control their merging forms accurately. Although metaballs have been usually used in 3D space, the same method can also be used in 2D space; 2D metaballs can generate a smooth curve. In this project, 2D metaballs are used to generate a procedural 2D pattern, and the pattern is used as a height map for displacement mapping to construct a 3D model. Further, shapes of density distributions in each metaball do not have to be conventional circular shapes; any shapes of density distributions such as squares or hexagons are applicable. This project used metaballs with regular polygonal density distributions as elements of a medallion (Fig. 2). Combining regular polygonal metaballs with the stepwise approach described next can generate a complicated merging shape, which has a mix of straight lines and various curves.

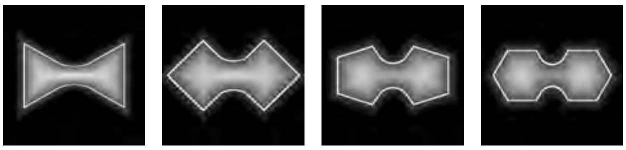


Figure 2 Merging shapes using regular polygonal metaballs

4-2. Metaball using stepwise approach

Unlike 3D metaballs, 2D metaballs can be drawn by calculating a density value of each pixel on the screen. Then, it is determined whether the density value satisfies an optional threshold value; if yes, the pixel is drawn. In a conventional algorithm for drawing 2D metaballs, the total density value in the current pixel is calculated before the threshold detection process (Fig.3, left). Therefore, the resultant shape is always a group of closed curves (Fig.4, left).

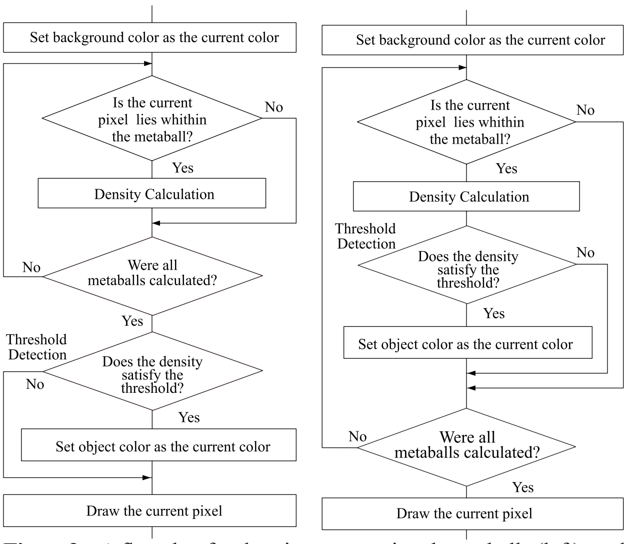


Figure3 A flowchat for drawing conventional metaballs (left), and a flowchart for metaball with stepwise threshold detection (right)

Contrarily, this project used an algorithm termed "stepwise threshold detection" to generate more complicated curves (Fig.3, right). In this procedure, if a metaball including the current pixel is found, the density value of the metaball is accumulated. Then, threshold detection using the accumulated value up to this time is also carried out, and this process is repeated as many times as the number of metaballs that include the current pixel. Consequently, drawing is performed at the pixel having a density value that once satisfied the threshold value. The repetition of this process leads to the generation of complicated curves, like rice terraces, and the curve of each metaball emerges partially (Fig.4, right).

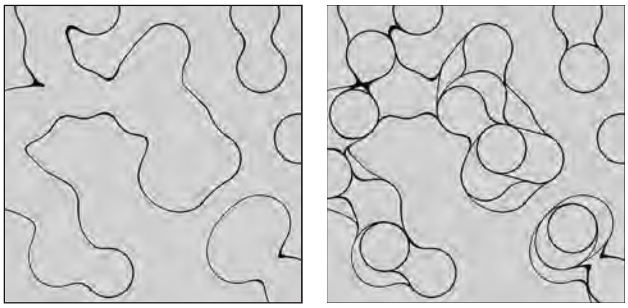


Figure 4 Conventional 2D metaballs (left), and 2D metaballs with stepwise approach (right)

Further, by using numerous metaballs, this algorithm can generate unexpected curves. On the basis of these morphological characteristics, these types of metaballs were used as elements of medallions. As shown in figure 5, in this project, the term "segment" refers to the number of symmetrical axes, and "element" refers to the number of metaballs in each segment. Changing parameters of each segment and element generates various types of symmetrical shapes. Figure 6 shows automatically generated patterns using the techniques. In the images on the figure 6, a black area indicates a lower part of the molding profile, and a white area indicates a higher part.

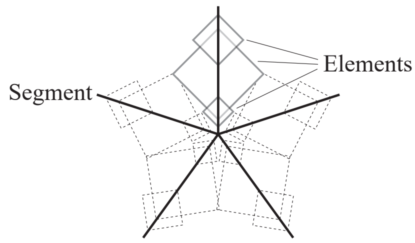


Figure 5 Segments and elements

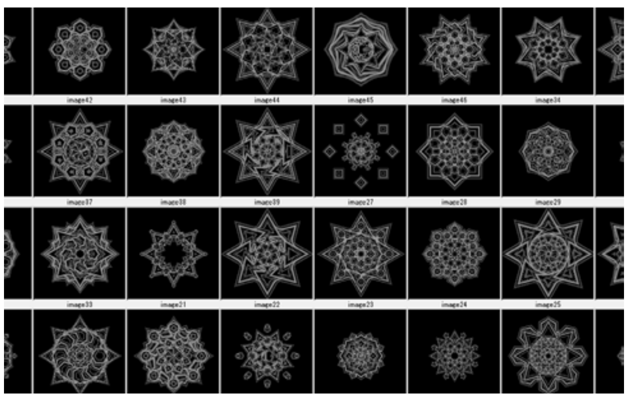


Figure 6 Examples of generated patterns

4-3. Pseudo-3D rendering

As a preview of an appearance of the resultant medallions, a pseudo-3D approach was used in this project. Although the resultant shapes thus far are 2D, a 3D shading can be performed to depict a relief-like effect by applying normal vectors to the shapes. The normal vectors can be calculated based on the density value in each pixel. Figure 7 shows examples of this method.

Figure 7 Medallions rendered with pseudo-3D method

4-4. Displacement Mapping

The shapes generated by using the abovementioned method were converted into 3d models using displacement mapping. Displacement mapping is a method to construct a 3D model using a black and white image which is regarded as a height map. However, there is an inconsistency that lines with height information overlap each other in the intersection points on the 2D image; an incorrect 3D model is generated as a result (Fig. 9, Left). To solve this problem, we used the algorithm shown in figure 8.

Algorithm Height map

```
for each pixel
    define variable p=0
    for each metaball
        calculate a density value
        calculate a height level h based on the density
        if the height level h exceeds p
            p = replaced with the current height level h
        end if
    end for
    output p
end for
```

Figure 8 Pseudocode for calculating correct height map

The algorithm compares the current height value with the peak level up to this time; if the current height level exceeds the peak level, the peak is replaced with the current level. Figure 9 shows a comparison of the resultant appearance. Lines on the right image intersect each other correctly without overlapping.

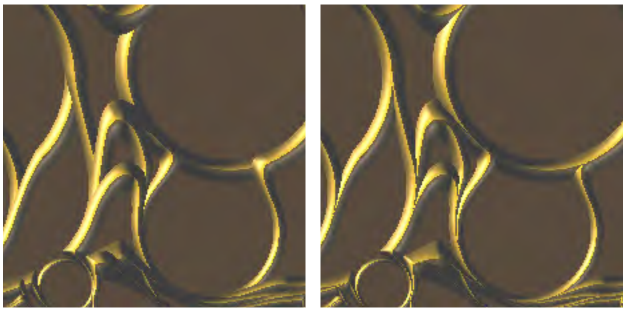


Figure 9 A comparison of the resultant appearance

The generated 2D black and white image described above were converted into 3D models by using displacement mapping (Fig. 10). Also, the generated 3D models were converted into STL data which is the most popular format in the field of 3D-printing. In this project, we used Pixologic ZBrush for displacement mapping and STL conversion.

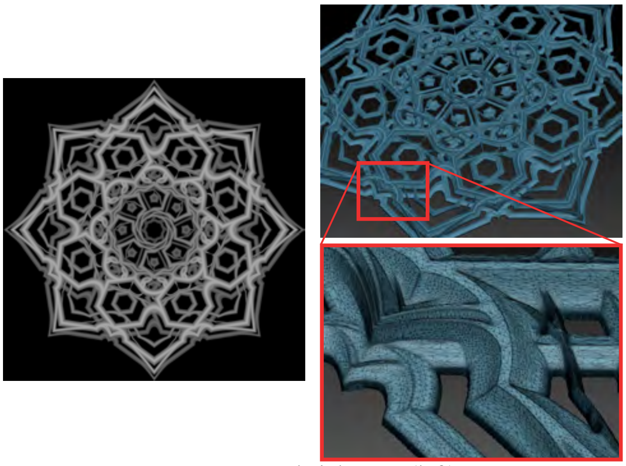


Figure 10 A height map (left),
and the result of displacement mapping (right)

5. Fabrication

The generated 3D models were printed out using professional 3D printers. In this project, Projet1000 by 3D systems was used at the prototype stage. The printer is characterized by using Film Transfer Image (FTI) system; the system can print a high-quality flat plane. The characteristic is expected to be beneficial for printing a relief-like object. However, we found out that the print result does not satisfy the resolution which is required in the field of decorative ornaments. Therefore, we used Projet3500, a more high-resolution 3D printer by the same manufacture, at the stage of finishing. Figure 11 shows a comparison of print results; the dimension is approximately 140mm diameter for each.

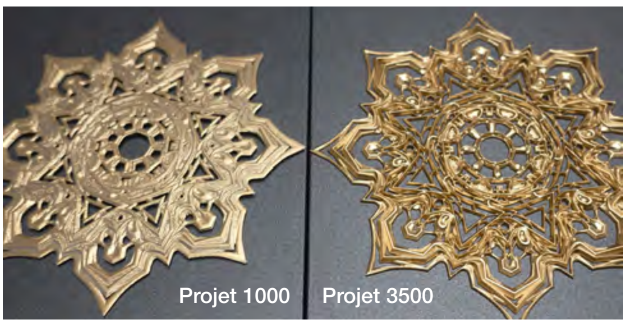


Figure 11 A comparison of print results

Since it was found out that casting and molding were difficult because the printed medallions were ultraprecise, printed objects were coated with gold directly. At the coating stage, a combination of black primer and gold lacquer paint showed the most beautiful gilded appearance as the result of trying various paints. As for colors of the back of the gold frame, color sheets with ultraviolet curable coating were affixed from the backside of the frame. Colorations of the sheets were selected based on the inspirations from historical decoration styles evoked by the resultant medallion shapes. Finally, the finished medallions were mounted on the frame carefully. The finished artwork comprises 6 pieces as shown in the figure 12.

Figure 13 shows another artwork using the similar method. The green patterns surrounding the medallion were also generated by use of 2D metaballs simulating malachite. Namely, everything on the artwork was made from metaballs.

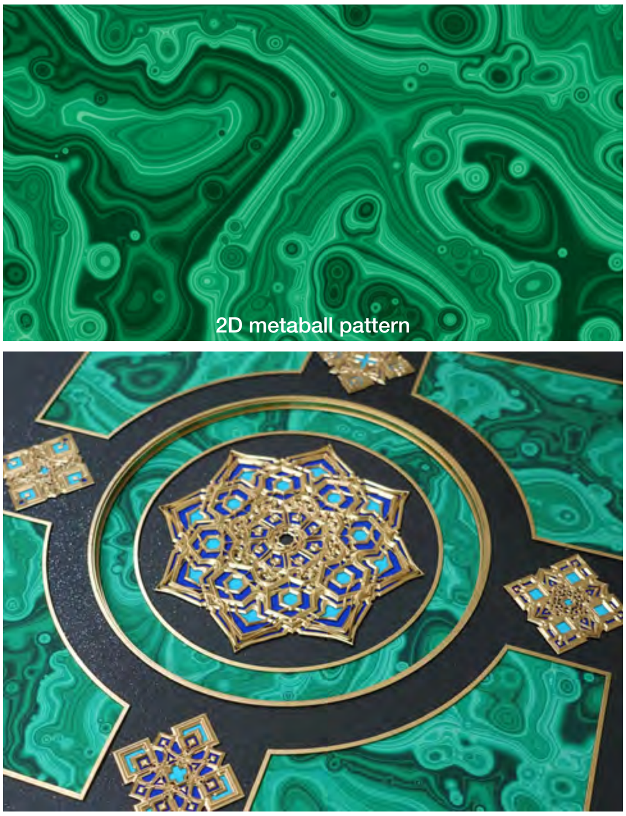


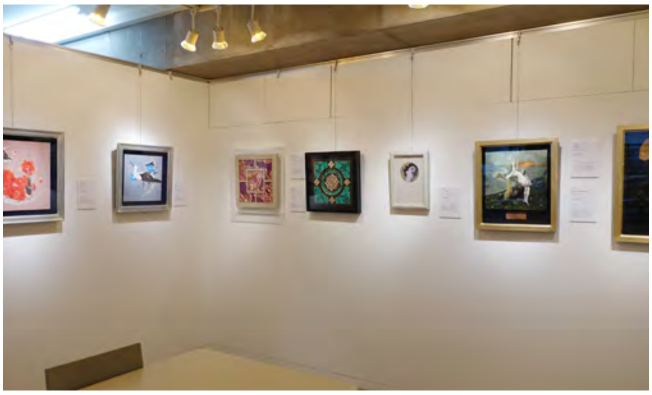
Figure 13 Medallion No.5399 (bottom), and procedural malachite pattern using 2D metaballs (top)

6. Exhibitions

Fortunately, the finished artworks got the opportunity to display at several art exhibitions (Fig.14) including SIGGRAPH Asia 2016 Art Gallery[14]. Among the exhibitions, some were focusing on not only digital arts, but also traditional art forms such as paintings and sculptures. At these exhibitions, this project was the only digital art. Namely, it means that this project was regarded as having an aesthetic value similar to traditional formative arts.

Figure 12 Medallions (2016)

Future Art Exhibition -DOORS-, Isetan Department Store, Feb. 2016



"Painter & Music" Exhibition, Gallery Shorewood, May. 2016

Contemporary Art Launching from Japan, Westin Tokyo, Jun. 2016

SIGGRAPH Asia 2016 Art Gallery: Mediated Aesthetics, Dec. 2016

Figure 14 Exhibitions

7. Conclusion

In this project, it was attempted that a combination of procedural modeling and 3D-printing was used for representing decorative ornaments. Also, the resultant artworks have been displayed at art exhibitions focusing on not only digital art, but also traditional formative arts. From the resultant patterns, it can be seen that a various patterns were generated by changing parameters. In addition, the patterns show exquisite details which are difficult by hand work; it satisfies that attractions of both procedural approach and decorative ornaments. Although the resultant medallions do not imitate historical ornaments accurately, this project was evaluated as having an aesthetic value which is similar to traditional ornaments.

At this time, there is a limitation in our method. Since the resultant shapes were generated by use of 2D data, generating shapes with overhang is impossible. To solve this issue, it will be necessary to construct data in 3D.

In conclusion, it was able to confirm that using a combination of 3D-printing and procedural modeling has a great potential in the field of decorative arts. As a future work, it can be expected that application of this method in not only wall plaques, but also sculptures and architectural elements.

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