"catching" and "turning" actions.

At the same time, there are two full color LEDs in each unit. The computer controls the switching and the color of light.

This device has one set of MIDI IN / MIDI OUT terminal. It sends MIDI note messages to the outside sound source. At the same time other MIDI devices can control PocoPoco via MIDI control change messages.

Users can (1) edit sound loops, (2) play notes like keyboards and (3) manipulate sound effects by intuitive actions such as "pushing", "catching" and "turning" with PocoPoco.

1.2 Background

Today, there are various types of displays as interfaces that transmit information in the computers to a user. The development of displays is not limited to the improvement of the resolution, various products have been realized such as touch displays, 3D displays and flexible displays. The background of this seems to be that we are needed to manage more and more complex information with computers, so their interfaces are needed to be user friendly. Displays that can change GUI dynamically can work as an IO interface for various contents. But the information users receive is still limited to visual and audio. On the other hand, there are some reports about shape-changing interface.

Physical movement of real object provides impression to audience that could not be expressed by pictures. G. Michelitsch et al. developed Haptic Chameleon[4] and they tried to control affordance that an interface provides to users dynamically. Physical movement of interface can provide dynamic affordance to a user.

In the field of art, movable works represented by kinetic sculpture have attracted audience for a long time. Early experiments with movement in art began in the 1910s, led by artists of the Dadaist and Constructivist traditions represented by Marcel Duchamp. In 1920, Constructivist artists Naum Gabo and Antoine Pevsner used the term "kinetic art" in their Realistic Manifesto. Most of kinetic art works early in the twenty century were put into action by the force of wind or water. On the other hand, in these days modern art works controlled by computer systems are increasingly being published. For example "MorphoTower" by Sachiko Kodama [5], a magnetic fluid composed of micro magnetic particles carried in a water or oil based fluid are controlled by dynamic magnetic fields manipulated by a computer. On the other hand Parkes, et al. argued about kinetic interaction, as they called "Kinetic Organic Interface"[6]. They mentioned its specification and possibility for Human Computer Interaction.

Physical movement of an object may express information that visual and audio approach can't express. And kinetic interface itself can be art. From such a background we proposed attempts intended to integrate physical information such as movement and tactile information, with image expression, such as displays that integrate magnets or feather with displays [1][2]. At the same time we started a research of an interface that uses physical movement of itself as a media to transmit information.

1.3 Abstract of a design process of PocoPoco

Here we show our PocoPoco's development process at figure 1.

2 RELATED WORKS

Here we introduce related works we studied for PocoPoco's development.

2.1 Shape changing displays

In the field of shape changing displays, various structures for kinetic movement are being proposed.

Hoggan et al. [7] showed that input on a touch screen can be improved by adding haptic feedback for typing tasks.

Iwata et al. made FEELEX[8], a kinetic display consisting of movable pin actuators using DC motors and Piston-crank mechanism. Relief [9] by Leithinger et al. and Recompose[10] by Blackshaw et al. are also kinetic displays using DC motors and faders. A kinetic display with a DC motor has speed and power, but it is noisy.

On the other hand kinetic displays powered by a shape memory alloy can move quietly. Poupyrev et al. proposed RGBH display, where RGB is a color components and H is a height of a pixel. Lumen [11]. is an implementation of such RGBH display. This box shape black display has a matrix of LEDs and thin shape memory alloy (SMA) wires built-in. 13 by 13 pixel bitmap can express 2D image by LEDs and each pixel can also physically move up and down by SMA wires. It allows users to feel shapes of virtual images through touch. PopUp! [12] by Nakatani et al. are kinetic displays using a shape memory alloy too. A shape memory alloy can move very quietly, but on the other hand, it's not so powerful. And it takes relatively long time to transform, so it is not convenient to materialize rhythmical movements.

2.2 Tabletop type musical interfaces

In the field of interaction design, various types of tabletop interfaces have been developed and proposed. PocoPoco is one of the tabletop interfaces for musical expression.

Iwai et al. published "musical chess"[13], one of the tabletop device inspired by chessboard. In this work users can play music by arranging balls on the board.

"Notes on Small Fish" [14]is a table top device developed to support musical education.

In this work multiple users play music on the round table at the same time. This seems to be good example of tabletop device that used an advantage of tabletop device.

Pompeu Fabra University Music Technology Group developed reactable [15]. This system captures objects on a table and generates electronic music. Sequence music is played corresponding to moving and turning objects. Compered to other musical interfaces to play live electronic music, because reactable has tangible object as a music controller, it is easier to understand for audience how the player is controlling the music. Being used many professional artists for live

In the case of Emerging keys, our previous work, our concept was making an interface that can change the shape of a controller dynamically. Then the role of solenoid units was just forming various shapes, so the movements of them were not being focused seriously. Emerging keys was designed as a device that outputs image and sound. Accordingly, it had a display and a set of speakers.

We turned attention to movement of solenoid units itself and started considering a new interface that can provide visual and haptic effect for interactive system. The interface provides advanced interactions by integration of input parts and output parts. To present the tactile sensations of all solenoid units, the device was considered to be large enough to fit both hands of the user. Then we changed the number of solenoid units, from vertical and horizontal 6×10 of Emerging keys to 4×4, and designed the size of device vertical and horizontal 205 × 205mm, it is suitable to feel all of the solenoid units' movements when a user covers the device with both hands.

4.2 Hardware

The prototype was designed as shape changing display, to be used for a multiplicity of uses such as a communication tool, game and musical instrument.

Original cylindrical units (Figure 2) that can move up-and-down by solenoid actuators, named "Poco", are mapped into a 4x4 matrix. A tactile switch is embedded in each of the unit. So this unit can work as button input device.

A micro controller board, Arduino Mega, processes all the input-output control system.

In addition, we installed two speakers and a sound generation module, to realize sound output. And we installed one USB terminal to communicate with the outside computers. The casing consists of plywood.

4.3 PocOthello

PocOthello is a game application of PocoPoco whose motif is famous board game "Othello". PocOthello uses concavo-convex shape of Solenoid units to tell the condition of pieces meanwhile ordinary Othello uses black and white color of the surface (Figure 3). When user pushes Solenoid units, PocOthello builds the concavo-convex shape by computerized control in each case and PocOthello expresses a passage of pieces by the motion of Solenoid units. The feature of this application is that users can recognize the condition of the game haptically by putting their hand on the device. Therefore, even visually impaired people who cannot play ordinary Othello can play this game. At the same time dynamic movements of the device is impressive as a visual expression.

4.4 Poco Sequencer

Poco sequencer is an application developed to use PocoPoco as a musical interface. Using this application, users can make loop music easily. Through the survey of sequencer type musical interfaces, we found most of them are making music

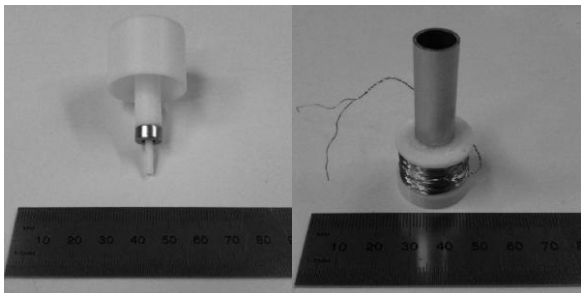

Figure2 a set of solenoid unit for the prototype
Left: movable parts, Right: base parts

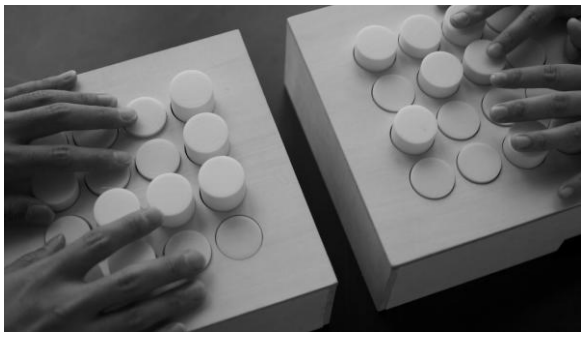

Figure3 playing appearance of pocOthello

by playing some musical phrases every bar or multiple bars. As seen in most of rhythm machines and music sequencers like Tenori-on, time progress in the sequence is expressed by a shift of timeline from left to right.

This system seems to be attributed by the fact that in general musical score time progress is expressed by a shift of timeline from left to right. In the case of Tenori-on, the device has 16×16 IO units and each row means one bar of a musical instrument. In the case of PocoPoco, to express sequence by 4×4 units, we applied a method to shift left top to right bottom, 16 units expresses one bar of a rhythm sequence (Figure 4). In the general musical score, time progress is expressed by a shift of timeline from one row to lower row, so this method seems to be easy to understand.

When a user pushes the top of a cylinder, its switch is flipped to the "on" position causing the cylinder to rise and a sound to play at regular intervals. When a Poco turned on is pushed down, its switch is moved to the "off" position and movements and the sound stops. Each Poco means a sixteenth notes, users can make loop phrase by selecting and pushing them freely. These tones are arranged so that a pleasant harmony results no matter which combination of notes is used.

Layers

PocoPoco has relatively few IO units and it can't express loops for multiple instruments at the same time. So we applied layers. Poco sequencer manages multiple layers in the program. Each layer keeps the sequence of one instrument. So users can pile up different musical phrases by changing layers. And each layer has a characteristic sound tone. Users can

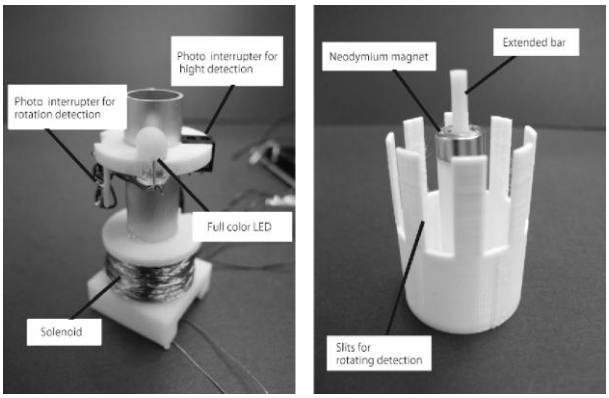

Figure5 a set of improved solenoid unit
Left: Base parts, Right: Movable parts

sound generators, workstations and speakers with PocoPoco, easily.

MIDI OUT

PocoPoco sends MIDI note messages from MIDI OUT, to play sound in the sound source. MIDI messages are sent to DAW (Digital Audio Workstation) software, Logic Pro in the computer, through a MIDI interface. Logic Pro play sounds, corresponding to the MIDI note messages.

MIDI IN

PocoPoco can be controlled by MIDI messages sent to MIDI IN. START, STOP, RESTART of sequence is controlled by general MIDI control messages. Users can send the control messages using DAW or MIDI controllers.

And users can control PocoPoco's rhythm by sending MIDI clock messages.

Users can synchronize multiple devices by sending same MIDI clock message to them.

We are using MAX / MSP application to synchronize 3 devices for 3 performers' ensemble.

5.3 Implementation of "catching" and "turning" functions

We witnessed many user tried to catch the popping units, or rotate or press cylindrical units. From the feedbacks we got by exhibitions of the prototype, some new ideas for more intuitive interactions occurred to us. Despite they didn't receive any explanations about playing methods, but they tried "catching" or "turning" actions to the moving units, as if they were granted actions. Then we considered these actions were quite intuitive for users, and we redesigned interactions and tried to map these actions to musical manipulations. To realize it, we implemented additional sensing system using multiple optical sensors. We installed three photo-interrupters in each solenoid unit, to detect units' rotation and up-and-down movements. To detect the height of movable parts, we fixed a photo-interrupter on the base parts (figure 5). This sensor tells the distance between base parts and the top of movable parts.

In addition, we installed two photo-interrupters to detect the rotation of the unit. The movable parts were rotatable around the axle of the unit. We made slits in the movable parts. Using these two photo-interrupters' data, the program detects rotation like rotary encoder (About these sensing system, please see [3] for details.).

Catching

PocoPoco's up-and-down movements are often compared to a certain arcade game, Whac-A-Mole.

A user who watched a rhythmically jumping or falling cylindrical unit, he or she can't stop to gaze it and try to catch it. We likened this operation to catching sound, and mapped it to sound sustain. During a user is holding the unit above, the sound tone doesn't attenuate.

Turning

Possibly because the cylindrical movable parts looks like some knob, many users try to turn the solenoid unit. Then we mapped the turning operation to the operation to control sound color. For example audio mixers and compact effectors for electric guitar, in general knobs are widely used to control sound color. Specifically, we mapped "turning" to volume and amount of modulation effect.

5.4 Implementation of full color LEDs

Through some demonstrations and live performances, the idea to install full color LEDs in solenoid units was occurred to us. The computer controls this full color light, so its color and timing can be corresponding to up-and-down movements. After this implementation, up-and-down movements with flash became more impressive and attractive for audience. At the same time, by changing light color corresponding to the editing layer, user can see the editing layer more clearly.

5.4 Implementation of Real-time mode

Through demonstrations in study groups and exhibitions, we found that most of musical beginners were supposing all the instruments generate sound after input gesture immediately.

In addition, PocoPoco's sequence function is suitable to compose some rhythm sequences like a drum set, but it is not suitable to play a melody. Then we implemented "Real-time mode" additionally. In this mode a sound note is played once the unit is pushed immediately.

5.4 Designing original score

As mentioned previously, this interface is optimized to play sequence phrases, and the playing method is not similar to the one of acoustic instruments like piano and guitar.

During making performance systems, we found ordinary musical score is not suitable for PocoPoco's play. So we designed original musical score (figure 6,7). In this score, the timeline moves left to right, and the units to be pushed is expressed visually.

and etc. on the stage. She performed in Japan SUMMER SONIC 2009 at first. Including solo performance in Japan, she continues to perform actively at home and abroad.

She found our research through the Internet, and offered the collaboration with us. At that time PocoPoco had never been played on commercial music stages.

By complying request from a professional artist, we could improve the interface efficiently. Thus we decided to collaborate with her. For this collaboration we had one meeting and exchanged emails about 150 times so far.

6.2 Process of the collaboration

This collaboration started from a meeting at Tokyo. As her artistic characteristic, he takes a lot of electronic instruments and synthesizers in musical performance. She says she demands for her musical interface to be as visual as possible for a live performance so the audience can see what is happening and understand how the sound is created. And she says if the audience can make a connection between what they are seeing and what they are hearing then that is the ultimate achievement for her for a live show. From this point of view, PocoPoco, an interface that physicalizes sound by object's movements and light, seems to be suitable interface for her live show. Also, because she mainly plays dance music, she often plays on the dark stage and light of PocoPoco fits to the music. Through meetings and exchanges of e-mail, we reached one conclusion that the new PocoPoco she would use should be able to play two bars long phrases, to play a motif phrase of her representative song "Shake". At the same time, the sequencer had to be controlled by an outside interface (For example other instrument players can stop and restart the sequence using a MIDI interface). To achieve this we had to develop a more advanced MIDI system. In addition, for the audience, she hoped more impressive visualization of sound.

6.3 TEMPoco

PocoPoco's 4x4 matrix units are suitable to express 16 beats phrases. On the other hand it is not good at expressing long bars phrases. To enable PocoPoco to play 2 bars phrases, we had to remedy a defect. Then we developed a new gadget named "TEMPoco". This device relays MIDI messages between the outside interfaces and PocoPoco.

It has 3 sets of MIDI I/O terminals. One is connected to the outside interface and others are connected to two PocoPoco (Figure 10, 11). TEMPoco receives MIDI clock messages from the outside, and sends one bar's MIDI clock messages to one PocoPoco alternately. Each PocoPoco play one bar phrase one by one, then two of them can consist 2 bars loop phrases.

TEMPoco bypasses all MIDI note messages from two PocoPoco to the outside interface. In addition, control messages such as "stop", "restart" and "reset" are sent from the outside interface and relayed to two PocoPoco at a time. A program in PocoPoco receives these control messages and controls its sequence. Using TEMPoco, we could enable PocoPoco to "play 2 bars long phrases" and make it "controllable from the outside".

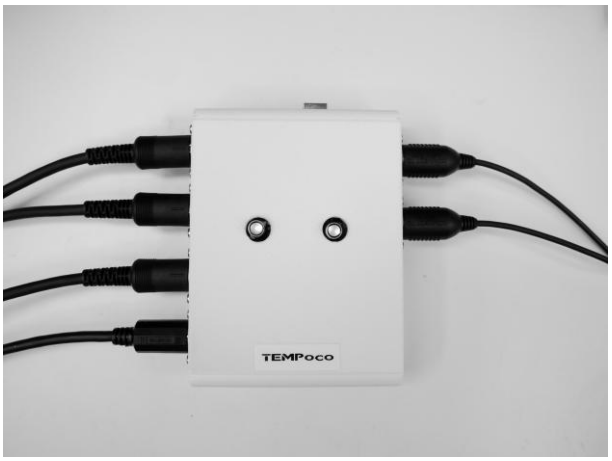

Figure10 appearance of TEMPoco

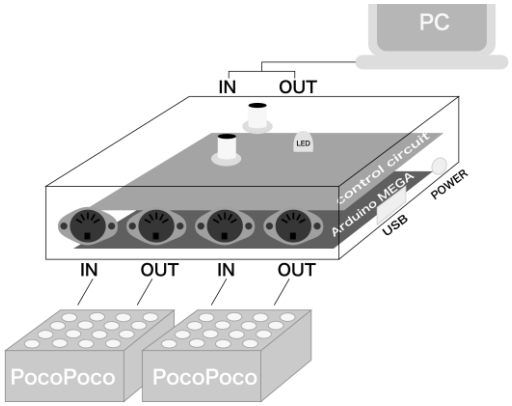

Figure11 communication system of TEMPoco

6.4 Visualization of the timeline

For more impressive interaction, we visualized sequence timeline by LEDs' flash. The flash pointed the timing of 16 beats. In addition, we set up respective light color for each layer. When some unit's switch is turned on, the unit continues to turn on the light. Using this system, users could compose rhythm sequence like drawing (figure 12).

6.5 Performance and feedback

May 4, 2012, at XOYO London, Little boots used PocoPoco for her public live performance at first. In this performance two PocoPoco were connected to TEMPoco, and could play her song "shake" without mishap.

After that we performed a questionnaire by e-mail to her about evaluation of PocoPoco as a musical interface. As good points, she mentioned

·a music novice or beginner could easily play with PocoPoco and start making music and begin to understand the connection between what they are playing and how the sound is reacting.

·a trained musician like herself can use it and get to a very

advanced level of programming and performing with it quickly

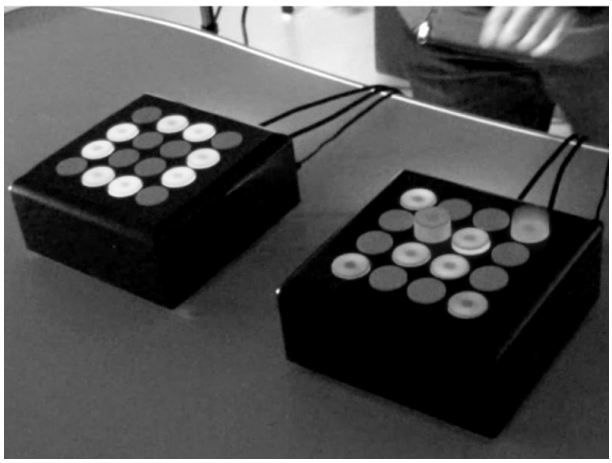

Figure12 Playing appearance of PocoPoco, the third phase

In fact she says that she witnessed large audience was gazing on and fascinated by PocoPoco's movements.
On the other hand, she mentioned bad points below

·The main difficulty for her with PocoPoco is it is not stable enough to be moved around for live performance and touring travel

·She had many problems with the solenoid units not reacting or getting stuck and having to open up the inside but repairing them was too hard for herself.

We consider that these problems are due to the fact that many of the current manufacturing steps of PocoPoco is dependent on the handwork. Changing the course of production, such as outsourcing some modules, may solve these problems.
Even though it has a difficult point about stability, she is highly approving the potential of PocoPoco as a musical interface for full-fledged musical performances. This collaboration will continue and additional improvements will be implemented. PocoPoco will be more stable and practical to be used for various performances.

7 CONCLUSIONS

In this paper we described a design process of PocoPoco. Through various design processes such as planning, implementation and evaluation, PocoPoco made refined as a practical interface. Especially, collaboration with a professional artist seemed to be an efficient process to improve the interface. PocoPoco can provide advanced interactions by integration of input parts, such as a tactile switch and photo-interrupters, and output parts, such as a solenoid actuator and full color LEDs into a small unit. This unit is just a cylinder as long as it has stopped, but once it starts to move and flash, it can provide various impressions such as Whac-A-Mole or a knob. More precise control of these movement and light may create other impressions. We will keep studying affordance that an interface provides to a user, and pursuing intuitive interactions with that a user can control the interface without any explanations. While we abandoned some applications such as "pocOthello" in the design process, shape-changing interface has possibility to be used for various applications. We would like to continue designing new interfaces, referring to PocoPoco's design process. PocoPoco is a so simple and intuitive interface that music novice or beginner could easily play with it. At the same time its physicalization of sound is valuable for full-fledged musical performances. But this interface is immature, for example about the stability or preciseness of control. We will keep refining them and pursuing artistic value, for example original sound or playing methods that only this interface can realize.

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