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SMAAD SURFACE

A tangible interface for smart material aided architectural design

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Abstract. In this paper, we present Smart Material Aided Architectural Design (SMAAD), the design technique to realize intuitive shape modelling with synchronizing a tangible user interface (TUI) and a 3D CAD system. To realize SMAAD, we first implemented SMAAD Surface, the TUI that imitates the free-form surface. The TUI is a fabric device, in which flex sensors and actuators (shape memory alloys) are embedded. As a designer changes the textile shape using his/her hands, its surface data will be sent to the CAD system through the sensor and a free-form surface can be created in the PC. The operation in the opposite direction is also possible, in which the CAD surface data is sent to the fabric device to dynamically change its shape. SMAAD releases architectural designers from complex GUI operations and visual programming and enables digital model creation through natural manual operations for physical models.

Keywords. Smart materials; tangible user interfaces; surface modelling; algorithmic design.

1. Introduction

Recently Frank Gehry, Norman Foster and many other architects produce buildings with organic surface shapes. The buildings retain smooth and non-uniform surface shapes. In their design process, it is essential to model and render the buildings using 3D CAD systems and computer graphics in order to grasp the shapes. Architectural designers, however, tend to like to grasp shapes and spaces through physical models in real space. Due to this, an additional process is required to materialize the virtual models into tangible ones that the architects can actually touch. Griffith and Sass (2006) developed a digital fabrication technique, which output complex surface shapes to physical models (Griffith et al, 2006), although the current 3D printers requires a long hours, from a several to several dozens of hours, to output models in many cases. Repeating the processes of confirmation, study and redesign of output physical models is temporally expensive. Besides, digital fabrication uses plaster or resin to output models, so that it is difficult to quickly modify and redesign them. If it is possible to output the physical models with plasticity such as paper or clay, the trial-and-error processes would be repeated in a short time.

The ultimate method to solve this issue is to use programmable matters. The technique called Claytronics (Goldstein et al, 2005) uses micro-sized robots whose shapes and colors change variously for dynamic shape design. The several-millimeter-long robot is called catom (claytronics atom). Since a group of catoms can be used as if they are clay, the vision to use them for product designs gathers a lot of attention. Although it requires much time to achieve practical use of this study, from this technique, we learn the effectiveness to introduce the material, whose shape and color dynamically changes, into design process.

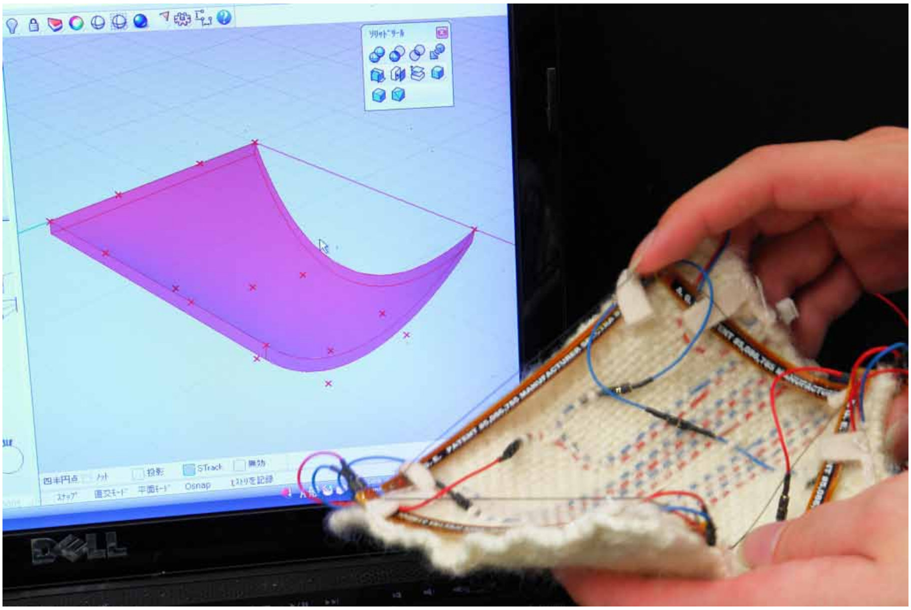

Figure 1. Overview of SMAAD Surface

On this standpoint, we paid attention to currently feasible smart materials and have developed Smart Material Aided Architectural Design (SMAAD), the design technique that introduces a tangible user interface (TUI) with morphological variation, into CAAD. To realize SMAAD, we first implemented SMAAD Surface, the TUI that imitates the free-form surface. The SMAAD Surface is a fabric input/output device that uses fibrous shape memory alloy (SMA). This fabric functions as a smart material and designers can modify its shape through manual operations. As the flex sensor detects the fabric shape and the actuator works to maintain the shape, a designer can model the fabric shape as if he/she manually models a free-form surface. The surface shape is sent to a 3D CAD through a microcontroller and the digital data can be modified in the same manner as the shape of the fabric device. In the same way, if the digital data is modified in the 3D CAD, the command is sent to the fabric device so that the fabric shape can be modified to follow the digital data (Figure 1).

SMAAD releases architectural designers from complex GUI operations and visual programming and enables digital model creation through natural manual operations for physical models. Since the SMAAD Surface is made of soft fabric, the designers can refine the surface shapes as they feel slight changes through sensitive fingers. In addition, sending the digital model to a 3D printer interlocks the process of existing digital fabrication/algorithmic design with SMAAD. If an architect has good computer skills, he/she might apply parametric modification processes to the surface shapes created using SMAAD.

The following chapters describe details of SMAAD Surface design and implementation and the study and evaluation of the effectiveness.

2. Relevant works

Our research deals with two issues: shape input interface and shape display in architectural design. For shape input interface, the former issue, a lot of techniques to support intuitive input have been developed: the technique in which CAAD is interlocked with general input interface (Aish, 1979; Lertsithichai, 2002), the natural operation performed using both hands (Bae et al, 2004; Huang et al, 2009), or the technique using flexible materials as the media (Balakrishnan et al, 1999). As for the approaches of TUI applied to architecture, TangiCAD (Abdelmohsen et al, 2008) that performs building layouts with using cube-shaped devices or the algorithmic design technique with using a pen-type input device (Tang et al, 2009).

Shape display, the latter issue, means the TUI that actuates information as tangible shapes, not as shapes shown in a 2-dimensional screen. The case in which fibrous shape memory alloy is modularized (Coelho et al, 2008; Parkes et al, 2010) and ShapeShift (ETH Zurich CAAD, 2010), the shape modification module made of electro-active polymer (EAP), are well known. The EAP enables modification in units of faces, while production process is complex and special devices are required, so that it lacks versatility. In contrast, using SMA requires to combine modifications in units of lines in order to implement face modification, while SMA is commercially available and easy to deal with.

The SMAAD Surface, described in this paper, retains the features of both input (intuitive shape modelling) and output (physical shape recognition). Besides, the SMAAD Surface can suggests the system that interlocks with 3D CAD digital data through materialized free-form surface devices, which makes our research unique. The main contribution of our method is coexistence with digital fabrication process while the TUI features are maintained.

3. SMAAD Surface

3.1. SMAAD CONCEPT

This paper proposes SMAAD (Smart Material Aided Architectural Design), the technique to realize intuitive shape creation with synchronizing a physical model and a 3D CAD system. In this technique, the TUI using with morphologically-variable smart materials interlocks with a 3D CAD system.

Designers change the TUI shape intuitively using their hands, so that both digital and physical models with organic surface shape can be created. As the shape of the physical model is changed, it will be actuated to maintain the shape. Due to this, dynamic shape design might be concise in physical world. Since the physical model created using this technique interlocks with a 3D CAD system, the physical model can be converted instantly to a digital model. The model can also be interlocked with the existing digital fabrication process. Besides, it is also possible to change the physical model to follow the change of the digital model. Synchronizing the physical world (atom) and the virtual one (bit) will support various design processes.

3.2 SMAAD SURFACE

To realize SMAAD, we first implemented SMAAD Surface, the TUI that imitates the free-form surface. The TUI is a fabric device, in which a sensor and an actuator are embedded. The sensor grasps the textile shape and the actuator changes the shape. As a designer changes the textile shape using his/her hands, its surface data will be sent to the CAD system through the flex sensor and a free-form surface can be created in the PC. The operation in the opposite direction is also possible, in which the CAD surface data is sent to the fabric device to dynamically change its shape (Figure 2,3).

As SMAAD Surface, as shown in Figure 5, rectangular and triangular modules of several sizes are prepared. A fabric device corresponds to a free-form surface and almost the same NURBS or Bezier patches as the ones used in CAD systems can be created. When two or more fabric devices are connected, the connectors are used so that the tangent-plane continuity is satisfied at the connection sections. The connector is also a long and thin fabric device. Changing its shape adjusts the cross boundary derivative between the surfaces. When two or more fabric devices are connected, it is desirable to hang them in the air in order to prevent the devices from being wavy due to interference between fabrics.

The SMAAD Surface was prototyped in order to evaluate the effectiveness of SMAAD more than the precision. The following sections describe the system overview of the TUI and its implementation.

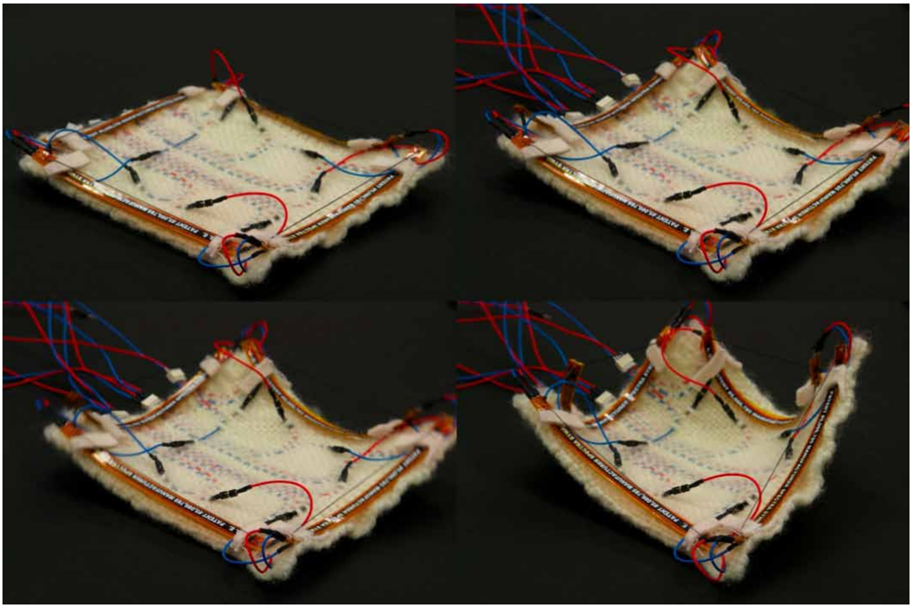

Figure 2. Examples of SMAAD Surface morphing (single module).

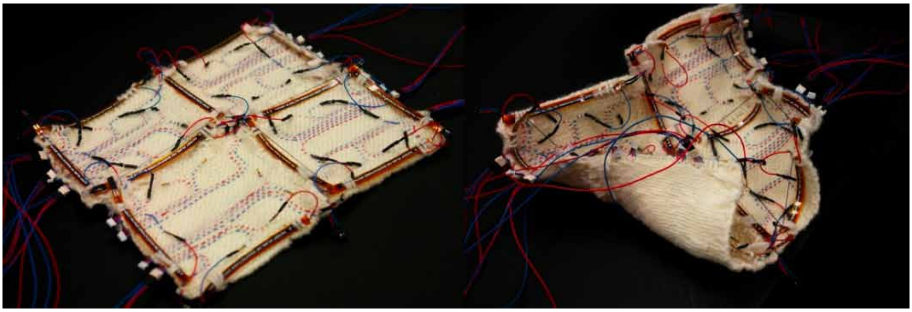

Figure 3. Examples of SMAAD Surface morphing (multiple modules).

3.3. SYSTEM OVERVIEW AND SOFTWARE

As Figure 4 shows, our system is composed of fabric devices, Arduino, middleware built with processing and Rhinoceros. The digital data is created from a fabric device in the procedure below.

The surface shape of a fabric device is obtained as a resistance value in the embedded flex sensor. This value is converted to a signal through the analog input terminal of Arduino and sent to the setup middleware built with processing by the serial communications. According to the resistance value of the flex sensor, the middleware changes the free-form surface shape created using the P3D class of the processing. The information of the modified surface is sent from the processing to Rhinoceros under the UDP (User Datagram Protocol). The value is polled in the VB(Visual Basic) module of Grasshopper and the obtained value is sent to the surface creation routine, then the free-form surface is created and drawn in Rhinoceros.

To change the fabric device shape according to the CAD data, the above operations are executed in the opposite direction. The surface information modified in Rhinoceros is sent to the middleware. Here, the displacement of coordinates of the control points between before and after the modification. According to the obtained value, the voltage for SMA is determined. With these operations, the fabric devices are tensed (or relaxed) and their shapes are changed to follow the digital data.

Firefry of freeware (Firefry, 2010) is often used to interlock Arduino with Grasshopper, while we have created the original middleware in order to enable application to 3D CAD systems other than Rhinoceros. Since the processing can be used in various protocols and a lot of plug-ins are prepared, it can be interlocked with various 3D CAD systems.

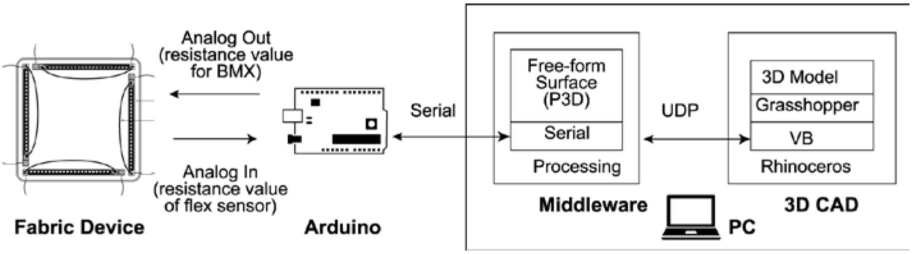

Figure 4. System configuration of SMAAD Surface.

3.4. HARDWARE

A fabric device (Figure 5) is a sheet of fabric produced by weaving white worsted yarns (3-strand No.6 thread). To each of the four sides, the flex sensor, which responses 10KΩ in normal time and 30 to 40KΩ when bent, is woven. At both ends of the flex sensor, the Ti-Ni series shape memory alloy (SMA) fiber (Toki corp. BMX 150, standard electric resistance 400 Ω/m) is set in an arch line. The values of the flex sensor, representing the shape change of the profile lines, are sent to the microcontroller (Arduino Duemilanove) through a conductive yarn (Naslon stainless steel fiber, resistance: 11±10%Ω/m). When electricity is given from the microcontroller, the SMA contracts and the PCB material of the flex sensor bows, so that the fabric shape changes. Controlling the extent of SMA contraction on the profile lines realizes various surface shapes. When 5V power supply is used, all SMAs complete their contraction in 5 to 10 seconds. Since conductive yarns are used, the wiring sections can be embedded in fabrics or the yarns can be embroidered to be combined with the fabrics.

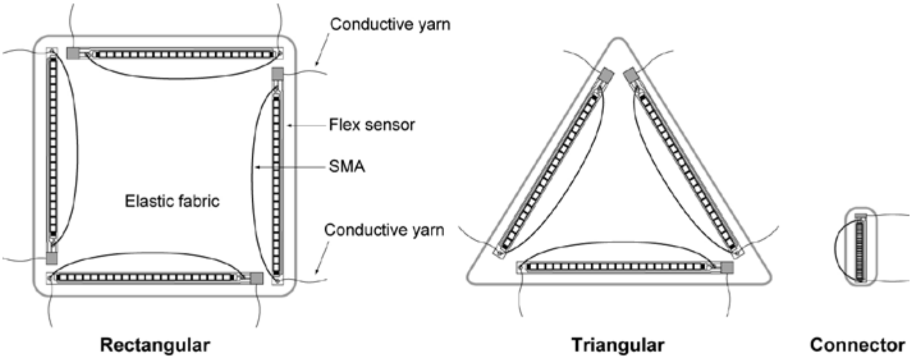

Figure 5. Modules and connectors.

4. Functions

4.1. DIRECT SURFACE MANIPULATION

With the feature, shape preservation, of fabric devices, direct shape modeling is provided. The direct operations to fabrics allow natural finger actions for both hands. Due to this, various interaction styles can be realized, from sensitive local operations such as pinching or pressing the fabric with fingers, to global operations such as crumpling the fabric into a ball, twisting, rolling or folding the fabric. Even after the direct operations, the SMA preserves the fabric shape as if soft wires are woven in the fabric. Therefore, designers can carry on the shape modeling as if they mold an expected object out of the fabric. The researches in recent years reveal that the TUI is more effective for perception and recognition of space than the GUI since the TUI allows natural manual operations (Kim et al, 2006). The functions to produce 3D digital data through natural manual operations are effective.

4.2. UNDO AND REDO

The surface shape data sent continuously from the flex sensor is saved as operation history and used for the operation replay. This allows the UNDO/REDO operations of the modeling. With this function, a new function to relive the modeling process may also be realized.

4.3. MOTION DESIGN FOR KINETIC ARCHITECTURE

The operation history saving and replay are also available as the function to record and reproduce motion design, executed in the two steps below. In the first step, the direct operations sent from the flex sensor are recorded in a certain period of time. In the next step, the recorded motion is applied to SMA in the same period of time to reproduce the motion. This function will be used for the design environment of kinetic architecture such as Hyposurface (Ritter, 2006) or The Muscle Projects (Oosterhuis et al, 2008), which are attracting attention in recent years.

4.4 CREATIVE UI

In addition to the three suggestions in the former sections, various functions will be realized depending on designers' creativity. For example, stroking a smooth wall surface with this interface imports the shape into a CAD system. Combining this function with the algorithm to create surfaces according to the extent of bending, our system will function as a device for interactive algorithmic design.

5. Discussion

We offered designers this system and interviewed them to get the following comments. “Since the system preserves the fabric shape, I could model it through intuitive operations with my hands. This is effective to repeat trial and error and refine the shape.” “When some CAD data is input to change the shape of a fabric device, the whole device size becomes too large to deal with.” The former comment indicates the effectiveness of this system as an input method. This also shows the possibility of this system functioning as a new prototyping material to replace paper or styrofoam. The latter comment indicates necessity for improvement of this device. Since the fabric device we prototyped had only one inflection point and the shape is similar to a quadric free-form surface, a lot of fabric devices are necessary to represent a complex surface shape. To solve this issue, the SMA on the boundary lines are divided into segments and SMAs are arranged further on a fabric surface, so that a single fabric device can deal with a broader area.

6. Conclusion and future work

In this paper, we proposed SMAAD, the design technique to realize intuitive shape modeling with synchronizing a physical model and a 3D CAD system. The prototype system enabled direct design of organic free-form surface shape with using the fabric TUI. At present, we succeeded in connecting four fabric devices. In the future, if several dozens of the devices can be connected, it will be possible to actuate versatile shapes. This means that the SMAAD functions as a rapid prototyping system beyond design systems. Long time to wait for the output from the 3D printer will not be necessary anymore and immediate prototyping will be possible to grasp shapes in a moment.

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