AnimaStage:
Hands-on Animated Craft on Pin-based Shape Displays

Ken Nakagaki   **Udayan Umapathi**   **Daniel Leithinger**   **Hiroshi Ishii**

MIT Media Lab

Cambridge, USA

{ken_n, udayan, daniell, ishii}@media.mit.edu

ABSTRACT

In this paper, we present AnimaStage: a hands-on animated craft platform based on an actuated stage. Utilizing a pin-based shape display, users can animate their crafts made from various materials. Through this system, we intend to lower the barrier for artists and designers to create actuated objects and to contribute to interaction design using shape changing interfaces for inter-material interactions.

We introduce a three-phase design process for AnimaStage with examples of animated crafts. We implemented the system with several control modalities that allow users to manipulate the motion of the crafts so that they could easily explore their desired motion through an iterative process. To complement the animated crafts, dynamic landscapes can also be rendered. We conducted a user study to observe the subject and process by which people make crafts using AnimaStage. We invited participants with different backgrounds to design and create crafts using multiple materials and craft techniques. A variety of outcomes and application spaces were found in this study.

Author Keywords

Animated Craft; Shape Display; Digital Puppet.

ACM Classification Keywords

H.5.2. User Interfaces: Haptic I/O.

INTRODUCTION

Crafting with various materials is an activity that nurtures creativity through exploration. The use of materials such as paper, wire and cardboard allows for the physical manifestation of one's imagination. While the outcome of this crafting has traditionally been static, researchers have been looking into developing tools to create crafts that can dynamically move and animate to expand the expression. These systems usually take an approach of attaching a miniature actuation unit or material to add motion to static objects [11, 20, 15].

In our work, we present AnimaStage, a hands-on animated craft platform that can animate passive objects using an actuated stage made of a shape display. Our system enables users to create animated objects using ordinary materials and crafting techniques (Figure 1). Multiple physical control modalities enable users to give motion to passive objects, allowing for tangible and spacial exploration (Figure 1b). Our system utilizes a pin-based shape display with custom software to supports an iterative process for shape and motion creation. Vertically actuated pins on the shape display allow users to create a variety of motions. Additionally, shape displays can also render dynamic shapes as a landscape or backdrop for the crafts (Figure 1c). This paper presents a three-phase craft process, example crafts, implementation of our system and a preliminary user study.

Through our work we aim to lower the barrier for artists and designers with no programming or engineering skills to create animated objects with a shape changing interface through tangible interaction. Our inspiration stems from automata toolkits, which allow for the creation of various moving objects from a general-purpose platform of a cam mechanism connected to a crank. We believe that AnimaStage enriches this idea further by leveraging shape displays as a platform for animated craft together with rich control modalities to create a wide range of motion. Although current shape displays are bulky and expensive, we believe they will become affordable in the near future. We imagine a way to use them not only as a displays, but also for enhancing creativity by enabling easy access to the dense, rich array of actuation and sensing provided by shape displays. We believe that our tools will enable rapid prototyping of complex physical motion.

Figure 1. Overview of AnimaStage (a: making craft using multiple materials, b: manipulating the motion of the craft, c: an animated scenery.)

RELATED WORK

Digital Animation System

HCI researchers have proposed several tools and techniques to overcome the steep learning curve of 3D modeling and animation software. Techniques for kinetic and spatial control

of digital puppets have been proposed for both 2D [2] and 3D [6]. *Tablescape Animation* enables users to create 3D animation with their own 2D sketches on a projected table top surface [8]. Also, *Draco* [10] and *Kitty* [9] allow users to add dynamic motion to elements of a digital sketch in a 2D GUI environment. Although these tools lower the barrier to add motion to digital sketches, they are restricted to screen based 2D environments.

Designing Motion for Physical Objects

On the other hand, various methods have been introduced to allow users to provide dynamic motion to physical objects. While shape-changing organic materials [11, 23, 15] were presented for animating crafts, they were focused only on actuation. Other research examined tangible interactions for design of physical motion. *LEGO Mindstorms* [13] and *Topobo* [18, 17] took the construction kit approach through building blocks and programmability. Topobo also introduced the concept of "Kinetic Memory" through manual record and play. *PINOKY* extends this idea with a device that is attached to existing physical objects [20]. While these systems are mostly embedded-actuated or external-actuated systems, we introduce a stage-like actuation system for animated craft. The large number of sensors and actuators accommodated by our approach enrich the possibility and variety of motions for crafts with additional scenery rendering capability. We also aim to extend hands-on motion design technique for physical objects proposed by *Topobo*, specifically for shape displays.

Tabletop Actuation System

Several tabletop actuation systems were proposed to animate physical objects. Arrays of electromagnets have been used for actuated tangibles [16], and kinetic arts [12, 21]. Pin-based shape displays have also been proposed for moving passive objects [4, 7, 22] and to assemble physical blocks [19]. *Shape Clip* [5] and *Shape Canvas*[3] lower the technical barrier for shape and motion creation, but with a focus on animating the display shape, rather than objects on top of it. While these prior systems utilized pre-programmed motion sequences and other sophisticated GUI control, this paper proposes an interaction system to directly craft and animate passive objects on the actuated shape display and iterate through the process entirely in physical space.

ANIMASTAGE - CREATION PROCESS

The creation process on AnimaStage takes place over three major phases: Make the Craft, Animate the Craft and Shape the Stage (Figure 2). By principally following the order of these three phases, users can interchange them for the iteration process to reach desired shapes and motion. This process is described below with example works created by authors.

1. Make the Craft

Users begin the process by making crafts with traditional crafting methods, while also imagining and planning the desired motion.

Various tools, materials and craft techniques such as paper, 3D pens, and wire can be used to construct the object. Paper can be cut and folded to create shapes and structures (Figure
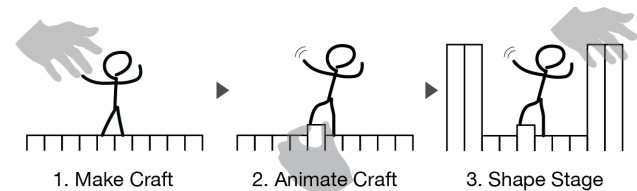

Figure 2. Design process with AnimaStage.

3a). Origami techniques can be used to create moving objects (Figure 3b). 3D pens and wires allow for the creation of a wide range of possible shapes. Specifically they can be used to "anchor" passive objects to pins to allow for additional points of movement (Figure 1a).

Materials with different physical properties afford a range of motion characteristics and appearance to the craft. For example, transparent materials can be used as invisible "anchors" to move visible material (Figure 3b), and flexible material can provide bending and stretching behavior (Figure 3c).

Crafted mechanisms are an important factor to design motion for animated craft. For rotational motion, users can create joints (a human arm in Figure 4) or hinges (a blooming flower in Figure 3a). For oscillation, a spring-like shape can be created for a wiggling motion (Figure 3d). External weights can be added to objects to create imbalance (Figure 3e). Users can combine multiple of these mechanisms, or create their own structures to achieve a desired motion.

2. Animate the Craft

Once a craft is made, users next explore how to add motion to them. We developed three control modalities for users to intuitively and physically animate the craft (Figure 4).

Control Modalities

Direct Pin Control: Users can directly manipulate the objects by grabbing the pins or the attached craft and moving them up and down. The direct control provides quick and intuitive sense for control of motion with no delay.

Indirect Pin Control: Users push in another shape display surface to control the motion of crafts as if the remote pins are physically connected. The remote pins are connected in the way that the controlled pin will move up when the control pin is pushed down.

Invisible String Control: Using the metaphor of marionette puppetry, users can manipulate the motion of craft with mid air gestures as if each finger is connected to a pin with string. Although this control doesn't have tangible feedback, the user can have the spacial sense of control above the stage.

3. Shape the Stage

In addition to making and animating crafts with various materials, AnimaStage can render dynamic shapes using the capabilities of the shape display itself.

The rendered shape can be used as scenery or landscape to complement the contents and story of the animated craft (Figure 1c). Users can control the shape of the entire stage either

Figure 3. Example animated crafts created on AnimaStage.

Figure 4. Three control modalities to animate crafts (a: Direct Pin Control, b: Indirect Pin Control, c: Invisible String Control.)

by manually manipulating pins (Figure 3f) or by loading pre-defined 3D models. This technique can also be utilized to represent horizontal movement of the craft by dynamically rendering the surrounding landscape, similar to the scrolling backgrounds in video games (Figure 3g).

IMPLEMENTATION
The AnimaStage system consists of a pin-based shape display, a computer and several input interfaces (Figure 5).

For the shape display, we utilized the *TRANSFORM* platform [7]. Each pin of the shape display can be individually actuated and detect user input such as pulling and pushing, which allows for the recording and playing back a motion. This shape display has three "stages", with 16x24 pins (406 X 610 mm) in each stage. Each pin can be actuated at a speed of 0.644 m/s at maximum and provide force of 1.08 Newtons.

For input interfaces, we developed a set of control buttons to let users access functions such as switching phase, or record/play. We installed a *Leap Motion* camera next to the shape display to capture finger gestures specifically for Invisible String Control. We used a trackball to enable users to control the horizontal movement of landscape data in the Shape Stage phase.
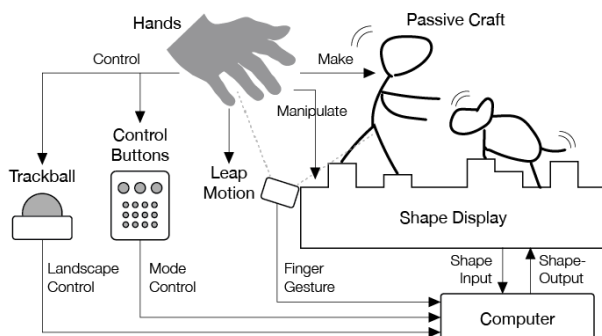

Figure 5. System overview of AnimaStage.

In software, we developed an additional mode "Assign Pin" between Make Craft and Animate Craft phases for users to select pins to be actuated by pushing the pins. Selected pins

pop up 10mm and can be pushed again to unselect. Thus, the system can provide appropriate physical interface according to selected pins for each of the control modalities; in Direct Pin Control, the selected pins will be slightly higher than the others so that users can easily grab the pins, and in Indirect Pin Control, only the correspondent pins will lift up to enable controls for pushing. A record and play function was developed to let users save and play back six sets of motion sequences through the control buttons.

USER STUDY
We conducted a preliminary qualitative user study to validate the *variety of works* to be created and the *creation process* using AnimaStage.

Study Procedure, Task and Participants
Each participants task was to create moving objects on AnimaStage. We did not limit this task to predefined scenarios, objects or materials in order to observe a variation of outcomes. Participants were given 60 minutes to create animated craft and interviewed about their process and work at the end. Before the actual task, each participant received an explanation on how to use the system and was shown examples (Figure 1 and 3). For practice, they were asked to make a paper person and animate it before the main task. At the end of the study, participants answered a questionnaire regarding their experience of using the system and their background. We prepared a variety of materials and tools, such as paper, thin sheets of foam, clay, 3D pen (3Doodler[1]) with rigid and flexible filaments, tapes, wire, scissors and other base craft materials. Also, within the three major phases of the creation process, we designed the study for participants to explore only the Make and Animate Craft phases. We excluded the Shape Stage phase, since we wanted to focus on observing the creation of 'animated crafts'.

Our study consisted of 7 participants (4 male and 3 female), ranging from 14 to 29 years old (mean=23.1, s=5.54). All of them were students from varied majors such as design, architecture, material science and engineering. We selected participants from a breadth of disciplines in order to gather basic insight into uses relevant to these disciplines.

Outcome Crafts
Six participants answered that they could create their intended motion and that they were satisfied with their work. All crafts are shown in Figure 6. Participants are identified by the label on the figure below (e.g. *p(a)*, *p(b)*...). Only *p(b)* took 30 minutes to create the work while others fully utilized the allotted 60 minutes.
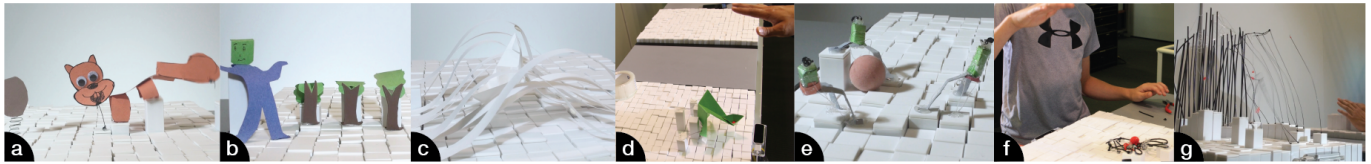
Figure 6. Outcome of the user study by seven participants.

Three participants made animated characters and scenery to narrate their stories or aesthetic motions. A design student *p(a)* created a scenery illustrating the story of a squirrel chasing a nut using hinge and wiggling structures. Participant *p(b)* created a scene where a forest losing its leaves brings down a human; depicting the harmful effects of deforestation on life. Rigid material was used for the tree trunk, so that only leaves disappear when seeing from the front as pins move. Participant *p(c)* prototyped a boat on a surface of ocean. The surface of the ocean with waves and ripples was made using paper strips of different length. By adding clay as additional weight, *p(c)* was able to create different wave patterns.

Some participants created a craft to interact with other objects. An architecture student *p(d)* made an origami catapult, referring to instructions found on the Internet. He was able to catapult small objects according to his hand movement using Invisible String Control and made a simple basketball game. Similarly, a table-top soccer game was created by participant *p(e)*. He created three people kicking a ball, though the ball did not move well due to the unevenness of the shape display. A 14 years-old participant *p(f)* tried to make a grasping hand. He used the flexible plastic filament sticks to construct the hand, but the shape display was too weak to move the sticks.

One unusual example was made by another architecture student *p(g)*. He used the system as an architectural modeling platform and made physical building models on the stage with mix of flexible and rigid plastic sticks. He intended to use the system to observe the deformation of different architectural structures under a mechanical stress.

Creation Process User Observation

Control Modality
For control modalities, five participants *p(a, b, c, e, g)* used Indirect Pin Control and while the other two used Invisible String Control. Indirect Pin Control seemed useful when the participants required a number of pins to control, as *p(c, f)* could use their forearms and hands to create a surface of pins to create wave motions. Direct Pin Control seemed difficult for most of the participants because of the limited number of pins to be controlled, while *p(a)* preferred it for quickly testing the motion in the iteration. Some said that they wanted to use hand gesture control, but that the number of pins were not sufficient. An advanced mapping algorithm beyond one finger to one pin would be required.

An observation that was interesting was, participants customizing the control modality itself. Although Indirect Pin Control was popular due to its ability support multiple pin control at a time, some users needed control over more pins than what this modality supports. Thus, they came up with

physically constraining the pins to certain heights by taping or putting weights (Figure 7a, b). The physical nature of the system allows people to add external objects to overcome the limitation. Also, *p(e)* marked on tip of pins for Indirect Pin Control to label which pins to control certain objects (Figure 7c). Although our initial intention for AnimaStage was to help users to customize animated objects (output), we believe giving enough freedom to customize control modalities (input) is a direction worth exploring.

Figure 7. Participants customizing input control in Indirect Pin Control using tapes(a), weights(b) and a pen(c).

Filling the Gap through Iterations
Some users commented that the resulting motions created by the system are unpredictable so that it required iterating to reach a desired motion. *p(a)* found this unexpected movement to be "surprisingly funny" which implies that the exploratory creation process sometimes gave useful accidental results. We found it interesting that the iterative creation process in AnimaStage relates to learning the skills of kinetic mechanical design. One participant commented that compared to systems that require planning and coding movement in advance, they perceived our system as "very quick and leaves a lot of room for potential exploration." We believe the number of actuators of shape display provide a lot of space for exploratory creation with instant iterations. Further user studies could be conducted to evaluate this aspect of skill improvement in the long term. We also plan to support the instant exploratory creation process with material simulation software.

CONCLUSION AND FUTURE WORK
In this paper, we introduced AnimaStage, a platform for supporting animated craft with an actuated stage. We presented the creation process for the system together with example crafts. Our preliminary user study revealed that our system provides a variety of possibilities for animated crafts. Through AnimaStage, we presented a novel capability of shape displays to give life to inert materials in a way that users can tangibly, intuitively, and expressively create the motion.

As future directions we believe our system could be improved by adding physical modules that convert vertical motion of the pins to horizontal and rotational motion like in Kinetic Blocks [19]. Collaborative animated crafts over a network could also be a possible space for further exploration [14].

REFERENCES
1. *3Doodler*. `http://the3doodler.com/`.

2. Barnes, C., Jacobs, D. E., Sanders, J., Goldman, D. B., Rusinkiewicz, S., Finkelstein, A., and Agrawala, M. Video puppetry: a performative interface for cutout animation. In *ACM Transactions on Graphics (TOG)*, vol. 27, ACM (2008), 124.

3. Everitt, A., Taher, F., and Alexander, J. Shapecanvas: An exploration of shape-changing content generation by members of the public. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ACM (2016), 2778–2782.

4. Follmer, S., Leithinger, D., Olwal, A., Hogge, A., and Ishii, H. inform: dynamic physical affordances and constraints through shape and object actuation. In *UIST*, vol. 13 (2013), 417–426.

5. Hardy, J., Weichel, C., Taher, F., Vidler, J., and Alexander, J. Shapeclip: towards rapid prototyping with shape-changing displays for designers. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM (2015), 19–28.

6. Held, R., Gupta, A., Curless, B., and Agrawala, M. 3d puppetry: a kinect-based interface for 3d animation. In *UIST*, Citeseer (2012), 423–434.

7. Ishii, H., Leithinger, D., Follmer, S., Zoran, A., Schoessler, P., and Counts, J. Transform: Embodiment of radical atoms at milano design week. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, ACM (2015), 687–694.

8. Kakehi, Y., Yamaoka, J., Akatsuka, D., and Naemura, T. Tablescape animation: a support system for making animations using tabletop physical objects. In *SIGGRAPH 2009: Talks*, ACM (2009), 70.

9. Kazi, R. H., Chevalier, F., Grossman, T., and Fitzmaurice, G. Kitty: sketching dynamic and interactive illustrations. In *Proceedings of the 27th annual ACM symposium on User interface software and technology*, ACM (2014), 395–405.

10. Kazi, R. H., Chevalier, F., Grossman, T., Zhao, S., and Fitzmaurice, G. Draco: bringing life to illustrations with kinetic textures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2014), 351–360.

11. Koizumi, N., Yasu, K., Liu, A., Sugimoto, M., and Inami, M. Animated paper: A toolkit for building moving toys. *Computers in Entertainment (CIE) 8*, 2 (2010), 7.

12. Kono, M., and Kakehi, Y. tamable looper: Creature-like expressions and interactions by movement and deformation of clusters of sphere magnets. In *ACM SIGGRAPH 2012 Posters*, ACM (2012), 25.

13. LEGO. *LEGO Mindstorm*. `http://mindstorms.lego.com/`.

14. Leithinger, D., Follmer, S., Olwal, A., and Ishii, H. Physical telepresence: shape capture and display for embodied, computer-mediated remote collaboration. In *Proceedings of the 27th annual ACM symposium on User interface software and technology*, ACM (2014), 461–470.

15. Niiyama, R., Sun, X., Yao, L., Ishii, H., Rus, D., and Kim, S. Sticky actuator: free-form planar actuators for animated objects. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, ACM (2015), 77–84.

16. Pangaro, G., Maynes-Aminzade, D., and Ishii, H. The actuated workbench: computer-controlled actuation in tabletop tangible interfaces. In *Proceedings of the 15th annual ACM symposium on User interface software and technology*, ACM (2002), 181–190.

17. Raffle, H., Ishii, H., and Yip, L. Remix and robo: sampling, sequencing and real-time control of a tangible robotic construction system. In *Proceedings of the 6th international conference on Interaction design and children*, ACM (2007), 89–96.

18. Raffle, H. S., Parkes, A. J., and Ishii, H. Topobo: a constructive assembly system with kinetic memory. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2004), 647–654.

19. Schoessler, P., Windham, D., Leithinger, D., Follmer, S., and Ishii, H. Kinetic blocks: Actuated constructive assembly for interaction and display. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, ACM (2015), 341–349.

20. Sugiura, Y., Lee, C., Ogata, M., Withana, A., Makino, Y., Sakamoto, D., Inami, M., and Igarashi, T. Pinoky: a ring that animates your plush toys. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 725–734.

21. Ugoita. *DANCING PAPER*, 2015. `https://www.youtube.com/watch?v=05gPzM7OJ34`.

22. Vink, L., Kan, V., Nakagaki, K., Leithinger, D., Follmer, S., Schoessler, P., Zoran, A., and Ishii, H. Transform as adaptive and dynamic furniture. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, ACM (2015), 183–183.

23. Zhu, K., and Zhao, S. Autogami: a low-cost rapid prototyping toolkit for automated movable paper craft. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 661–670.