Ninja Track: Design of Electronic Toy Variable in Shape and Flexibility

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ABSTRACT
In this paper, we introduce a design for an electronic toy that is variable in shape and flexibility by using a structural object called “Ninja Track,” which is a belt-shaped object that consists of ABS parts hinged both longitudinally and transversely. When lying flat, Ninja Track is adequately flexible. When the user folds Ninja Track at the longitudinal hinges, it loses its flexibility and becomes a rigid stick. We have created two types of electronic toys as applications of this structure. During the toy prototyping process, we discovered five interactional considerations for Ninja Track. Whilst showing toys at public exhibitions over a period of two weeks, we discovered a few problems with Ninja Track, and we have implemented solutions to these problems.

Author Keywords
TUI, material computing, organic user interface, flexible, transform.

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces: Input devices and strategies.

General Terms
Design.

INTRODUCTION
Digital content consists of software and hardware. The software is not only an operating system (OS) that controls a computer but also the applications that run on the OS. The software is thus an intangible asset, not a tangible object. On the other hand, the hardware is a computer in itself and man-machine interfaces such as a display, speaker, keyboard, and mouse. As the name suggests, the hardware is composed of hard substances and is covered with dense metal or tough plastic.

Today, we live surrounded by rigid commodities such as hardware. By contrast, humans have soft and flexible bodies. This is because water makes up most of any living thing. Water is normally a fluid and is able to alter its form accordingly when poured into a container. Water can also be a solid, which is known as ice. That is, water can change its shape and flexibility through a phase transition of the thermodynamic system. In this paper, we present our vision of a future where everyday objects are made of substances that are variable in shape and flexibility.

Think of a key—if it were made of such a substance, we could keep it in the flexible mode while in our pocket; think of garments; if they were made of such a fabric, we could make a dress that could suddenly be transformed into body armor. Within the same context, think of computer hardware; if they were made of a substance that can change its shape and flexibility, what type of digital content could we produce? Thus, what kind of interactional considerations would be required, and how might we enjoy this new experience?

To answer these questions, we developed a structural object called “Ninja Track” (Figure 1) that can change its shape and flexibility. We also created two types of electronic toys as examples of digital content that use Ninja Track. During the toy prototyping process, we discovered five interactional considerations for Ninja Track. Whilst showing toys at public exhibitions over a period of two weeks, we discovered a few problems with Ninja Track, and we have implemented solutions to these problems.

Figure 1. Ninja Track: (left) inflexible mode; (right) flexible mode.
weeks, we discovered a few problems with Ninja Track, and eventually we found effective solutions to these problems.

RELATED WORK
In this chapter, human-computer interaction studies that focus on a soft and flexible interface are described.

Within the last several years, new research topics such as the organic user interface (OUI) [22] and material computing (MC) [2] have arisen. One common interest of these researches is the adoption of materials or objects that are soft and flexible, such as clothes and liquids, as interfaces for ubiquitous or wearable computing. The examples of the OUI and MC are described below.


The representative example of a liquid interface is the kinetic art of Sachiko Kodama [9], which uses a ferrofluid (magnetic fluid) controlled by an electromagnet. Liquid interface [10] also uses a ferrofluid and can be connected to an interactive display. Blob Motility [23] uses a low-viscosity ferrofluid as a programmable blob display. Moreover, Sensing through structure [17] and ARForce [8] use a gel-like material for their soft input devices.

The preceding examples use materials or objects that are soft and flexible as their interfaces. In the interaction designs and the applications, the flexibility of the shape was taken into consideration but a change in the flexibility itself was not.

The display by Sato [15] is an interface that can change its flexibility as envisaged in our research. This display changes the softness of a projection surface by changing the airtightness of a plastic bag that contains bead cushions, and it was created for use as a touch display. Although such research has a vision similar to that of our research, there are obvious differences in the interaction design and the realization.

DESIGN OF NINJA TRACK
Before creating digital content with changes is shape and flexibility, we developed the structural object “Ninja Track” for this purpose. In this chapter, the development process of the Ninja Track structure is described.

First, we defined the following four requirements for developing a structure:

- The structure must be able to transform into two or more shapes. Preferably, it should be able to transform into a flexible-mode shape, an inflexible-mode shape, and other shapes.
- The structure must be usable for hardware. This means that it should have space to accommodate microcontrollers, sensors, and actuators.
- The structure must change its shape and flexibility by means of an actuator, which should be of a reasonable size and scale for use in an electronic toy.

After defining these requirements, we set a belt-shaped object as our ideal structure, inspired by several snake-swords that appear in comics, videogames, and animations [12][14][16][18]. Normally, the structure is pliable, like a ribbon or whip, and can be transformed into a ring shape. When an external force is applied, the structure becomes a rigid stick, like a sword. Since we imagined the ideal structure to look like a Ninja tool, we named it “Ninja Track.”

In order to realize Ninja Track, we designed three types of structures as hypotheses and we developed several prototypes for verification. Every structure was made of layered acrylonitrile butadiene styrene (ABS) by a 3D printer [6]. Each concept and its verification result are described in the subsection below.

String of Beads
The first hypothesis is the “string of beads (SOB),” which is a design that links small pieces of ABS by a thread and changes its flexibility to match the tension of the thread. In our prototype, we used a kite string, a fish line, and an elastic string as the thread (Figure 2).

![Figure 2. SOB Prototypes: (top) concept; (bottom) test pieces.](image-url)
The structures made using the SOB method had the suppleness of a ribbon that we required. In addition, the structure that uses an elastic string as the thread could be expanded longitudinally.

However, this SOB structure continuously needs a strong tensional force to maintain stick shape (inflexible mode). It is impossible to maintain the stick shape using a geared motor that consumes little power. Therefore, we decided to change the method in developing Ninja Track.

**Nests and Hinges**
The second hypothesis is “nests and hinges (NH).” The prototype of the NH method consists of outer parts and inner parts linked by hinges longitudinally. The flexibility of an NH structure can be changed depending on the relative position of the inner and outer parts (Figure 3).

The NH structure can inherently hold the inflexible mode without continuous external forces such as those needed by the SOB structure. Furthermore, the NH structure has adequate flexibility when in the flexible mode.

However, we found that the inner parts were difficult to slide promptly by means of a small actuator. The NH prototypes suffer from a large friction that arises between the inner parts and the outer parts. Additionally, the structure is so thin that it is difficult to reduce the twist and deflection in the inflexible mode. We therefore decided to seek a method to solve these problems.

**Longitudinal-Transverse Hinges**
The third concept is the “longitudinal-transverse hinge (LTH).” The prototype of the LTH method consists of small pieces of ABS that are linked by the hinges both longitudinally and transversely. When flat, the structure is fluid and wavy. However, when the user folds the structure at the longitudinal hinges, it loses its flexibility and becomes a rigid stick (Figures 1 and 4).

The LTH structure can also inherently hold the inflexible mode without any external forces. Since the cross-section is L-shaped, the twist and deflection that were a problem in the NH method are reduced significantly.

Furthermore, the rotational movement of the small servomotor can fold the LTH structure easily. That is, the shape and flexibility of the structure can be changed with an actuator of reasonable size.

However, the structure needs to be straight when it changes to the inflexible mode from the flexible mode. We judged that this problem was solvable in the application design.

Therefore, we decided to adopt the LTH method in the design of Ninja Track.

**DESIGN OF NINJA TRACK APPLICATIONS**
Next, we created two types of electronic toys as applications of Ninja Track. One is a gaming gadget, which
can transform from a whip into a sword both virtually and physically. The other is a musical instrument, which can produces sounds depending on its shape and user interaction.

**Ninja Track for Games**

Ninja Track for Games (NTG) is an example of the use of the Ninja Track as a physical controller for video games (Figure 5).

In NTG, a black Ninja Track is connected to a cylindrical grip that contains a servomotor, 3-axis accelerometer, switch, and microcontroller unit (MCU, Arduino Pro Mini 3.3 V [1]). A sponge sheet is added to the back of the Ninja Track in the second prototype as a spring to reduce the structural tangle and make NTG suitably whip-like (Figures 5-B and 5-C). In addition, each hinge was greased to reduce its friction. The MCU exchanges several data with the MacBook Pro through a USB (serial communication). The sound player running on the Mac was programmed in Max/MSP, and the software can generate sound effects according to the movements of NTG by the user.

With NTG in the flexible mode, the user can swing it as a whip. That is, the user can experience NTG as a whip through the tactile feedback of the flexible-mode Ninja Track and the whip-sound feedback reproduced by the Mac. When the switch is turned on, Ninja Track is automatically folded into the inflexible mode by the servomotor and the user can play with it as a sword. Responding to physical manipulations, Ninja Track alters its form, giving the user tangible feedback and a more immersive experience.

**Ninja Track for Music**

Ninja Track for Music (NTM) is a musical instrument that can produce sounds depending on its shape and user interaction (Figure 6).

NTM consists of a white Ninja Track, MCU (xtel [20]), 3-axis accelerometer, tact switches, reed switches, neodymium magnets, and Li-Po battery. In the first prototype, all the switches, sensors, and cables were put on the surface of Ninja Track (Figure 6-A). Therefore, the prototype was liable to break down easily. We then developed a hollow Ninja Track that is able to contain sensors and cables for NTM (Figures 6-B and 6-C). All switches and sensors are connected to the MCU in the rectangular box. The MCU exchanges data with the MacBook Pro through the XBee connection and the sound player runs on the Mac as well as on NTG.

When Ninja Track has a flat shape and the tact switch is pressed, NTM produces the sound of a recorder. That is, the user can have the feeling of performing with a recorder when the switch is pressed and the Mac reproduces the

![Figure 5. Ninja Track for Games:](image)

(A) the first prototype; (B) the second prototype; (C) schematic; (D) playing NTG.
sound of a recorder. When Ninja Track is bent into the shape of a saxophone and the tact switch is pressed, NTM detects the shape change via the bend sensor and produces the sound of a saxophone. Further, when the user folds Ninja Track into a stick shape (inflexible mode) and shakes it, NTM detects the stick shape via the reed switch and produces the sound of a drum. When Ninja Track is curled into a ring shape and shaken while holding a tact switch, the sound of a bell is heard. NTM also produces the sound of a harp roll when rotated in a ring shape.

**INTERACTIONAL CONSIDERATIONS OF NINJA TRACK**

Ninja Track is a structure that can change not only its flexibility but also its shape; for example, it can take a flat shape, a stick shape, or a ring shape. Based on this characteristic and the experience of making electronic toys with Ninja Track, we found five interactional considerations as described below.

**Metaphor**

When Ninja Track changes its shape, the affordance also changes. We can easily liken a flat-shaped Ninja Track to a ribbon, but it can hardly be compared to a ball. Although a ring-shaped Ninja Track can be likened to a tambourine, it does not have the appearance of a piano. To design digital content using Ninja Track, the designer needs to consider the visual metaphor evoked by the shape transformation.

On this point, our toys are designed appropriately. In the case of NTG, the whip mode corresponds to the flaccid-looking flexible mode of Ninja Track, and the sword mode
corresponds to the rigid-looking inflexible mode of Ninja Track. In the case of NTM, visual metaphors are coordinated as follows: the flat shape denotes a recorder, the bent shape denotes a saxophone, the stick shape denotes a drum stick, and the ring shape denotes a bell. In addition, the harp-roll uses the word “roll” as the metaphor.

**Behavior**

The user behavior is changed by the shape and flexibility of the object that is held by the user. For example, swinging a rhythmic gymnastics ribbon is totally different from swinging a baseball bat, although these are both examples of “swinging” behavior. When using Ninja Track for digital content, the designer needs to consider the user behavior caused by Ninja Track.

This point is also considered with our electronic toys. In NTG, the user can behave naturally since the flexible and inflexible modes are appropriately assigned to the whip mode and the sword mode. In NTM, a bending action in the flexible mode is reasonably used for a change into a recorder or a saxophone. A swinging action with the stick shape is naturally used for producing the sound of a drum kit. Likewise, a shaking action with the ring shape is used to replicate the action of ringing a bell.

**Feedback**

With the change in the shape and flexibility, the tactile feedback from Ninja Track also changes. For example, there are many differences in the sensation between swinging a chain and swinging a stick. A designer who creates digital content using Ninja Track should note this feedback difference.

The electronic toys that we make are well-considered designs that consider this feedback. In NTG, the user can feel the tactile feedback produced by swinging a flexible or inflexible Ninja Track and can hear the appropriate sound feedback. In NTM, the tactile feedback of playing a musical instrument is also connected appropriately with reproduced sounds.

**Inevitability of Transformation**

The VF-1 Valkyrie that appears in the animation “The Super Dimension Fortress Macross” [19] can seamlessly change into a humanoid robot from a fighter aircraft. This is because the fighter mode is the best shape for combating the enemy in the sky, and the robot mode is a suitable shape for battling with aliens on the ground. We think it reasonable that applications of Ninja Track should make its transformation inevitable as well.

In the case of NTG, a weapon that can change into a sword from a whip is a very popular prop in fantasy creations, as mentioned previously. Since NTG was designed for use as a game controller, its user can be told the meaning of its change by the story of the game. In NTM, there is commonality among the musical instruments and no discrepancy about the transformation, since the user can play each musical instrument with the best shape and flexibility.

**Function Follows Form**

The VF-1 Valkyrie can fight against each different enemy by means of its transformation. Similarly, the Leatherman [11], which is an all-purpose knife, can be utilized by changing the shape from pliers into a knife or vice versa. On the other hand, the Swiss Army Knife [21] is an all-purpose knife too, but every tool is pulled out from its handle. It does not need to transform in order to change its function.

Both Leatherman and Swiss Army Knife can be a good motif for designing applications of Ninja Track. However, we think that the Leatherman is a better motif for making a novel standalone device such as our electronic toy. This is because people are already using smartphones that can switch their function like a Swiss Army Knife.

**DISCUSSION**

We exhibited Ninja Track electronic toys for two weeks at the WISS 2011 (December 3, 2011, in Kyoto), SIGGRAPH Asia 2011 Emerging Technologies (December 13–15, 2011, in Hong Kong), and the 15th Japan Media Arts Festival (February 22–March 4, 2012, in Tokyo). Although each toy was highly appreciated by the audiences, we discovered two sets of problems with the structural and the interactional considerations. In this chapter, we discuss these problems with Ninja Track and their solutions. We also discuss the versatility of Ninja Track.

**Structure**

The earlier Ninja Track created using 3D-printed ABS did not have as much strength as an ordinary toy that is made from metal and cast plastic. During the WISS and SIGGRAPH Asia exhibitions, the hinges of NTG sometimes cracked due to overuse. Moreover, the surfaces of the hinges were so rough that the friction of Ninja Track increased continuously with its length. On the other hand, Ninja Track sagged under its own weight when it was fully extended. The maximum length of early Ninja Track that can be folded by a small servomotor is about 30 cm.

However, we solved these problems by using a suitable material for Ninja Track. We created Ultimate NTG by utilizing commercial stainless-steel hinges (Figure 7). We also replaced the USB connection with an XBee wireless connection (Arduino FIO [1], Figure 7-B). We exhibited Ultimate NTG at the Japan Media Arts Festival and it did not break, even though people of all ages played with it enthusiastically. That is, we discovered that it was possible to make a long yet robust Ninja Track by using the same structure with a tough low-friction material.

**Interactional Considerations**

At the Japan Media Arts Festival, we observed two children playing the ring-shaped NTM by shaking hands in a circular motion to make a harp-roll sound (Figure 8). That
is, we found an incentive to examine the application and interactional considerations of Ninja Track when two or more people play with it. We may also design for collaborative play if two or more NTMs are connected with each other through a network.

Versatility
Ninja Track is a belt-shaped structure that can change its shape and flexibility. If this structure is manufactured using a suitable material, as mentioned previously, Ninja Track can avoid the problems of length and overuse. In this case, Ninja Track can be used as a mountain-climbing aid that changes from a belt into a cane or a splint.

In this paper, we have proposed uses of Ninja Track for electronic toys. Further, if a camera unit were embedded in Ninja Track, a digital camera that can be looped around a tree or stuck in the ground can be made.

We think that Ninja Track can also be used as robot parts. Imagine that Ninja Track is adopted in the drive system of a robot; in this case, the robot can use the ring-shaped Ninja Track as a caterpillar track for roads. It can also walk on irregular ground by using the stick-shaped Ninja Track as its legs. If Ninja Track is adopted in the arm of a robot, then the robot would be able to reach its hand into curved pipes. Moreover, if a computer is embedded in each of the Ninja Track pieces, a concept like a modular robot will be possible.

CONCLUSION
We developed a structure called Ninja Track, which can instantly change its shape and flexibility. Moreover, we also created two types of electronic toys as examples of its application. One is a gaming gadget that can transform from a whip into a sword both virtually and physically. The other is a musical instrument that can produce sounds depending on its shape and user interaction. During the prototyping process, five interactional considerations for Ninja Track applications were discovered: metaphor, behavior, feedback, inevitability of transformation, and function follows form. Through three public exhibitions, we gradually improved the structure of Ninja Track; however, we found that there is potential for considerations of interactions and applications when two or more people play with Ninja Track.

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