Co-Designed Paper Devices

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Abstract
We describe our techniques for making paper devices using nitinol wire, gold foil, and paper. We outline an evolutionary approach to enable end-users to design their own paper devices.

Keywords
Actuation, co-design, end-user, craft

ACM Classification Keywords
H.5.2 User Interfaces; H.5.m Miscellaneous

Introduction

Paper devices are small paper interactive objects that use nitinol shape-memory alloy wire for actuation, gold leaf printed circuits, embedded microchips for control, and paper outer shells for form and structure. Paper devices offer a convenient domain to investigate how new material technologies and software processes can be used to co-create designs in a dialogue between an end user and a designer. We describe our manufacturing techniques and outline our first efforts to employ a genetic algorithm that enables end-users to create custom designs.

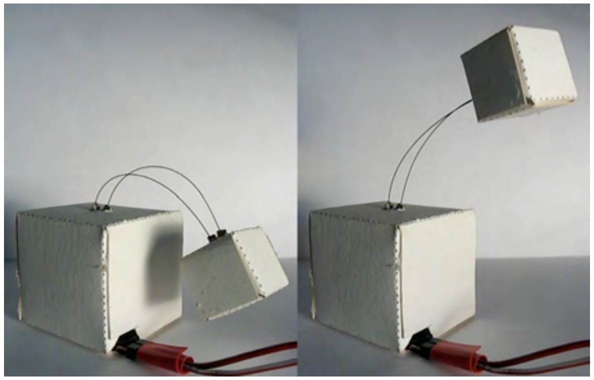

Figure 1. A paper device: Interactive sleeping box toy (SMA and paper) responds physically to ambient noise.

Materials and Manufacture

Paper Devices are made from paper or card stock, shape-memory nitinol alloy (SMA) wire and embedded electronics on gold leaf circuits. Paper is a suitable medium for building paper devices as it is easily available, easy to work with, lightweight and strong. Designs made from paper can be generated, simulated computationally and patterns produced using rapid prototyping methods such as computer controlled laser cutters or by hand.

SMA wire is easily actuated using an embedded computer and controlled with a square wave PWM (pulse-width modulation) signal. SMA can be incorporated into materials such as paper to create smart materials [1]. SMA is light and so adds little weight to a product. SMA is a material (not a discrete component) so we can vary its length and form to produce varied desired results. These results are computable as they follow set rules that relate resistance per inch with force exerted at different voltages. This allows us to simulate the SMA wire behavior in an evolutionary parametric design program.

We use gold leaf circuits applied to the paper to route power to the SMA wire from a microcontroller as well as to connect support electronics such as sensors. Gold leaf circuits add less weight than a printed circuit board and can be manufactured at a lower cost when producing one-off circuits.

Clips and crimping:

In paper devices, the SMA wire that actuates the devices must be connected physically to the parts (e.g., paper surfaces) that are to be actuated, and also connected electrically to the wires that supply power. To attach the SMA wire to the paper and provide a way to connect it electrically, we designed a clip that is easily and affordable to manufacture. Our clips consist of a small strip of brass plate crimped around the SMA wire. We then heat the clip to set the SMA wire in a shape so that it will not wiggle out from the crimp during use. Finally the end of the crimp is formed into a clip that allows the muscle to be easily and rapidly attached to paper device's shell at electrical contact points (see figure 2).

Muscles

We investigated different methods of using SMA wire to actuate paper devices. Each method had different advantages, weaknesses and applications.

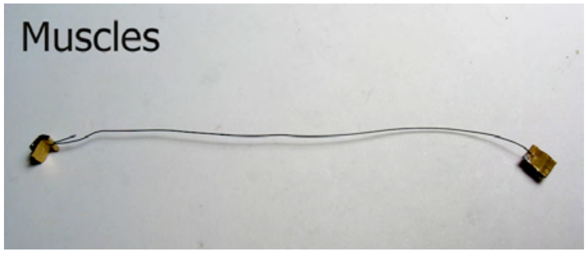

Figure 2. A small SMA muscle. It is approximately 7cm (3") long and made of .008" nitinol. At each end the wire is terminated with a brass clip.

INVISIBLE MUSCLE:

We use SMA wire in pairs (positive and negative) in lengths of approximately 15mm to create a neck-like link between two paper elements (See figure 1). When powered the SMA straightens, lifting one paper element (the head) into the air. Gravity returns the head to its down position when the SMA is not being powered, eliminating the need for counter springs. This method allows allowing the extent of movement to be controlled by a microcontroller by pulsing the SMA wire. Using SMA in this way provides several benefits: Muscles can be varied in length and placement allowing for an open design system; and because only SMA wire and a crimp are used in this joint it is also relatively inexpensive. The muscle is very light and the mystery around how it works creates a novel excitement.

PAPER HINGE

This method consists in sewing a small amount of SMA into two adjoining pieces of paper to create a hinge (figure 3). This method provides a quick and simple method for obtaining movement at a joint as it requires no crimps and uses very little SMA wire. It is also a reasonably power-efficient method of obtaining movement.

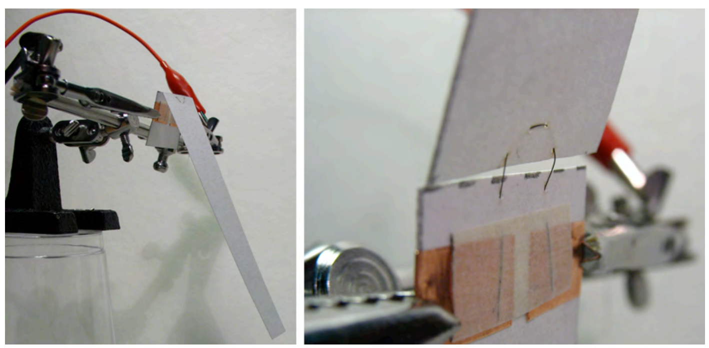

Figure 3. SMA wire hinge sewn between two pieces of paper, brass adhesive tape for contacts.

Circuits on Paper

We investigated different techniques for providing circuit paths to the sensor, actuator, and support electronics components in paper devices. It is essential to minimize the mass that must be moved and therefore we want to use lightweight circuit paths.

GOLD LEAF FOIL

We developed a method for "printing" circuits on paper. This allows the paper devices provided a method of production that could be mass customized, rendering the design and interaction behavior of the paper devices open to a co-design process. The circuit shown in figure 4 was made by applying a spray-on adhesive through a laser cut stencil. Gold leaf was then applied to the resulting glue traces and brushed away in a process similar to gold leaf gilding. Components were then glued to the circuit using conductive glue, brass clips connect the circuit with external components such as the power supply and muscles. (A method of printing glue directly onto the paper would enable unique circuits to be produced quickly.)

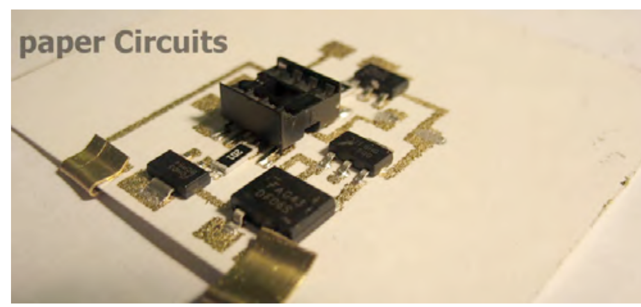

Figure 4. Gold leaf circuit for controlling a SMA wire and rectifying external AC power.

Co-Design

We are particularly interested in paper devices as a product for co-design, in which the end user has control over the final product. Paper devices lend themselves to co-design as their materials and production enable custom one-off designs to be made easily with readily available materials and tools. Our genetic algorithm produces combinations of differently proportioned boxes (see figure 5) separated by a SMA wire muscle. As the program generates different designs, the user selects one with aesthetically pleasing proportions. The selected form is then "mated" with other selected forms to produce new designs. In this manner new designs produced by the program tend towards proportions that the end user prefers. The program then generates a pattern for making the chosen form out of paper.

In testing users favored an iterative approach to design. They could easily make split-second judgments on the "best" form. This avoids requiring users to deliberate consciously about the desired form, because at each step they need only decide which among presented options is better [3].

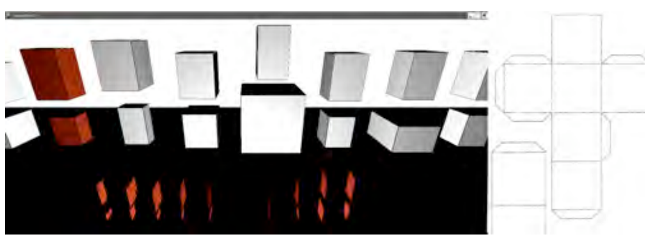

Figure 5. Output of a computer program (screen, left; laser-cut template right) that enables users to co-design proportions of paper devices.

Applications

We have explored several playful applications for paper devices. For example, a physical status icon raises its head when a particular user is online, or the desktop "sleeping box" toy shown in figure 1 that sits sleeping (head nodding slightly) until the user wakes it with a loud noise. At this the box raises its head, but eventually falls back asleep. We have also experimented with small paper LED lamps that respond kinetically to external stimuli.

Acknowledgements

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