TOPAOKO: Interactive Construction Kit

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Figure 1. The TOPAOKO kit is made of laser cut hardboard embedded with circuit.

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Abstract
If you have a laser cutter, you can build your own TOPAOKO. We describe work in progress on TOPAOKO, an interactive construction kit that encourages experimentation and play with pieces of a hardboard based, embedded circuit, kit. We describe each component of the kit and examples of constructions built with it.

Keywords
Interactive Construction Kit, Tangible Interface

ACM Classification Keywords
H.5.2 User Interface: Haptic I/O

General Terms
Design, Experimentation, Human Factors

1. Introduction
In Ishii and Ullmer's vision of "Tangible Bits" [1], tangible user interfaces augment the physical world by coupling digital information to everyday objects and environments. They envision a more human-friendly interface with input/output modalities beyond window, icon, menu and pointing devices. However, long before Ishii and Ullmer's research, the construction kit has been considered a suitable object for interacting with computation. Twenty years ago Fischer pointed out that a construction kit was an appropriate human problem-domain communication

interface for controlling and understanding a computer system, especially in user interface design [3]. Soon, behavior construction kits such as LEGO/Logo emerged that not only enabled children to embed computation in machines they built, but also spread computation throughout their world [4]. Construction kits have long been utilized not only as educational artifacts fostering children's creativity but also as a tool to support and encourage engineering and design exploration.

TOPAOKO is a new generation interactive construction kit intended for high school students and college freshmen. Students in these ages are creative and have enough experience making things. Students can learn electronics and make toys while playing with TOPAOKO. With it, students not only create buildings or machines, but also to make the kit itself. Just as color printers, once very costly, are now a consumer product, in the near future laser cutters will become more accessible as the price decreases. In the meantime, Craft ROBO[2] is an affordable cutting machine that enables users to cut thin materials such as paper or plastic film.

The name, "TOPAOKO" comes from Ch'ing dynasty China: A Topaoko is a curio box with surprising twists and secret drawers for emperors to store their prized objects. TOPAOKO is a construction kit made of 3 mm thick hardboard and simple electronics. Students can download TOPAOKO pdf pattern files and use the laser cutter to print them out; also, they can design their own patterns using graphic design or CAD software such as Adobe Illustrator or Rhino. TOPAOKO is a construction kit with which students build not only spatial structures but also a "behaving machine" [3].

2. The KIT

Figure 1 shows our TOPAOKO construction kit. It contains a microcontroller block, an assortment of sensor blocks and actuator blocks, a battery block, and some hardboard pieces. Each component is made of laser cut hardboard. Components can be connected electrically via copper foil traces and embedded magnets keep connections tight. The individual block names are Chinese words that represent the various functions of the kit components.

2.1 HSIN (mind/brain) BOX: The Microcontroller

HSIN, the Chinese character shown on the box represents "mind" or "brain". The central component of an interactive construction kit design is its "mind/brain", usually an embedded microcontroller or several chips. The HSIN BOX consists of a laser cut HSIN-BOX hard board sheet, a printed circuit board (PCB), an integrated circuit (IC) socket, a voltage regulator, two 10 uF capacitor, two 22 pF capacitors, one 10K resistor, a 16MHz clock crystal, and a 28 pin ATMEGA168-20PU microcontroller. Figure 2 (left) shows an inside view of the HSIN BOX. We used five of the microcontroller's 20 pins I/0 for connections between boxes.

Each copper foil trace leads from one of the microcontroller's pins to one of the ports visible on the sides of the package. The entire package is approximately a 42mm cube, made of 3mm hardboard. To employ the microcontroller in a HSIN BOX, first we put an IC socket, a piece of hardboard for circuit (the one with 15*15 holes), and a PCB together to make a sandwich. Then we soldered the circuit on the PCB side. Using the TOPAOKO kit as a base to build a circuit gives us a three dimensional space for the circuit in which the circuit can be embedded stably.

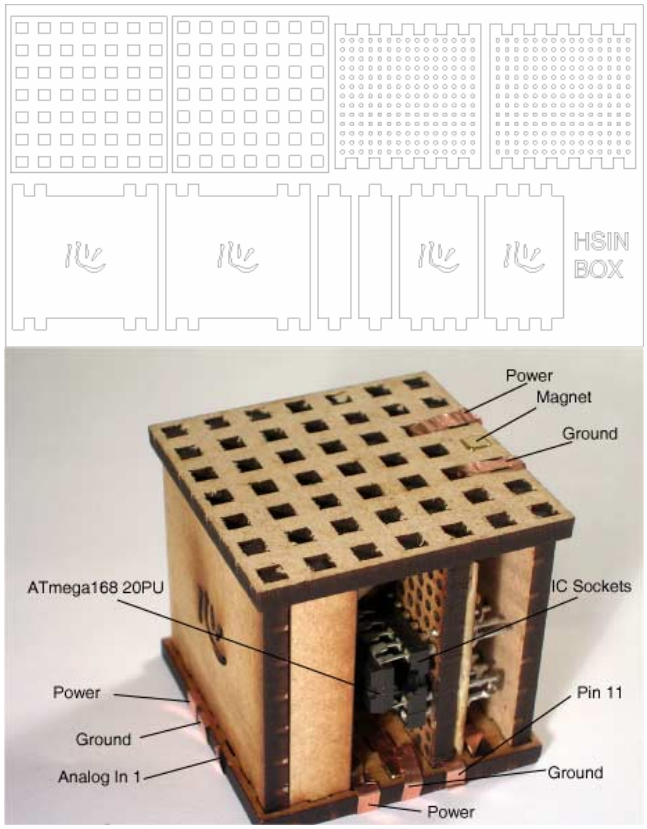

Figure 2: Upper: the HSIN BOX pattern for laser cutting. Lower: microcontroller and electronic components are embedded in the HSIN BOX.

2.2 CHI BOX: Battery Pack

The Chinese word "Chi" means the energy flowing inside our body. TOPAOKO constructions require power. We designed a CHI BOX pattern to contain a 9V battery, which is sufficient for all of our applications. As shown in Figure 3 two pieces of copper foil tape form our connection ports: power and ground. Each piece of copper foil tape is approximately 3 mm wide, which fits our TOPAOKO grid base kit (The base kit grid is 3 mm square). The CHI BOX can connect directly to a LI BOX (see below) or connected to a HSIN BOX to drive the microcontroller. We embedded a 3 mm cube magnet to secure the physical connection between two boxes. The complete CHI BOX is approximately 59 x 42 x 42 mm.

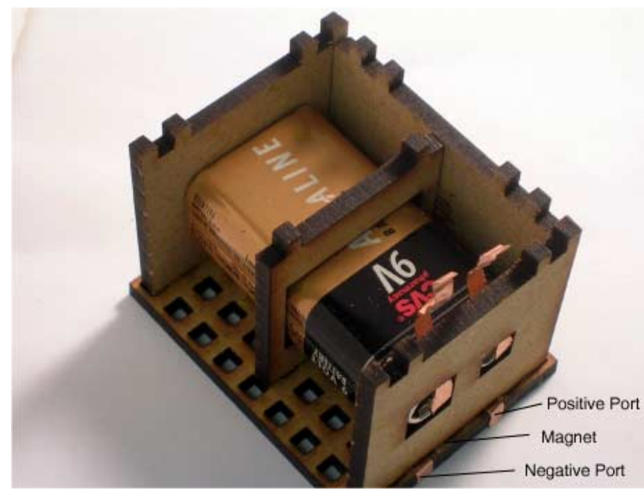

Figure 3: The CHI BOX connection ports on the right side are made by copper foil tape.

2.3 LI BOX: Actuators

LI means force. The LI BOXs are the most exciting boxes: Creating motion and light makes the construction kit come alive. A LI BOX contains one of three different output devices: motors, light emitting diodes (LEDs), and muscle wires. Figure 4 shows these devices and their interior mechanisms. The LI motor box (Figure 4 left) is made like the HSIN BOX and CHI BOX, using copper foil tape as electrical connections and magnets to connect with other boxes. The LI motor BOX has three connection ports: Power, ground, and the Enable port to the output pin port on HSIN BOX. The LI BOX package is approximately 42 x 42 x 42 mm. (excluding the bending bronze tube).

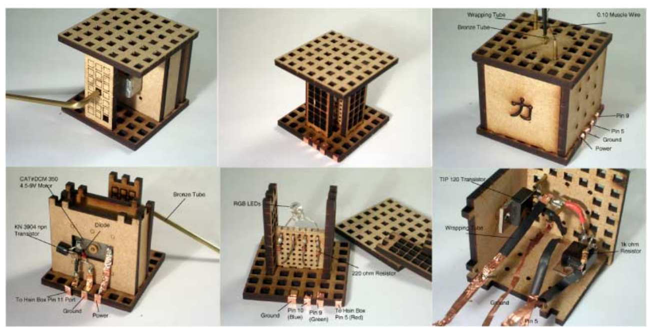

Figure 4: Left column: LI Motor BOX. Middle column: LI RGB BOX . Right column: LI Muscle wire BOX.

Figure 4 also shows other output devices included in the kit: LI RGB BOX (red green blue LED), and LI muscle wire BOX . The LI RGB BOX has five ports (Power, Red, Green, Blue and Ground) that attach to the output ports and ground port on the HSIN BOX. The LI muscle wire BOX uses the same external power circuit as the LI motor BOX. The actuator consists of two shape memory alloy wires (an alloy that "remembers" its original, cold, forged shape, and which returns to that shape after being deformed, by applying heat) and a steel wire wrapped with a tube. One end of the muscle wire connects through the steel wire to ground and the other end connects to the enable port.

When the LI BOX receives an enable signal from the HSIN BOX, it starts actuating: LI motor BOX rotates the gears; LI RGB BOX turns the light on; LI muscle wire BOX bends the steel mast. The amount of actuation (speed, brightness, and angle) depends on the voltage provided by HSIN BOX.

2.4 GUANG BOX: Sensors

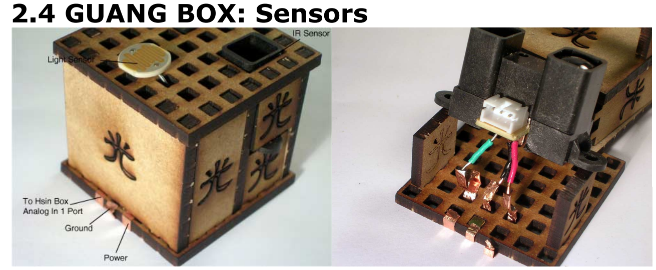

Figure 5: The GUANG BOX consists of a photocell sensor and a infrared ray sensor.

In Chinese, GUANG means light. The GUANG BOX is a signal receiver that responds to real-world stimuli, in this case, light (Figure 5). It contains a photocell and an Infrared Radiation (IR) light sensor. Working as a variable resistor, the GUANG BOX transmits voltage (brightness and distance) provided by sensors to the HSIN BOX through its three connection ports: power, ground, and voltage input. The embedded magnets enhance the connection between the GUANG BOX and HSIN BOX. The complete GUANG BOX is approximately 42 x 42 x 42 mm.

3. Application of the Kit

To explore the range of constructions that can be built with the TOPAOKO kit, we put together a few simple playful constructions. This section describes: the Moving Machine, Moving Robot, and Moving Creature.

3.1 CHI BOX + LI BOX: Moving Machine

The first application (shown in the top two rows in Figure 6) is Moving Machine. It uses only two kinds of TOPAOKO BOXes: the CHI BOX and LI BOX. As shown in Figure 5 the student can connect CHI BOX to LI motor BOX or LI RGB BOX. For most users, seeing the motor spinning or the LED shining is the simplest but surprising part of the TOPAOKO construction kit: power + actuator = moving machine. For novices with no electronic experience this is a fun application they can start playing with.

3.2 CHI BOX + GUANG BOX + LI BOX + HSIN BOX: Moving Robot

This application includes all the TOPAOKO BOXes: CHI BOX, GUANG BOX, LI BOX and HSIN BOX. These boxes represent four basic devices for building a robot: Power, Input, Output, and Controller. The program in this "Moving Robot" application transmits the input signal received from the GUANG BOX to the LI BOX. In the third row of Figure 6 we connected GUANG BOX – IR sensor and LI muscle wire BOX. The GUANG BOX senses the distance between the approaching object and the GUANG BOX itself, and the LI BOX actuates the movement. The closer the hand, the more bent the muscle wire actuator will be. Because it embodies a sensor, this construction is more like a robot than the Moving Machine application.

Figure 6: Some TOPAOKO constructions. First and second row: Moving Machine. Third and Forth row: Moving Robot. Fifth row: Moving Creature.

3.3 CHI BOX + GUANG BOX + LI BOX + HSIN BOX + Random: Moving Creature

The Moving Creature application (Figure 6, bottom row) includes a random function in the program. When something approaches the construction, LI RGB BOX shines and the LI muscle wire BOX swings back and forth. The color of LI RGB BOX and the movement of LI muscle wire BOX are randomly generated; the randomness makes the construction unpredictable. Compared to the Moving Robot application, the Moving Creature is more interesting to interact with.

4. Related Work

The TOPAOKO project is similar in spirit to several other computationally-enhanced construction kits. Buechley's Electronic Textiles project [5] is a "Build Your Own" construction kit in fabric. This project resulted in the Lilypad Arduino that has been widely adopted by textile artists, hobbyists, and in learning environments. LEGO MindStorms NXT [6] has the most applications but it is a closed system, limited to the plastic parts manufactured by the LEGO Company. In Topobo [7], children assemble robotic structures and program their behavior by twisting their plastic body parts. The Osaka University's Active Cube [8] project uses physical cubes as tangible interfaces to interact with a virtual 3 Dimensional environment. Schweikardt and Gross's roBlocks system [9], comprises a kit of sensor, action, and operator blocks that users snap together to build Braitenberg-like robots. And the Speech-Enabled Alphabet Blocks [10] can be arranged to construct words that are then pronounced through a speech synthesizer.

5. Final Remarks

TOPAOKO needs further development in both hardware and software so that students with little electronic experience can more easily build the BOXes and programs. Developing software that enables students to design their own kit in a three-dimensional virtual environment is another goal. We plan to evaluate the kit with high school and college students. Based on this, we will create additional kit components and applications to increase the kit's playability.

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