SilverCodes: Thin, Flexible, and Single-Line Connected Identifiers Inputted by Swiping with a Finger

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Abstract. This study investigates SilverCodes, thin and flexible identifiers that serve to constitute an input interface. SilverCodes are thin and flexible barcode-shaped identifiers. User input is achieved by swiping an identifier with a finger. SilverCodes are made from two sheets of paper pasted with conductive ink. Identifiers can thus be conveniently printed using an ordinary ink-jet printer. Multiple SilverCodes can be connected by a single-line wire to an external module that recognizes the identifier swiped by the user. Furthermore, SilverCodes can be stacked and identifiers can be recognized to an average accuracy of 95.3%.

Keywords: Paper Interface · Conductive Ink · Tangible · Interactive Book.

1 Introduction

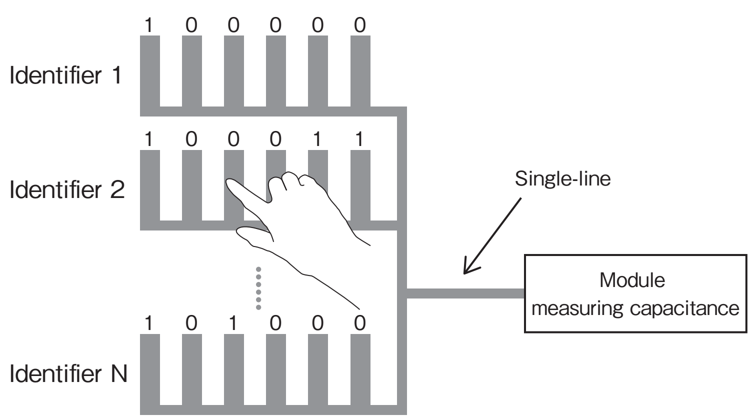

Fig. 1. SilverCodes concept.

By applying suitable crafting skills (e.g., drawing, coloring, stacking, cutting, or folding), a designer can transform simple sheets of paper into a picture book or can achieve various forms of papercraft. The scope of possibilities for making objects from the paper is fascinating, but even more can be achieved by including an interactive component. For example, the inclusion of an interactive interface, whereby touch electrodes are created on paper with conductive ink or conductive tapes, can provide the paper a functionality that allows user interactions through a computer.

The following methods for fabricating an interactive paper interface using a conductive ink or conductive tapes have been proposed:

1. pasting RFIDs on a piece of paper [7],
2. attaching LEDs and a microcomputer to paper [8], and
3. forming touch electrodes [9].

Methods for pasting or attaching circuit elements to a sheet of paper (points 1 and 2) allow complex input configurations, which typically results in a thickening of the paper and reduced flexibility. A method for forming touch electrodes on paper (point 3) can allow touch-based interaction. However, implementing many such electrodes simultaneously for complex applications requires many wire connections. This significantly complicates the wiring configuration between the sheet of paper and a sensing module used to identify which electrodes have been touched by the user.

This study investigates SilverCodes, thin and flexible identifiers that serve to constitute an input interface. The concept is illustrated in Fig. 1. SilverCodes are thin and flexible barcode-shaped identifiers. User input is achieved by swiping an identifier with one finger. SilverCodes are made from two sheets of paper printed with conductive ink. Identifiers can thus be conveniently printed using an ordinary ink-jet printer. Multiple SilverCodes can be connected by a single-line wire to an external module that recognizes the identifier swiped by the user. This feature allows designers to implement multiple touch electrodes on a paper sheet using simple wiring. Furthermore, SilverCodes can be stacked, which allows the design of more complex input structures with multiple surfaces while maintaining the simplicity in electrical connections, since the stacked SilverCodes can also be connected to the module using single-line wires.

2 Related Work

In this section, we discuss the research on existing identifiers that can be embedded into objects, the one on interactive paper using conductive ink, and the book-type system that users can interact with.

2.1 Identifier

Various identifiers have been found suitable for embedding within objects. Harrison et al. [3] proposed Acoustic Barcodes that can be realized by forming striped grooves on an object. They can be engraved on various materials, such as paper, wood, or glass, and read using the sound generated when traced with a fingernail. Fetter et al. [1] proposed MagnetiCode, a tag that can be read by a smartphone equipped with a magnetic sensor. The tag consists of a microcomputer, a solenoid, and a solenoid-driving circuit. Identifier information is conveyed by changing the surrounding magnetic field with the solenoid. Li et al. [6] proposed AirCode, a tag that can be realized by creating a QR code or a character-like cavity within an object. The object is illuminated and photographed with a camera. The light reflected from the object surface and the light scattered within the object are then separated using a computational imaging method. The tag generated by the cavity is read by analyzing the scattered light.

In our study, an identifier is fabricated from two sheets of paper. Conductive ink is pasted onto the sheets and read by detecting the change in capacitance caused by a user swiping their finger over the identifier.

2.2 Interactive paper with conductive ink

Various scenarios of interactive paper with conductive ink have been explored. Jacoby et al. [4] developed StoryClip, which uses illustrations drawn with conductive ink as an interface for recording and playing back audio signals. Klamka et al. [5] proposed IllumiPaper, an interface that allows input through a stylus or by touch, and visual feedback using a light-emitting display. Li et al. [7] proposed a touch interface using an RFID tag equipped with an RF antenna that can be printed with conductive ink and whose characteristics change when touched by a user. Gestures such as touchdown and swiping motions on the antenna are demonstrably identified by detecting changes in the RF antenna characteristics.

StoryClip [4] and IllumiPaper [5] use multiple wires to connect the paper with external hardware. In contrast, SilverCodes use a single-line wire connection. Furthermore, fabricating SilverCodes does not require manually pasting a circuit element. The manufacturing process is facilitated because the identifier and the connection within the page are made only by ink-jet printing using conductive ink.

2.3 Interactive book system

Qi et al. [8] proposed Electronic Popables, a pop-up book with interactive elements composed of copper-foil tape, conductive cloth, conductive ink, and electronic components. Each page features switches, buttons, LEDs, and other input/output elements. The conductive ink is used to wire the light-emitting display and the touchpad. Yoshino et al. [9] proposed FLIPPIN', a book-type interface for use in public spaces, in which a capacitive touchpad made from conductive ink is printed onto each page and connected by an FPC. As an interactive book-type system that does not require electrical wiring, a method that uses RFID tags to identify which page the user is looking at and provides visual or audible feedback tailored to the page being viewed proposed. Figueiredo et al. [2] used a magnetic sensor mounted onto each page to identify the page being viewed by the user. The book-type system we propose involves making a connection to each page (composed of paper and conductive ink) and binding the pages into a book. The structure is simpler and easier to manufacture than in previous attempts since the connection is made by making holes in each page and pouring conductive ink.

3 SilverCodes

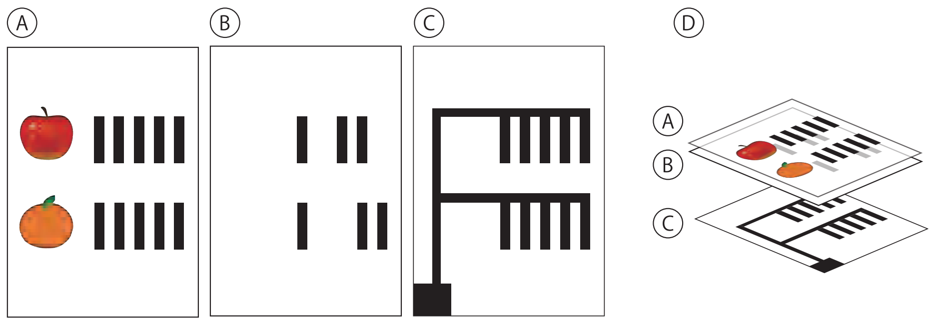

Fig. 2. Example of a SilverCodes implementation, consisting of two identifiers. A) The front side of the top sheet (first layer). B) The reverse side of the top sheet (second layer). C) The front side of the second sheet (third layer). D) Superposition of the two sheets.

The next section first describes the structure of a SilverCodes implementation consisting of multiple identifiers, as illustrated in Fig. 2 for the case of two identifiers. SilverCodes are made from two sheets of paper and conductive ink. Each SilverCodes identifier consists of a sequence of bars, used to represent binary values 1 and 0. Thus, the identifier encodes data as a bit sequence (e.g., 10001 or 1110).

Next, we describe the principle behind identifier recognition based on the swipe of a finger, which involves a capacitance measurement. The measured capacitance switches between three different values as a user swipes their finger over an identifier. This change in capacitance is then decoded into a bit sequence.

3.1 Structure of SilverCodes

SilverCodes consist of three layers made from two sheets of paper and conductive ink (Fig. 2): the front of the top sheet (first layer), the reverse of the top sheet (second layer), and the top of the bottom sheet (third layer).

First, we describe the structure of a SilverCodes identifier, illustrated in Fig. 3. A sequence of bars is printed onto the first layer. An identifier is recognized by swiping across these bars with a finger. As on the first layer, a bar sequence is also printed on the second layer, located on the reverse side of the first layer.

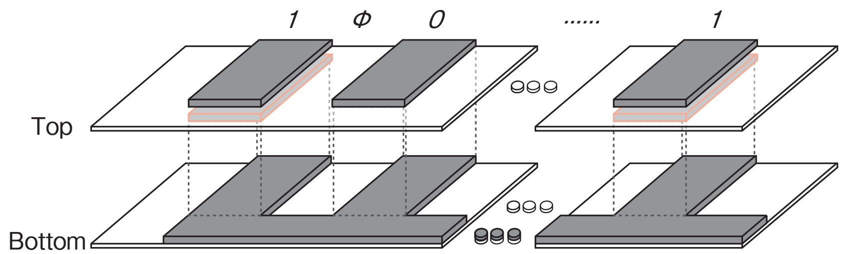

Fig. 3. Structure of an identifier.

The presence or absence of a bar on the second layer, directly above a bar on the first layer, constitutes a bit of value 1 or 0, respectively. The second sheet of paper (bearing the third printed layer) differs from the first sheet. The bar sequence is here the same as that of the first layer, and a long bar is printed to connect them. The conductive ink printed on the third layer is connected to the capacitance-sensing module by a single-line wire.

3.2 Capacitance of the Identifier

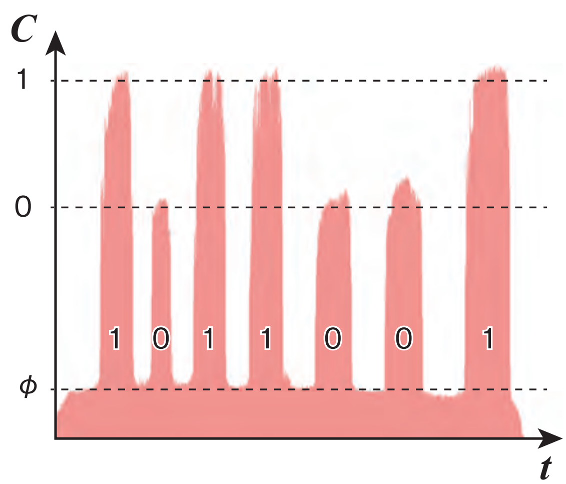

Fig. 4. Capacitance change induced by a user swiping the identifier with a finger.

Capacitor electrodes are formed by the conductive ink patterns printed on the two sheets of paper. During a finger swipe, the measured capacitance varies over time depending on the printed patterns because the instantaneous capacitance depends on the distance between the electrodes. The human body also has capacitance, which becomes connected in series with the condenser when

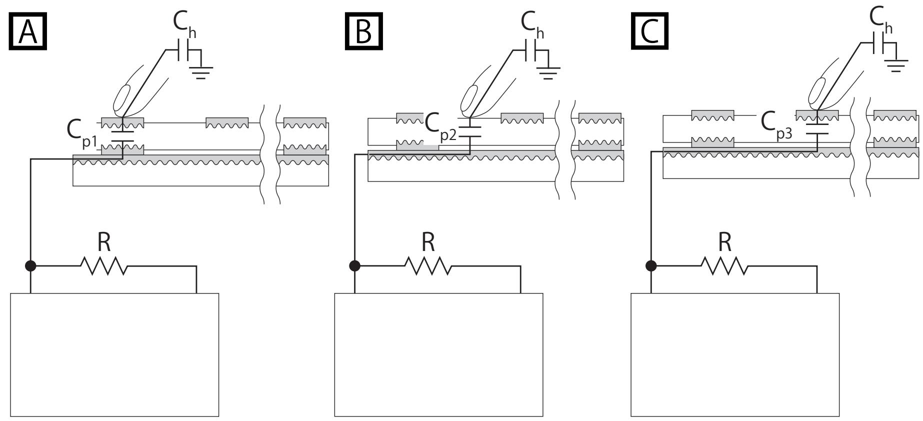

Fig. 5. Circuit when a user touches the identifier of SilverCodes: the states which a user touching the area conductive ink printed on both sides (A), no side (B), and front side (C).

touching the identifier. Thus, as the user's finger swipes the identifier, a circuit is formed by the module used to measure the capacitance, the conductive ink, and the human body, as shown in Fig. 5. The capacitance signal is then measured as a variation between three levels as shown in Fig. 4. The system can hence recognize the swiped identifier by analyzing the measured capacitance signal.

4 Implementation

This section describes the implementation of SilverCodes and of the system used for recognizing the swiped identifier, as illustrated in Fig. 6. The system consists of a module for measuring the capacitance and a PC for analyzing it. The module was implemented using a microcomputer (Arduino Mega 2560 R3) and its library (Capacitive Sensing Library[1]). The module was connected to the SilverCodes by a single-line wire and to the PC by a USB cable.

4.1 SilverCodes

SilverCodes were fabricated by printing conductive ink (Mitsubishi Paper Mills, Ltd., NBSIJ-MU01) on two sheets of glossy paper (KOKUYO Co., Ltd., KJ-G23A430) of thickness 0.25 mm. The printer used was a PX-S160T (Seiko Epson Corp.).

The first and second SilverCodes layers were printed on the same paper sheet. The third layer was printed on another sheet. Because the SilverCodes identifiers are constituted by stacking the two paper sheets as shown in Fig. 2D.

[1] https://playground.arduino.cc/Main/CapacitiveSensor/

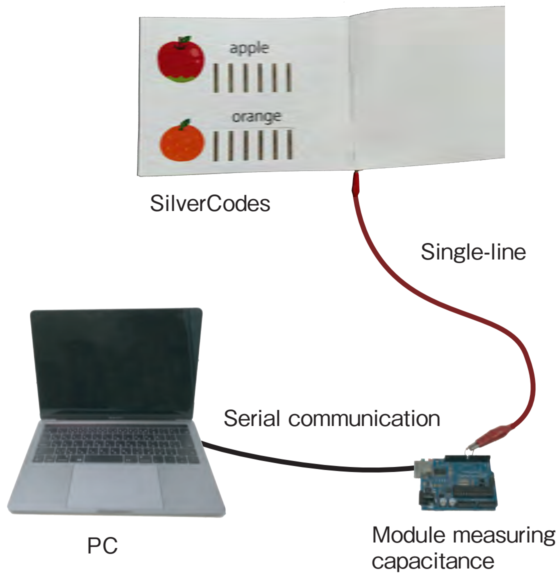

Fig. 6. Overview of our system.

We printed the same pattern on the paper twice for improved recognition accuracy. We performed a pilot study and confirmed a decrease in the resistance achieved by printing the conductive ink twice. Additional printings were found not to yield significant improvements.

The identifiers can be recognized by connecting the SilverCodes with the module as shown in Fig. 6. The third SilverCodes layer and the module are connected by single-line wire. Then, the capacitance change is measured as shown in Fig. 4 while the user swipes the identifier with their finger.

4.2 Algorithm for Reading

The identifier data are read as a bit sequence by analyzing the capacitance changes, as shown in Fig. 4. However, the magnitude of capacitance change varies from one user to another. Therefore, the system must calculate the magnitude of capacitance change specific to the user. By including a header sequence with a set bit sequence 10, the system can calibrate the capacitance values corresponding to 1 and 0.

The system analyzes the magnitude of capacitance change according to the state transitions shown in Fig. 7. Let C_ϕ represent the measured capacitance when the user does not touch the conductive ink, and C_t the measured capacitance when the system recognizes the identifier. The states shown in Fig. 7 can undergo the following transitions:

a: No change in state for 5 s.

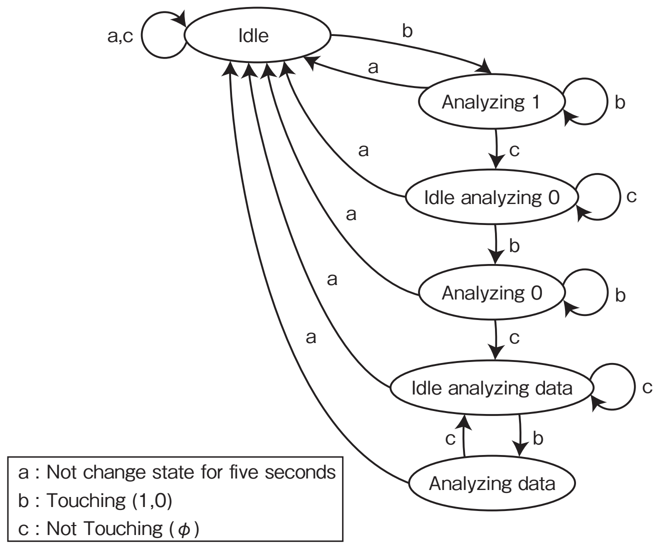

Fig. 7. State transition of analyzing the identifier.

b: $1.2C_\phi < C_t$ by touching conductive ink.
c: $1.2C_\phi \geq C_t$ by not touching conductive ink.

5 User Study

We investigated the recognition accuracy of stacked SilverCodes. Of particular relevance to a SilverCodes application such as a booklet is whether each identifier functions correctly even if the SilverCodes are stacked. We evaluated the effect of the number of pages and of the bar width on the accuracy.

5.1 System

The system used in the experiment was a booklet consisting of four A4 sheets of SilverCodes stapled on the left-hand short side. The booklet was connected to the module by an alligator clip.

Four identifiers were printed on each sheet. The feature dimensions are labeled as shown in Fig. 8. The distance between the bars was $W_{gap} = 15$ mm, the bar height was $H = 40$ mm, and the bar width W_{bar} was 5, 7.5, 10, or 15 mm. Each identifier had the same printed pattern to allow a comparison of the read-error rates due to SilverCodes stacking or to the choice of W_{bar}. In all the cases, the bit sequence used was 11001.

5.2 Participant and Task

The authors themselves, 2 males aged 22 to 23, each performed 20 swipes per identifier on the booklet using the index finger of the right hand. The reading

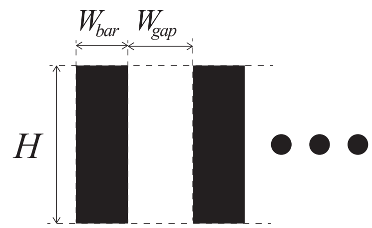

Fig. 8. Identifier dimension labels.

outcome was fed back to the participant. Thus, the experiment comprised a total of 960 trials (20 swipes × 4 identifiers × 4 sheets × 3 persons). The calibration of ϕ was performed for each person at the start of the experiment.

5.3 Result

Table 1 shows the result of this study. The recognition accuracy for stacked SilverCodes was 95.3% on average. With regard to W_{bar} in particular, the reading accuracy at $W_{bar} = 15$ mm was the worst (91.3% on average).

In addition, 31.1% of the reading errors involved returning a signal consisting entirely of the same bit value, i.e., 11111 or 00000. This read error may have arisen owing to a miscalibration of 1 or 0 in the header.

Table 1. Result of the pilot study.

Width	Accuracy (%)									
	On 1st page		On 2nd page		On 3rd page		On 4th page		Average	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
5mm	96.7	2.36	98.3	2.36	100	0.00	95.0	7.07	97.5	4.33
7.5mm	100	0.00	93.3	9.43	98.3	2.36	96.7	4.71	97.1	5.94
10mm	100	0.00	98.3	2.36	96.7	4.71	86.7	9.43	95.4	7.49
15mm	88.3	13.1	90.0	4.08	96.7	2.36	90.0	14.1	91.3	10.4
Average	96.3	8.20	95.0	6.45	97.9	3.20	92.1	10.3	95.3	7.80

5.4 Discussion

A measured signal consisting entirely of bit values 1 or 0 is a common read error. Identical bit sequences should be avoided. This will prompt the user to re-swipe the identifier if an error occurs.

Also, we found that the identifiers on stacked SilverCodes can be read with sufficient accuracy. The recognition accuracy of identifiers is typically higher for thinner bars. One advantage is that it allows more information to be packed into SilverCodes. However, there may be a limit to miniaturization associated with misregistration of the printing and bookbinding. Future work will investigate the limits of the information density achievable by SilverCodes.

6 Applications

This section considers SilverCodes applications.

6.1 Audio Book

A sound-emitting picture book can be fabricated using stacked SilverCodes (Fig. 9). The picture book can be made straightforwardly using only sheets of paper and conductive ink. It can then be connected to the identifier-recognition module by a single-line wire. Therefore, the reconnection of the other book is very easy.

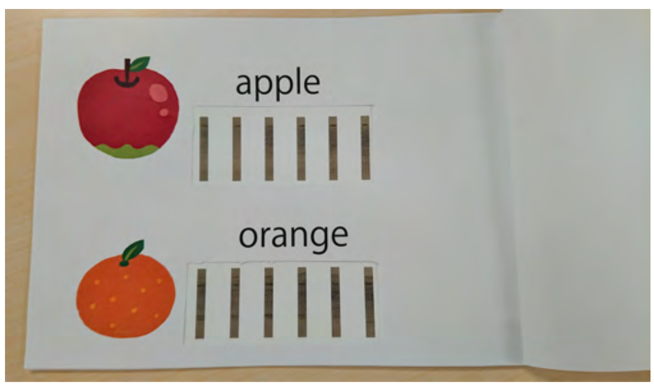

Fig. 9. Audio book application.

6.2 Personalized Controller

SilverCodes can be used to implement personalized controllers, operated by swiping a finger over printed identifiers. Because the SilverCodes are made of paper, they can be bent, folded, and attached to various personal objects. For example, Fig. 10 shows a volume controller with SilverCodes printed on a plastic bottle.

Multiple SilverCodes, serving as replaceable controllers, can also be fastened on a clipboard connected to a capacitance measuring module. Moreover, since the discarded SilverCodes controllers are made of paper, the device as a whole is relatively compact.

Fig. 10. Personalized controller made from SilverCodes. The user can control the volume by swiping a finger over the identifiers.

6.3 Interactive paper using a speed of swipe

The swipe duration can also be exploited for interactive applications. For example, Fig. 11 shows a picture book where a ball, rendered on an external display, is thrown by swiping an identifier. The speed of the ball is thus controlled by the speed of the swipe.

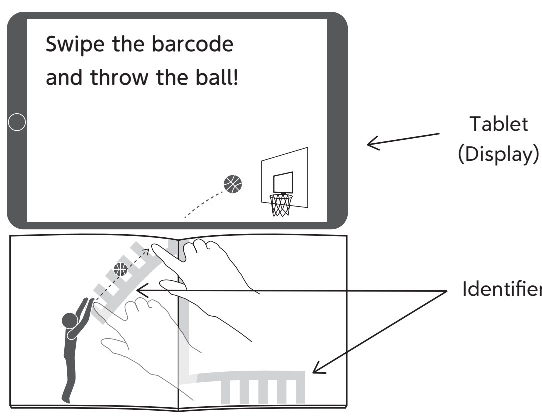

Fig. 11. Interactive picture book, where the user can throw a ball using a swiping motion.

6.4 Notice Board

SilverCodes can be implemented on a notice board to allow interactions with attached paper sheets as shown in Fig. 12. Connection to the wiring within the notice board can be achieved by pinning the SilverCodes. For example, it is possible to create an accessible paper that reads out the content by swiping the identifier on the paper.

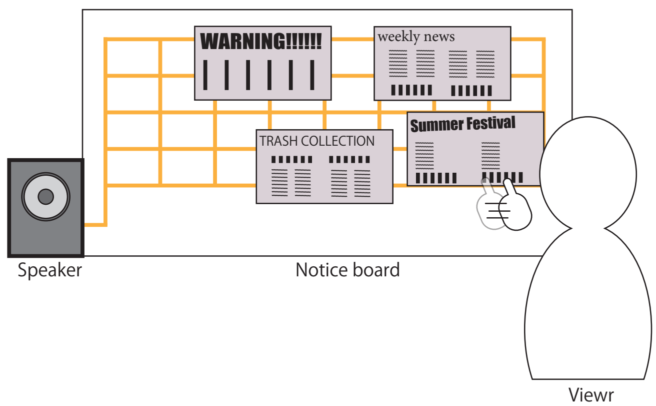

Fig. 12. Notice board using SilverCodes.A viewer can receive speech information by swiping SilverCodes.

7 Conclusion

We have shown that SilverCodes can be used to fabricate flexible and paper-thin identifiers for use as an input interface. SilverCodes are made from two sheets of paper and conductive ink patterned into a barcode-like identifier. SilverCodes are connected to a module by a single-line wire. Data input is achieved by the swipe of a finger. Identifier recognition is based on a capacitance measurement. Furthermore, SilverCodes can be stacked and identifiers can be recognized to an average accuracy of 95.3%.

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