A Gesture-Based Interaction Technique for a Passive RFID Card with an Acceleration Sensor

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Abstract. Contactless integrated circuit (IC) cards, such as employee ID and prepaid cards, are widely used. However, the contactless IC card is only used for 'hold over' operations. Here, we develop AccelTag, a contactless IC card equipped with an acceleration sensor and a liquid crystal display (LCD); we thus extend the functionality of contactless IC cards. AccelTag employs high-function radiofrequency identification (RFID) technology, driving the acceleration sensor and the LCD without a battery. AccelTag supports gestural operations such as *slide* and *flip*, and also accepts *orientation* as an input. We created a prototype of AccelTag and investigated its electrical characteristics and gesture recognition accuracy. The results showed that AccelTag can be used in the range of 3 cm to 15 cm from the reader and that the accuracy of recognizing the slide and flip gesture, and sensing card orientation was 65.8%, 99.2%, and 83.4% accuracy on average, respectively.

Keywords: Acceleration sensor · Gesture · High-function RFID · RFID

1 INTRODUCTION

It is often necessary to enter user IDs and passwords when logging into Websites and home entry control systems. In such situations, contactless, passive integrated circuit (IC) cards are often used because they allow easy identification. The cards transmit and receive ID and other information when simply passed over a reader. However, this is the only operation they support; they cannot be used for other gestural operations, such as slide and flip.

To address this issue, we developed AccelTag, a contactless IC card equipped with an acceleration sensor and a liquid crystal display (LCD). AccelTag uses high-function radiofrequency identification (RFID) technology driving both the sensor and the LCD. No battery is required; the power supply is wireless. The acceleration sensor allows AccelTag to support gestural operations, such as *slide* and *flip*, and accepts *orientation* as an input. Therefore, AccelTag enables successive combined operations such as holding the card with its right side down and then sliding to the left. Here, we present an overview of AccelTag and its interactions. We also present an AccelTag prototype implementation.

2 RELATED WORK

RFID is usually employed to identify objects, IC cards, electronic money, and so on. However, it is applied to various fields because it can transmit power and exchange information wirelessly. PaperID [1] showed that it is possible to recognize various gestures by changes in radiofrequency intensity. All movement across the RFID tag: tag tracing, touch, hover, rotation, and movement, were detectable. Beauty Tech Nails [2] attached is RFID tags to nails to identify which finger touched an RFID reader. The tags can be rendered inconspicuous by manicurists. The examples featured a piano performance and a new disc jockey controller; the fingers touching inbuilt RFID readers were identified. Berlin et al. [3] developed a system featuring an RFID reader and an acceleration sensor attached to an arm, reflecting how the arm manipulated an object to which the RFID tag was attached. For example, it was possible to detect when a hammer was swung downward.

WISP [4] and NFC-WISP [5] are research projects using high-function RFID to drive sensors and microcontrollers via a wireless power supply. WISP uses UHF-band RFID to drive microcontrollers and external sensors via a wireless power supply. NFC-WISP uses near field communication (NFC) (a type of RFID) to feed power wirelessly to a microcontroller, an air temperature sensor, and electronic paper (which reports the temperature). Buettner et al. [6] employed WISP and an acceleration sensor to detect human activity. Shu et al. [7] enabled individual authentication via the movement of contactless IC cards.

3 ACCELTAG

3.1 Overview

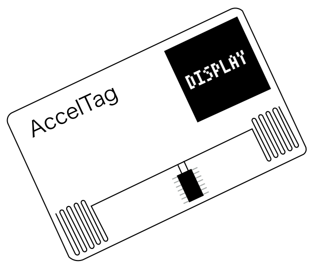

Fig. 1: The AccelTag. This is a card-type device equipped with an acceleration sensor and an LCD.

AccelTag is a card-type RFID tag featuring an acceleration sensor and an LCD, as shown in Fig. 1. AccelTag utilizes advanced RFID technology. Normally, the IC of an RFID is driven by a wireless power supply via radio waves.

High-function RFID technology enables the powering of sensors and other micro-controllers. Thus, the acceleration sensor and the LCD mounted on the AccelTag do not require a battery; they are also driven by RFID radio waves.

3.2 Interaction

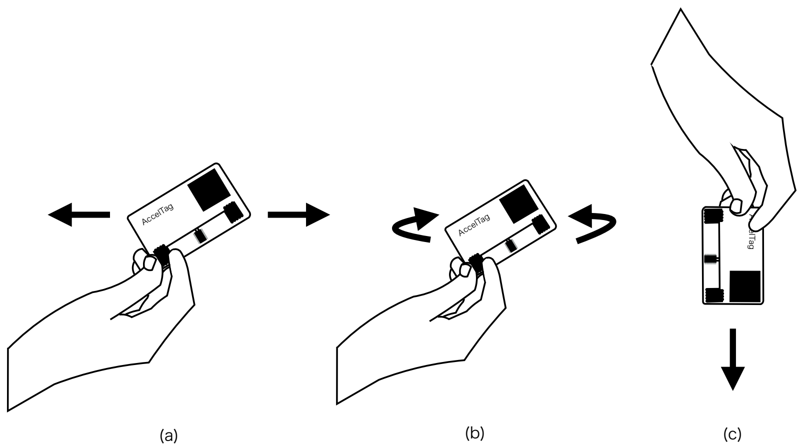

Fig. 2: (a) Slide and (b) flip gestures, and input of (c) orientation. The slide gesture is a horizontal straight movement and the flip gesture is a twisting or rotating gesture of the card over the reader. The orientation input means that the reader recognizes the side of the card placed on the reader.

Using the built-in acceleration sensor, AccelTag can sense movement when it is passed over a card reader. The current implementation of AccelTag supports three types of gestures over the card reader: slide (Fig. 2a), flip (Fig. 2b), and orientation (Fig. 2c). The slide gesture is a horizontal straight movement of the card over the reader. The direction of the slide gesture is also used for interaction. The flip gesture is a twisting or rotating operation over the card reader. In addition to these operations, the orientation of the card serves as an input.

AccelTag has an LCD screen displaying text and graphics. The screen can also be powered simply by holding it over the card reader. Thus, the screen can be utilized during card interactions. For example, if AccelTag is used as an employee ID card, the user's face can be displayed on the LCD screen. If the card is a prepaid card, the account balance and other information can be displayed on the screen.

4 PROTOTYPE IMPLEMENTATION

The system configuration of the prototype is shown in Fig. 3. The system consists of the AccelTag, an RFID reader, and a PC. The RFID reader is controlled by the PC, and not only transmits power to the AccelTag but also send commands to the AccelTag and receives responses. Depending on the commands, AccelTag returns accelerations or visually shows these data on the LCD. The PC controls the RFID reader and recognizes the slide and flip gestures based on the received acceleration data. We used a Nordic ID RFID reader Stix[1] in this prototype implementation.

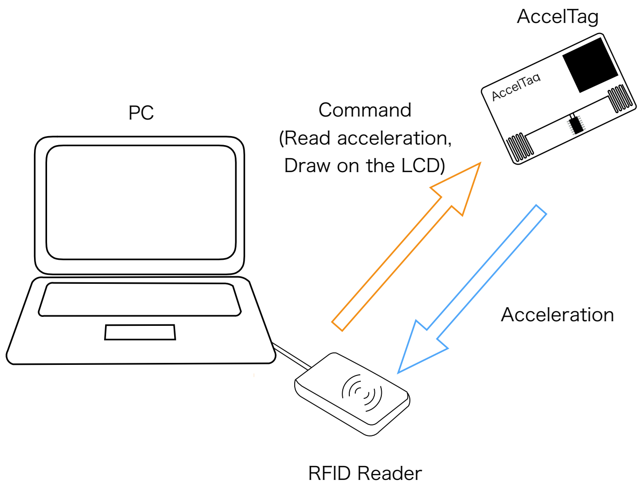

Fig. 3: System configuration of the prototype.

4.1 AccelTag Implementation

We prototyped an AccelTag device as shown in Fig. 4. The prototype was equipped with a low-power-consumption microcontroller, an acceleration sensor, and an LCD. The circuit diagram is shown in Fig. 5. The RFID IC was a Farsens device Andy100[2]. The Andy100 has both a power and an SPI port allowing communication with other microcontrollers and sensors. As the power supplied by the RFID is very small, we employed the ultra-low power consumption microcontroller (Texas Instruments MSP430FR5739[3]). The Maxim Integrated device

[1] https://www.nordicid.com/en/home/products-barcode-uhf-rfid-reader-writer/fixed-area-readers/nordic-id-stix/
[2] http://www.farsens.com/en/products/andy100/
[3] http://www.ti.com/product/msp430fr5739

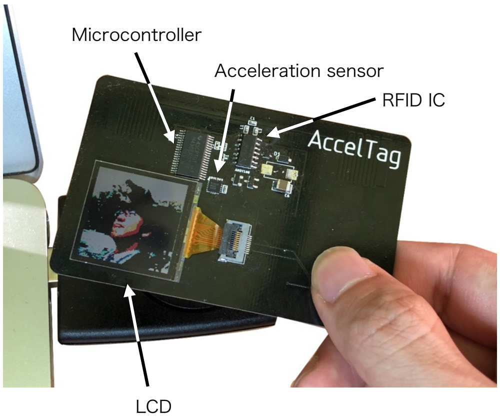

Fig. 4: Prototype of AccelTag. A microcontroller, an acceleration sensor, and an LCD are mounted on a board of the same size as the IC card.

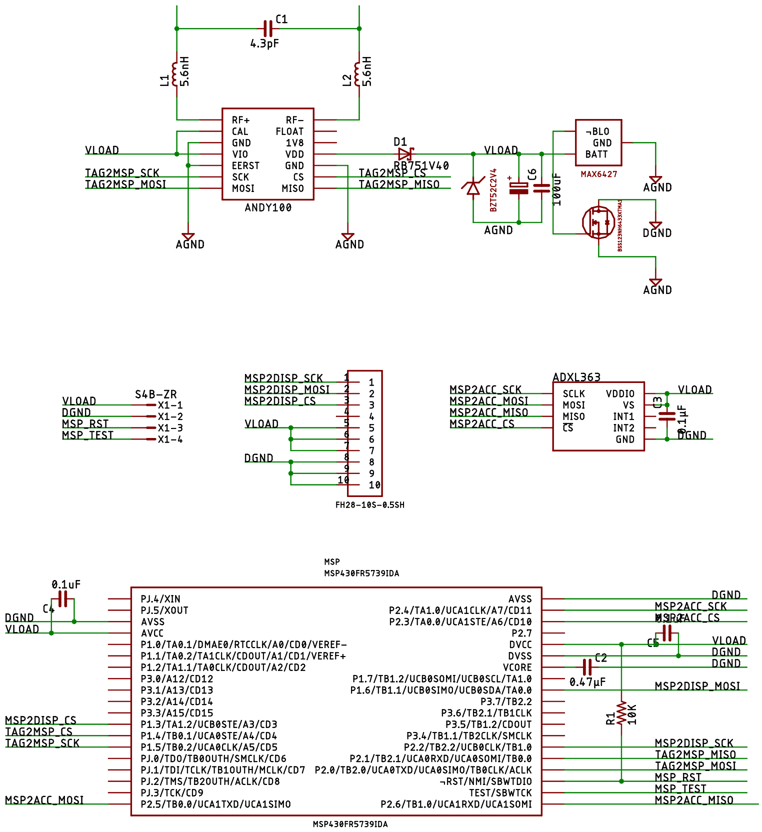

Fig. 5: Schematic of AccelTag.

MAX6427[4] is a voltage monitoring IC that does not supply additional voltage when the microcontroller or sensor voltage falls. The acceleration sensor was an Analog Devices ADXL363[5]. The display was a reflection-type, memory liquid crystal LPM013M126A[6] of the Japan Display Company; this display is not backlit. In addition, with this display, it is not necessary to continuously write information, and thus the power consumption is minimized.

The microcontroller is in the sleep state at idle time to reduce power consumption. Upon receipt of a command (getting acceleration data or drawing on the LCD) from the RFID reader, the RFID IC forwards the command to the microcontroller via a serial peripheral interface (SPI) feed. When the microcontroller receives the command, it is interrupted to wake up, and executes the command, that is, returns acceleration data or draws the received information on the LCD. The microcontroller controls the acceleration sensor and the LCD through the SPI. To periodically read accelerations from the sensor, the microcontroller wakes up at regular intervals using a timer.

5 GESTURE RECOGNITION

The PC recognizes gestures based on the acceleration data obtained from AccelTag through the RFID reader. The three gestures currently supported are the slide, the flip, and the orientation gesture. In the slide gesture, AccelTag moves horizontally; therefore, a change in horizontal acceleration is detected. As preprocessing, the raw reading of the acceleration sensor is high-pass-filtered and the effect of gravitational force is eliminated. Then, on each axis, the change in acceleration is observed to figure out if a slide gesture is performed, and if so, the direction of the gesture is identified.

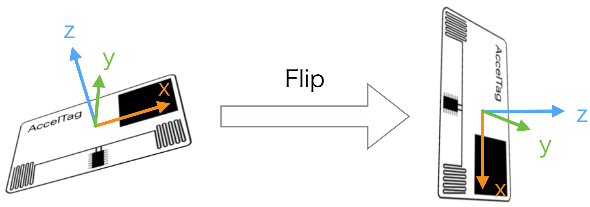

Fig. 6: Change in the axis during flipping. During the flip gesture, the axis along which gravitational acceleration is applied changes from −z to +x.

[4] https://www.maximintegrated.com/en/products/power/supervisors-voltage-monitors-sequencers/MAX6427.html
[5] http://www.analog.com/en/products/mems/accelerometers/adxl363.html
[6] http://www.j-display.com/english/product/reflective.html

Algorithm 1 shows the recognition algorithm of the slide gesture. a_x and a_y are the acceleration values obtained from the acceleration sensor. g_x and g_y are the acceleration values that do not involve the gravitational acceleration, and *thres* is a threshold value. α is a moothing factor.

In the case of the flip gesture recognition, a change in the relative direction of the gravity is observed. For example, as shown in Fig. 6, the gravitational acceleration applied along the −z direction changes to the +x direction on flipping. Such change in acceleration data is detected and recognized as flipping.

The orientation of the card is similarly identified. When AccelTag is held over the RFID reader, the acceleration value of each axis is examined to calculate which side of the card is faced down vertically.

Algorithm 1 Recognize slide gesture.

```
                                              ▷ High-pass-filter
g_x ⇐ α × g_x + (1 − α) × a_x
g_y ⇐ α × g_y + (1 − α) × a_y
                                              ▷ Eliminate the affect of gravity
c_x ⇐ a_x − g_x
c_y ⇐ a_y − g_y
                    ▷ Acquire axis with large absolute value of acceleration
index ⇐ arg max_i |c_i|   (i ⇐ x, y)
if |c_index| > thres then
    if index is x then
        if c_index > 0 then
            return Right
        else
            return Left
        end if
    else if index is y then
        if c_index > 0 then
            return Back
        else
            return Front
        end if
    end if
else
    return None
end if
```

6 EVALUATION

We explored how much power AccelTag could secure from the RFID reader, and evaluated the recognition accuracies of the three gestures.

6.1 Evaluation of Electrical Characteristics

We placed AccelTag on 10 positions at regular intervals of 3 cm and measured the power secured at the positions. We experimented with constant microcontroller sleep to minimize power use. The measured power indicates the maximum power obtained from the reader.

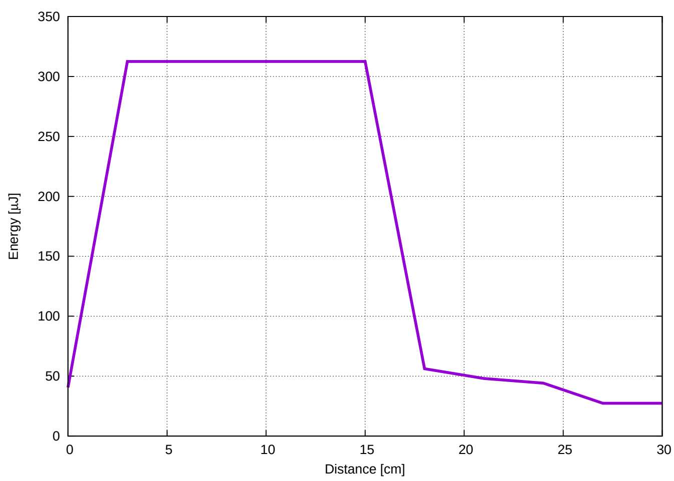

Fig. 7: Distance from reader and power held by AccelTag.

The result is shown in Fig. 7. When the AccelTag and the reader were put very close or apart 18 cm or more, only small power is available. Thus, in this prototype implementation, AccelTag can be used within the distance of 3 cm to 15 cm.

6.2 Accuracy of Gesture Recognition

We evaluated the recognition accuracies of the flip, slide, and orientation gestures. For convenience, we performed these tests while supplying power by wire, thus not under RFID power. For the slide gesture, each subject randomly slid the card 10 times to each of the right and left, to the back, and to the front. For the flip gesture, all participants performed left and right, to the back, and to the front flips 10 times in random order. In terms of the orientation gesture, AccelTag was placed on the reader 10 times in random order of six orientations. The participants were three college and graduate students aged 21–24 years. All participants had AccelTag with the right hand.

Table 1: Confuion matrix of slide gesture.

	Right	Left	Front	Back
Right	73.3	23.3	0.0	3.3
Left	40.0	50.0	10.0	0.0
Front	6.7	3.3	76.7	13.3
Back	6.7	3.3	26.7	63.3

Table 1 shows the confusion matrix of the slide gesture. The average accuracy was 65.8%. The slide gestures were often misrecognized as the gesture in the opposite direction. In particular, the left gesture was often misrecognized as the right gesture. One reason of this problem is that the recognition algorithm only considers the acceleration change at the start of the gestures but at the end of the gestures. For example, at the start of the left gesture, the acceleration values show acceleration to the left, but at the end of the left gesture, acceleration in the reverse direction occurs, which causes the misrecognition. In future work, we will improve the recognition algorithm so that the sequence of acceleration values is examined to correctly recognize the gestures.

The confusion matrix of flip gesture is shown in Table 2. The accuracy of the flip gesture was high, averaging 99.2%.

Table 2: Confuion matrix of flip gesture.

	Right	Left	Front	Back
Right	96.7	0.0	0.0	3.3
Left	0.0	100.0	0.0	0.0
Front	0.0	0.0	100.0	0.0
Back	0.0	0.0	0.0	100.0

Table 3 shows the confusion matrix of orientation gesture. The average accuracy was 83.4%. In many cases, the orientation was often misrecognized as bottom. This is because the orientation is recognized before the change of the orientation is done.

Table 3: Confuion matrix of orientation gesture.

	Right	Left	Front	Back	Top	Bottom
Right	90.0	0.0	0.0	0.0	0.0	10.0
Left	0.0	93.3	0.0	0.0	0.0	6.7
Front	0.0	0.0	90.0	0.0	0.0	10.0
Back	6.7	0.0	0.0	66.7	0.0	26.7
Top	6.7	0.0	3.3	3.3	76.7	10.0
Bottom	3.3	0.0	6.7	0.0	3.3	86.7

7 CONCLUSION AND FUTURE WORK

We developed AccelTag, a contactless IC card equipped with an acceleration sensor and an LCD. AccelTag utilizes high-function RFID technology to drive an acceleration sensor and an LCD without a battery. With the help of the acceleration sensor, AccelTag supports gestural interactions such as slide, flip, and orientation.

Our electrical characteristics investigation suggested that AccelTag can be used within the range of 3 cm to 15 cm over a reader. In the gesture accuracy evaluation, the accuracy of the slide gesture, the flip gesture, and the orientation gesture was 65.8%, 99.2%, and 83.4% on average accuracy.

In future, we will design and implement more complex gestures to expand the utility of AccelTag. Also, we will improve recognition accuracy and explore usability further.

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