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A BATTERY-LESS (PASSIVE) IRID TAG IMPLEMENTED WITH AN ENERGY-HARVESTING SCHEME

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Abstract. *Infrared lights and radio waves are commonly used for information transferring wirelessly. Infrared lights are usually employed in point-to-point connection; however, radio waves are better for broadcasting. Wireless identification with radio waves has been developed for various purposes and popular in our daily life. In this paper, a battery-less wireless identification is achieved with infrared lights, and the proposed passive IRID tags harvest energy from the lights nearby with the solar cells to support their work. In our design, the tags start to send codes out according to their identity with the infrared light of 940 nm when they approach the reader and receive the energy delivered with the infrared light of 850 nm from it. According to the performance of the prototype system applied in an access control, the passive IRID tag can be activated 5 times at most in one second and transmit 250 data bits in total while it is continuously exposed to the infrared light emitted by the reader within a distance of 5 cm. In addition, the prototype of the tag is smaller than a business card and never needs to replace the battery.*
Keywords: IRID, Passive tag, Wireless identification, Infrared, Solar cell, Energy harvesting

1. **Introduction.** Lights and radio waves are commonly used for wireless communications. For wireless identification, RFID is a widespread omni-directional technology. In this paper, infrared lights are used to develop another identification technology when some directionality is preferable or radio waves work uneasily. The energy of radio waves naturally propagates in all directions, which makes it easy to arrive at mobile and stationary receivers. However, it might therefore become interference to other electronic devices. For example, significant noise was found while an RFID-based system was equipped in hospital environments [1]. And unacceptable costs might have to be compromised to counter the inherent interference [2]. With the help of optical lens, lights travelling in straight lines can be easily focused to the direction of the targets, seen by them and invisible to the others outside the line-of-sight paths. However, more efforts have to be made for the use of radio waves, such as employing directional antennas for the RFID readers working at 2.45 GHz to direct the energy from them to the area of greatest tag likelihood [2].

Similar to RFID technology, infrared-based identification can be operated in active and passive modes [3]. According to the definitions of the operation modes, infrared-based identification in active mode can be implemented in some way by following IrDA standards and the technology developed for them [4-6], such as the remote control commonly used in consumer electronics. However, the infrared-based identification running in passive mode is still not found. Although some infrared-based tags had been developed for identification and interrogation [7-10], they were equipped with batteries that could support themselves to produce stronger signals for long-distance transmission or to work for a longer time. Obviously, these infrared-based tags are still operated in active mode.

An optical ID tag usually used for remote identification and verification of objects proposed in [11] can be regarded as operated in passive mode. However, the information on the tag is not transmitted through a light channel as IRID does; instead, it is basically expressed with a specific image or signature. The optical tag is usually stuck on the object under surveillance. When the tag is illuminated, a remote receiver, such as a camera, reads and decodes the image to identify the object. This identification can be achieved real-time by means of optical devices and computer aid. Evidently, the optical identification has its cost mostly spent on the receiver. The optical ID tag will be much cheaper. However, there is no secret about the exposed image or signature on the tag. It is easy to capture and possible to fake another one intentionally.

To work with a battery-less electronic device, the first task is to harvest enough energy from outside to support its operation. The energy stored in ambient light, wind, or heat is usually considered to be used to generate electricity if the performance of the energy conversion is satisfied [12]. In addition, it is more convenient to gather energy from the signal received. For example, an RFID reader can generate a radio wave with some code inside to command a passive RFID tag. The tag receives the radio wave not only for the code but also for the energy converted from the radio wave to electricity in order to support its operation for the code [3]. To optical communication devices, the energy of the light emitted by a transmitter can also be utilized by its receiver. It is the basis of the energy harvesting used in the proposed infrared-based identification running in passive mode. Another interesting energy harvesting from light used by LEDs is being developed, where LEDs function like solar cells when they pause displaying [13-15].

The techniques used here to develop infrared-based identification are totally different from those used for RFID. To label the brand-new wireless identification technology, the name IRID is used. In this paper, an infrared-based identification system operated in passive mode is developed to fulfill the IRID technology. The methods used to implement the battery-less IRID tag and its reader are described in Section 2. In Section 3, the proposed IRID technology was applied in an access control to demonstrate how it works in passive mode. The energy harvesting scheme used in the battery-less IRID tag is also investigated in this section. In the end, Section 4 concludes the paper. The performance exhibits that identification with infrared lights conducted in passive mode proposed here is especially suitable for the scenarios that identification will proceed while tags stay on the line-of-sight path and in the proximity of the reader.

2. Passive IRID System Design.

In order to carry out the identification, the tags operated in passive mode have to gather energy outside by themselves because batteries are excluded from them. Reviewing passive RFID technology, battery-less tags are used to convert the energy of the radio waves received by them to the needed electricity. Following this energy-harvesting approach, the passive IRID tags created here collect their energy from ambient lights. The energy-harvesting scheme is implemented among the passive tags and their reader separately and will be described in the following.

2.1. Battery-less IRID tag.

The battery-less IRID tag is designed to collect energy mainly from the infrared light emitted by its reader. However, the tag can also convert the energy of other artificial or natural lights into electricity with the help of GaAs solar cells attached on it. As shown in Figure 1, the series-parallel circuit of GaAs solar cells can provide 3.0 V and 12.8 mA at most. The passive tag stays at rest till the energy stored in the capacitor of Figure 1 is enough for it to complete at least one cycle of data transmission. The data for identification is transmitted by an IR LED on the tag and received by an IR receiver on its reader. The radiant power of the IR LED is considered to come to its maximum at or around the wavelength of 940 nm in order to fall in with the peak sensitivity of the IR receiver to infrared lights. According to the requirements of the off-the-shelf IR receiver, data have to be conveyed by a carrier signal of 38 KHz. In addition, each data pulse is required to have its pulse duration or pulse spacing last more than 400 us typically. In other words, the data produced serially must have its bit rate less than 2500 bps. To match the requirement of the IR receiver, the generation of the data bits for identification on the tag is implemented by a microcontroller with its AUSART interface following the protocol of EIA232 to generate data bits at a baud rate of 2404 bps and its CCP module to produce a carrier signal having the frequency (38.461 KHz) close to the target one. The scheme of the data generation on the tag is illustrated in Figure 2. As shown in Figure 1, the passive tag starts to work when the transistor (2N2222A) leaves from its cutoff condition and comes into the active mode, and ceases when the transistor goes back to the cutoff condition because the energy stored in the capacitor is used up and insufficient to keep the transistor stay in the active mode. As a result, it is better to have the operating current of the microcontroller for the generation of data bits on the tag as low as possible in order to extend the operation time of the passive tag. The microcontroller used in Figure 2 consumes current of 76 uA when it is supplied with a voltage of 2 V and uses its internal oscillator running at 1 MHz. The

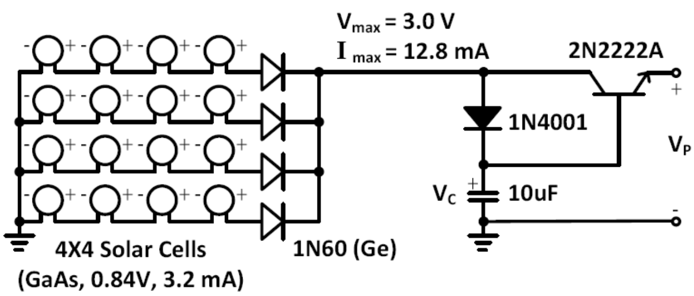

Figure 1. Energy collector on the passive IRID tag

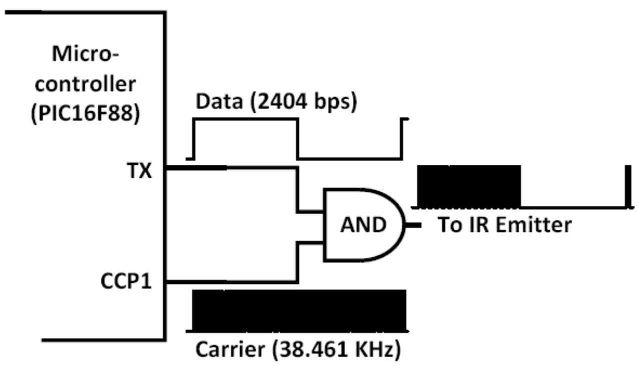

Figure 2. Data generation for identification on the passive tag implemented with a microcontroller

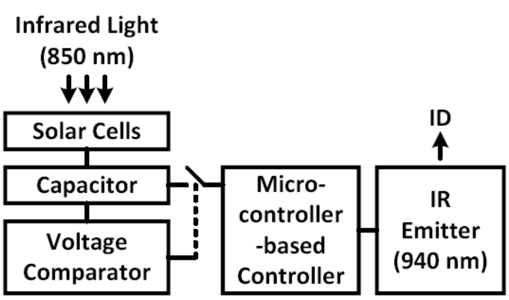

Figure 3. Block diagram of the passive IRID tag

function block diagram exhibiting the hardware of the IRID tag operating in passive mode partially shown in Figures 1 and 2 is depicted in Figure 3.

2.2. **Reader for the passive tag.** Besides receiving data bits transmitted from the passive tag for identification, another important task of the reader is to serve as an energy provider to offer the tags on the light-of-sight path and in the proximity of it the energy conveyed with the light produced by it and absorbed by the energy collector on the passive tags, in order to shorten the time needed to accumulate enough energy for the operation of each tag.

As shown in Figure 4, the reader generates infrared lights around 850 nm with a high-power IR LED to provide energy quietly to the tags close to it. Besides powering passive tags, the reader has to read the data transmitted from them. As mentioned above, the IR receiver has the maximum sensitivity to the light having the wavelength of 940 nm. As a result, the reader can receive the light emitted from the IR LED employed on the passive tag well. The data for identification conveyed by the light were further retrieved and investigated by the same microcontroller with its AUSART interface coordinated under the same parameters as those preset on the passive tags.

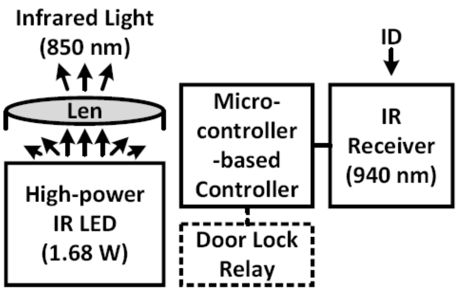

FIGURE 4. Block diagram of the IRID reader working together with the passive tag in Figure 3 for identification

3. **The Passive IRID Technology in an Access Control.** For access control, a list of authorized ID codes was stored in the EEPROM of the microcontroller on the reader. The size of the built-in EEPROM is 256 bytes. An IRID tag becomes authorized by storing one of these ID codes to a memory at a specific address of the EEPROM in the microcontroller on the tag. Only authorized tags can pass the examination of the reader and keep the door unlocked for a few seconds. The operation of the access control with the passive IRID technology is illustrated in Figure 5.

Figure 6 is the prototype of the passive IRID tag and its reader developed for the access control application depicted in Figure 5. The viewing angle of the IR LED on the reader is 120° that allows the passive tag close to it to receive the infrared light emitted from it in a wider angle. However, a lens with a much smaller viewing angle (15°) is used here, as shown in Figure 6, to focus most of the light on the passive tag to shorten its charging time further. To investigate the performance of the solar cells on the tag used to gain

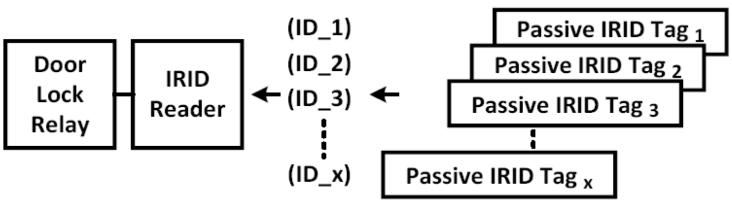

FIGURE 5. The passive IRID technology in an access control

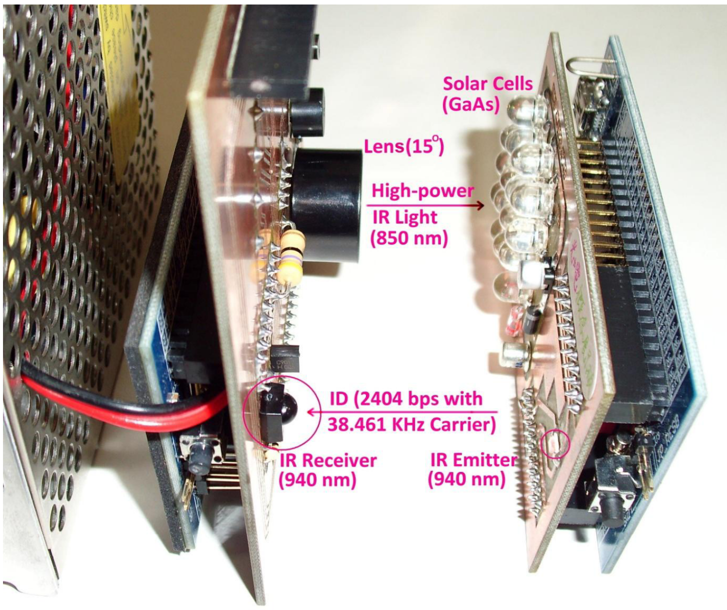

Figure 6. Prototype of the passive IRID tag (on the right) and its reader (on the left)

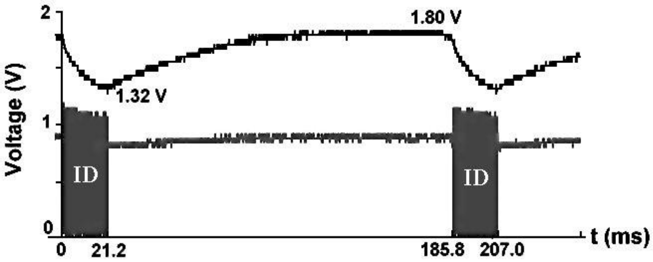

Figure 7. Performance of the energy-harvesting on the passive tag. The upper curve shows the voltage across the capacitor (V_C) in Figure 1 varying with the change of the energy stored in it. The voltage determines when the tag starts to transmit data for identification (the duration marked with "ID" at the lower curve) and stops to harvest energy for the next transmission.

the energy from the infrared light emitted by the reader, the solar cells are exposed to the infrared light at a distance of 5 cm, and the result is shown in Figure 7. The energy collector in Figure 1 spends 164.6 ms from the time 21.2 ms to 185.8 ms to charge its capacitor and increase the voltage across it from 1.32 V to 1.80 V, and supplies the tag with the energy stored in the capacitor from the time 0 ms to 21.2 ms and from the time 185.8 ms to 207.0 ms. As mentioned before, the baud rate of the data transmission is 2404 bps. As a result, the tag can transmit 50 data bits at most during its working time of 21.2 ms. The cycle from energy harvesting to data transmission is 185.8 ms. Consequently, the tag can be activated 5 times and totally transmits 250 data bits in one second while it is continuously exposed to the infrared light emitted by the reader at a distance of 5 cm.

4. **Conclusion.** Lights are simpler and easier to use than radio waves, so the systems are built on them. Instead of radio waves, passive wireless identification is implemented with infrared lights as the design presented in this paper. The size of the tag in Figure 6 is 80 × 50 × 15 mm that is very close to the size of a business card and can be smaller

further. Although alignment for the tag and its reader is still required, it becomes quite flexible because of the wide viewing angle of the IR LED on the reader and the help of other optical lenses. Besides, there are no batteries needed to replace for the passive tags. Of course, the passive tag proposed here only works briefly. To keep running, it has to harvest energy and transmit data by turns in a regular order. Future work includes shortening the time for energy harvesting, increasing the baud rate, and offering security design.

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