RF Power Detector for Location Sensing

Myungsik Kim, Takashi Kubo, and Nak Young Chong

School of Information Science, Japan Advanced Institute of Science and Technology, Ishikawa 923-1292, Japan
(Tel : +81-761-51-1248; E-mail: myungsik@jaist.ac.jp)

Abstract: Recently, RFID has become popular in the field of remote sensing applications. Location awareness is one of the most important keys to deploying RFID for advanced object tracking. Generally, multiple reference RF stations or additional sensors are used for the location sensing with RFID, but, particularly in indoor environments, spatial layout and cost problems limit the applicability of those approaches. In this paper, we propose a novel method for location sensing with active RFID systems not requiring the need for reference stations or additional sensors. The system triangulates the position of RF signal source using the signal pattern of the loop antenna connected to the power detector. The power detector consists of a signal strength detector and a signal analysis unit. The signal analysis unit indicates the signal strength and serial number using the signal from the strength detector, and provides the direction of the signal to the application target. We designed three different signal analysis units depending on the threshold type. The developed system can sense the direction to the transponder located over 10 m away within the maximum error of 5 °. It falls within a reasonable range in our normal office environment.

Keywords: RFID, localization, loop antenna, power detector, triangulation

1. INTRODUCTION

A new recognition system is required to digitize the information related to our physical environments. One of the most promising solutions available to date is Radio Frequency Identification (RFID). Recently, RFID gains increasing attention in various remote sensing applications. Basically, RFID does not require a direct line-of-sight and provides bi-directional information flow between communicating pairs [1]. Location awareness is one of the most important keys to enabling many types of services and applications using RFID [2]. Despite the well-known capability of RFID, it is still not possible to locate objects without having to have multiple reference RF stations or additional sensors. [3], [4], [5]. Particularly, installing a multitude of reference stations throughout the indoor environment requires extra efforts and costs for spatial allocations and the conditions necessary for using additional sensors limit the applicability of current approaches. Also, ordinary users may want to develop their in-house RFID applications using the proprietary software the commercial RFID product provides. This sometimes makes the users difficult to incorporate RFID products into their application targets such as mobile devices or robot systems. Thus, in this work, we develop a stand-alone real-time RFID location sensing system which does not require any reference stations and/or proprietary protocols.

Omni-directional antennas are generally used for RFID to radiate or receive maximum power uniformly in all directions. Instead of using the omni-directional antenna, the new location sensing RFID system employs a loop antenna connected to a power detector. The proposed system, equipped with the antenna rotating unit, can estimate the direction of the incoming RF signals by measuring the signal strength. The serial number and the signal strength are generated by the detector and the strength is measured at different points of measurement to triangulate the position of the signal source.

To verify the proposed concept and system architecture, we install the developed system onto the pan/tilt mount and investigate the direction sensing accuracy in an indoor environment. Current experimental results show that the developed system can sense the direction to the transponder located over 10 m away within the maximum error of 5 °. Thus, the proposed location sensing system is expected to play a decisive role in various indoor location aware applications where a clear line-of-sight might not be available. Details of the prototype development are addressed in this paper.

2. LOCATION SENSING

2.1 Experimental Set-up

The schematic of the developed location sensing system is shown in Fig. 1. The system is composed of an electrically small loop antenna attached to pan/tilt mount and its power detector. The power detector contains a signal strength detector and a signal analysis unit. When an RF signal is transmitted from the transponder, the signal received at the loop antenna is transmitted to the signal strength detector. The signal strength detector can convert the signal below -100 dBm to the DC voltage, and the voltage is transmitted to the signal analysis unit built using the H8 microprocessor. The signal analysis unit generates the strength and serial number of the incoming signal using the analog-to-digital converter (ADC) and the timer. The serial number is the data encoded in the transponder. The generated signal strength and the serial number accompanied by the direction data are provided to the application target through a serial communication interface. Then, finally the direction to the transponder can be determined using the signal pattern formed by the direction and signal strength data.

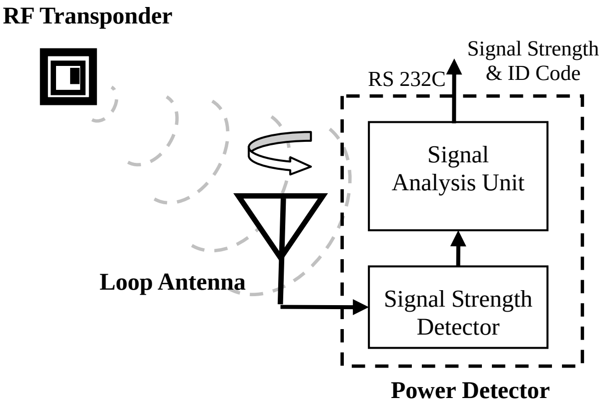

Fig.1 Schematic of Experimental System

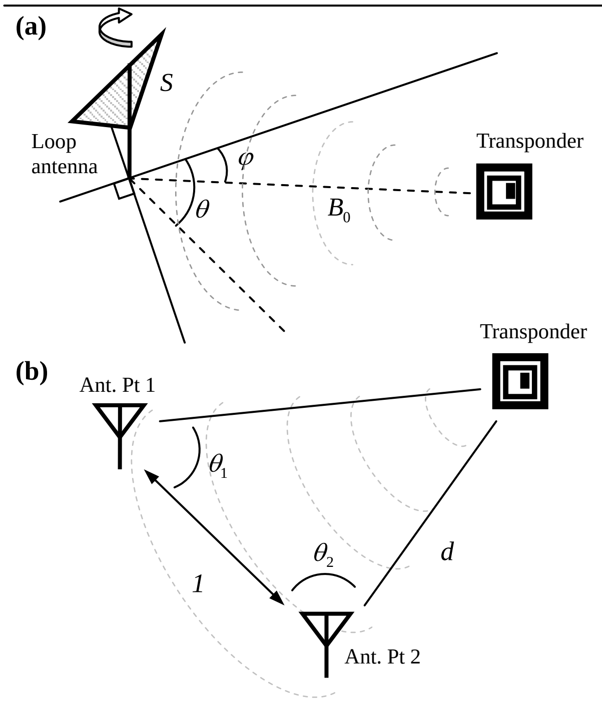

Fig. 2 Geometry of the localization
(a) Plane wave and antenna rotation
(b) Triangulation technique

2.2 Underlying Theory

The location information can be divided into direction and distance. The direction to the RF transponder can be determined by signal receiving patterns of the loop antenna. If an electromagnetic wave from RF transponder passes through the loop antenna as shown in Fig.2-(a), a voltage V is generated as

$$V \propto CSB_0 \left|\sin(\theta - \varphi)\right| + V_0 , \tag{1}$$

,where C is the environmental effect constant, S the surface area of the antenna coil, B_0 the magnetic flux of the transmitted signal, V_0 the offset voltage, θ the antenna rotation angle, and φ the direction to the transponder [6]. Because C , S , B_0 , and V_0 are all constant, it is straightforward to simplify Eq. (1) as $V \propto \left|\sin(\theta - \varphi)\right|$. The patterns of the equation are ideally the Arabic number '8' in polar coordinates. Then the pattern has apparently two maximums, when the antenna direction is parallel to the transponder and two minimums, when perpendicular. If we rotate the antenna to the voltage level is minimized or maximized, the direction to the transponder can be determined. Comparing with the maximum level, the minimum level is more dominant, then less affected by environmental effects, we can find the direction with high accuracy using the minimum value [7].

The distance can be determined by the time of flight with passive RFID systems, and triangulation techniques with active RFID systems. For the indoor localization, the sensing range of at least several meters is needed. Among the general commercial RFID systems, only active type RFID systems can send the signal over some dozen meters. Then we use triangulation techniques for measuring the distance. If the direction to the transponder is measured at two different positions as shown in Fig. 2-(b), the distance d to the transponder is calculated using the interval l between antenna position 1 and antenna 2 and two bearings θ_1 and θ_2 from the line between two positions as

$$d = \frac{l}{\left(\frac{\tan\theta_2}{\tan\theta_1} + 1\right)\cos\theta_2} . \tag{2}$$

While the interval l is quite small than the distance d, the measuring angle θ_1 and θ_2 is getting bigger to a right angle and the denominator of the equation is about zero then the distance can not be calculated correctly. The interval l that needs to reduce the error is about more than 1/5 d.

3. EXPERIMENT SYSTEMS AND RESULTS

3.1 Antenna

We have developed a prototype 315 MHz active RFID reader. Fig. 3 shows the electrically small loop antenna manufactured by printed circuit board etching, with a width of 78 mm and a height of 32 mm. The rear side is shielded and perpendicularly opened to improve the sensitivity of measuring the signal strength in the horizontal plane. The antenna is mounted onto the pan/tilt unit and the received signal is transmitted to the strength detector.

3.2 Power Detector Version 1

Fig. 4 shows the power detector version 1 and the received signal patterns. Fig. 4-(a) is the prototype signal strength detector which requires the operating voltage of 5 DCV. It converts the signals within the range of -100 dBm to -30 dBm to 0 to 5 DCV. Fig. 4-(b) shows the signal analyzing unit built using the H8 microprocessor. The signal from the detector is divided into two parts: one is transmitted to the A/D converter of the microprocessor and the other to the hardware threshold. The hardware threshold generates 5 V uniform pulses of ons and offs which are sent to the timer. The timer counts ons and offs to generate the serial number encoded in the transponder. When the pulses are on, the digitalized signal strengths are summed and averaged over the period. Finally, the signal strength and ID code are transmitted through a serial communication interface.

Fig. 4-(c) shows the signal pattern measured by the power detector in the hallway. The signal source is a 315 MHz active transponder manufactured by Circuit Design Inc. The

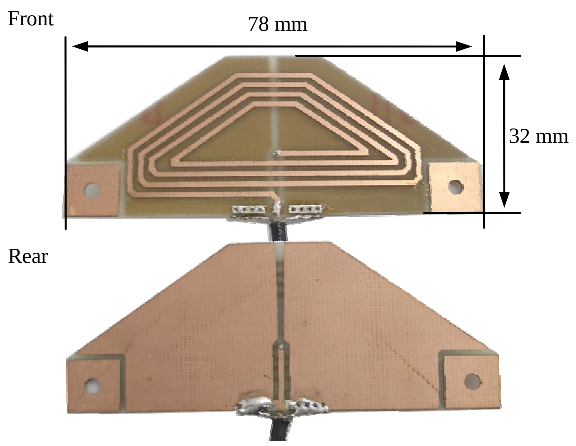

Fig. 3 Prototype loop antenna

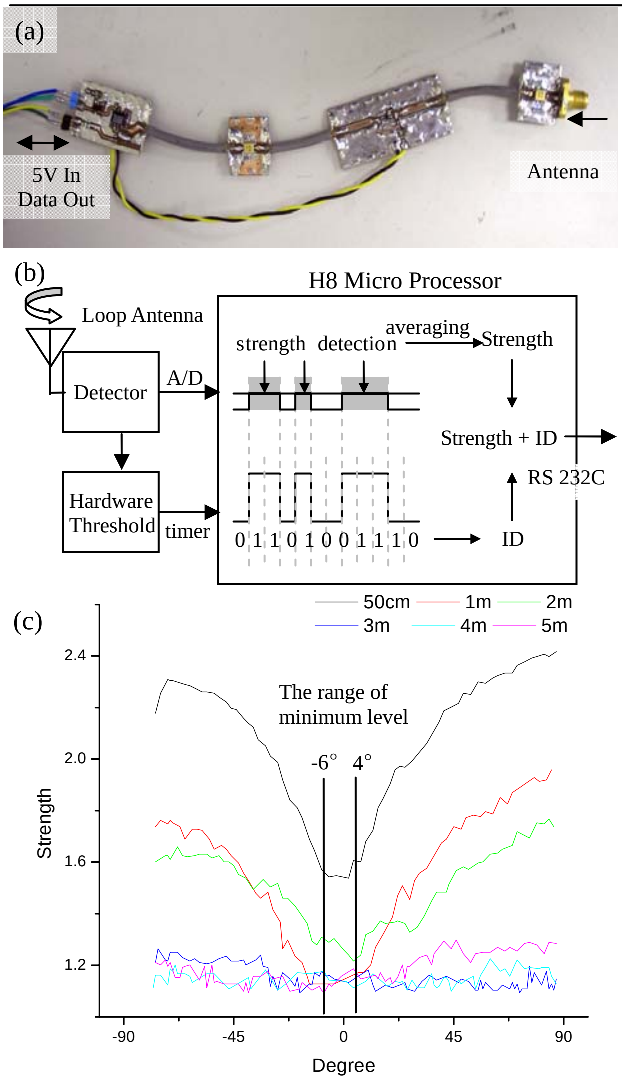

Fig. 4 Power detector module ver.1
(a)Signal strength detector (b) Signal analysis unit
(c) Received signal patterns

transponder continuously sends the RF signal, having a uniform time interval with four selectable twenty bytes serial numbers through a quarter wavelength whip antenna. Note that the direction that the antenna faces the transponder is 0 ° in Fig. 4-(c) along which the strength is minimized. It can be observed that the maximum signal strength is inversely proportional to the square root of the distance. Thus, as the distance increases, the detected power decreases accordingly. The threshold level is fixed with some margins above the offset of the detector to reject the white noise. The hardware threshold can not generate the pulses of ons and offs correctly if the signal is below the threshold. Because the signal strength and the ID code are generated based on the pulse passing the hardware threshold, the signal pattern starts to become distorted from 3 m. It is hard to find the minimum level of the signal source beyond 3 m.

3.2 Power Detector Version 2

To extend the sensing range, we modify the structure of the signal analysis unit. The schematic of the module and the results of the received signal patterns are shown in Fig. 5.

The signal analysis unit version 2, instead of using the hardware threshold, uses an additional 315 MHz receiver which generates the pulses with the signal directly from the antenna. The additional receiver can detect signals below -100 dBm and accordingly cover the whole range of the detector.

The signal pattern with this version is shown in Fig. 5-(b). Comparing with Fig. 4-(c) under the same measurement condition, the signal pattern is clearer in the overall range of measurement distance. The additional receiver enables the strength detector to extend its sensing range up to 5 m.

It should be also noted that as the measurement distance increases, the maximum signal decrease, but the white noise by the environmental effect remains unchanged. Thus, the signal pattern over 3 m is contaminated by the white noise as shown in Fig. 5-(b).

3.2 Power Detector Version 3

To extend the sensing range of the system, we modify the signal strength detector as shown in Fig. 6-(a). The detector can detect the signal at a minimum level of -120 dBm with an additional operational amplifier circuit synchronized with a receiver chip. The size is also reduced to one small board with a width of 54 mm and a height of 24 mm.

Since the sensing range of the detector is extended to -120 dBm, the signal can be read even from a far distance. But the offset level of the detector is not stable and often changes, which is worse than the previous versions. It can be affected by the addition circuitry and the white noise due to the improved sensitivity. Thus, in this version, the hardware threshold or the additional receiver is not used. Instead, the software threshold is used as shown in Fig. 6-(b) incorporating

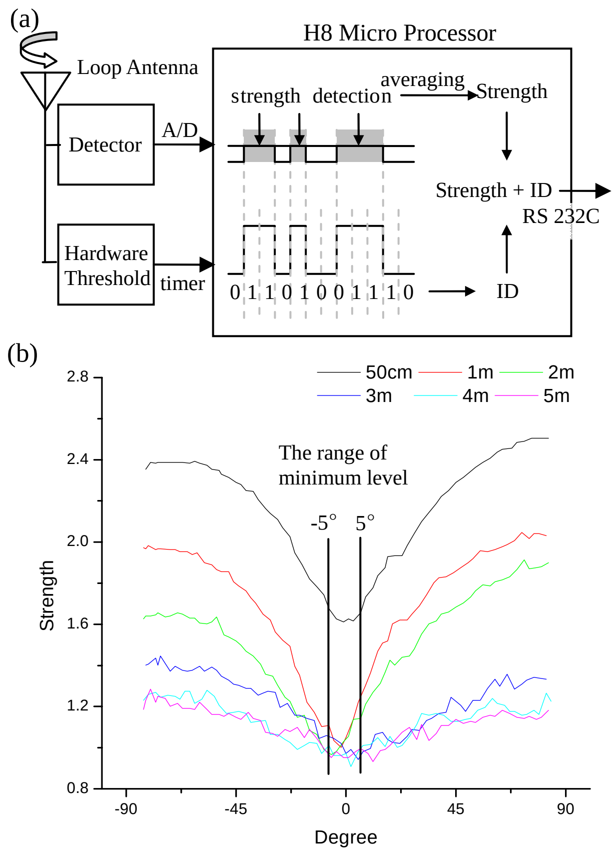

Fig. 5 Power detector module ver.2
(a) Signal analysis unit (b) Received signal patterns

the improved detector. The signal from the detector is transmitted to the A/D converter of the H8 microprocessor which counts ons and offs and sums the signal strength if the signal is over the threshold. The threshold is dynamically chosen in accordance with the offset level of the transmitted signal.

Fig. 6-(c) shows the signal receiving pattern with the power detector version 3. Under the same measurement condition, the sensing range is increased over 10 m. Moreover, the converted signal level is much higher than the white noise even in the long distance, enabling the signal to exhibit clear patterns. The error of the direction sensing remains within an acceptable limit of 5 °.

4. CONCLUSIONS

Location awareness is one of the most important keys to deploying RFID systems for advanced object tracking in our unstructured environments. In this paper, we proposed a novel location sensing method with the active RFID system having an electrically small loop antenna and a power detector. The system senses the location based on the strength of the signal from the power detector and the rotation angle of the loop antenna. To maximize the sensing distance, we designed three different type signal analysis units depending on the threshold type: the hardware threshold, the additional receiver, and the software threshold, keeping them in step with the development of the signal strength detector. The developed system was mounted onto the pan/tilt unit to verify the direction sensing accuracy in the indoor environment. As the result, the final version of the location sensing RFID system can sense the transponder located over 10 m away within the maximum error of 5 °. The accuracy falls within the reasonable range for various indoor applications where a clear line of sight might not be available.

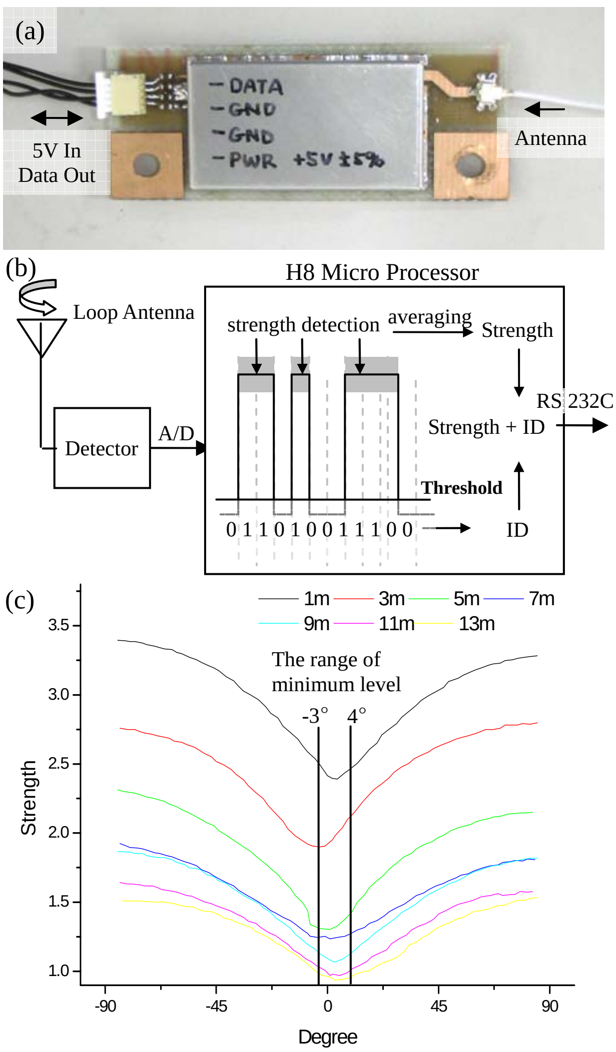

Fig. 6 Power detector module ver.2
(a) Signal strength detector
(a) Signal analysis unit (b) Received signal patterns

ACKNOWLEDGMENT

This research is conducted as a program for the "Fostering Talent in Emergent Research Fields" in Special Coordination Funds for Promoting Science and Technology by Ministry of Education, Culture, Sports, Science and Technology. The authors would like to thank Y. Murakami and T. Chiyojima of PFU, a Fujitsu company, for helping with the experiment.

REFERENCES

[1] K. Finkenzeller, *RFID Handbook : Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd Ed., John Wiley & Sons Ltd., 2003

[2] N. Y. Chong, H. Hongu, K. Ohba, S. Hirai, and K. Tanie, "A Distributed Knowledge Network for Real World Robot Applications," *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp. 187-192, 2004

[3] L. M. Ni, Y. Liu, Y. C. Lau, and A. P. Patil, "LANDMARC : Indoor Location Sensing Using Active RFID," *Pervasive Computing and Communications*, pp. 407-415, 2003

[4] A Harter, A. Hopper, P. Steggles, A. Ward, and P. Webster, "The Anatomy of a Context-Aware Application," *Proc. 5th Ann. Int. Conf. Mobile Computing and Networking*, ACM press, New York, pp. 59~68, 1999

[5] N.B. Priyantha, A. Chalraborty, and H. Balakrishnan, "The Cricket Location-Support System," *Proc. 6th Ann. Int. Conf. Mobile Computing and Networking*, ACM press, New York, pp. 32~43, 2000

[6] D.M. Pozar, *Microwave and RF Wireless Systems*, Wiley Text Books, 2000

[7] M. Kim, T. Tsunenori, and N. Y. Chong, "Object Location Sensing Using Active RFID Systems," *Proc. Int. Symposium on Robotics and Automation*, pp. 440-445, 2004