EM Package: Augmenting Robotic Intimate Space Interaction Using EM Field Fluctuation Sensing

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JST PRESTO
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Abstract
While seamless switching between accompanying and handling mode for an outdoor personal robot is required, the lack of sensor that can robustly detect proximity and touch of the user hindered its practical development. In this study, a novel sensing technology using electromagnetic field fluctuation is presented. The experiment using a suitcase with the sensor showed that direction of surrounding user, as well as direct touch of the user can be separately detected.

Author Keywords
Touch; proximity; electromagnetic field; intra body communication; near field communication; sensors; personal robot.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces – Input devices and strategies; interaction styles.

Introduction
Recent technological developments such as cheaper sensors, more powerful processors and capacity increase of power cells made personal robots affordable with much lower cost [1][2]. While current personal

robots are mostly used indoors because of technical problems and legal constraints, technology that robots can be used safely and easily outdoors is required to expand its daily use, such as carrying luggage, riding babies, playing with kids, and so on.

Outdoor environment is characterized by its large noise. A user recognition system of the robot is confused by numerous surrounding people, bright sunlight disables camera based sensors, and various road conditions generate huge vibrations, deteriorating normal driving or even stumbling the robot.

One practical solution to cope with this issue is to enable switching between "accompanying mode" and "handling mode". When the surrounding environment is relatively calm, the robot accompanies the user. When the environment is rough, the user handles the robot. To achieve seamless interaction, the mode switching should be designed as a simple operation like touching to a handling part of the robot.

In this study, a novel sensing technology to achieve this seamless switching using electromagnetic field fluctuation is presented. In the technology named *Electro-Magnetic Package* (EM Package), the user is wrapped in an electromagnetic field with body-attached emitter, and the robot is equipped with the electromagnetic field fluctuation sensors. The sensor detects and discriminate the proximity and touch of the user by RSSI (Received Signal Strength Indicator). The robot can accompany the user by chasing after the electromagnetic field (Figure 1a). The modes can be switched seamlessly by using the touch timing (Figure 1b).

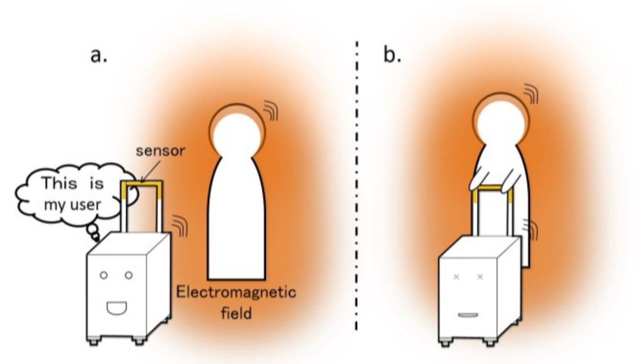

Figure 1. Personal robot with EM Package enables seamless switching between accompanying mode (a) and carrying mode (b).

Related Work

The recognition and accompaniment of the user has been studied in the field of human-robot interaction, and user sensing is one of the key issues of this field. Most of them employed camera based systems [3][4], or ultrasonic sensors [5][6]. While the camera based systems achieved real-time robust user recognition, they have limitations such as weakness to the change of lighting condition, low refresh rate, and limited viewing angle. The ultrasonic sensors also have limitations such as weakness to changes of wind and temperature condition, low refresh rate, and attenuation by clothes. In other words, both of these systems are basically for relatively calm environment.

One way to achieve robust user sensing is to use radio wave. *Hop!* [7] is an electro-actuation suitcase that can follow radio wave emitted from the user's mobile phone by the RSSI. Since mobile phones prevail, it can provide service easily. However, the RSSI of highfrequently radio wave is not stable because of its sensitivity to multipath and motions of the others. Stabilization filter causes a decline of a control cycle. Our idea is that this problem can be solved by using lower-frequency electromagnetic field.

The lower-frequency electromagnetic field has been used in Near-field intrabody communication [8]. The electromagnetic field is emitted from the user's body by an oscillator attached to the user [9], and the characteristics of air propagation can be designed by the oscillation frequency [10][11]. Unique interactions have been proposed utilizing its capacity to start communication by proximity and touch of people and a receiver [12][13][14]. While these work used the RSSI for helping robust communications, we used it for high-speed, low-noise measurement to catch a user's motion easily.

To the best of our knowledge, there is still no work that used electromagnetic field that packaged the user, detecting the user presence and achieving switching of the modes of the personal robot seamlessly. In this paper, a principle and features of *EM Package* is presented, and its performance is shown through experiments.

EM Package

EM field fluctuation sensing principle

EM Package is composed of an emitter and a receiver (Figure 2 and Figure 3). The user touches the electrode connected to oscillator of the emitter. Skin surface works as an electrode and EM field is emitted around the whole body of the user (Figure 3a). This is *The Human Transmitter* that Zimmerman presented [9]. As for oscillation frequency, 10.7 MHz was selected, which is the intermediate frequency of FM radio and high performance ICs and passive device are easy-available.

Then the user approaches the receiver up to a detectable distance. Capacitive coupling between the receiver electrode and the user's body enables one way communication (Figure 3b). As the distance decreases, the coupling increases and the signal strength increases, enabling the estimation of the distance of the user and the receiver from RSSI.

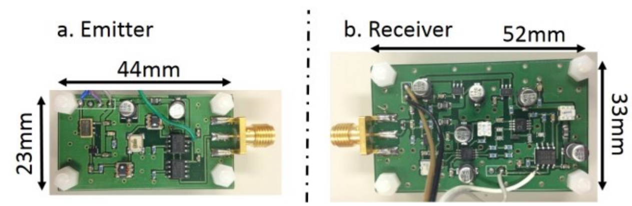

Figure 2. Prototype circuits of *EM Package* can be used only by attaching a battery and an electrode. Size of emitter is 44mm×23mm(a) and receiver is 52mm×33mm(b).

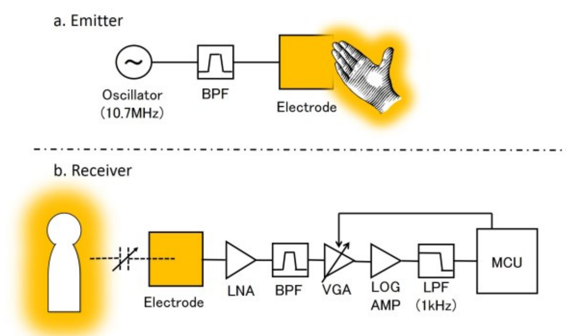

Figure 3. Circuit architecture of *EM Package* was designed by design methodology of the communication circuit.

RSSI is obtained as follows. First, the received signal is amplified by LNA (Low Noise Amplifier) with little deterioration of SNR (Signal-to-Noise Ratio), and the noise is reduced by BPF (Band-Pass Filter). By this processing, the receiver can detect weak EM field. Next, the signal is amplified by VGA (Variable Gain Amplifier) to moderate power. The gain is limited by MCU (Micro Control Unit), when there is high-power received signal. Then, the dynamic power fluctuation is converted to voltage amplitude (RSSI) by LOGAMP (Logarithmic Amplifier). Finally, the RSSI is averaged by LPF (Low-Pass Filter), and measured by analog-digital converter on MCU.

Features of the receiver
RSSI – Received signal power characteristic of the prototype receiver is shown in Figure 4. While this data was measured, the emitter and the receiver were connected directly using the variable attenuator instead of the user's body and air (i.e. background-free measurement). The output power of the emitter was 0dBm and variable attenuation range was -110dB ~ 0dB.

RSSI increases as received signal power increases, and it was saturated with -20dBm. That is, the receiver's dynamic range was 90dB. The upper limit of the range was determined by the saturation of the VGA, and it was sufficient because the strongest received power is not over -30dBm (e.g., the user has the emitter with the right hand, and touches the receiver with the right hand too [10]). The lower limit was determined by *Johnson noise*. In this receiver, -120dBm noise exists at room temperature, and it can measure to -110dBm with 10dB SNR.

The maximum sampling rate of the receiver was 500Hz, which was determined by LPF and limitation algorithm of the VGA. This is fast enough compared with the motion of the user. These characteristics showed that the receiver have sufficient performance for measuring EM field fluctuation that emitted from the user.

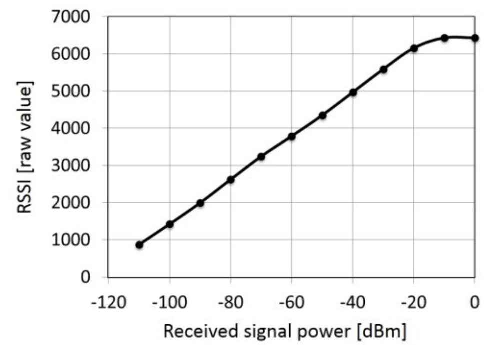

Figure 4. The receiver converted received signal power to RSSI with good linearity and about 59/dBm conversion rate.

Measurement of EM field fluctuation

Experimental condition
As one case of personal robots, we assumed suitcase type robot that accompany the user in a low-noise environment and handled by the user in a noisy environment. Two experiments were conducted to clarify the performance of the EM Package. The size of the suitcase was 250mm×350mm×500mm, and the receiver electrodes were attached on the front, back, right and left side at 350mm high (Figure 5 and Figure 6a). Size of the parallel plate electrodes was 40mm×40mm, dielectric material was 2mm thickness glass-epoxy substrate (Figure 6b).

Figure 5. The suitcase was constituted by polycarbonate and ABS resin, and had a metal key lock and some fasteners (i.e. stable EM field environment).

Detection of the user's proximity and touch

The first experiment was to show a transition of RSSI caused by the user's proximity and touch to the static suitcase. The measurement scenario is shown in Figure 7a. The user had emitter on the left hand, and approached the front of the static suitcase 1.5m away. Then, the user touched electrode. After lifting the hand, the user step away to the start position again.

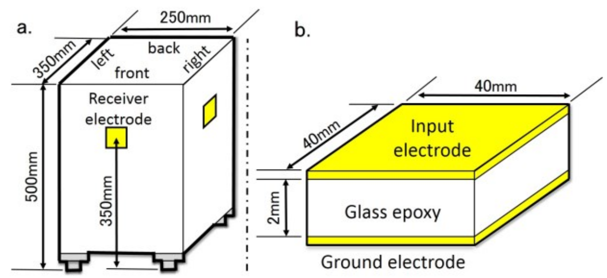

Figure 6. Four receivers with 40mm×40mm parallel plate electrodes (b) were attached on each side of the suitcase (a).

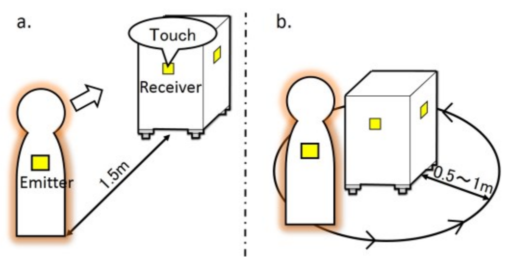

Figure 7. The transitions of RSSI which caused by the user's proximity, touch (a) and walking around (b) were measured.

Figure 8 show the transition of RSSI. We observe relatively linear relationship between the RSSI and distance between the user and the suitcase, and drastic rise and fall according to user's touch. Since there was enough gap of RSSI level between each ranges, and other three electrodes also had the transition (decrease) of RSSI too, the robust separation of the two states are possible by combining each electrode information. As a result, "proximity range" and "touch range" are separable, the user's distance can be measured at proximity range, and the user's touch can be detected at touch range. In other words, basic recognition required for intimate space interaction was achieved.

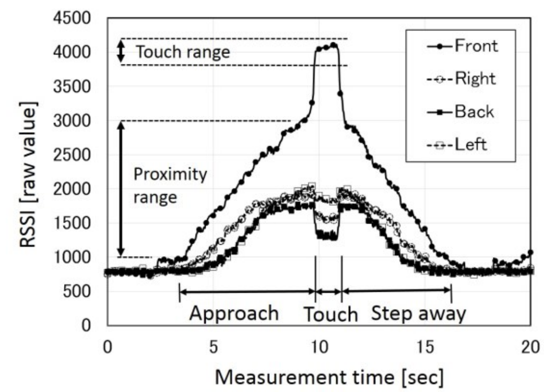

Figure 8. RSSI increased and decreased according to user's position, rinsed and fallen drastically according to user's touch.

Detection of the direction of the surrounding user

The second experiment was to show directional sensing ability of the EM package when the user walked around the suitcase (Figure 7b). Figure 9 shows transition of RSSI, exhibiting periodic transitions like sinusoidal wave, and intersections of neighboring waves. This means that the neighboring receivable area had overlap due to the broad directivity of the receiver. The direction of the surrounding user can be calculated by the ratio of each RSSI level.

Conclusions

We presented novel EM field sensing technology for outdoor robots. Two experiments using the suitcase and the prototype circuits showed that distance of the proximity user and direction of the user can be stably measured, and states of proximity and touch is separable. We believe this EM package will be one of the low cost and robust sensing technologies for personal robots that accompany and handled by the users.

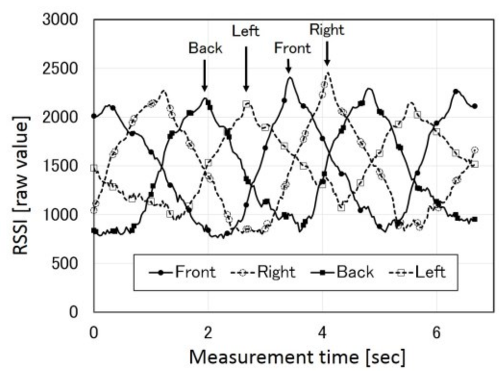

Figure 9. RSSI transitioned periodically like a sign wave, and the rise and fall of neighboring wave intersected.

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