A hand posture estimation method using multi IR-UWB radar in 2D space

Young Hoon Shin[1,2], **Jiwon Seo**[1,2]

[1]***School of Integrated Technology, Yonsei University***
85 Songdogwahak-ro, Yeonsu-gu, Incheon 21983, Korea
Email: jiwon.seo@yonsei.ac.kr

[2]***Yonsei Institute of Convergence Technology, Yonsei University***
85 Songdogwahak-ro, Yeonsu-gu, Incheon 21983, Korea

BIOGRAPHY

Young Hoon Shin received his B.S. in School of Electrical and Electronic Engineering, Yonsei University, in 2013. Since then, he has been studying for his M.Sc. and Ph.D degrees at the School of Integrated Technology, Yonsei University. His research interests include IR-UWB radar, user interface device, sensor fusion, and multi-mobile robots.

ABSTRACT

A user interface device is an input device that facilitates the interactions between human and machine. Despite significant research efforts in the last decade, most user interface devices are based on a touch user interface. The touch user interface is an intuitive, convenient, and usable interface for display-based devices, and is mainly applied to smartphones, tablet computers, and car entertainment systems. However, the touch user interface requires a physical contact which is not always convenient for users. Thus, researchers are developing non-contact user interface devices. Single cameras, stereo cameras, infrared depth cameras, and Leap motion sensors have been applied as non-contact solutions, and these sensors have demonstrated satisfactory performance under certain conditions. Since these sensors are light based, their outdoor performance can be significantly influenced by environmental factors, such as the amount of light and weather conditions.

In this paper, we propose a method to estimate hand posture using Impulse Radio Ultra-Wide Band (IR-UWB) radar as a non-contact interface device. The IR-UWB radar has advantages over light-based sensors. It is robust to outdoor environmental factors, such as weather conditions and illumination changes, and the IR-UWB signals can penetrate a non-metallic object, and detect the target behind the object. In comparison with other types of radar such as Continuous Wave (CW) radar and Doppler radar, the IR-UWB radar offers extraordinary resolution and detection precision, because of its short duration pulses. This paper proposes a real-time hand position and posture estimation method using multiple IR-UWB radars in 2D space. Although the size of this system is larger than a single radar based system, the multi-radar based system covers a wider area, and demonstrates better estimation performance. Two IR-UWB radars are installed for the experiment, with the directions of the radars perpendicular to one another. While highly precise hand posture estimation using two independent radars is very complex, such high precision estimation is not required for the purpose of a hand posture based interface device. Thus, we focus on an estimation method with reasonable accuracy for user interface applications and low computational cost. We suggest a simple probability-based algorithm to estimate the hand posture, and demonstrate its performance by experiments.

Keywords: IR-UWB, Radar, Position Estimation, Posture Estimation, Non-Contact User Interface Device

INTRODUCTION

Notwithstanding the significant research effort in the last decade, most user interface devices are still based on the touch user interface. However, to use them, users should always concentrate their eyes on the display, which is inconvenient, and sometimes puts them in a dangerous situation. Also, such application can be restricted by the size of the display, if it is too large or too small. Thus, researchers try to find other ways to solve these problems through non-contact sensor based interfaces.

By definition, a non-contact user interface device can input user commands without any physical contact. Single cameras, stereo cameras, and infrared depth cameras sensors have been applied as its solutions. The camera sensor based input device has been researched, and applied to various applications, including face recognition, hand gesture recognition, finger gesture recognition and body motion recognition [1-2]. Also, the two-camera based sensor, which is termed a 'stereo camera', exploits two different view images to find the distance and shape of the targets for gesture recognition [3]. IR depth cameras, such as Kinect and Leap motion, use infrared rays to find the shape and distance of targets [4-6]. Because of their accurate measurement, they show high performance in target recognition. While these sensors have drawn attention to new interface systems, they have the limitation of being vulnerable in outdoor environments, especially where light is unstable.

IR-UWB radar uses impulse-radio electromagnetic waves to detect an object, and is more robust to environmental interference than other sensors. Since a single radar can only detect a target in one dimension, our proposed hand posture estimation method installs two IR-UWB radars in perpendicular directions to find the hand posture in 2D space.

Figure.1 shows the process of the proposed method in this paper. First, we reduce the DC component from the reflected signal, and apply a clutter reduction method to remove background signal from the raw data. Next, we apply a correlation algorithm to find the power, and also to reduce the noise. Third, we normalize the reflected radar signals. Finally, we acquire the estimation value of the hand posture.

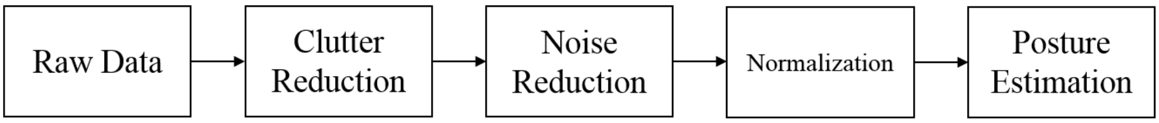

Figure. 1. Concept of the hand posture estimation method using two IR-UWB sensors.

In the following sections, we describe the proposed hand posture estimation algorithm though some matrices, and evaluate the potential of our proposed algorithm through experiment.

HAND POSTURE ESTIMATION ALGORITHM USING IR-UWB RADAR SIGNAL

The general radar based system needs many processing steps; thus, high computational power is required. Since our goal is to apply this system to a real-time interface device, we require a low computational method. The approach of proposed hand posture estimation method is divided in following steps.

A. Clutter and Noise Reduction Algorithm

A transmitted signal can be represented as $Ap(t)$, where A is the amplitude of signal, and p is a generated impulse signal from radar at time sequence t. We can represent the amplitude of the received signal at t and time-of-arrival τ, as the sum of the reflected signal from the target and multipath components.

$$\mathrm{w}(t,\tau) = \sum_{i=1}^{N} A_i p(\tau - \tau_i) + n(t,\tau) \quad (1)$$

where, $\mathrm{w}(t,\tau)$ is the amplitude of the received signal at (t,τ), $A_i p(\tau - \tau_i)$ is the sum of the reflected signals, and $n(t,\tau)$ is a noise signal that has high frequency components. In a static environment, the clutter can be considered as a DC-component in the domain of t [7]. Thus, we can remove the of background signal by subtracting the average of initial 100 rows of matrix of $\mathrm{w}(t,\tau)$, which is $r_0(\tau)$:

$$\mathrm{x}(t,\tau) = \mathrm{w}(t,\tau) - r_0(\tau) \quad (2)$$

where, $\mathrm{x}(t,\tau)$ is a clutter reduced signal. To reduce the noise $n(t,\tau)$, we apply cross-correlation to $\mathrm{x}(t,\tau)$ with the normalized transmitted signal:

$$\mathrm{y}(t,\tau) = \sum_{\mathrm{m}=1}^{N} \mathrm{x}(t,\mathrm{m}+\tau) * p_{norm}(\mathrm{m}) \quad (3)$$

Finally, we can find $\mathrm{y}(t,\tau)$, the power of the received signal at each (t,τ), with clutter and noise reduced.

B. Normalization

In this section, we find the normalized signal of $y(t,\tau)$, which is termed the probability density function (PDF) function. From Eqs. (5) and (6), we acquire the mean and variance of the power at each time sequence t, which we need to find the hand posture.

$$\bar{y}(t,\tau) = \frac{|y(t,\tau)|}{\sum_{\tau} |y(t,\tau)|} \tag{4}$$

$$\mu(t) = \sum_{k=1}^{N} k * \bar{y}(t,k) \tag{5}$$

$$\sigma^2(t) = \sum_{k=1}^{N} (k-\mu)^2 * \bar{y}(t,k) \tag{6}$$

C. Posture estimation algorithm

In this paper, we assume that if there is just one target in front of radar, the shape of the target can be predicted by the power of the received signal. Since high precision estimation is not required for the purpose of the hand posture based interface device, we apply a simple method that uses the variances of the reflected signal power. When a large area of hand is perpendicular to the radar antenna direction, then the variance of the power will be large; and if they are parallel, then it will be small. We acquire this data from each posture, and apply a linear interpolation method to find the relation between the variance of the reflected signal power and the hand posture.

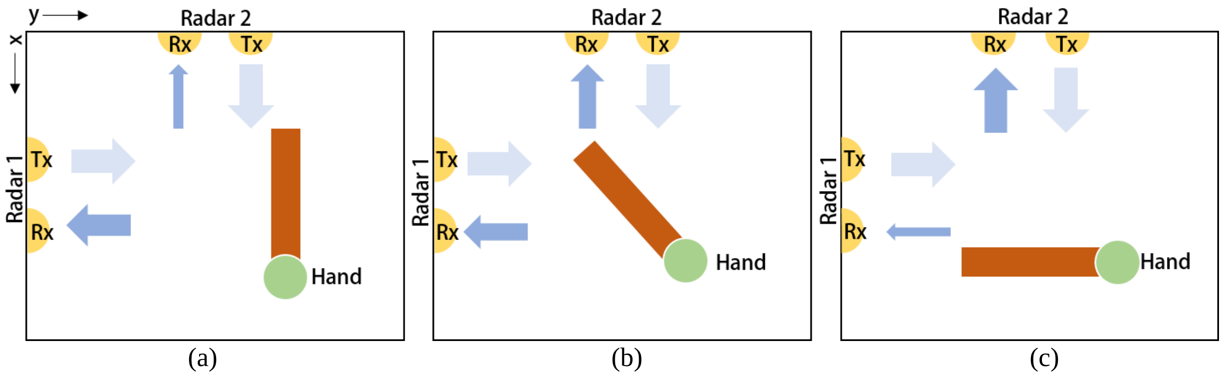

Figure. 2. The relation between the power of reflected signals and user's hand posture in 2D space. (a) The case when the hand direction is parallel to Radar 1 (0 degree). (b) The case when the hand direction is slanted to both radars (45 degree). (c) The case when the hand direction is almost parallel to Radar 2 (90 degree).

EXPERIMENT RESULTS

Figure 3 shows the test bed of the experiment we installed to verify the proposed method. The IR-UWB radars we used in this experiment are the NVA-661 module produced by Novelda, which has approximately 15m maximum detection range, and 4mm depth resolution. The frequency range of the transmitted signal is 3.1 to 5.6 GHz [8].

Figure 2 shows that the distance between radars is 15cm in the x direction and 15cm in the y direction. We assume that the user's wrist is fixed at a certain location, at 20cm distance from both radars. In this experiment, we acquire 30 sample data for evaluation from three postures (0 degree, 45 degree, 90 degree).

Table 1 shows the results of the performance of the hand posture estimation method. The estimation error values for each posture are 0.88%, 3.21%, and 2.82%, and the average error is 2.31%. Through this experiment, we verify that our proposed method shows adequate performance to applying this method to a hand posture based non-contact interface.

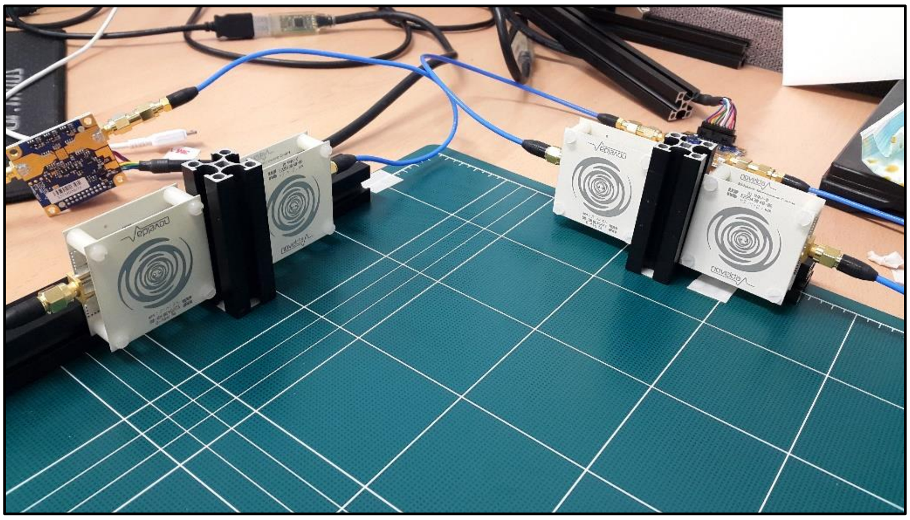

Figure.3. Test-bed for hand posture estimation method using multiple IR-UWB radars.

Real value	Posture (a): 0 degree	Posture (b): 45 degree	Posture(c): 90 degree
Estimation value	-0.794 degree	42.122 degree	92.539 degree

Table.1. Estimation values of each hand posture.

CONCLUSION

While IR-UWB radar has the advantage of robustness, little research has been conducted because of its complex signal processing algorithm. In this paper, we introduced a simple hand estimation method using multiple IR-UWB radars for a real-time interface system.

Through a simple experiment, we show the performance of the proposed hand posture estimation method. Since the proposed algorithm has constraints, such as fixed hand shape and fixed position of user's wrist, our future goal is to overcome these limitations, and develop a hardware platform by considering usability and convenience.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Science, ICT, and Future Planning (MSIP), Korea, under the "IT Consilience Creative Program" (IITP-2015-R0346-15-1008), supervised by the Institute for Information & Communications Technology Promotion (IITP).

REFERENCES

[1] Zimmerman, Thomas G., et al. "A hand gesture interface device." ACM SIGCHI Bulletin. Vol. 18. No. 4. ACM, 1987.

[2] Wachs, Juan Pablo, et al. "Vision-based hand-gesture applications." Communications of the ACM 54.2 (2011): 60-71.

[3] Yamamoto, Yu, Ikushi Yoda, and Katsuhiko Sakaue. "Arm-pointing gesture interface using surrounded stereo cameras system." Pattern Recognition, 2004. ICPR 2004. Proceedings of the 17th International Conference on. Vol. 4. IEEE, 2004.

[4] Lai, Kam, Janusz Konrad, and Prakash Ishwar. "A gesture-driven computer interface using Kinect." Image Analysis and Interpretation (SSIAI), 2012 IEEE Southwest Symposium on. IEEE, 2012.

[5] Raheja, Jagdish L., Ankit Chaudhary, and Kunal Singal. "Tracking of fingertips and centers of palm using kinect." Computational intelligence, modelling and simulation (CIMSiM), 2011 third international conference on. IEEE, 2011.

[6] Weichert, Frank, et al. "Analysis of the accuracy and robustness of the leap motion controller." Sensors 13.5 (2013): 6380-6393.

[7] Lazaro, Antonio, David Girbau, and Ramon Villarino. "Analysis of vital signs monitoring using an IR-UWB radar." Progress In Electromagnetics Research 100 (2010): 265-284.

[8] Taylor, J. D., and Dag T. Wisland. "Novelda nanoscale impulse radar." Ultra-wideband Radar: Applications and Design (2012): 373-388.