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Design of 3-Dimension Remote Controller Applying the EMD Algorithm which Attenuates the Effect of Noise

Sang-Rae Yeo[1], Heon Ho Choi[1], Jae Young Ko[2], Chansik Park[3], Sang Jeong Lee[1†]
[1]Department of Electronics Engineering, Chungnam National University, Daejeon 305-764, Korea
[2]Korea Institute of Ocean Science and Technology, Daejeon 305-343, Korea
[3]Department of Electronics Engineering, Chungbuk National University, Cheongju 361-763, Korea

ABSTRACT

In this study, a remote controller was designed using localization technique. The designed remote controller system consists of infrared transmit/receive module for time synchronization, ultrasonic transmit/receive module for measuring the TOA value, and micro-controller for processing the measured data value. For the position estimation method of remote controller, the Savarese method was used which does not have a problem of diverging solution depending on initial value. The noise included in the measured value was removed by separating the signal and noise with the use of EMD method which is the non-stationary signal analysis technique. The designed system was tested by constructing a simulation environment, and the improvement of accuracy and precision for the application of EMD method was examined.

Keywords: savarese, empirical mode decomposition, time of arrival

1. INTRODUCTION

The recent advance in IT technology has brought about the convergence technology where a single system is supplemented with various small subsystems, and the smart TV which not only provides the image and sound, but also has the functions of computer and internet. Accordingly, the communication method has been changed from the one-way communication method where the transmitter unidirectionally transmits the information to users into the two-way communication method where the data is transmitted based on the demands of receivers. As the system gets complicated and the range of choices for users broadens, the existing button type remote controller is no longer able to perform all the necessary functions efficiently. To complement this, intuitive and convenient input technology such as mouse has been introduced and is currently in use. For this technique, the position coordinate value of remote controller is perceived as the input of user, and it is performed based on the localization technique which is the method for self-positioning within a certain space.

The existing localization technique has been used for the indoor systems such as Active bat, Active badge, Cricket, and USAT. These systems are the methods which estimate the position using the pseudorange from transmitter to receiver, and the medium for measuring the pseudorange is very important. For the indoor positioning system, the methods using ultrasonic wave and infrared ray are currently in use besides the method using radio wave. The radio wave is robust to external noise, and thus widely used for the localization technique. However, as it has a low time resolution due to the fast propagation speed, there are difficulties in the measurement of distance in a small space such as TV. The ultrasonic wave is sensitive to external noise due to the nature of sound wave which vibrates air. However, as it has a slower propagation speed than the radio wave or ray, the time resolution is superior and the accuracy is relatively high, which is advantageous for taking a measurement (Jimenez & Seco 2005).

In this study, a system was designed which estimates the position of remote controller using the ultrasonic wave. The designed system estimates the position using

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†**Corresponding Author**
E-mail: eesjl@cnu.ac.kr
Tel: +82-42-821-6582 Fax: +82-42-823-4494

the triangulation method which is one of the most representative localization techniques, and consists of infrared transmit/receive unit, ultrasonic transmit/receive unit, and micro-controller. The time synchronization between transmitter and receiver is essential for the system which estimates the position using the pseudorange. In the case of the designed system, the time synchronization was achieved using the infrared signal. The pseudorange from transmitter to receiver was calculated using the Time Of Arrival (TOA) value which was measured using the ultrasonic signal, and the position of transmitter was estimated using the Savarese method which is one of the positioning methods. For the error included in the measured value, the reliability of estimated solution was improved by attenuating the measurement noise included in the measured TOA value through the application of Empirical Mode Decomposition (EMD) transform which is the non-stationary signal analysis technique. As the steps for attenuating the measurement noise, the value measured at each receiver was decomposed into the sum of Intrinsic Mode Function (IMF) by applying the EMD method. After decomposing the IMFs that are estimated to be the signal and noise, the IMF which has the noise component was removed.

The content of this paper is as follows. In Chapter 2, the designed remote controller system is described, and in Chapter 3, the EMD method and the noise attenuation method using EMD are explained. In Chapter 4, the simulation environment for testing the designed system is presented and the performance is evaluated, and the conclusion is drawn in Chapter 5.

2. DESIGN OF REMOTE CONTROLLER SYSTEM

The remote controller system consists of infrared transmit/receive unit, ultrasonic transmit/receive unit, and micro-controller for processing the data.

The TOA based triangulation method estimates the position using the pseudorange obtained from the time of arrival between transmitter and receiver, and the time synchronization between transmitter and receiver is essential for measuring the time of arrival (Munoz et al. 2009). Representative time synchronization methods include the method using the same clock, GPS time synchronization, and the method using atomic clock, but they incur additional cost and are not suitable for a simple system such as remote controller. For the designed system, the time synchronization between transmitter and receiver

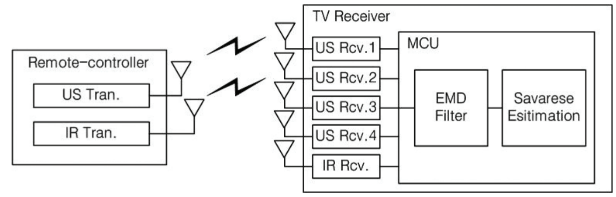

Fig. 1. Design of remote controller system.

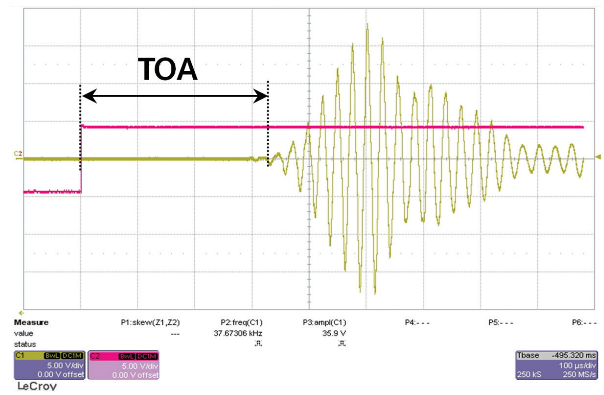

Fig. 2. Measurement of infrared and ultrasonic wave.

was performed using the infrared signal which is used in the existing remote controller system. As the infrared signal has a fast propagation speed, for the TV and remote controller which are very close, the difference in the transmitting and receiving times of infrared signal is insignificant and can be ignored. Thus, the time synchronization is achieved by regarding the time that the infrared signal arrives at TV as the transmitting time of ultrasonic wave.

For the position estimation method based on the triangulation method, the Dilution of Precision (DOP) varies depending on the geometrical arrangement of transmitter and receiver, which also changes the accuracy of the estimated position (Kawamura & Tanaka 2006). Therefore, the ultrasonic receiver was installed at each corner of TV considering the DOP of the system. The designed system is shown in Fig. 1.

The micro-controller calculates the TOA value using the receiving times of collected signals, and the EMD noise attenuation filter is applied to the obtained TOA value, which is then used for estimating the position. The TOA is calculated from the difference in the receiving times of the received infrared signal and ultrasonic signal. Fig. 2 shows the infrared signal and ultrasonic signal collected from the micro-controller. For the infrared signal, the EL-23G of KODENSHI EL company was used which transmits in the form of pulse, and for the ultrasonic signal, the SRF-04 of Devantech company was used which transmits in the form of sinusoidal wave. When the receiving time of infrared signal is assumed as the transmitting time, the TOA value can be calculated from the time interval between the infrared signal receiving time and the time that the ultrasonic signal arrives.

As for the positioning method, the Savarese method was used to estimate the position of remote controller from the measured pseudorange. The Savarese method is the position estimation method introduced by C. Savarese in 2002, and is mainly used for the indoor navigation or WSN. As the Savarese method does not require linearization procedure, it does not have a problem of diverging solution depending on initial position, which is suitable for the remote controller system having a small operation range (Savarese et al. 2002). However, as the Savarese method estimates the position from the square of the measured value without considering the measurement noise, the measurement noise also has an effect in the form of square. Therefore, it is necessary to design a filter for removing the noise included in the pseudorange prior to applying the Savarese method, and the effect of noise was attenuated based on the EMD algorithm which considers the noise characteristics.

3. DESIGN OF NOISE ATTENUATION FILTER USING THE EMD ALGORITHM

For the ultrasonic signal used in the remote controller system, the error included in the measured value has non-stationary characteristics because the effect from the TV sound or surrounding environment changes depending on time. In the past, as the analysis method for the noise included in data, the method which analyzes the frequency component of signal from the Fourier transform was frequently used. However, when the signal has non-stationary characteristics, a proper result cannot be obtained by the application of Fourier transform. Therefore, to analyze the TOA value when the measurement error has non-stationary characteristics, the EMD algorithm was applied which is one of the analysis methods for the non-linear and non-stationary signals, and the noise component was removed by decomposing the noise component IMF and signal component IMF through the analysis of signal power.

3.1 EMD algorithm

The EMD defined by Huang et al is the method for analyzing the non-stationary and non-linear signals, and is one of the signal analysis methods on a time domain. The EMD algorithm assumes that a signal consists of the bases which are a number of IMFs (Flandrin et al. 2004). The IMF indicates a monotonous signal which passes the origin and has the component of narrow frequency band, and it can be obtained from the difference between the average value for target signal and the average values for the spline signal of target signal's maximum value and the spline signal of target signal's minimum value. As the EMD algorithm only uses simple subtraction for the signal decomposition, the loss or distortion of signal do not occur in the process of decomposing and recombining the non-stationary or non-linear signals, which is effective for analyzing the non-stationary and non-linear signals.

The IMF signal, which is the base of signal, has the following two characteristics.

1. The IMF signal passes 0 from the extreme value to the next extreme value.
2. At all points, the average value of upper envelope and lower envelope is 0.

When the EMD algorithm is applied, the signal consists of one or more IMFs, and the number of IMFs which constitute the signal varies depending on the type and characteristic of signal. The signal is decomposed until the frequency of residual signal is 0 or has the frequency component characteristic that is close to 0. When the EMD is applied, the signal can be expressed as in Eq. (1). Here, $C_n(t)$ represents the IMF, and $r_n(t)$ represents the residual signal.

$$S(t) = \sum_{n=1}^{N} C_n(t) + r_N(t) \tag{1}$$

3.2 Design of noise separation filter

The EMD algorithm decomposes the target signal into the sum of one or more IMFs, and the noise included in the signal can be removed by eliminating the IMF which contains the noise component. The IMF could be distinguished by the frequency component analysis of signal and signal power analysis.

The motion of remote controller is determined by the human behavior pattern, and considering the human motion, the signal has a low frequency component. When the EMD method is applied, the signal is sequentially decomposed from the IMF having a high frequency component to the IMF having a low frequency component. The noise component and signal component of signal can be expressed as in Eq. (2).

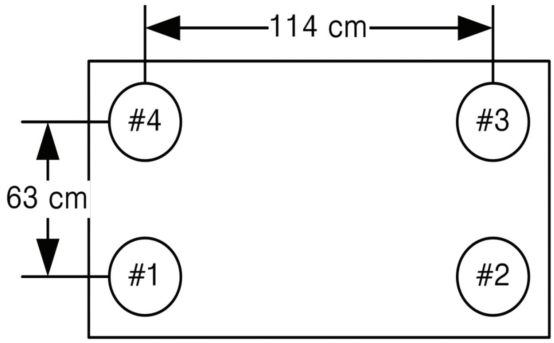

Fig. 3. Coordination of ultrasonic sensor.

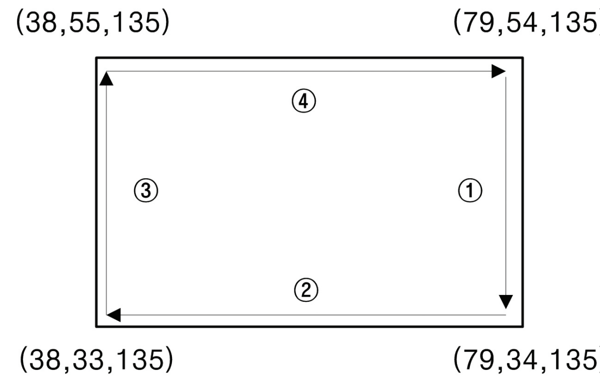

Fig. 4. Dynamic experiment.

$$S(t)=\left(\sum_{n=m+1}^{N} C_n(t)+r_N(t)\right)+\sum_{n=1}^{m} C_n(t) \quad (2)$$

In Eq. (2), the signal is divided into the IMFs containing the noise component from 1st to m^{th}, and the IMFs containing the signal component from $(m+1)^{th}$. Therefore, the noise included in the signal can be removed by eliminating the IMFs of 1st to m^{th} (Sun et al. 2008). Regarding the method for obtaining m, the noise is generally removed by calculating the instantaneous frequency after the Hilbert transform and constituting the IMF of the frequency which is included in the frequency bandwidth of signal (Wu & Huang 2004). However, for the remote controller system, as the input signal is dependent on user 's pattern, the frequency bandwidth of signal varies depending on user, and therefore the method applying the instantaneous frequency after the Hilbert transform is not appropriate. Thus, the noise IMF was distinguished by analyzing the signal power. If the signal power of remote controller is high, the signal power would account for most of the total signal power. Based on this, the boundary point for IMF where the sum of IMFs is more than 90% of the total power was calculated as in Eq. (3), and this component was interpreted as signal. The remaining IMF was regarded as noise, and removed.

$$0.9 \geq \frac{P\left(\sum_{n=m+1}^{N} C_n(t)+r_N(t)\right)}{P\left(\sum_{n+1}^{N} C_n(t)+r_N(t)\right)} \quad (3)$$

4. SIMULATION ENVIRONMENT AND PERFORMANCE EVALUATION

To test the designed system, a simulation was constructed as show in Fig. 3. Four ultrasonic sensors were attached at each corner of wooden panel which has the same size as 42inch TV, and the data was collected by connecting with PC using the micro-controller. For the position coordinate of each receiver, the receiver #1 was set as (0 0 0) and the coordinates of the remaining receivers were set based on the receiver #1.

In the experiment, the position estimation performance of remote controller was evaluated for the static environment and dynamic environment. As for the static environment, the position was estimated using the measured value when the remote controller is fixed at a reference point (57 25 100) cm, and the accuracy of position solution that is estimated from the position estimation algorithm was analyzed. As for the dynamic environment, the position estimation performance when the remote controller moves in a regular trajectory as shown in Fig. 4 and the improvement of accuracy and precision of solution for the application of EMD algorithm were examined.

For the static experiment, with the use of least square method and Savarese method, the position of remote controller was estimated using the measured TOA value when the remote controller is fixed at a reference point (57 25 100) cm. In the least square method, the value converged or diverged depending on the change of initial position. In the Savarese method, an initial position value is not necessary for estimating the position, and the estimated value converged at all times. Fig. 5 shows the true position value and estimated position value for the application of Savarese method. As indicated in Table 1, the estimated value had a standard deviation of less than 1cm, and had an error of about 2.3 cm when compared to the true value. The Z-axis coordinate estimated the coordinate which is far from the true position, and also had a high standard deviation of 21.777 cm. This could be due to the effect of DOP because the receivers are located at the same Z-axis. For the designed system, as the X and Y coordinates of remote controller are

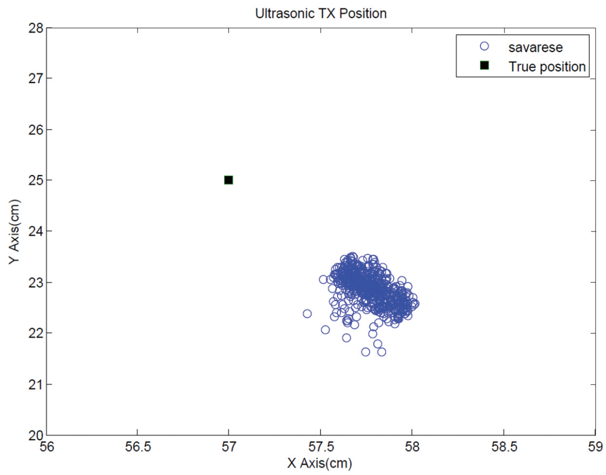

Fig. 5. Localization of remote controller on horizontal plane in static tests.

Table 1. Performance evaluation in static tests.

	Savarese	True position
Average x-axis (cm) /standard deviation (cm)	57.774 0.1067	57
Average y-axis (cm) /standard deviation (cm)	22.843 0.3134	25
Average z-axis (cm) /standard deviation (cm)	193.33 21.777	100

used as the input, the position estimation accuracy of Z-axis coordinate does not affect the performance of the system.

For the dynamic experiment, the pseudorange value obtained from each receiver was decomposed into 8 IMFs with the use of EMD algorithm. The EMD algorithm was made to operate in real time by applying the algorithm to the data during 2 seconds before the collected sample. Fig. 6 shows the IMF wave forms for the pseudorange values obtained from the receiver #1. The signal is decomposed from the IMF having a high frequency component, and the signal power analysis method was used to remove noise. The IMF 1~3 were regarded as noise, and removed. Fig. 7 shows the pseudorange value obtained from each receiver, and the value after the removal of noise by applying the EMD algorithm.

The Savarese method was applied to estimate the position of transmitter. The position was estimated by applying the Savarese method to the pseudorange before and after the application of EMD method, and the result is shown in Fig. 8. The position estimation value does not diverge, and it tracks the dynamic movement of receivers. As shown in Table 2, the position estimation performance was evaluated by examining the average and standard deviation at each section when the transmitter moves in a trajectory of ①→④. When the standard deviations of X and Y values were compared between before and after the application of EMD, the standard deviation after the application of EMD was lower at every section compared to that before the application of EMD.

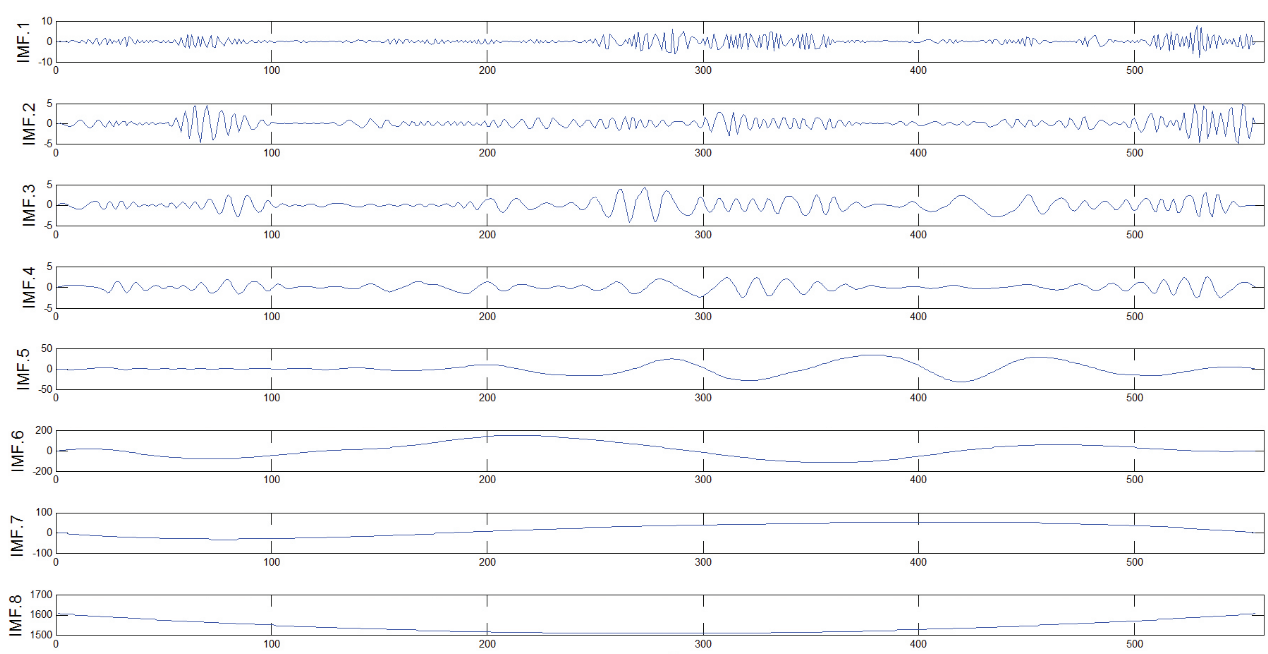

Fig. 6. IMF's of pseudorange.

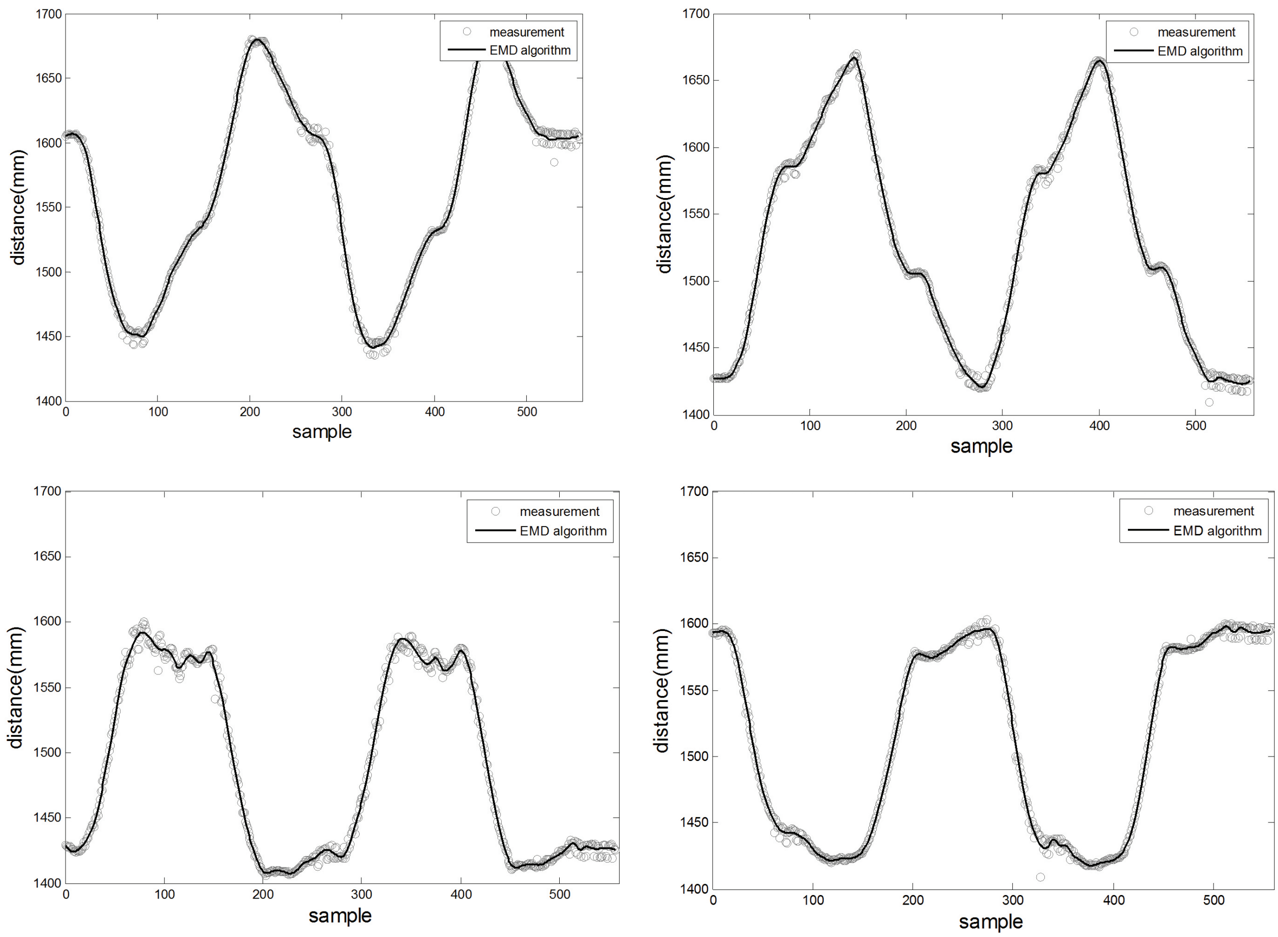

Fig. 7. Pseudorange of each receiver in dynamic test.

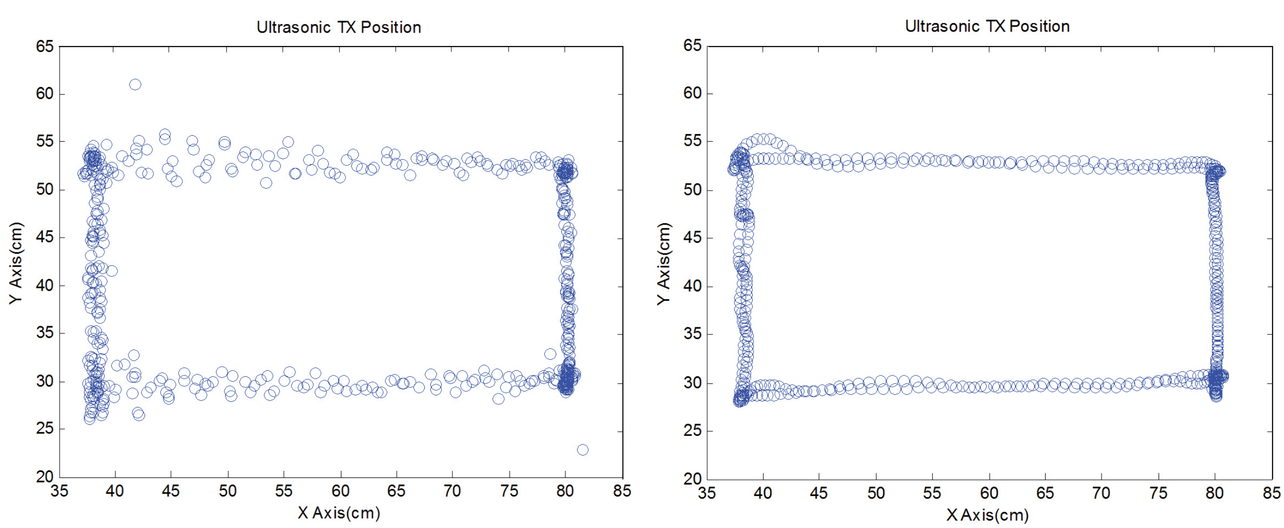

Fig. 8. Localization of remote controller on horizontal plane in dynamic test (left: Savarese , right: Savarese+EMD).

5. RESULT

In this study, a remote controller system was designed which uses a ultrasonic wave based position estimation method. The system consists of infrared transmit/receive module for time synchronization, ultrasonic transmit/

Table 2. Performance evaluation in dynamic tests.

		Savarese	Savarese+EMD
①	Average x-axis (cm) /standard deviation (cm)	80.068 0.266	80.071 0.213
	Average y-axis (cm) /standard deviation (cm)	-	-
	Average z-axis (cm) /standard deviation (cm)	916.185 239.331	919.603 198.462
②	Average x-axis (cm) /standard deviation (cm)	-	-
	Average y-axis (cm) /standard deviation (cm)	29.915 1.141	29.800 0.576
	Average z-axis (cm) /standard deviation (cm)	895.120 256.688	88.763 126.668
③	Average x-axis (cm) /standard deviation (cm)	38.302 0.424	38.162 0.304
	Average y-axis (cm) /standard deviation (cm)	-	-
	Average z-axis (cm) /standard deviation (cm)	829.703 485.543	834.920 214.052
④	Average x-axis (cm) /standard deviation (cm)	-	-
	Average y-axis (cm) /standard deviation (cm)	53.096 1.397	52.924 0.706
	Average z-axis (cm) /standard deviation (cm)	843.819 332.648	877.981 193.756

receive module for measuring the TOA, and micro-controller for processing the data. For the position estimation algorithm, the Savarese method was used which does not have a problem of diverging solution depending on initial value. To improve the accuracy of position estimation, the collected signal during 2 seconds before the collection time was decomposed into 8 IMFs in real time by applying the EMD algorithm which is capable of non-stationary signal analysis, and the IMF which has the noise component was separated and removed through the signal power analysis.

The designed system was tested by constructing a simulation environment. As for the simulation, the static experiment was conducted to evaluate the performance of position estimation algorithm, and the dynamic experiment was conducted to evaluate the performance of EMD algorithm. In the static experiment, the least square method had a problem of diverging value depending on the change of initial value. This indicates that when TV is turned on, the value can converge or diverge depending on the initial position of remote controller, which is not suitable for the remote controller system. For the Savarese method, the position estimation value converged at all times, and the true position and measured position showed a bias error of less than about 3 cm and a solution precision of less than 1cm. In the case of remote controller system where the position of remote controller is perceived with the naked eye, the relative motion of true position and estimated position is important. Therefore, it is thought that the bias component of less than 3 cm would not be a problem for the operation of remote controller system.

In the dynamic experiment, the measured value was decomposed into 8 IMFs by applying the EMD algorithm, and the IMF which has the noise component was distinguished through the signal power analysis. Regarding the noise component IMF, the noise component included in the measured value was found to have non-stationary characteristics depending on time, and the reliability of position solution was improved by removing the noise component IMF. Based on the result of dynamic experiment, it was shown that the designed system estimates the true trajectory and the application of EMD algorithm attenuates noise.

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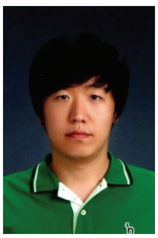
Sang Rae Yeo received the Bachelor of degree in electronics from Chung-nam National University in 2012. His research interests include GNSS SDR and precise time Anti-jamming.



Heon Ho Choi received the Master's degree in electronics from Chung-nam National University in 2010. His research interests include GNSS and Anti-Jamming.

Jae Young Ko received the Master's degree in electronics from Chung-nam National University in 2012. His research interests include GNSS and indoor navigation

Chansik Park received the Doctor's degree in Control and Measurement in Seoul National University in 1997. His research interests include GNSS, SDR, AJ, ITS and WSN.

Sang Jeong Lee received the Doctor's degree in Control and Measurement in Seoul National University in 1987. His research interests include GNSS and Robust Control.