Improvement of RTLS Performance Using Recursive RF Active Echo Algorithm

Hyekyung JEON, Chulho LEE, Younsik HONG

Department of Computer Science and Engineering, College of Information Engineering, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, 22012, Republic of Korea

mjacad@naver.com, jullio@chol.com, yshong@inu.ac.kr

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Abstract. *When it comes to indoor Real-Time Location Systems (RTLS) for an Automatic Guided Vehicle (AGV), the most important factor is to minimize the location estimation error. In industrial sites, centimetre-level accuracy is required for the AGV. Since the duration for measuring the position of an AGV is slower than the speed of arriving RF signals, the margin of error inevitably becomes larger than in systems that use low-speed media such as ultrasonic waves. To minimize such errors, a short-range location estimation Recursive RF Active Echo (RRFAE) algorithm is presented. Increasing the time ratio by repeatedly and interactively reflecting the signal can reduce measurement error. That is, there is an effect of expanding the measurement distance by the number of iterations. We propose and implement a precise positioning algorithm in an indoor environment where many reflections exist. The error analysis of the RRFAE algorithm after hardware correction shows that the level of the RRFAE's errors is only one tenth that of an RTLS system that uses other RF signals.*

Keywords

Active echo, Automatic Guided Vehicle (AGV), indoor location tracking, Real-Time Location Systems (RTLS).

1. Introduction

A Real-Time Location System (RTLS) is used for locating objects or people. A real-time position tracking system is used for tracking the position of an object in outdoor or indoor environments and tracking the moving path of the object. Global Positioning System (GPS) satellite [16] and mobile communication network-based technologies are applied for wide area tracking, and Wi-Fi [2] and [7], BLE [17], ZigBee [5], UWB [19], and RFID [4], [6], and [18] are applied for indoor location tracking. A system for tracking the position of an object in an indoor space is called an Indoor Positioning System (IPS). In this paper, we propose an indoor location tracking method for Automatic Guided Vehicles (AGVs), which are being used for transporting goods in the industrial field [6], [9], and [10]. Localization is a main requirement for autonomous navigation of AGV.

For an indoor location tracking, we adopted a well-known RFID-based positioning technique [4], [6], and [18] that measures position using wireless communication between devices. As shown in Fig. 1, RTLS consists of an RTLS tag, RTLS reader, and RTLS engine. The RTLS tag (or mobile node) represents a mobile device to be tracked. The RTLS reader (or reference point) knows its location information to measure the distance to the RTLS tag.

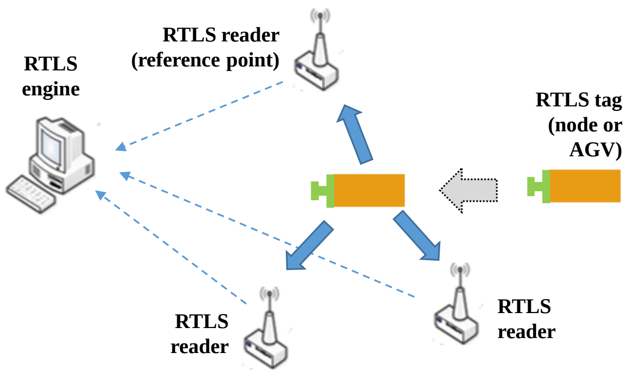


Fig. 1: An illustration of the RFID-based position tracking system.

The reader and the tag can communicate with each other using Radio Frequency (RF) signals. The reader can fetch the tag information of the moving object within the reception range. The reader collects information such as the Received Signal Strength (RSS) and the received time of the RF signal transmitted by the tag. This information is sent to the RTLS engine, which estimates the position of the tag by trilateration [14] and [15] based on information gathered from at least three readers.

When applying an RFID-based RTLS to an indoor industrial field, the most problematic thing is positioning error [3] and [11]. Let us consider a moving object, i.e., AGV, to estimate its location as a mobile node. It transmits a RF signal, and the reference point sense this signal. Each reference point reflects the received wave, and then it receives the reflected wave as shown in Fig. 2. Then it estimates the relative distance to the reference point by calculating the phase difference $\Delta\phi$ between the transmitted wave and the received wave.

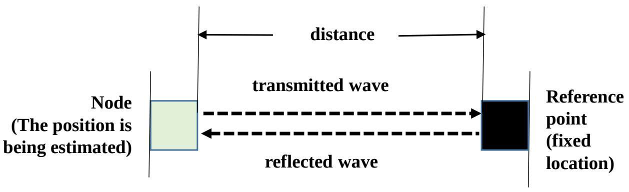


Fig. 2: Location estimation using RF signal.

In general, $\Delta\phi$ is proportional to the distance between them. That is, the distance measurement can be obtained from the time ratio T_r by using $\Delta\phi$ as shown in Eq. (1):

$$T_r \propto \frac{\Delta\phi}{t_{round\text{-}trip}}. \qquad (1)$$

Notice that $t_{round\text{-}trip}$ is the elapsed time during round-trip. Consider the case of hardware implementation to obtain the phase difference $\Delta\phi$. The voltages of the above two waves can be measured with an ADC (Analog-to-Digit Converter). A FPGA (Field Programmable Gate Array) stores these voltages transmitted through the ADC in its buffer. A built-in CPU reads them and then calculates $\Delta\phi$. However, the processing time to calculate $\Delta\phi$ with these devices is relatively slow compared to the transmission speed (300000 km$\cdot$s^{-1}) of the RF signal. Since the node is still moving, it is impossible to perform an accurate position estimation due to the processing delay at the node. As the distance between the node and the reference point becomes shorter, the estimation error becomes larger.

To solve this problem, the reference point reflects the received wave to the node, and the node reflects it to the reference point. This process is repeated a predetermined number of times. At last, the node detects the phase difference $\Delta\phi'$ between the first transmitted wave ϕ_{first} and the last received reflected wave ϕ_{last} as shown in Eq. (2). That is, there is an effect of expanding the measurement distance by the number of iterations, n.

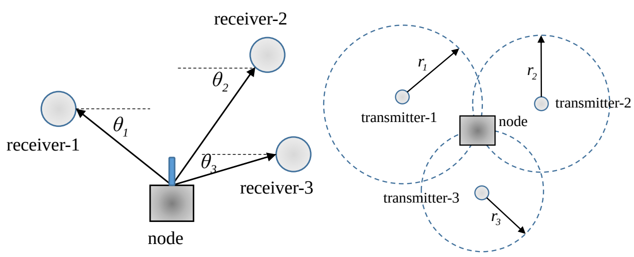
$$T_r' \propto \frac{\Delta\phi'}{t_{round\text{-}trip}} = \frac{\phi_{last} - \phi_{first}}{n \cdot t_{round\text{-}trip}}. \qquad (2)$$

In this paper, we propose a Recursive RF Active Echo (RRFAE) algorithm to estimate distance precisely by reducing the errors of position estimation caused due to the delay in processing time at the node. We design and implement the proposed algorithm in an indoor environment. The proposed positioning algorithm can be applied indoors as well as outdoors. The composition of this paper is as follows. Section 1. introduces indoor location tracking. Section 2. describes the related work, Sec. 3. explains the RRFAE algorithm proposed in this paper, Sec. 4. presents experimental results, and the conclusion is in Sec. 5.

2. Related Works

In trilateration-based RTLS, information on at least three distances with Line of Sight (LoS) [8] are required for estimating a two-dimensional position. To measure the distance between a reference point and a node, there are three typical methods: Angle of Arrival (AoA) [13], Time of Arrival (ToA) [12], and Time Difference of Arrival (TDoA) [1].

In the typical case of the AoA method (Fig. 3(a)), four to 12 antennas are arranged in each direction in one anchor (i.e., reference point). Each anchor finds the number of the antenna that received the signal. Then it estimates the location of the node where the cell site (i.e., coverage area) and the signal source met. This method does not require time synchronization, but it does require the use of a smart antenna, and it is essential to mount the correct antenna. Also, if the node is near the anchor or the signal is scattered by the surrounding environment, a large positioning error may be introduced.



(a) AoA. (b) ToA.

Fig. 3: An illustration of the related works.

The ToA method (Fig. 3(b)), is a method of estimating the position of a node by measuring the signal transmission time between reference points with their known location and a node. It is a typical GPS-based positioning method. The position of a node can be calculated by a recursive least squares method. In this method, the distance between reference points and nodes can be calculated only after time synchronization between these has been established.

Unlike the ToA method, the TDoA method does not require time synchronization between reference points and nodes. It can perform position estimation with only time synchronization among reference points. In ToA, the node records the time the signal was sent to the reference point. However, TDoA needs to record the time in the reference point when a signal is received from the node. Like ToA, the clocks of each reference point must be synchronized, and the accuracy of the location engine is related to the accuracy of the clock used in the reference point. In addition, TDoA is more likely to be affected by multipath propagation, noise, interference, and so on.

RFID technology uses RF to identify tags attached to an object without direct contact. Specifically, RFID tags have a long recognition range due to the characteristics of RF and can recognize many tags at the same time. The RF method is relatively accurate because it easily passes through obstacles such as buildings and walls and the transmission speed is fast. In addition, it has the advantage of easy data modification.

ToA and TDoA methods cannot estimate a long distance. AoA may produce a large estimation error when the signal is scattered. In addition, a high-performance hardware with Tera Hz sampling rate is required to modulate and demodulate RF signals. To solve these problems, we propose a RRFAE algorithm that can estimate the position with the hardware of Giga-Hz sampling rate while maximizing the advantage of RF signal.

3. Recursive RF Active Echo Algorithm

3.1. RRFAE Algorithm Overview

Active echo means that the reference point receiving the signal transmitted by the node does not simply reflect, but amplifies and retransmits the received wave. Since the active reflected wave is transmitted with stronger energy than the simple reflected wave, the node can easily distinguish the active echo from interference signals. It retransmits the active reflected signal back to the reference point and repeats this process a certain number of times, as shown in Fig. 4. This is called recursive active echo.

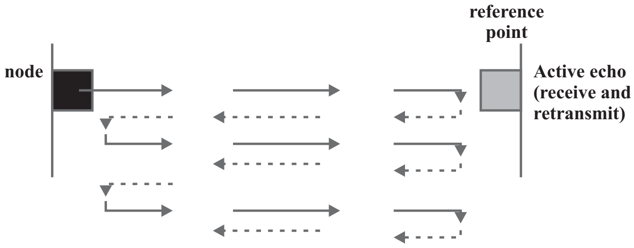


Fig. 4: Recursive active echo.

Repeated RF transmission and reception between the node and the reference point can ensure sufficient processing time when the node converts the phase difference into the corresponding distance. In other words, repetitive active reflection has the effect of extending the distance between the node and the reference point. As shown in Fig. 5, after the active echo is repeated 100 times, the phase difference between the original signal and the finally received signal is clear.

Notice that the phase difference between the reference signal and the reflected signal is very small when the distance between them is short. When the RRFAE algorithm is applied, it is possible to estimate the distance by enlarging the extremely small difference in phase.

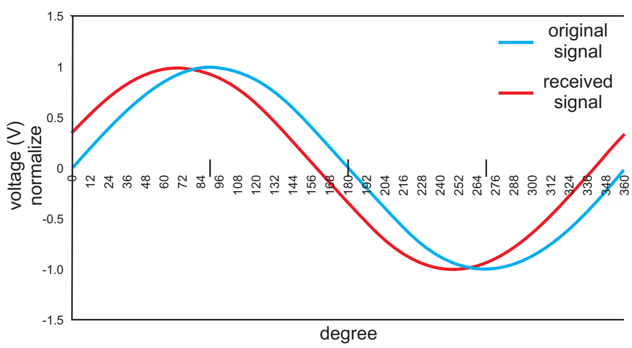


Fig. 5: The original signal and the received signal after 100 active echoes.

Let's define the distance resolution as the minimum distance of measurement. That is, it is the unit of the distance measured. Suppose that the transmission speed of the RF signal is $3 \cdot 10^8$ m$\cdot$s^{-1} and the distance resolution is 10 cm. Assume that the two reference points are located 5.1 m and 4.9 m from the node, respectively. The times required for the two reference points to detect the RF signal is 34.0 ns and 32.667 ns, respectively, where the time difference $\Delta\tau$ is 1.33 ns. If the distance resolution is reduced to 1 cm, the time difference becomes 0.013 ns. Thus, a measurement hardware with the sampling rate higher than tera-level is required. The use of such a tera-level receiver for near-field measurement is impractical because the implementation cost is too expensive.

Let's apply the RRFAE algorithm, which has 100 active reflections, to the same situation as explained above. In the case of the distance resolution with 1 cm, the time difference becomes 1.3 ns. Therefore, it is possible to measure the distance sufficiently using 10 mega or 100 mega-level receivers for calculating the phase difference. In other words, when applying the RRFAE algorithm, the distance resolution can be increased more than 100 times while using the same measuring device.

3.2. Location Estimation Based on the RRFAE Algorithm

As shown in Fig. 6, the mobile node generates the modulated reference signal, and it is amplified by the output amplifier. Then the node transmits it to the Reference Point (RP). When the node receives the reflected signal sent from the RP, it is amplified by the input amplifier, and after demodulation, the node transmits the processed signal again. Notice that the node and the RP uses the $f_{carrier\text{-}NODE}$ and the $f_{carrier\text{-}RP}$ as a carrier frequency, respectively. We are ready to apply the RRFAE algorithm when the node and the RP are signalled to each other and the corresponding frequencies are locked by the PLL (Phase Locked Loop) circuits.

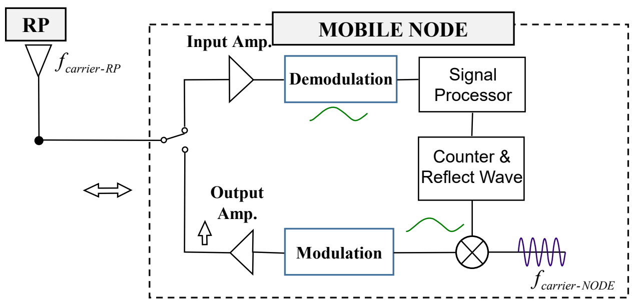


Fig. 6: A diagram of an active echo scheme between the mobile node and the Reference Point (RP).

Figure 7 shows the process of location estimation using the RRFAE algorithm. It is applied sequentially to each RP to prevent signal interferences. The node sends a RF signal to the RP with an Identifier (ID). Only the RP with the same ID specified by the node can receive the signal sent from the node. The RP responds to the node at $f_{carrier\text{-}RP}$, and the node receiving this signal retransmits the signal at $f_{carrier\text{-}NODE}$. This process is repeated a predetermined number of times. At last, the node calculates the phase difference between the first transmitted signal and the last received reflected signal using the correlation coefficient technique. The time ratio required to estimate the distance is proportional to the phase difference as shown in Eq. (1). Therefore, the node can detect the relative distance to each RP by using the phase difference.

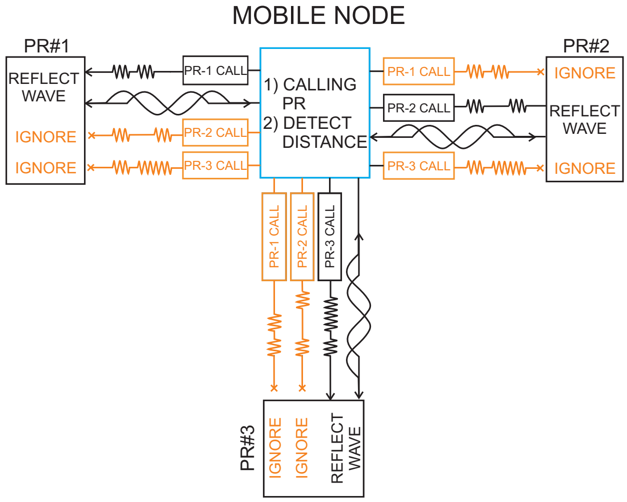


Fig. 7: The process of location estimation using the RRFAE algorithm.

3.3. Performance Analysis of the RRFAE Algorithm

In this section, we evaluate the performance metrics of the RRFAE algorithm: measurement resolution, measurement time, maximum measurement error, and minimum measurable distance. It is assumed that the node moves indoors at the speed of 5 km·h^{-1}) and the carrier frequency for transmitting the RF signal is 2.4 GHz. Note that the RFID recognition time for selecting the reference points is not considered during the performance evaluation. This is because it has little effect on the performance.

The most important factor during the performance evaluation of the RRFAE algorithm is the number of iterations. In order to determine the number of iterations, the processing time and the errors with respect to the number of iterations were measured and summarized, as shown in Tab. 1. T is the time elapsed to transmit and receive the RF signal between the node and the reference point. T also includes both the idle time and the time at which the reference point exchanges its ID with the node. At least three reference points are required to measure a node's position, but in practical applications it is common to use more than four reference points. $4T$ means the sum of the times for the node that are taken to transmit and receive RF signals with four reference points. As the number of iterations increases, T, $4T$ and the moving distances increase as well.

As can be seen in Tab. 1, when the number of iterations is less than or equal to 100 times, the error of the location estimation is within the allowable error range. However, when the number of iterations is 50, the time required for the node to measure the distance by using the phase difference was not enough. Therefore, in this paper, the number of iterations of the RRFAE algorithm was set to 100 and an experiment was conducted.

Tab. 1: Errors with respect to the number of iterations while the node moves.

Iterations	T (µs)	$4T$ (µs)	Moving distances during $4T$ (mm)	Implementation errors (mm) (stop and move during $4T$)
50	81.3	325.2	0.45	0.71
100	124.2	496.8	0.69	1.08
150	167.0	668.0	0.93	1.45
200	209.9	839.6	1.17	1.82
250	252.8	1011.2	1.40	2.20
300	295.7	1182.8	1.64	2.57
1000	896.0	3584.0	4.98	7.78

The main parameters used for position measurements are summarized in Tab. 2. Notice that the minimum measurement time is the minimum processing speed of the actual implemented FPGA. In other words, the unit of measurement time is ns.

Tab. 2: System parameters.

Parameters	Setup values
carrier frequency for RF signal transmission	2.4 GHz
speed of a node (AGV) (indoor)	5 km·h^{-1}
propagation speed of RF signal ν_{RF}	300000 km·s^{-1} = 0.3 m·ns^{-1}
distance between a node and a reference point	10 m (minimum 2 m)
number of iterations	100

1) Measurement Resolution

In the case of repeating 100 times based on a distance of 10 m, the total round-trip time, $t_{rtt\text{-}100}$, for the RF signal excluding all possible delays is 6667 ns. When the measurement distance is increased by 1 cm, the $t_{rtt\text{-}100}$ will be 6673.3 ns. So, the time difference becomes around 6.67 ns. Since the minimum measurement time is assumed to be 1 ns, the measurement resolution will be 1.5 mm.

2) Measurement Time and Maximum Measurement Error

Let us define the system latency as the delay time of the node (or the reference point). That is, the system latency is the sum of all the delay times until the output is generated through the H/W modules such as filter, demodulator, modulator, and amplifier at the node (or at the reference point).

Although the system latency at the node and the system latency at the reference point are different, we assume that it is 50 ns for convenience of calculation. Then, the total system latency is 10 µs when the iteration of the RRFAE algorithm is applied 100 times. Suppose that the time for setting the reference point for each RFID is 10 µs. Thus, the total time required for the measurement is given by Eq. (3):

$$\begin{aligned}\text{measurement time} &= \text{system delay} + t_{rtt\text{-}100} + \\ &+ \text{RFID recognition time} + \text{other delays} = \\ &= 36.67\ \mu\text{s}.\end{aligned} \tag{3}$$

At least three reference points are required to measure a node's position, but in practical applications it is common to use more than four reference points. If the idle time is 50 µs, the time required to measure the distance between the four reference points and the node is $(36.67\ \mu s + 50\ \mu s) \cdot 4 = 0.347$ ms. In other words, the time taken to measure the position of the moving node with respect to four reference points is less than 0.5 ms. If the node moves at the speed of 5 km·h^{-1}), the distance moved for 0.5 ms is 0.69 mm. Therefore, the maximum measurement error is less than 2.5 mm as in the following: 1.5 mm (*measurement resolution at the time of stop*) + 0.69 mm (*error due to movement*) $<$ 2.5 mm.

3) Minimum Measureable Distance

In order to obtain the minimum measurable distance $l_{distance(\min)}$, the relationship between the round-trip time for the RF signal and the cycle of the RF pulse is required. As shown in Fig. 8, the single cycle of the RF pulse consists of the pulse holding time $T_{holding}$ and the pulse spacing time $T_{spacing}$.

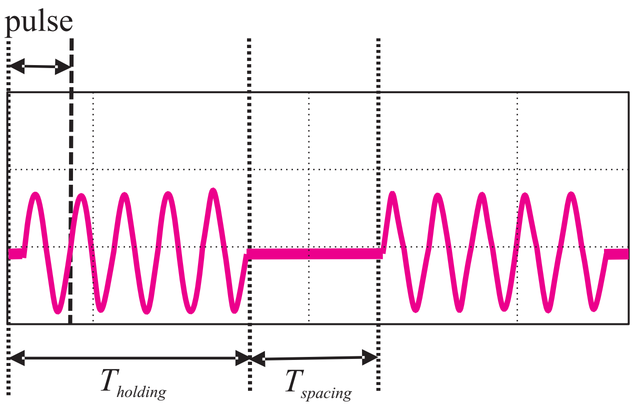


Fig. 8: The definitions of $T_{holding}$ and $T_{spacing}$.

The time taken to transmit and receive the RF signal between the node and the reference point is the sum of the transmission time and the system delay T_{delay} for generating an active echo signal. Since it is larger than the period of the RF pulse, $l_{distance(\min)}$ can be obtained using Eq. (4).

$$\begin{aligned} \frac{distance}{\nu_{RF}} + T_{delay} = \frac{2 \cdot l_{distance(\min)}}{\nu_{RF}} + T_{delay} > \\ > T_{holding} + T_{spacing}, \qquad (4) \\ l_{distance(\min)} > \frac{\nu_{RF}}{2} \cdot (T_{holding} + T_{spacing} - T_{delay}). \end{aligned}$$

Since ν_{RF} is a constant, the shorter the holding time of the RF pulse, the smaller the minimum measuring distance. In addition, the larger the system delay, the smaller the minimum measuring distance. If $T_{holding} = 60$ ns, $T_{delay} = 20$ ns, $T_{spacing} = 60$ ns, $l_{distance(\min)}$ becomes 1.5 m. Since the distance between the node and the reference point is at least 2 m in a typical RTLS, so it is applicable to practical applications.

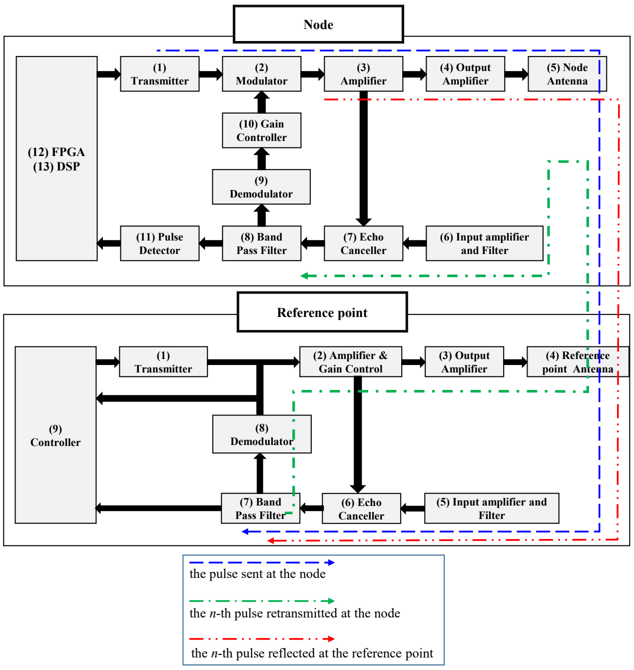


Fig. 9: The block diagram of the RRFAE system.

4. Experimental Results

4.1. System Configuration

Figure 9 shows a block diagram of the node and the reference point to be used in the RRFAE-based location estimation system. The transmitter converts the output waveform of the FPGA into a sine waveform that is the reference signal. The modulator modulates the reference signal with $f_{carrier\text{-}NODE} = 2.4$ GHz. This modulated signal is the first signal transmitted by the node. The demodulator demodulates the reflected signal sent from the reference point using $f_{carrier\text{-}RP} = 5.4$ GH).

The amplifier amplifies the incoming wave and then delivers it to the output amplifier. The output amplifier acts as a kind of power amplifier for driving the node antenna. The input amplifier amplifies the input signal. The filter at the node performs the filtering operation with the carrier band of $f_{carrier\text{-}NODE}$. Similarly, the filter at the reference point performs the filtering operation with the carrier band of $f_{carrier\text{-}RP}$.

The FPGA implements the logic of generating the reference signal, the logic of detecting signals, and the logic of controlling the modules. Kintex-7 class FPGA of XILNIX with 1 GHz-band was used. In addition, it has the control logic of implementing the ADC with high sampling rate of 400 MHz by serializing ADCs with low sampling rate of 100 MHz and controlling the time sequences.

As explained earlier, the echo canceller is a self-echo attenuating circuit to prevent the output signal from being received at the input. On the other hand, when the reference signal is repeatedly reflected to each other, the amplitude may continuously increase or continuously decrease so that the signal may be completely attenuated or completely saturated. To avoid this situation, the gain controller maintains the level of the reference signal within a specific range by controlling its gain every time a reflected signal is received.

The pulse detector is a circuit for detecting a demodulated reference pulse from an active echo. It performs a function for counting the number of reference pulses. Also, it enables an ADC function for calculating the phase difference when receiving the reference pulse. The ADC operates in parallel for high speed processing. The control of the ADC for such parallel processing is handled in FPGA. The Band Pass Filter (BPF) acts as a secondary input filter to pass the carrier band.

The controller at the reference point checks the ID of the received pulse. When the ID is recognized as its own code, it controls the process of generating the active echo.

4.2. Waveforms Measured on the Modules

The experiments in this paper were done indoors and the distance between the node and the reference point was fixed at 10 m. The oscilloscope with a 10 Giga-sampling rate is used to measure high-speed analog signals. We used Teledyne Lecroy HD4096 which has the sampling rate of 10 GS·s^{-1}), and the bandwidth of 200 MHz up to 1 GHz.

Figure 10 shows the modulated waveform and the reference waveform in the process of active echoes. Since the node adjusts the voltage level of the reference waveform through the AGC (Automatic Gain Control), it maintains a constant amplitude. Figure 11 shows the final waveform received at the node.

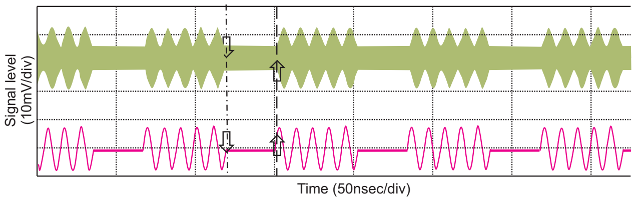


Fig. 10: The active echoes of the reference pulse.

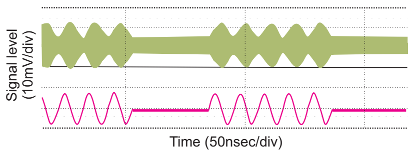


Fig. 11: The final waveform received at the node.

4.3. Measurement of Distance

The actual distance between the node and the reference point is 10 m, and the moving speed of the node is 5 km·h^{-1}). A total of 200 measurements were made, of which only 10 are shown in Tab. 2. As can be seen in Tab. 2, the maximum absolute error and the maximum standard deviation is 25.08 mm and 14.81 mm, respectively. Although the actual measurement error is larger than the computed error, it is only 1/4 of the conventional RF-based RTLS. The reason why there is an increase in the measurement error compared with the theoretical value is the cumulative errors due to the delay times in the module, environmental factors, and AGC correction accuracy.

As can be seen in Fig. 12, the phase difference $\Delta\phi$ is calculated between the last received reflected wave ϕ_{last} (Fig. 11) and the first transmitted wave ϕ_{first} (Fig. 10). Then the distance can be estimated by using $\Delta\phi$.

The distance starting from 2 m to 12 m was measured in 1 m increments, and the measurement was repeated 100 times for each distance. Table 2 shows the measured distance (on average) and its errors for the reference points. As shown in Tab. 2, both the error and standard deviation tend to decrease as the distance between the reference point and the node increases. The ratio of RF transmission time to total delay time increases as the node is gets farther away from the reference point.

As a result of analysing the factors affecting errors in the location estimation process in the distance measurement experiment, there was the circuit delay time, filter delay time, delay time in modulation/demodulation, and AGC delay time. These factors do not vary much in every run unless environmental factors are considered. The important point is not how much time each delay is, but how each deviation will occur. This is because the delay time can be overcome by the tuning process of the system.

While checking the repeated loop operation state of the AGC with measurement variance, it was confirmed that deviation in the delay time occurs largely due to gain adjustment by the AGC. This is because the delay time of the circuit varies depending on the gain of the

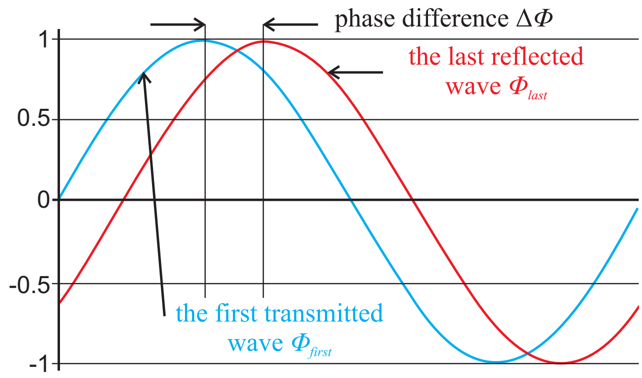


Fig. 12: The phase difference between ϕ_{first} and ϕ_{last}.

Tab. 3: Comparison of errors between conventional RF-based RTLS and the RRAFE system.

Iterations	Measured avg. (mm)	Max. error (mm)	Standard deviation
1	10001.85	21.14	14.67
2	9997.70	25.08	14.13
3	9997.94	21.83	14.31
4	10003.00	22.53	13.97
5	10002.89	24.21	14.28
6	10002.90	21.63	14.80
7	10003.82	22.56	14.55
8	10002.26	21.76	14.81
9	9996.47	21.86	14.64
10	9999.10	21.52	14.62
max	10003.82	25.08	14.81

Tab. 4: Measured data and error by distance.

Iter.	Measured avg. (mm)	Actual distance (mm)	Max. error (mm)	Standard deviation
1	1998.34	2000	25.10	14.99
2	2998.70	3000	25.14	15.93
3	4006.23	4000	24.97	15.37
4	5011.62	5000	24.74	14.50
5	5998.05	6000	24.80	15.06
6	7007.80	7000	24.75	14.00
7	7983.95	8000	24.73	14.68
8	9000.33	9000	24.90	14.42
9	10017.57	10000	24.80	14.53
10	10964.11	11000	24.74	14.52
11	12000.04	12000	24.73	13.99

AGC. Therefore, level 7 of the AGC control applied to each loop iteration was recorded and buffered in the FPGA, and the correction value for the AGC step applied in every iteration loop was obtained, as shown in Tab. 4.

Table 5 summarizes the results of 10 consecutive measurements when the distance between the node and the reference point is 10 m by applying AGC calibration. Because of applying the AGC correction, the maximum error was 9.98 mm, and the maximum standard deviation was 7.48 mm. As shown in Tab. 5, the measurement error is 2.5 times less than the error of 25.08 mm before AGC correction. Compared to the conventional RF-based RTLS system, the error is reduced to about 1/10.

Tab. 5: AGC correction table.

AGC level	Gain (dB)	Correction time (ns)
0	-3	+4.0
1	-2	+2.2
2	-1	+1.2
3	0	0
4	1	−2.5
5	2	−7.0
6	3	−21

Tab. 6: Results after applying AGC correction (when the distance is 10 m).

Iterations	Measured (avg.) (mm)	Max. error (mm)	Standard deviation
1	10001.51	7.96	6.41
2	9999.04	9.79	7.06
3	10001.97	9.95	6.78
4	10000.99	9.08	7.14
5	10000.86	8.88	6.78
6	9998.76	8.06	6.45
7	10000.76	9.98	7.31
8	10000.04	8.92	6.55
9	10000.77	9.20	6.73
10	9998.89	9.67	7.48

5. Conclusion

The fundamental reason why an AGV does not have a precise position for driving is the delay in processing speed when it acquires its location information. In the case of an RF signal, which is mainly used in the conventional RTLS system, its transmission speed is close to the speed of light. Since the delay in measurement for the AGV is larger than the arrival time of an RF signal, a relatively large error will occur compared to a system using a low-speed medium such as ultrasonic waves.

In this paper, we proposed two methods to solve the problem of localization using an RF signal. The first method is to use an RF signal as a medium for position estimation. However, the method of measuring the low frequency as a reference frequency was experimented and it was possible to solve the problem of diffraction and reflected waves, and to reduce the position estimation error. The second method is to apply a recursive active echo algorithm between the AGV (i.e., node) and the reference point. Our proposed RRFAE algorithm can effectively reduce the error of location estimation between the transmitter and the receiver so that accurate position estimation is possible.

Experimental results show that the RRFAE algorithm produces 10 times the accuracy compared to the conventional RF-based RTLS. It was confirmed that the error range is reduced to 1/2 when the AGV correction is applied. On the other hand, the actual measurement results are somewhat different from the computed error range. The reason why is that it is caused by the delay of the circuit, the filter delay and the AGC delay.

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About Authors

Hye-Kyung JEON received her Ph.D. degree from Incheon National University in 2017. In 2007, based on her work experience in hardware control at a communications company. She holds several patents related to automation. Her current research interest is RTLS in indoor environment.

Chul-Ho LEE earned his Ph.D. degree from Incheon National University in 2016. In 2012, he acquired the industrial measurement and control professional engineer certification. His current research interests include process instrumentation in smart factory.

Youn-Sik HONG received his M.Sc. and Ph.D. degrees from Korea Advanced Institute of Science and Technology, in 1985 and 1989, respectively. He is currently Professor at the Department of Computer Science and Engineering at Incheon National University. His current research interests include IoT based application.