An Enhanced Distance Measuring Scheme for DS-UWB Radar Systems

Youngpo Lee, Junhwan Kim, Dahae Chong, and Seokho Yoon†
School of Information and Communication Engineering, Sungkyunkwan University, Suwon, Korea
Email: {leeyp204, ourlife3, lvjs1019, and †syoon}@skku.edu
†*Corresponding author*

***Abstract*—This paper proposes a novel distance measuring scheme based on repeated PN sequence for ultra wide-band vehicle radar systems. The proposed scheme measures the distance between a vehicle and an obstacle based on repeated use of a single short pseudo random sequence. Simulation results show that the proposed scheme provides a shorter mean distance measuring time while keeping a similar measurement error performance to that of the conventional scheme.**

***Keywords*-PN sequence; DS-UWB; distance measuring; SRR; vehicle radar**

I. Introduction

Recently, the vehicle radar system has attracted much interest for improved road safety, since it enables drivers to safely control their vehicles by providing them with information on the distance between the vehicles and obstacles [1]-[4]. The vehicle radar system can be classified into two categories: long-range radar (LRR) and short-range radar (SRR) systems [3]. Specifically, we are concerned with the SRR system since it has lower cost and higher distance accuracy than those of the LRR system [3].

Due to its high resolution requirement, the SRR system generally employs the ultra wide-band (UWB) signal [1], [3], and its distance measuring accuracy becomes higher as the length of the pseudo-noise (PN) sequence used in the UWB increases [5]-[7]. However, a long PN sequence leads to a long distance measuring time, and consequently, is not appropriate for the vehicle radar system requiring a short distance measuring time to avoid a collision among high-speed vehicles.

To tackle this problem, recently, a distance measuring method using multiple PN sequences with different lengths instead of a single long PN sequence was proposed [7]. In this paper, on the other hand, a novel distance measuring scheme based on repeated use of a single short PN sequence is proposed. The simulation results demonstrate that the proposed scheme offers a shorter mean distance measuring time while maintaining a similar measurement error performance to that of [7].

The remainder of this paper is organized as follows. Section II describes the signal model and proposed distance measuring scheme. Simulation results are presented in Section III. Finally, Section IV concludes this paper.

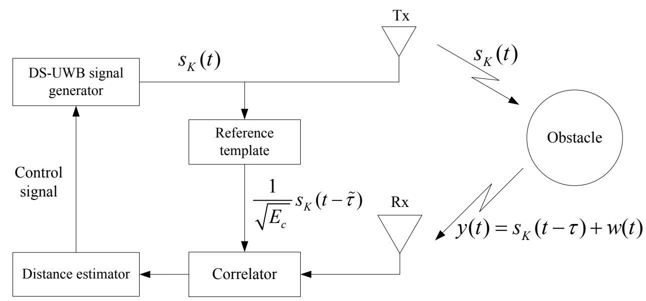

Figure 1. The system model of the proposed distance measuring scheme.

II. Proposed Scheme

Fig. 1 shows the system model of the proposed distance measuring scheme. To measure the distance between a vehicle and an obstacle, first, the direct sequence (DS)-UWB signal generator transmits the following DS-UWB signal $s_K(t)$ to the obstacle:

$$s_K(t) = \sqrt{E_c} \sum_{j=0}^{KN-1} p_{\text{mod}(j,N)} g(t - jT_c), \tag{1}$$

where E_c and T_c are the chip energy and duration of a PN sequence with a length of N, respectively, K is the number of repeated use of the PN sequence, $p_j \in \{-1, +1\}$ is the jth chip, $\text{mod}(\cdot,\cdot)$ is the modulo operation, and $g(t)$ is a UWB waveform with unit energy over $[0, T_c)$. Subsequently, the transmitted signal $s_K(t)$ is reflected from the obstacle and returns to the radar with a time delay τ, and thus, the received signal $y(t)$ can be expressed as

$$y(t) = s_K(t - \tau) + w(t), \tag{2}$$

where $w(t)$ represents the additive white Gaussian noise (AWGN) process with double-sided power spectral density of $N_0/2$. To estimate the delay τ, next, a correlation between the received signal and a reference template $s_K(t-\tilde{\tau})/\sqrt{E_c}$, where $\tilde{\tau}$ is a trial value for τ, is performed as

$$\begin{aligned} R_K(\tau, \tilde{\tau}) &= \int_{t_1}^{t_1+KNT_c} \frac{1}{\sqrt{E_c}} y(t) s_K(t - \tilde{\tau}) dt \\ &= \int_{t_1}^{t_1+KNT_c} \frac{1}{\sqrt{E_c}} \{ s_K(t - \tilde{\tau}) s_K(t - \tau) \\ &\quad + s_K(t - \tilde{\tau}) w(t) \} dt \end{aligned} \tag{3}$$

 ISBN: 978-1-61208-126-7

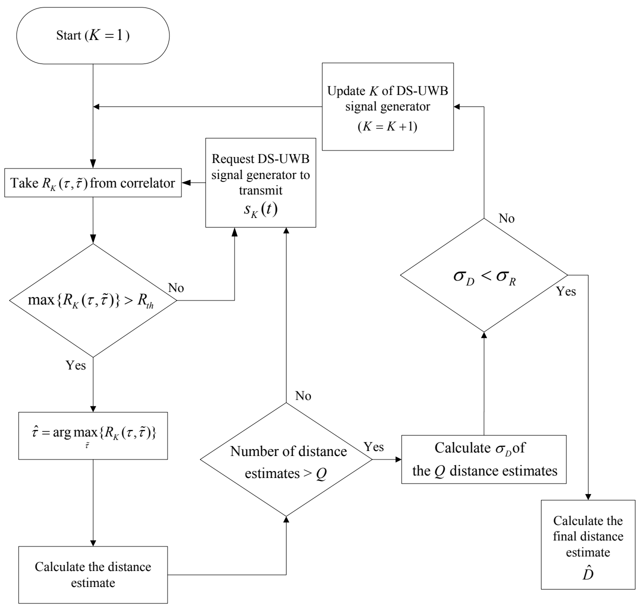

Figure 2. The algorithm of the distance estimator.

for $\tilde{\tau} = 0,\ T_c,\ 2T_c,\ \cdots,\ KNT_c$, where t_1 denotes the initial time of correlation. Finally, the distance estimator block estimates the distance between the vehicle and obstacle based on $R_K(\tau, \tilde{\tau})$, whose detailed process is shown in Fig. 2.

The maximum correlation value of $R_K(\tau, \tilde{\tau})$ is first selected and then compared with a threshold R_{th}. If the maximum value is larger than R_{th}, the delay estimate $\hat{\tau}$ is obtained as

$$\hat{\tau} = \arg\max_{\tilde{\tau}}\{R_K(\tau, \tilde{\tau})\}, \quad (4)$$

otherwise, the selection and comparison process resumes with newly transmitted $s_K(t)$. Once a delay estimate is obtained, the estimate of the distance D between the radar and obstacle is calculated as $\frac{c\hat{\tau}}{2}$, where c is the velocity of light (3×10^8 m/sec). To get a more reliable distance estimate, Q delay estimates and the corresponding Q distance estimates are obtained, and then, the standard deviation σ_D of the Q distance estimates is compared with a threshold σ_R specified by the system. If σ_D is less than σ_R, the final distance estimate $\hat{D}$ is obtained by averaging the Q distance estimates; otherwise, the overall distance estimation process is repeated with increasing K by 1. It should be noted that the proposed scheme is based on $R_K(\tau, \tilde{\tau})$, R_{th}, and σ_R independent from the speed of vehicles, and thus, valid for any speed of vehicles.

III. Simulation Results

In this section, the proposed scheme is compared with the conventional scheme [7] in terms of the mean distance measuring time and mean distance measuring error defined as the mean time that elapses prior to obtaining $\hat{D}$ satisfying

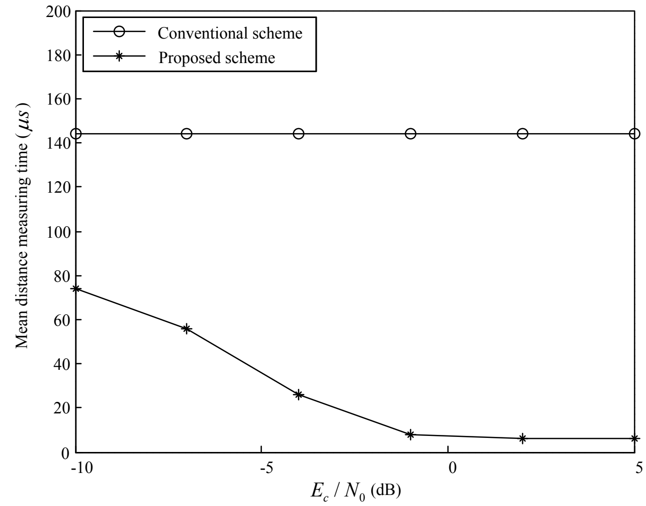

Figure 3. The mean distance measuring time of the proposed and conventional schemes.

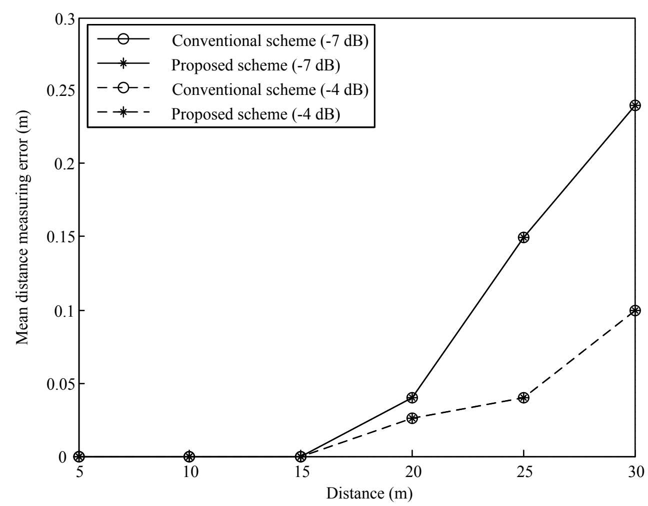

Figure 4. The mean distance measuring error of the proposed and conventional schemes at E_c/N_0 of -7 dB and -4 dB.

$\sigma_D < \sigma_R$ and $E\{D - \hat{D}\}$, respectively. For simulations, we assume the following parameters: $N = 15$, $Q = 100$, $\sigma_R = 3$ m (10% of the maximum detectable range 30 m [2] of the SRR systems), and $T_c = 2$ ns. R_{th} is set with a false alarm probability of 0.01, and D is assumed to be distributed uniformly over the detectable range $[5, 30]$ of the SRR systems. For the conventional scheme, we use PN sequences with lengths of 15, 30, 60, 120, and 240 as in [7]

Fig. 3 shows the mean distance measuring time of the proposed and conventional schemes as a function of E_c/N_0. From the figure, the proposed scheme is observed to outperform the conventional one as expected. This is due to the fact that the proposed scheme uses a single short PN sequence repeatedly unlike the conventional scheme employing multiple PN sequences with different lengths.

 ISBN: 978-1-61208-126-7

Fig. 4 shows the mean distance measuring error performance of the proposed and conventional schemes when E_c/N_0 is -7 dB and -4 dB. As we can see from the figure, the proposed scheme exhibits a similar measurement error performance to that of the conventional scheme in the detectable range of the SRR systems.

IV. Conclusion

In this paper, we have proposed a novel rapid distance measuring scheme for UWB vehicle radar systems, where a single short PN sequence is repeatedly used to yield a distance estimate, resulting in a shorter mean distance measuring time than that of the conventional scheme using multiple PN sequences with different lengths. The simulation results confirm that the proposed scheme outperforms the conventional scheme in terms of the mean distance measuring time while exhibiting a similar measurement error performance to that of the conventional scheme in the detectable range of the SRR systems.

Acknowledgment

This research was supported by the National Research Foundation (NRF) of Korea under Grant 2010-0014610 with funding from the Ministry of Education, Science and Technology (MEST), Korea, and by the Information Technology Research Center program of the National IT Industry Promotion Agency under Grant NIPA-2010-C1090-1011-0005 with funding from the Ministry of Knowledge Economy, Korea.

References

[1] I. Gresham, A. Jenkins, R. Egri, C. Eswarappa, N. Kinayman, N. Jain, R. Anderson, F. Kolak, R. Wonhlert, S. P. Bawell, J. Bennelt, and J. P. Lanteri, "Ultra-wideband radar sensors for short-range vehicular applications," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 9, pp. 2105-2122, Sep. 2004.

[2] K. M. Strohm, H.-L. Bloecher, R. Schneider, and J. Wenger, "Development of future short range radar technology," in *Proc. European Radar Conf. (EuRAD)*, pp. 165-168, Paris, France, Oct. 2005.

[3] J. Wenger, "Automotive radar - status and perspectives," in *Proc. Compound Semiconductor Integrated Circuit Symp. (CSIC)*, pp. 21-24, Palm Springs, CA, Nov. 2005.

[4] A. Komijani and A. Hajimiri, "A wideband 77-GHz, 17.5-dBm fully integrated power amplifier in silicon," *IEEE J. Solid-state Circuits*, vol. 41, no. 8, pp. 1749-1756, Aug. 2006.

[5] J. D. Taylor, *Introduction to Ultra-Wideband Radar Systems*, 1st ed. CRC Press, 2000.

[6] S. J. Xu, Y. Chen, and P. Zhang, "Integrated radar and communication based on DS-UWB," in *Proc. Int. Conf. Ultrawideband and Ultrashort Impulse Signals (UWBUSIS)*, pp. 142-144, Sevastopol, Ukraine, Sep. 2006.

[7] Y. Nakayama and R. Kohno, "Novel variable spreading sequence length system for improving the processing speed of DS-UWB radar," in *Proc. Int. Conf. Intel. Transport Sys. Telecommun. (ITST)*, pp. 357-361, Phuket, Thailand, Oct. 2008.