Study on Improving Ranging Performance of UWB Radar System with Inter-Vehicle Communication

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Abstract
A cooperative system of ultra-wideband (UWB) radar and an inter-vehicle communication (IVC) scheme was proposed in a previous study. However, in this system, when the time synchronization is not accurate, the ranging cannot be well performed. To solve this problem, a system that realizes time synchronization between the transmitter and the receiver by using the two-way ranging (TWR) method is proposed in this paper. This scheme is evaluated by computer simulations in an environment where the number of interference vehicles is increased. However, the reception characteristics deteriorate when the number of interference vehicles increases. In order to reduce the interference from other vehicles, a repetitive detection scheme using a successive interference cancellation (SIC) technique is adopted. As a result, better reception characteristics are obtained up to a distance of 90m without using SIC. When SIC is used, good reception characteristics are maintained up to 90m even when there are seven interference vehicles.

1. Introduction
Intelligent transport systems (ITS) have been widely researched and developed to solve various problems such as traffic accidents and traffic jams using advanced technologies. In ITS applications, active safety technology to prevent accidents is increasingly being researched and practically used. In order to realize active safety systems, ultra-wideband (UWB) radar is expected to be used as one of the sensors monitoring the area around the vehicle [1][2][3].

A UWB system is used in short-range data transmission in wireless personal area network (WPAN). A UWB system can achieve very fast data transmission because it has an absolute bandwidth of more than 500MHz[5]. In UWB systems, two modulation schemes, UWB Impulse Radio (UWB-IR) and Multiband OFDM (MB-OFDM), are mainly used. In UWB-IR transmission, ranging with high time resolution can also be realized because the signal pulse duration is very short. Thus, very accurate distance measurement is possible by using a UWB-IR system.

In a previous study, a cooperative system of UWB radar and an IVC scheme was proposed[4]. However, in this system, the distance between the ranging vehicle and the target vehicle is measured using the time index of the transmitted signal. Therefore, when the time synchronization is not accurate, the sufficiently accurate measurement of distance cannot be performed. To solve this problem, a system using a TWR scheme is proposed in this paper. However, in this scheme, the reception characteristics are degraded when the number of interference vehicles increases. To reduce the interference from other vehicles, the SIC scheme is also adopted in this study and its performance is evaluated.

2. UWB Communication Scheme
The UWB impulse signal used in this paper is expressed by

\[ s(t) = w(t)\sin(2\pi f_0 t) \]  

where \( f_0 \) denotes the center frequency of the signal and \( w(t) \) is the Hann window function expressed as

\[ w(t) = \begin{cases} \frac{1}{2}(1 - \cos(2\pi t)) & (0 \leq t < 1) \\ 0 & \text{(Otherwise)} \end{cases} \]

Figure 1: Waveform of \( s(t) \)  
Figure 2: Power spectrum of \( s(t) \)

The shape of \( s(t) \) and its power spectrum when \( f_0 = 26 \text{GHz} \) and the pulse width is 1ns are shown in Figures 1 and 2, respectively.
3. System Model

3.1 UWB radar system

In this subsection, the proposed UWB radar system is described. The model used in the simulation is shown in Figure 3, and the radar system is shown in Figure 4.

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As shown in Figures 3 and 4, vehicle B transmits a UWB signal toward the target vehicle (vehicle A in the figure), then the round-trip time of the reflected signal from the target vehicle is measured and the distance to the target vehicle is calculated. The distance to the target vehicle, the resolution of the distance, the round-trip propagation time of the transmitted signal, the pulse width, and the velocity of light are denoted by $R$[m], $d$[m], $T$[s], $\tau$[s], and $c = 3 \times 10^8$[m/s], respectively. In addition, they are related by the following formulas.

\[
R = \frac{\tau c}{2} \tag{3}
\]

\[
d = \frac{\tau c}{2} \tag{4}
\]

3.2 UWB radar system with IVC

In this subsection, the proposed UWB radar system combined with IVC is described. This system is shown in Figure 5.

The target vehicle A receives the signal from vehicle B. After a certain period of time after receiving the signal, vehicle A sends back its own information to vehicle B. Then vehicle B receives the IVC signal from vehicle A and demodulates it to obtain information on vehicle A. Moreover, vehicle B is able to perform additional ranging using the received IVC signal. The IVC signal has the same format as the radar, and even when vehicle A does not have a receiver, the distance can be measured by the radar. The time until vehicle A sends back the signal can be determined freely in the simulation. Since the interference vehicles are assumed as those within 100m of vehicle B, it is necessary to avoid interference with reflected waves from these vehicles. Therefore, the time before the signal is sent back is set to 0.5$\mu$s in this paper.

3.3 Receiver structure

The receiver structure of the proposed UWB radar system combined with IVC is shown in Figure 6.

At the receiver, the signal is observed for a certain period of ranging time, a threshold judgment is carried out at each correlator, and the signal is detected. After that, distance measurement and data demodulation are performed using the detected signal. If the appropriate value of the output is not found by threshold detection, the received signal is discarded.

In this system, the so-called “near-far problem” occurs
due to interference vehicles. For the case that the number of interference vehicles, \( N_{IV} \), is increased, the detection rate of the signal and the bit error rate (BER) performance in this system are respectively shown in Figures 7 and 8 and the simulation parameters are shown in Table 1. As shown in Figures 7 and 8, the system can achieve good reception characteristics within a distance of up to 90m.

In this paper, M sequences are assigned to each vehicle to perform multiple access. As shown in Figure 3, if the distance from each vehicle is different, the received power from each vehicle is also different. Therefore, the likelihood of the near-far problem increases and the detection rate of the signal and the BER performance are degraded.

![Figure 7: Detection rate against distance](image)

![Figure 8: BER against distance](image)

| Table 1: Simulation parameters |
|-------------------------------|
| Channel Model | Free Space Loss Model |
| Pulse Width | 1ns |
| Center Frequency | 26GHz |
| Bandwidth | 4GHz |
| PN Code | M Sequence (Length: 127) |
| Data Modulation Scheme | BPSK |
| Error Correcting Code | Convolutional Code (Constraint length: 7, Rate: 1/2) |
| Reflection Loss | 3dB |
| Transmission Power | -41.3dBm/MHz |
| Noise | AWGN (-103dBm) |
| Number of Interference Vehicles | 0-7 |
| Antenna | Isotropic Antenna (Gain: 0dB) |
| Number of Simulations | 20000 |

3.4 Proposed system

In order to reduce the influence of the near-far problem, iterative detection using SIC is proposed. A block diagram of the SIC system is shown in Figure 9.

First, the received signal is passed to each correlator, and the signal whose power is largest among them is detected and demodulated. Then, a replica signal of the demodulated signal is regenerated and subtracted from the received signal. By repeating this operation until the signal whose power is smallest is detected, multiple signals can be detected in descending order of power to improve the reception characteristics.

Next, the iterative detection using SIC is described. The block diagram is shown in Figure 10.

Among the detected signals, signals other than the desired signal are subtracted from the original received signal in ascending order of power, and the subtracted received signal is passed to the correlator of the desired signal to detect and demodulate the desired signal. By subtracting other signals that interfere with the desired signal, it is possible to reduce the influence of the interference.
4. Results of Simulation

4.1 Simulation parameters
The proposed system is evaluated by computer simulations for the case that the number of interference vehicles increases. The simulation parameters are also those in Table 1.

4.2 Performance of the proposed system
For the case that interference vehicles exist, the detection rate of the desired signal and the BER performance in the proposed system are shown in Figures 11 and 12, respectively. The number of interference vehicles is seven.

As shown in Figures 11 and 12, both the detection rate and the BER characteristic improve as the number of subtractions in the SIC increases. It can be seen that the characteristics are markedly improved by performing the subtraction up to four times. However, as shown in Figure 12, the improvement of the BER performance is small at a short distance. Since the received power is very large from a vehicle at a short distance, subtraction of the erroneous signal is considered to have a large influence on the demodulation result.

5. Conclusions
In this paper, a TWR scheme was proposed and evaluated by computer simulations. It was found that the proposed scheme realizes better reception characteristics up to a distance of 90m. However, the reception characteristics are degraded when the number of interference vehicles increases. To reduce the interference from other vehicles, an SIC scheme was proposed. When SIC is performed, it is possible to improve the reception characteristics in the near field up to 90m even if seven interference vehicles exist.

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