Frequency Hopping Ultra Wideband Inter-Vehicle Radar System Using Chirp Waveforms

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***Abstract*— In this paper we propose a inter-vehicle UWB ranging system using chirp waveforms instead of the conventional UWB-IR ranging system that uses modulated gaussian pulse. In the proposed system, the transmitted signal consists of a linear combination of chirp signals with the same time duration but different frequency bands. It is assumed that The channel model of inter-vehicle communication system is a two-path channel model. The proposed system and conventional UWB-IR ranging system is evaluated in such a two-path channel model. The proposed system achieve better performance.**

***Index Terms*— UWB, ITS, Radar, Chirp waveform**

I. Introduction

Recently, advanced traffic systems such as Intelligent Transport Systems (ITS) has attracted much attention. Such an ITS can improve traffic safety and efficiency by networking information of road facilities and vehicles by current technology. The prevention of traffic accidents is the major purpose of ITS, where the technologies to achieve this goal are ranging, road conditions sensing and road operation controlling. This paper proposes a novel UWB ranging system and its performance analysis.

The UWB radar system used by the USA Army transmits very short pulses intermittently, occupying an extensive frequency band. This system is robust against interference from other systems and provides a high time-resolution. Since vehicular radar requires high-precision technologies, range resolution and interference resistance, UWB as a good candidate that satisfies these requirements [1],[2].

But there is concern that a UWB signal can potentially interferes other existing communication systems. Thus the Federal Communications Commission (FCC) of USA created a spectrum mask which restricts the power emission of UWB systems. For transmissions UWB vehicular radar systems the spectrum mask allows from 22GHz to 29GHz. The proposed UWB ranging system using chirp waveform is evaluated from 1GHz to 4GHz in a first approach [3].

Chirp signals for inter-vehicle ranging systems allows a different method for identifying and locating users compared to the conventional time hopping structure. In the proposed scheme, the transmitted signal consists of a linear combination of chirp signals with the same time duration but different frequency bands. Their combination pattern is determined by a Pseudo Noise (PN) sequence.

On the road the received signal consists of the direct signal and the signals reflected from the walls, other cars and the road. So the channel model can be assumed a multi path channel. The signal reflected from the road causes a great degradation of the received signal because the difference in the direction of arrival between the direct signal and the reflected signal is small and so the amplitude of the reflected signal near the direct signal. Consequently, the channel model of inter-vehicle ranging system is modeled as a two-path channel model.

The proposed system is compared with a conventional UWB-IR radar system in the 22-27GHz band by computer simulations. The comparison criterion is the rate of ranging errors and the rate of non-detected measurements. The gaussian monocycle used in UWB-IR systems have a low band spectrum, so it isn't suitable for vehicular radar systems. In this simulations modulated gaussian pulse is applied for UWB-IR ranging system.

The simulation results show that the ranging error rate of the proposed system is better than the UWB-IR ranging system and has less non-detected rate than the UWB-IR ranging system.

II. Two Path Channel Model

Fig.1 shows the propagation scenario of the inter-vehicle communication system. The received signal consists of the direct signal and the signals reflected from the walls, other cars and the road. The signal reflected off the road causes a great degradation of the received signal because the difference in the arrival of direction between the direct signal and the reflected signal is small. The difference of time of arrival between the direct and reflected signal is small as well. So the UWB signal can't distinguish between both signals.

Fig.2 shows an image of two path channel model. In the

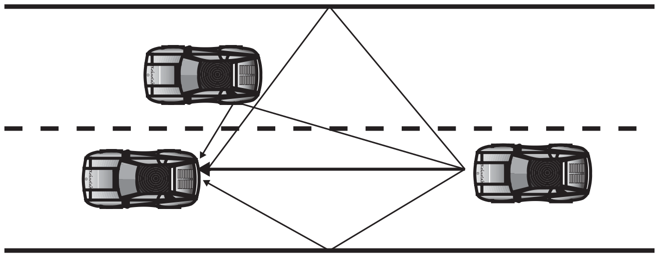

Fig. 1. Multi path propagation model

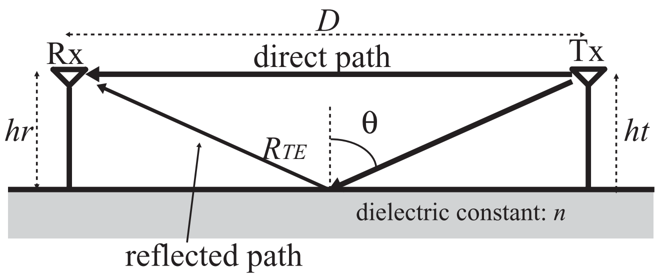

Fig. 2. Two path channel model

free space propagation the received power $P(D)$ is given by

$$P(D) = P_t + 20log\left(\frac{4\pi D}{\lambda}\right) \text{ [dB]} \quad (1)$$

where D_t is the transmitted power, D is the distance and λ is the wave length. The angle of arrival θ is given by

$$\theta = \arctan\left(\frac{D}{h_t + h_r}\right) \quad (2)$$

where h_t is the transmission antenna length, h_r is the reception antenna length, and Δd is the path difference.

$$\Delta d = \frac{h_t + h_r}{\cos\theta} - \sqrt{(h_t - h_r)^2 + D^2} \quad (3)$$

The road's asphalt is assumed to have a dielectric constant $n = 2.00 - j0.05$ [4]. If a signal has vertical polarization, a reflection parameter R_{TE} is given by

$$R_{TE} = \frac{\cos\theta - \sqrt{n - sin^2\theta}}{\cos\theta + \sqrt{n - sin^2\theta}} \quad (4)$$

So the received signal $r(t)$ is

$$r(t) = t(t) + R_{TE}t\left(t - \frac{\delta d}{c}\right) \quad (5)$$

where, $t(t)$ is the transmitted signal and c is the speed of light.

III. UWB-IR Ranging System

UWB-IR ranging system transmits modulated gaussian pulses with a time hopping structure [1].

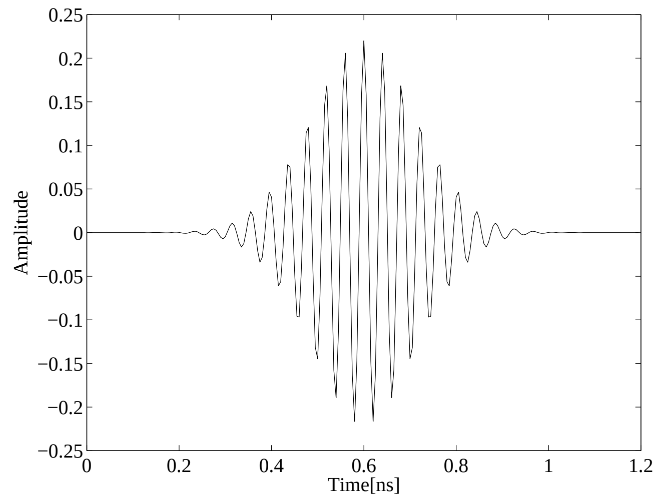

Fig. 3. Modulated Gaussian Pulse

A. Modulated Gaussian Pulse

The UWB signal must adapt its spectrum to the spectrum mask issued by FCC. A band base impulse signal can't be used in the 22-29GHz. So, a modulated gaussian pulse is used for UWB-IR system [5]. Fig.3 shows a modulated gaussian pulse waveform. It can change its center frequency and frequency width band. The modulated gaussian pulse $r(t)$is given by

$$r(t) = \cos(2\pi f_k t) \times exp\left\{-\alpha\left(\frac{t}{\tau_m}\right)^2\right\} \quad (6)$$

where f_k is the center frequency, α and τ_m are the parameters of the frequency width band.

B. Transmitter's Description

The transmitted signal $f(t)$ is given by

$$f(t) = \sum_{j=0}^{N_s-1} \delta(t - jT_f - c_jT_c) \quad (7)$$

where, $\delta(t)$ is the generated impulse signal, T_f is the frame time, T_c is the time slot, c_j is a Time Hopping (TH) sequence, and N_s is the number of frames transmitted.

C. Receiver's Description

The received signal, f_{rec}, is given by

$$f_{rec}(t) = \sum_{j=0}^{N_s-1} \omega(t - jT_f - c_jT_c) + n(t) \quad (8)$$

where $n(t) \sim \mathcal{N}(0, \sigma^2)$.

At the receiver, the time hopping sequence is assumed to be known, and the template function to be correlated with the received signal is assumed to be $\omega(t)$. Thus the signal generated at the receiver, $f_{rep}(t)$, is given by

$$f_{rep}(t) \quad = \quad \sum_{I=0}^{N_s-1} w(t - iT_f - c_i T_c) \tag{9}$$

$R(\tau)$is the correlation function between $f_{rec}(t)$ and $f_{rep}(t)$. which is calculated as

$$R(\tau) \quad = \quad \int_{-\frac{N_s T_f}{2}}^{\frac{N_s T_f}{2}} f_{rec}(t) f_{rep}(t+\tau)\, dt \tag{10}$$

where, τ is is time delay between the transmitted signal and the received signal, also known as jitter. The distance between the transmitter and target vehicle can be calculated from this time delay τ and described in Section IV.

IV. UWB Ranging System Using Chirp Waveform

The block diagram of the proposed system is shown in Fig.4. This system uses liner combination of multiple chirp waveforms. The combination is decided by PN sequence, which is assigned to each user.

A. Description of the Chirp Waveform

The linear FM chirp waveform is represented by

$$s(t) = \begin{cases} \sin(2\pi f_0 t + \frac{1}{2}2\pi\mu t^2) & |t| < \frac{T}{2} \\ 0 & otherwise \end{cases} \tag{11}$$

where, μ is the frequency sweeping rate, f_0 is the center frequency, T is the length of chirp waveform, and Δf is frequency sweeping range. So that $\mu = \Delta f / T$.

B. Transmitter's Description

The transmitted signal of the proposed system consists of N up-chirp and N down-chirp waveforms.

- The time duration of all chirp waveforms is T.
- The available spectrum F is divided into N bands such that the frequency response of every chirp waveform occupies an individual band.

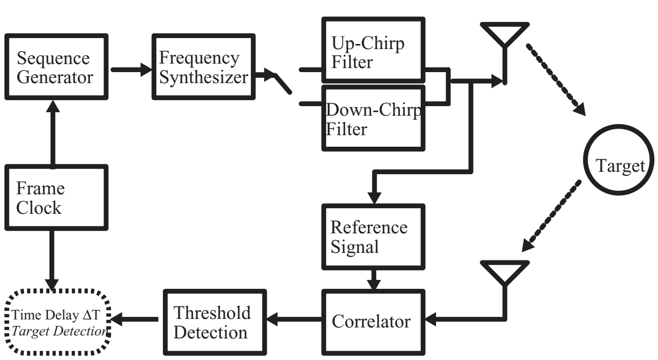

Fig. 4. Block diagram of proposed ranging system

TABLE I

PARAMETER OF CHIRP WAVEFORMS

c_j	α	f_{c_j}[GHz]	c_j	α	f_{c_j}[GHz]
1	1	22.3125	9	-1	22.3125
2	1	22.9375	10	-1	22.9375
3	1	23.5625	11	-1	23.5625
4	1	24.1875	12	-1	24.1875
5	1	24.8125	13	-1	24.8125
6	1	25.4375	14	-1	25.4375
7	1	26.0625	15	-1	26.0625
8	1	26.6875	16	-1	26.6875

The bandwidth of each chirp waveform Δf is given by

$$\Delta f = \frac{F}{N} \tag{12}$$

The transmitted signal $m(t)$ is given by

$$m(t) \quad = \quad \sum_{j=0}^{N_s-1} s_j(t - jT) \tag{13}$$

where

$$s_j(t) = \sin\left\{2\pi f_{c_j}\left(t - \frac{T}{2}\right) + \pi\alpha\mu\left(t - \frac{T}{2}\right)^2\right\} \tag{14}$$

wN_s is the number of transmitted chirp waveforms, $\mu = \Delta f / T$ is the frequency sweeping rate, s_j is jth chirp waveform, f_{c_j} is the center frequency. $\alpha = 1$ means up-chirp, $\alpha = -1$ means down-chirp. f_{c_j} and α are changing according to a PN sequence given by c_j. A different PN sequence is assigned to each user. TableI shows the parameter of the chirp waveform employed. Each chirp waveform is chosen such that its frequency response goes up from $f_{c_j} - \frac{\Delta f}{2}$ to $f_{c_j} + \frac{\Delta f}{2}$ (linear up-chirp) or goes down from $f_{c_j} + \frac{\Delta f}{2}$ to $f_{c_j} - \frac{\Delta f}{2}$ (linear down-chirp).

Fig5 shows the proposed system's transmitted signal. Each chirp waveform, which has different frequency band is frequency orthogonal. Moreover a up-chirp waveform and down-chirp waveform which have the same frequency band is pseudo frequency orthogonal.

C. Receiver's Description

The received signal is given by

$$m_{rec}(t) = m(t) + n(t) \tag{15}$$

where $n(t) \sim \mathcal{N}(0, \sigma^2)$.

A replica of the transmitted signal is generated at the receiver and given by

$$m_{rep}(t) \quad = \quad \sum_{j=0}^{N_s-1} s_{c_j}(t - jT_f) \tag{16}$$

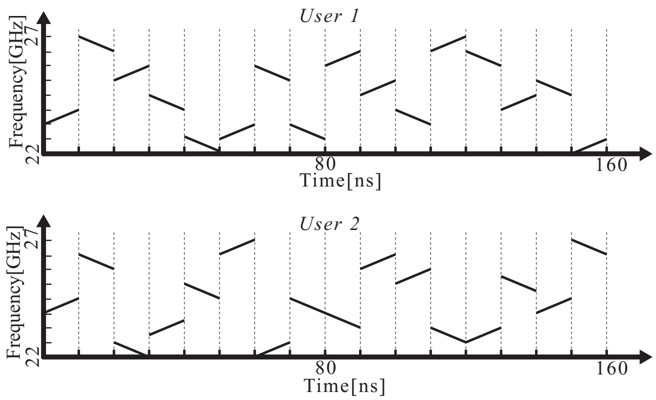

Fig. 5. Transmitted signal of the proposed system

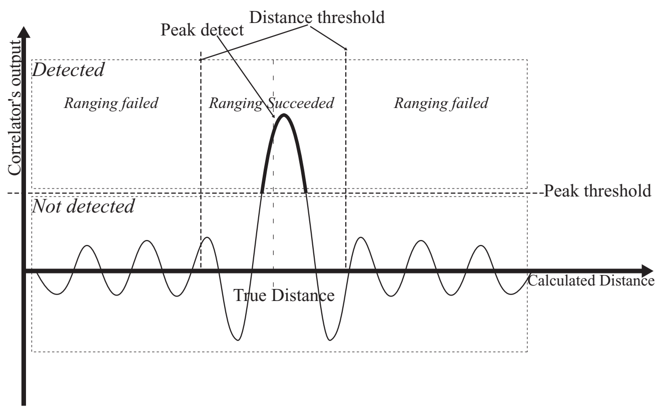

Fig. 6. Threshold detection

The correlation between of $m_{rec}(t)$ and $m_{rep}(t)$ is calculated as

$$R(\tau) = \int_{-\frac{N_s T_f}{2}}^{\frac{N_s T_f}{2}} m_{rec}(t) m_{rep}(t+\tau)\, dt \qquad (17)$$

The distance between the transmitter and target vehicle D can be calculated by this time delay τ as

$$D = \frac{c\tau}{2} \qquad (18)$$

where c is the speed of light.

D. Threshold Detection

A threshold detection was carried out at the correlator's output. When the peak correlation don't exceed the peak threshold, the transmitted signal isn't detected. If the peak's time width exceed the distance threshold, it is declared erroneous distance measurement.

TABLE II

PARAMETERS OF SIMULATIONS

Number of Measurements	10000
Length of chirp waveform T	10ns
Number of Vehicles	5
PN Sequence	gold sequence
Available Band Width F	5GHz (22GHz to 27GHz)
Chirp waveform bandwidth Δf_n	0.625GHz
Number of Chirp Waveforms	16
Number of Pulse Repetition Ns	20
Channel Model	2-path
Ranging Distance	5-20m
Polarization	vertical
Peak Threshold	max output$\times 1/\sqrt{2}$
Distance Threshold	30cm
Antenna Height h_t,h_r	0.5m

V. Performance Evaluation

In this section, the proposed system's performance as ranging error rate and non-detected rate is compared respect to the conventional UWB-IR ranging system.

A. Definition of Ranging Error Rate

The ranging error rate is defined as

$$\frac{\textbf{number of erroneous distance measurements}}{\textbf{total number of detected distance measurements}} \qquad (19)$$

B. Parameters of simulations

The simulation parameters of both systems are shown in Table II. The detection of distance is considered to be erroneous when it differs by 30cm or more from the true distance. Peak threshold is set up $\sqrt{2}$ of the maximum correlator's output. The ranging distance was varied from the 5m to 20m.

C. Ranging Error Rate Performance

The ranging error rate performance of 5 users is shown in Fig.7. It illustrates that the ranging error rate of the proposed system is better than the conventional UWB-IR ranging system.

The proposed system employs a frequency hopping technique, where frequency diversity gain is achieved. Moreover the proposed system consists of multiple waveforms. So, it can reduce sidelobes at the correlator's output. Consequently it can distinguish other vehicles radar signals as well.

D. Non-detected Rate Performance

The non-detected error rate performance for both systems in a 5 users senario is shown in Fig.8. It shows that the UWB-IR ranging system has a higher non-detected rate than the proposed system. Because in the conventional system correlator's output is decreased due to the interference from other vehicle's radar signals. The radar system for ITS applications requires a high quality and low non-detected error performance is desired.

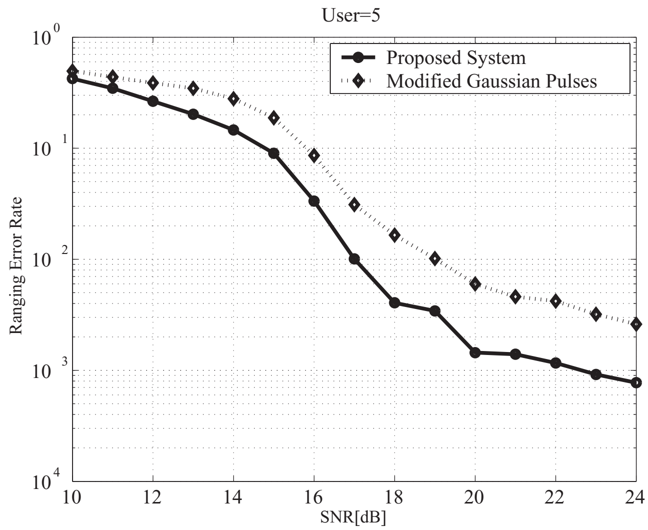

Fig. 7. Ranging Error Rate versus SNR in a 5 users environment

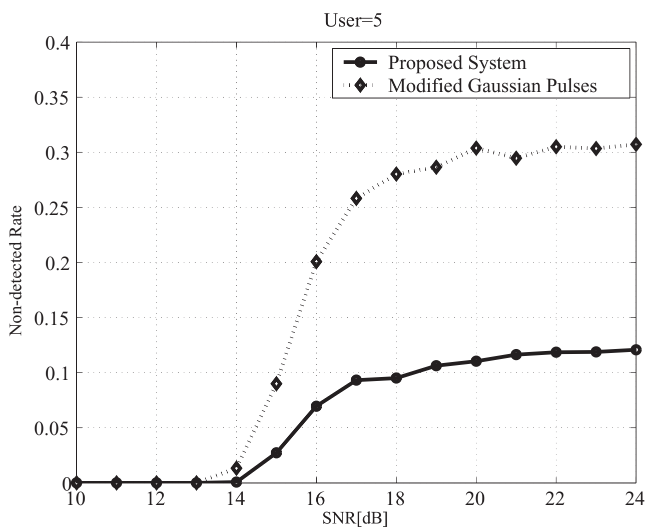

Fig. 8. Non-detected Rate versus SNR in a 5 users environment

VI. CONCLUSION

This paper evaluated a UWB radar system based on a linear combination of chirp signals. It is shown the ranging error rate of the proposed system is better than the UWB-IR ranging system. The proposed system has a lower non-detected rate than the conventional UWB-IR ranging system. So the proposed system is suitable for ITS applications.

Future research will consider the proposed system's performance of a multi target detection strategy, and the impact on the performance due to interference from other radar systems.

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