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Proposing adaptive PN sequence length scheme for testing non-destructive structure using DS-UWB

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***Abstract*—The ultra wideband (UWB) technology has many advantages in positioning, measurement systems, however powers of UWB signals rapidly reduces while traveling in propagation environments, especially in concrete or soil propagation environment. Therefore, we proposes an adaptive pseudo random (PN) sequence length searching method of direct sequence ultra wideband (DS-UWB) transmission system for reducing signal processing time while remaining the quality of detection. The proposed scheme measures the depth of non-destructive structure using variable PN sequence length, and then based on the calculated distance errors, the minimum PN sequence length is determined. Simulation results show that both processing time and accuracy could be improved by the proposed scheme.**

***Index Terms*—DS-UWB, PN sequence, distance estimation, non-destructive.**

I. Introduction

Ultra Wide Band (UWB) technology has attracted a lot of researches in radar and communication applications due to its ability to provide high data rates, low cost, low power consumption. The UWB system generally use impulse or nonsinusoidal wave signals in the range of $0.5 \quad 10GHz$ and based on the repetition of short pulses from a single pulse - usually a Gaussian pulse [1]. There fore, UWB signals has extremely low power spectral density, occupy the bandwidth from several hundred MHz (at least $500MHz$) to several GHz, and UWB systems can operate without interference to other radio systems. However, with the FCC regulations making UWB technology not only potential but also other challenges such as limited pulse output power, ... [2]. The UWB system has two typical techniques: one is time-hopping UWB (TH-UWB) technology and the other is direct sequence UWB (DS-UWB) [3]. In the TH-UWB systems, user data is assigned into time frames and pulse position modulation (PPM) is used to avoid the conflicts in multi-user communication networks [4]. Besides that, in the DS-UWB techniques, the spreading codes is used similar to traditional direct-sequence spreading spectrum (DSSS) techniques, so they have the advantages of DSSS techniques, such as reduce impulse power which is limited by FCC, and increase bandwidth efficiency [5].

In wireless sensor networks, DS-UWB systems performance is significantly reduced due to inter symbol interferences (ISI) and multi-access interferences (MAI) [6], [7], [8]. There are many studies have focused to reduce the impact of ISI and MAI for DS-UWB systems based on the generator pulses using multi-carrier [3], [9], [10], or wavelet transform signals [11], or proposing algorithms to estimate the signal-to-noise ratio for DS-UWB wireless sensor network [12], [13]. DS-UWB techniques also have many applications in telemedicine [14], [15], distance measurement [16], [17], [8], ...

In the distance measurement systems using DS-UWB technology, to improving the processing time and reducing the mean distance measuring error, the variation of the spreading sequence length is studied in [16], and the repeatition of a fixed spreading sequence length is presented in [17], [8]. In [16], to determine the distance in vehicle radar systems, the DS-UWB configuration using five variable PN lengths (15, 31, 63, 127, 255) is proposed. The performance of this configuration is compared to conventional DS-UWB systems which using a fixed- spreading code length in term of the mean processing time and distance estimation error. With the use of proposed method, the average processing time and the mean value of the distance errors both are reduced. However, the authors have not mentioned the cases of which the measurement distances are changed during processing time and the maximum detectable distance is constrained by the number and length of selected spreading sequences.

Besides that, in the short-range radar (SRR) system, Seung Goo Kang *et al* in [17] proposed a distance measurement scheme based on repeted PN sequence for DS-UWB technique and the length of PN sequence is selected according to standard deviation of estimated distances. Simulation is implemented with a PN sequence length of 15 and the results are compared to scheme in [16] in terms of the detection range and distance measurement errors in the SRR system. The proposed method in [17] reduced the distance measurement time while keeping the effect of distance estimation in comparison to [16]. However, the scheme still requires long length PN sequences at low SNR because the standard deviation becomes larger at lower level of SNR.

So, in the DS-UWB ranging systems, the use of speading sequences are important to decide their properties and ranging performance. The distance measuring errors becomes smaller as the length of the PN sequence used in the DS-UWB increases [5], [16]. However, with a longer PN sequence length, the processing of distance estimation data will take more

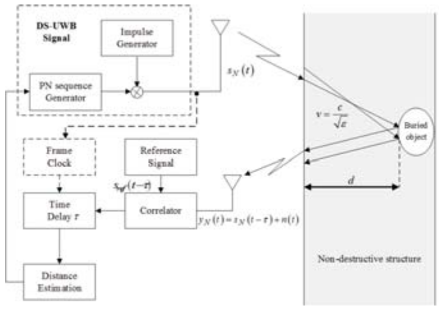


Fig. 1. The block diagram of the proposed distance estimation configuration.

longer time. To reduce the mean correlation processing time in distance estimation using DS-UWB technique, in a different way, the PN sequence length is changed in accordance with the detectable distance. The proposed scheme is used to determine the appropriate length of PN sequence according to the depth of the non-destructive structures (concrete, soil, ...). Simulation results show that the mean processing time of the proposed method is reduced in comparison to conventional DS-UWB systems and errors of estimated distance is calculated to evaluate the performance of the scheme.

The rest of the paper is organized as follows. Section II introduces the DS-UWB system and in section III, performances of the proposed distance measuring scheme. Simulation results are presented in Section IV, and finally, section V concludes the paper.

II. DS-UWB RADAR SYSTEMS

The system model of the proposed distance estimation configuration is shown in Fig. 1. A DS-UWB radar system is used to transmit a chain of impulse modulated by PN sequence, $s_N(t)$, through a non-destructive structure with a depth of d. The signal is reflected and returned to the receive antenna with a delay corresponding to the distance. The received signals are detected by the matched filter, and the estimated distances can be calculated from the delay time between the transmitted and received signals. Assuming that the environment is homogeneous, the dielectric constant of it is ϵ. The transmitted and the received signals are respectivelly denoted by $s(t)$ and $r(t) = s(t-\tau)$. Because the delay of received signal is twice of propagation time from the transmit antenna to the object, hence the depth d is given by:

$$d = \frac{c\tau}{2\sqrt{\epsilon}}. \tag{1}$$

where c is the velocity of light, and ϵ is dielectric constant.

A. Transmitted signals

The transmitted signal for DS-UWB $s_N(t)$ using the spreading sequence has the length of N is presented by:

$$s_N(t) = \sqrt{E_c}\sum_{i=0}^{N-1} p_i g(t - iT_c), \tag{2}$$

where E_c, T_c, p_i are the chip energy, chip width, and $i-$th component of a PN sequence with a length of N, respectively; $p_i \in \{-1, 1\}$, $g(t)$ represents the transmitted monocycle waveform (the second derivative of Gaussian pulse) normalised to have unit energy as bellows.

$$g(t) = \left[1 - 4\pi\left(\frac{t}{\tau_p}\right)^2\right] e^{-2\pi(\frac{t}{\tau_p})^2}, \tag{3}$$

where τ_p is a time normalization factor to make $g(t)$ independent of a specific impulse duration [18] and is calculated from pulse width.

B. Received signal

The transmitted signal $s_N(t)$ through the non-destructive which has the deep of d and returned to the receiver with a time delay τ. The received signal $r(t)$ can be expressed as:

$$r(t) = s_N(t - \tau) + n(t), \tag{4}$$

where $n(t)$ is the additive white Gaussian noise (AWGN) with double sided power spectral density of $N_0/2$. And the reference signal, $s_{ref}(t)$, is given by:

$$s_{ref}(t) = \frac{1}{\sqrt{E_c}}\sum_{i=0}^{N-1} p_i g(t - iT_c), \tag{5}$$

The output of correlator block $R(\tau)$ between $r(t)$ and $s_ref(t)$ is calculated as

$$R(\tau) = \int_{-\frac{NT_c}{2}}^{\frac{NT_c}{2}} r(t)s_{ref}(t-\tau)dt \tag{6}$$

The depth of non-destructive testing (NDT) can be estimated from the delay time τ from Equation 1.

III. ADAPTIVE PN SEQUENCE LENGTH FOR DS-UWB RADAR SYSTEMS

A. Required PN sequence length corresponding to distance

In a DS-UWB ranging system, the relation between required spreading sequence length (RSSL) and distance to the target is calculated as follows [19].

$$L = 10^{\frac{\mathrm{SNR}}{10}} \frac{(4\pi)^3 d^4 N_0}{P_t G^2 \lambda^2 \sigma}, \tag{7}$$

where L, SNR, d, N_0, P_t, G, λ, and σ are, respectively, the spreading sequence length, signal to noise ration, distance to the target, noise power, transmitted peak power, antenna gain (assuming that the gain of both the transmitter and receiver antennas is equal), wave-length, and radar cross section. The RSSL is continuous according to (7) and shown in Fig. 2. However, the length of spreading sequence used for DS-UWB scheme is not generally continuous, for example, when spreading sequence is PN sequence, the length of PN sequence N_m is calculated as bellows.

$$N_m = 2^m - 1, \tag{8}$$

where m is order of PN sequence.

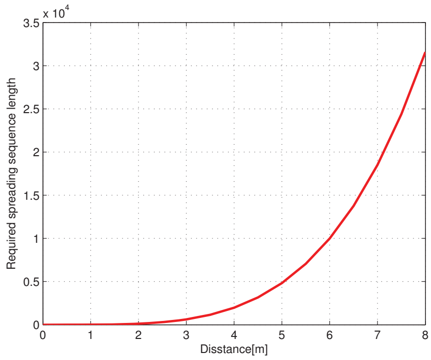


Fig. 2. RSSL and distance to target with center frequency is 5GHz, P_t/N_0 is 30 dB, antenna gain is 30 dB, radar reflection area is $2m^2$ and SNR=1 dB.

B. Minimum PN sequence length searching method

The proposed method is linear searching method and shown in Fig. 3. This is an algorithm is used to search a PN sequence which has minimum length according to the depth of non-destructive structure. The searching is started with the shortest

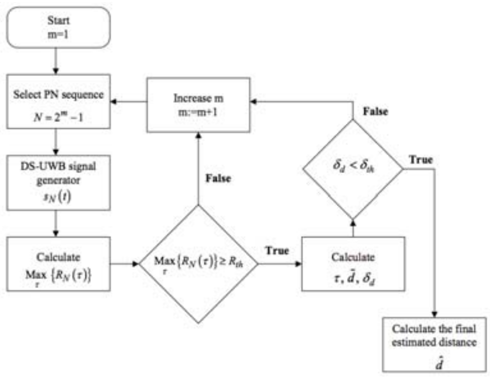


Fig. 3. The algorithm of searching PN sequence length and estimation the distance.

sequence (length of PN sequence equal three) and increase the length one-by-one. The maximum value of the correlation function $R_N(\tau)$ is calculated according to the length of the PN sequence, τ, and compared to the threshold value R_{th}. This threshold value is selected depending on the depth of the NDT structure. If the maximum value of $R_N(\tau)$ is larger than R_{th}, the estimation of delay time $\hat{\tau}$ is obtained as bellows.

$$\hat{\tau} = arg \ \max_{\tau}\{R_N(\tau)\}, \tag{9}$$

otherwise, the comparison procedure resumes with longer PN sequence and newly transmitted signal $s_N(t)$. Once a delay time is calculated, the depth $\tilde{d}$ of NDT is estimated according (1). To achieve a more accuracy distance estimate, the standard deviation σ_d of the K distance estimates is compared with a

TABLE I
SIMULATION PARAMETERS

Parameter	Notation	Value
Chip Width	T_c	0.2 ns
Time normalizatin factor	τ_p	0.28 ns
Impulse Width	T_p	0.8ns
Dielectric constant	ϵ	2.5

threshold σ_{th}. If σ_d is less than σ_{th}, the final distance estimate $\hat{d}$ and the minimum length of PN sequence is determined; otherwise, the searching process is repeated with increasing m by 1. When the accuracy of distance estimation increases, the standard deviation σ_d decreases accordingly, and in order to reduce the processing time in the correlation process, the minimum PN sequence is selected depending on the detected distance. This PN sequence is used to modulated the transmitted signal to test and identify buried object in non-destructive environment. When the depth of NDT is comparatively small, the proposal method could reduce processing time in updating of ranging data because a minimum length PN sequence is used. Therefore, the proposed method could be used for testing and measuring a non-destructive structure with a higher precision and more reliably than the conventional using a fixed length PN sequence.

IV. Simulation Results

A. Simulation parameters

In this section, performance of proposed method is evaluated based on computer simulations. The simulation parameters are shown in Table 1 where the time normalization factor equal $1/2.5$ of pule width with the second order Gaussian pulse. In the simulation, the PN sequences have an increasing length from the minimum value of 7, the maximum value of the correlation function in (6) is determined with each PN sequence. Then, the estimation of the non-destructive structures depth (detection distance) and the distance measurement error are calculated according to (1) and (12). The channel model used is AWGN. The ranging is successful if the distance measurement error is equal to or less than the threshold value, the length of corresponding PN sequence and the detection distance are saved.

The pulse shape used is the second derivative of Gaussian pulse. According to (3), the autocorrelation function of this pulse is obtained as

$$R(\tau) = \left[1 - 4\pi(\frac{\tau}{\tau_p})^2 + \frac{4\pi^2}{3}(\frac{\tau}{\tau_p})^4\right] e^{-\pi(\frac{\tau}{\tau_p})^2}. \tag{10}$$

The 2nd Gaussian pulse shape and its autocorrelation function $R(\tau)$ are shown in Fig.4 and 5, respectively.

B. The length of PN sequences corresponding to the distances

Firstly, the length of the PN sequences determined from the proposed method are compared to the length of the spreading sequence used in the conventional UWB radar system. The simulation results are shown in Fig. 6. In conventional systems,

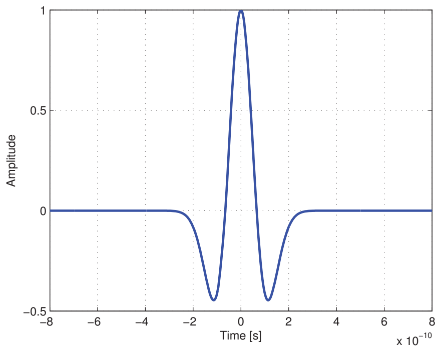


Fig. 4. The 2nd Gaussian pulse shape.

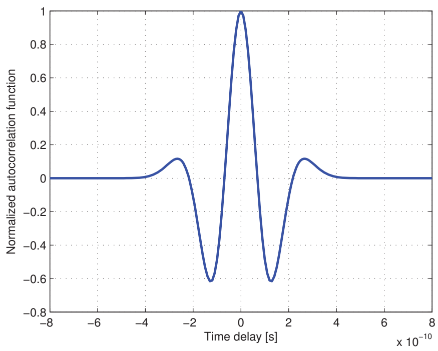


Fig. 5. Autocorrelation function of the 2nd Gaussian pulse.

the length of the spreading sequence is continuous theoretically and the PN sequence length is shortened in the proposed one. When the detection distance is short-range, the shorter PN sequence is used, so the proposed method could speed up the updating of the ranging data. Therefore, the proposed method could measure the depth of non-destructive structures with more reliability and accuracy than conventional DS-UWB systems using a fixed length spreading.

C. Evaluating the proposed method based on processing time

The signal processing time T_p of the DS-UWB system is defined [16] as

$$T_p = 2LT_cK, \tag{11}$$

where L is the spreading sequence length, T_c is the chip width and $K = 50$ is repetition number. Fig.7 shows that the signal processing time is shorter when using the proposed method compared to conventional one. In order to detect the depth of the non-destructive structure, the searching of a desired length by increasing gradually from the smallest value known as the linear search method. With depths in short range ($< 30m$), the algorithm could rapidly search the desired sequence because

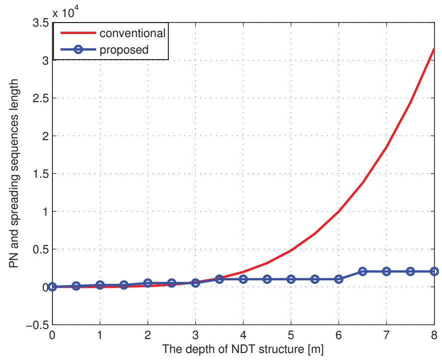
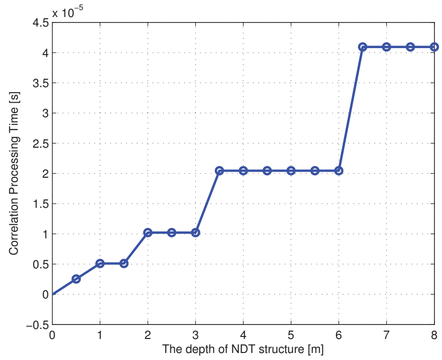
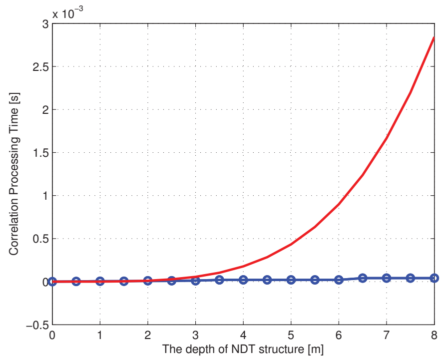


Fig. 6. Relation between required spreading sequence length and distance in the cases of theory and proposed scheme.



(a)



(b)

Fig. 7. Processing time of the proposed scheme (a) and in comparison with the conventional system (b).

there is not so much difference between those PN sequence lengths.

D. Evaluating the proposed method according to the distance measurement error

The measurement distance errors are obtained as

$$\Delta d = \sqrt{\frac{1}{K}\sum_{k=1}^{K}(\hat{d}_k - d_0)}, \qquad (12)$$

where $\hat{d}_k$ is the estimation distance calculated from the time delay which make the $k-$th correlation function is maximum and d_0 is the actually value. The performance of the system is evaluated based on the difference between the distance estimated by the proposed and its actual value after K repetitions ($K = 50$ in the simulation). In Fig.8, the mean value of the errors of estimation in the proposed method is less than 10% of the maximum detection distance [8]. And it also smaller in compared to DS-UWB system error for SRR [16] which has the mean distance measuaring errors of approximately $0.14m$, and $0.5m$ [17] while the average error of the proposed method is about $0.02m$. It is because in the proposed method, the PN sequence length chosen adaptively according to the detection distance, while in [17], [8] use the repeated fixed length ($N = 15$). In addition, the signal processing time and

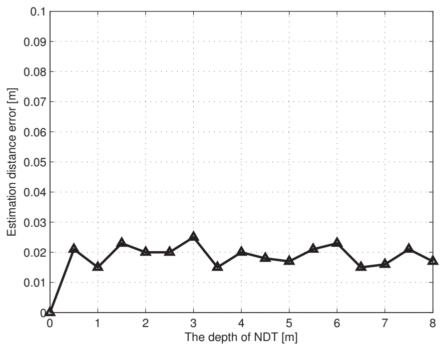


Fig. 8. Errors of the estimated distances of the proposed method.

distance estimation accuracy are constant in the conventional DS-UWB system. The proposed method has an advantage over the conventional one, it reduces the processing time when keeping the distance errors within in allowed range.

V. Conclusion

In this paper, we have proposed a method which measure the depth of the non-destructive structures (concrete walls, soil, stone, ...) using the DS-UWB system with variable PN lengths coresponding to the depth. Determining the length of the PN sequence to purpose speed up the processing time and reducing the errors of estimation. The length of PN sequence, the processing time, and errors of estimation are used as parameters to evaluate the performance of the proposed method. The simulation results show that the proposed scheme performs better than conventional systems in term of processing time and also has shorter RSSL. In addition, our proposed scheme can be applied to explore the non-destructive structures which are homogeneous environments. In future studies, based on signal processing, the location as well as the classification of buried objects will be determined.

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