Long Range Detection of UWB Radar using Inter-pulse Cyclic Phase Code

Masato Watanabe[1], Manabu Akita[1], Takayuki Inaba[1]
[1]Department of Mechanical Engineering and Intelligent Systems, Graduate School of Informatics and Engineering,
The University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan
watanabe.masato@inabalab.ee.uec.ac.jp

Abstract – UWB impulse radar is generally used just for short range measurements because of transmitted power restrictions and due to its ultra wide bandwidth. In this paper, we consider the advantage of the coherent integration between pulses. The transmitted energy can be increased by adopting short PRI mode. The S/N ratio of the receiving signal is also able to be improved by the coherent integration. We suggest a method for enhancement of long range detection performance of UWB impulse radar using inter-pulse cyclic phase code, which mitigates the range ambiguity problem on short PRI mode. In this method, each transmitted pulse is modulated by P4 code and is modulated by the same phase in intra-pulse. The range of the target is obtained by adding the PRI delay and the corresponding range bin. We show the experimental results conducted on public way using 24GHz radar with power of 10mW based on the specified low power radio station to verify the effectiveness of the method.

I. INTRODUCTION

The ultra wide band (UWB) radar system provides a high performance in spatial resolution. UWB radar transmitted very short pulses at constant pulse repetition interval (PRI). It measures the range of the target from the time difference between the transmitted and received pulses. UWB radar system generally achieves a high performance in spatial resolution by using very short pulses. However, UWB radar is used just for short range measurements because of the transmitted power restrictions and the increasing noise level due to the ultra wideband frequency [1]. Thus a procedure to extend the detection range of UWB radar without increasing the peak power is required, which corresponds to improving S/N in a CPI (coherent processing interval). In this research, we consider the advantage of the coherent integration between pulses. By this procedure, the range detection performance is expected to be enhanced, because the transmitted energy can be increased by adopting short PRI and the S/N ratio of the receiving signal is also able to be improved by the coherent integration. While the short PRI causes a serious problem of the range ambiguity. We cannot identify which transmitted pulses corresponds to the received pulses in the cases of that the delay times of round trip are longer than a PRI. In these cases, we have to resolve the delay on PRI (PRI delay). When the number of PRI delay is enough small using relatively long PRI, we can also estimate the PRI delay by multi-PRI ranging [2] [3], in which the radar transmitted pulses that have different PRI. However, multi-PRI ranging has limitation of the number of targets and it requires relatively long observation time.

On the other hand, the methods to mitigate the range ambiguity problem have reported using inter-pulse phase coding [4] [5]. However, the methods using inter-pulse phase coding in the previous research adopts cross-correlation procedure on whole integration interval (1CPI). The procedure also causes a problem of computation load.

In this paper, we consider the situations that the PRI delays are shorter than 1CPI. The condition setting in this paper is considered to be appropriate as described in Experimental Result section. The phase coding CW radar that transmits multiple cyclic phase codes continuously in a CPI has also been suggested. This method using P3 or P4 [6] [7] makes it possible to estimate the PRI delay by FFT instead of cross-correlation. The result in previous research [8] using this method was based on computer simulations. Experimental results to verify the effectiveness of the method have not been reported.

In this paper, we suggest a method for long range detection of UWB impulse radar using inter-pulse cyclic phase code. We improve S/N to extend the range of UWB radar by high pulse repetition. In this method, each transmitted pulse is modulated by P4 code and is modulated by the same phase in intra-pulse. We calculate the PRI delay at each range bin and then we obtain the range from the target by adding the PRI delay and the range bin. We also show fundamental results of experiment conducted on public way using 24GHz radar with power of 10mW based on specified low power radio station to verify the effectiveness of the method. Finally, we discuss the improvement of S/N between the method proposed in this paper and conventional UWB radar and demonstrate the enhancement of its range detection performance.

II. UWB IMPULSE RADAR USING INTER-PULSE CYCLIC PHASE CODING

The transmitted signal is consisted of N pulses which are phase modulated by $u(n)$. Then the transmitted signal is created by mixing with the carrier signal. Thus transmitted signal is expressed by

$$s(t,n)=\exp[2\pi j(ft)]\cdot u(n)\,, \tag{1}$$

where the transmitted pulse width and PRI are T_p and T_{pri}, respectively. $u(n)$ is given by

$$u(n)=\exp[j\phi_n]. \tag{2}$$

In this research, we adopt P4 given by

$$\phi_n = \frac{\pi}{N}(n-1)^2 - \pi(n-1)\cdot \tag{3}$$

The receiving signal corresponding to the transmitted signal is given by following equation with consideration for the time delay τ and its Doppler shift

$$r(t,n)=\exp[2\pi j(ft+f_d t-f\tau)]\cdot u(n), \tag{4}$$

where τ and f_d are $2R/c$ and $2vf/c$, respectively. R, v, f, and c are the distance from the target, the target velocity, the carrier frequency and speed of light, respectively. The receiving signal is mixed with the local signal. Then we obtain the observed signal, which is given by

$$r(t,n)=\exp[2\pi j(f_d t-f\tau)]\cdot u(n)\cdot \tag{5}$$

The time of 0 corresponds to the initiation time of transmission of the first pulse (n=0). The time delay of each receiving pulse is given by

$$\tau(d,k)=k\cdot\Delta T+d\cdot T_{PRI}, \tag{6}$$

where k is the range bin in the PRI and ΔT is the time interval between range bins. d is the PRI delay. In a CPI, we repeat transmitting the cyclic phase code with N length M times. That means that we transmit and receive N×M pulses.

Then we execute following signal processing for received signals on each range bin. First, we execute FFT in the m direction as shown in figure 2. Then the output is multiplied by the reference signal which is the complex conjugate of transmitted phase code ϕ_n^*. By the procedure, we obtain direct current (DC) in the case of that the phase code of the observed signal coincides with the reference signal. On the other hand, we obtain a sine wave whose frequency depends on the PRI delay. The frequency spectrum depending on the PRI delay is obtained by executing FFT in the n direction for each Doppler frequency.

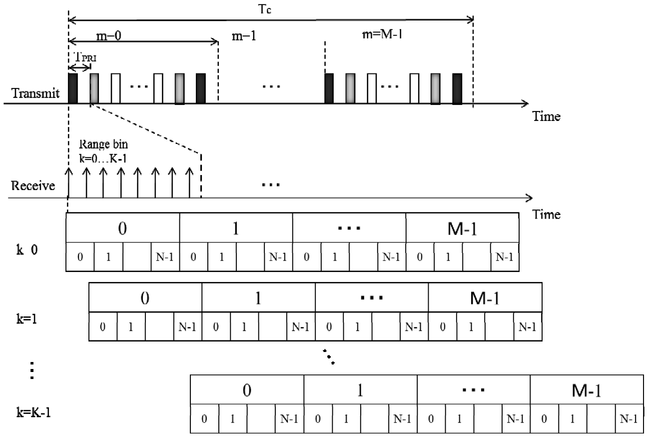


Fig.1 Transmitting signal sequence with inter-pulse phase coding

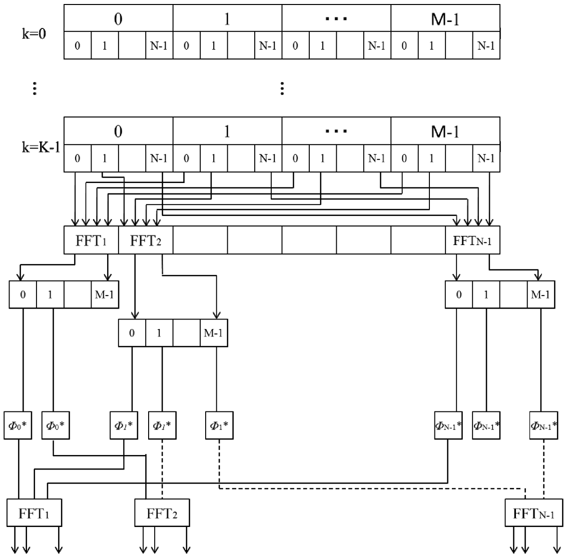


Fig.2 Data processing flowchart of Range/velocity estimation for inter-pulse cyclic phase coding (P4 code)

After a detection procedure by a threshold, we finally obtain the estimated the range from the target by adding the PRI delay and the corresponding range bin.

$$R=\frac{c\cdot(k\cdot\Delta T+d\cdot T_{PRI})}{2} \tag{7}$$

Therefore the maximum instrument range $R_{\max}$ can be expanded to N times of pulse repetition interval.

$$R_{\max}=\frac{c}{2}\cdot T_{PRI}\cdot N \tag{8}$$

III. EXPERIMENTS RESULT

The 24GHz radar with power of 10mW based on the specified low power radio station was used in the experiment on a public way. Table 1 shows the radar parameter. In this experiment, the bandwidth was limited to 50 MHz for a reason of the specification of the hardware. The 24 GHz radar is installed on a bridge for pedestrians with the height of 8.5m above the road as shown in figure 3. The beam center of the antenna is tilted at 10 degree from the horizontal plane. The azimuth and elevation beam widths of the receiving antenna are ±30deg and ±8deg, respectively. As shown in figure 3,

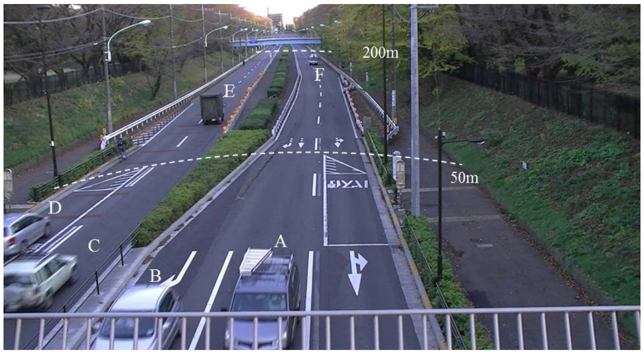


Fig.3 Experimental set up on a bridge for pedestrians

Table 1 Radar Parameter on the experiment

Parameters	Specifications
Transmit Frequency	24.15GHz
Bandwidth	50MHz
Pulse width	20ns (Range：3m)
PRI	80ns (Range：12m)
Code Length N	256
Transmit code	P4 code
Repetition M	1024
Number of Pulse	262144
Coherent Pulse Interval	21msec
Sampling interval ⊿T	10nsec

the targets are the 6 moving vehicles on the road (A-F in figure 3). Figures 4 and 5 show the processing results on k=3 and k=7, respectively. Hamming window is adopted in the FFT procedure for estimating Doppler frequency. The horizontal axes of figures 4 and 5 are relative velocity (Doppler frequency) and PRI delay d. The vertical axis is amplitude in dB. We set the threshold of -49dB that is 13 dB higher than the noise floor level of -62dB. We can identify two peaks in figure 4. One peak is 28 dB higher than the noise floor at -18.0km/h of relative velocity and d=1. The range from the correspondent target is calculated by equation (7). The calculated distance of 16.5m corresponds to target A in figure 3. The other peak is identified at 40.5km/h of relative velocity and d=3. The calculated distance of 40.5m corresponds to target D. We can also identify two peaks in figure 5. We can obtain the peaks at d=2 that corresponds to target C and at d=6 that corresponds to target E. The results indicate that the radar using inter-pulse cyclic phase code can estimate the ranges from the targets that are located at different PRI delay in the same range bin.

Figure 6 shows the processing results for the targets that exist at same PRI delay in different range bins. As shown in figures 6 (a) and (b), the peaks at d=1 are sufficiently higher than the noise floor. The correspondent ranges are 16.5m and 19.5m by adding their range bins. These ranges coincide with the ranges of targets A and B. Thus these results also indicate

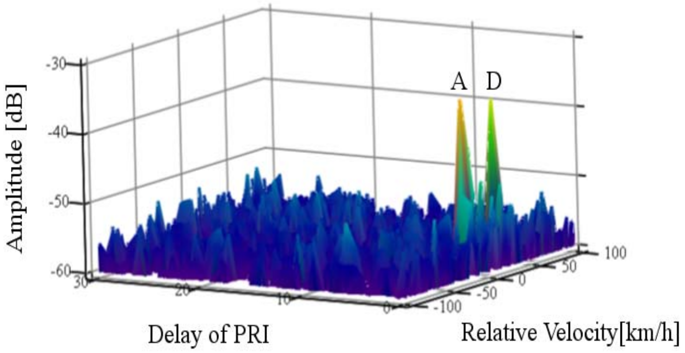


Fig.4 Experimental result on a public road (k=3)

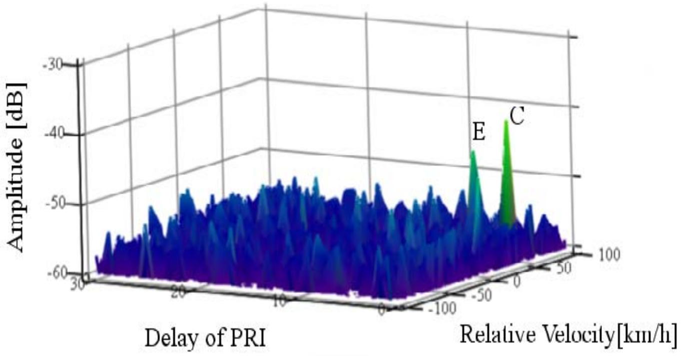
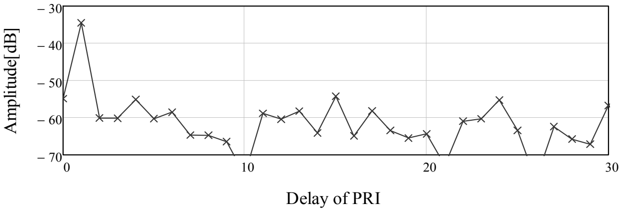
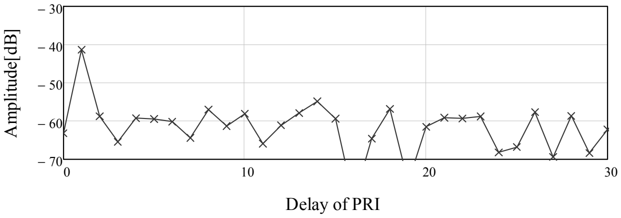


Fig.5 Experimental result on a public road (k=7)

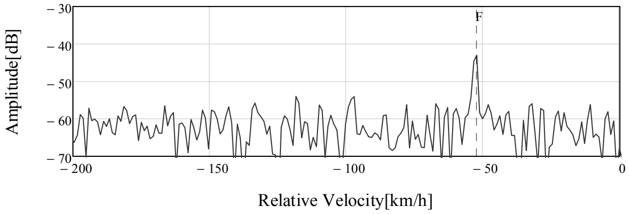


(a) Target A (k=3)

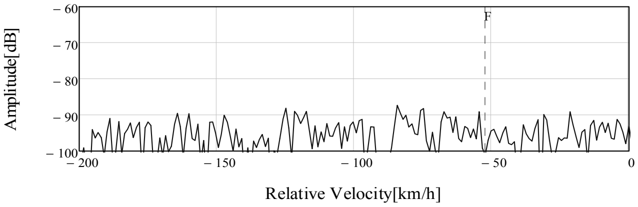


(b) Target B(k=5)

Fig.6 The estimation results on the PRI delay



(a) UWB impulse Radar using Inter-pulse Cyclic Phase Coding



(b) Conventional UWB impulse radar

Fig.7 Comparison of the method proposed in this paper with conventional UWB radar on S/N Ratio (Target F)

Table 2 Experiment result

Target	Range bin	Delay of PRI	Range [m]	Relative velocity [km/h]	S/N [dB]
A	3	1	16.5	-18.0	28
B	5	1	19.5	-18.0	21
C	7	2	34.5	54.4	22
D	3	3	40.5	42.6	25
E	7	6	82.5	61.8	17.
F	4	15	186	-53.3	19

that the radar maintains the spatial resolution of 3m that is equivalent to the pulse width of 20ns. The estimation results for all targets are summarized in table 2.

Finally, we focus on target F. Figures 7 (a) and (b) show the estimation results of the relative velocity by the method proposed in this paper and conventional UWB impulse radar, respectively. Here we adopt 2.56us for the PRI of UWB impulse radar not to occur the range ambiguity problem. The total numbers of transmitted pulses in the method proposed in this paper is 262144 as shown in table 1 and the counterparts of conventional UWB radar is 8192 (not shown here). Therefore the S/N in proposed method is expected to be 21dB superior to that of UWB impulse radar. As shown in figure 7 (a), the peak for target F of the proposed method takes 19dB. On the other hand, the peak cannot be identified in figure 7 (b). This result is consistent with the estimation for S/N improvement described above. Thus we demonstrate the enhancement of long range detection performance of UWB radar using inter-pulse cyclic phase code by showing the observation result for the target at the distance of 186m.

IV. CONCLUSIONS

In this paper, we proposed the method for long range detection of UWB radar using inter-pulse cyclic phase code. In this method, each transmitted pulse is modulated by P4 code and is modulated by the same phase in intra-pulse. We calculated the PRI delay at each range bin and then we obtained the ranges from the targets by adding the PRI delays and the number of range bins. By this procedure, the range detection performance was enhanced, since the transmitted energy could be increased by adopting short PRI. Thus S/N ratio of the receiving signal was also able to be improved by the coherent integration process. We also showed the experimental results conducted on a public way using 24GHz radar to verify the effectiveness of the method. As a result, we could estimate the ranges of the targets that are located at different PRI delay in the same range bin. We also demonstrated that the radar has the spatial resolution of 3m that is equivalent to the pulse width of 20ns by showing the result for the targets that exist at same PRI delay in different range bins. Finally, we discussed the improvement of S/N of the method proposed in this paper by comparing with the conventional UWB radar. We demonstrated that the range detection performance of proposed method was superior to that of UWB impulse radar by showing the observation result for the target at the distance of 186m. We note that we could detect the target at such a long range in spite of the power limitation and adopting relatively wide-angle antenna.

REFERENCES

[1] Uchino Masaharu, Hirose Toshiyuki,Aoyagi Yasushi,Takizawa Kenichi,Hamaguchi Kiyoshi, "Report on field experiment and measurement of 26GHz UWB Short-range radar ", THE INSTITUTE OF ELECTRONICS, TECHNICAL REPORT OF IEICE. INFORMATION AND COMMUNICATION ENGINEERS, WBS, vol.105, no.365, pp.43-48, Oct. 2005.

[2] Hovanessian, S. A. , “An algorithm for calculation of range in multiple PRF radar”, IEEE Transactions on Aerospace and Electronic Systems, vol.12, no.2, 287-290,Mar. 1976.

[3] Wiley, D., Parry, S., Alabaster, C., and Hughes, E., “Performance comparison of PRF schedules for medium PRF radar”, .IEEE Transactions on Aerospace and Electronic Systems, vol42, no.2, pp.601-611, Apr. 2006.

[4] Shinkichi Nishimoto, Osamu Hashimoto, “Coded High PRF Radar Coped with Range-Doppler Ambiguity ” , IEEJ Transaction C,vol.112, No.1,Jun,1992

[5] N.Levanon, “Mitigating Range Ambiguity in High PRF Radar using Inter-Pulse Binary Coding”, IEEE Transactions on, vol.45, no.2, Apr 2009

[6] Lewis, B.L.; Kretschmer, F.F., "Linear Frequency Modulation Derived Polyphase Pulse Compression Codes," Aerospace and Electronic Systems, IEEE Transactions on , vol.18, no.5, Sept. 1982

[7] N.Levenon, E.Mozeson, “Radar Signals”, John Wiley & Sons, Inc., New York, 2004.

[8] N.Levanon, B.Getz, “Comparison between linear FM and phase-coded CW radars “, Radar, Sonar and Navigation, IEE Proceedings - , vol.141, no.4, Aug 1994