Correlation Characteristics of Radar Signals for the Object Identification to Urban Autonomous Driving

Masahiro Watanabe [#1]
[#]Oita National College of Technology, Japan
[#1]ma-watanabe@oita-ct.ac.jp

Abstract — In automatic driving, the object is the vehicle on the centre of the express highway, although. It is necessary to identify of the dogs, people, motor cycles, vehicles etc and predict their behaviours in the urban area. We propose the identification procedures based on the utilizations of unique code sequence contained in the reflection signals from an object by millimeter wave radar for urban autonomous driving. We demonstrate the identification performance of the symmetric high S/N ratio equivalent to the unique code sequence of the vehicle's itself on autocorrelation and 34% suppression effect with the different vehicle code sequence on cross correlation.

Keywords — autonomous driving, millimeter wave radar, object identification, correlation characteristics, complex conjugate.

I. Introduction

The role of a radar for current auto cruising is the detection of the forward vehicles and the exhibition of its distance, velocity and angle on the designed course of express highway. Even though, in urban areas, radar is necessary of the identification for the objects; dogs, people, motorcycle, and vehicles and the prediction of their behaviours additively for the safety to urban autonomous driving.

In recently, the image processing by the camera is often used to the identification, the popular installations are the car devices for auto cruising. The cameras are relatively inexpensive, so that the stereo camera with a compound 3D is also possible to recognize the shape of the objects. However, its operation of the identification is not guaranteed in the cases of at night, in heavy rain, in fog, with lens raindrops, either blind spot of the car side. Moreover, the possibility of the recognition for identification by camera is degraded in case that the object is a plain wall or a vertical stripes pattern wall.

In this paper, we propose the procedures of the identification into the radar system that is high-level robustness compared with the same function of the image processing. Further, we show that it is possible to identify a real motorcycle or a vehicle by using a 24GHz band radar.

In recent years, 24GHz band radar becomes to be inexpensive, compact and lightweight owing to the advances in semiconductor manufacturing technology. Technical standards conformity certification from the regulations can be adopted without a user's license for this application. From these points, a 24GHz band radar is expanded to use in Europe and United States and Japan [1] [2].

II. Conventional RESEARCH

As the image processing by camera, the 3D shape can be estimated due to the information of three-dimensional motion due to the large number of frames by motion camera [3]. However, in the evening, and at bad weather including rain fog, the reduction of imaging performance forces to the limited usage of the camera [4].

By using a millimetre radar, a study has done to detect the white lines in rapid adverse weather conditions or in the environments where its illuminance changes rapidly [5]. Its radar is 79GHz UWB radar which detect the white lines by including the dielectric materials or forming the irregular shape of materials. Their study is under validation of the possibility to the detection of the shapes such as image processing by camera.

In addition, the ideas are necessary against the interferences in the multiple radars on the road according to the widespread installations to the cars. A FMCW radar of common automotive radar is becoming the standard equipment. The canceller process due to the feedback loop of mixer has the possibility to reduce the DC fluctuations in time domain of received impulse interferences [6] to [9].

Common automotive radar uses millimetre wave which has wide band-width of frequency, so that improves the range resolution for accuracy of distance. It becomes to be useful for the performance of our proposal.

III. PROPOSED METHOD

We propose the identification procedures based on the utilizations of unique code sequence contained in the reflection signals from an object by millimeter wave radar.

Figure1 shows the example of the images of 5 reflections from the vehicle. The collision avoidance or auto cruising radar use the first reflection signal which means the shortest distance of a forward car. The code sequences contained in reflection signals from objects are different from each other. We think the unique code sequence to identify the object from others.

Figure 2 shows the transmitting and receiving procedures for the identification. A code sequence with a complex conjugate against the unique code sequence is transmitted, and reflected wave is to be a convolution integral in time domain.

Figure 3 shows the result of convolution in time domain. In case of correlation, the received signal is obtained to be a high S/N ratio equivalent to the unique code numbers, so that it is judged to be identified completely.

Figure 4 shows a high S/N ratio in identification. If there is no correlation between the reflected wave and the transmitted wave, the received signal results to be low S/N ratio such as

[#1]Advanced Technology Research and Development Center,
Mitsubishi Electric Corporation

noise level, so that it is judged to be not identified and is judged to be other object, too.

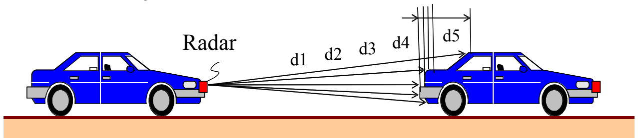

Figure 1. Reflections of the Vehicle (Example)

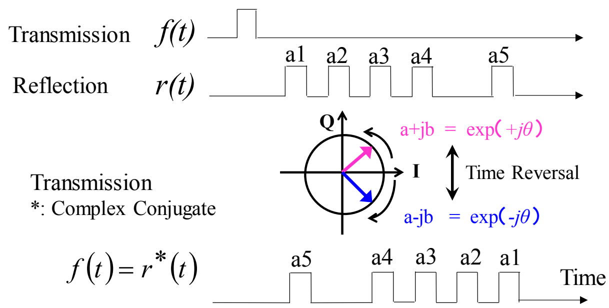

Figure 2. Transmission Procedures

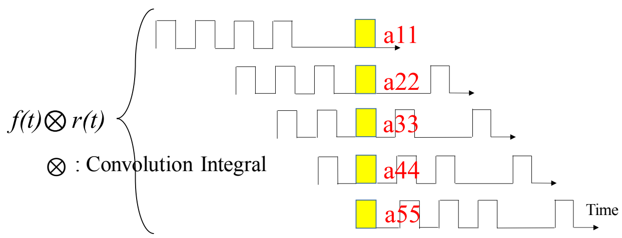

Figure 3. Result of Convolution in Time Direction

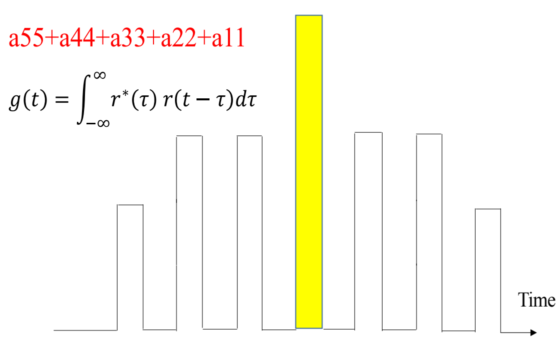

Figure 4. High S/N Ratio of Identification

IV. DEMONSTRATION EXPERIMENT

A. Preparation

The experiment is executed in the grand field. The 24GHz radar is situated at 1.5m height on the grand with the avoidance for the burst degradation point at a distance. The polarization is vertical which is popular of automotive radar to reduce the power of the reflection wave. There prepared some objects; the reflectors, a bicycle, a motorcycle and a vehicle for the acknowledgment of the performance of the identification between auto correlation and cross correlation. The specifications of 24GHz FMCW radar is as follows, Tx power: 10dBm, Band width (FM charp width): 187MHz < 200MHz (Japanese Regulation), range resolution: 0.8m.

B. Correlation Characteristics

There prepared the target of 3 reflectors on the grand. Figure 5 shows the experiment scene situated 3 reflectors at the front of 24GHz FMCW radar. Figure 6 shows the reflection power spectrum in frequency domain. Fig.7 shows the digitized magnitude of reflection power spectrum. Figure 8 shoes the auto correlation magnitude with complex conjugate code sequence, in phase code sequence and random code sequence. These experiments result to be the symmetric high S/N ratio equivalent to the 32 chips code numbers with complex conjugate, asymmetric middle level S/N ratio with in phase and lower level S/N ratio with random code sequence.

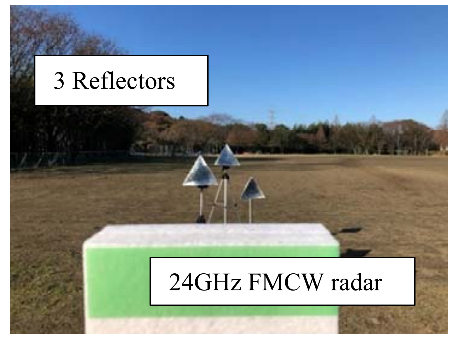

Figure 5. Experiment Scene of 3 Reflectors

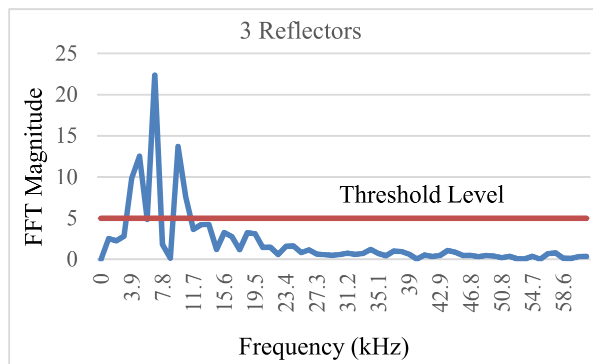

Figure 6. Reflection Power Spectrum

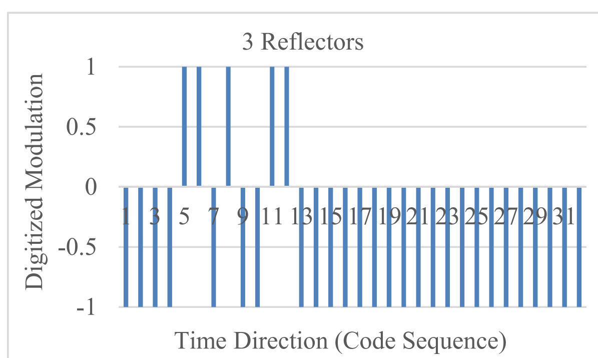

Figure 7. Digitized Modulation

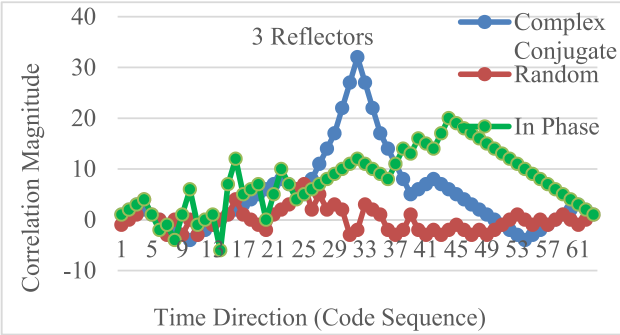

Figure 8. Auto Correlation Magnitude

C. Demonstration (1); Auto Correlation

There prepared the target of motorcycle on the grand. Figure 9 shows the experiment scene situated a motorcycle at the front of 24GHz FMCW radar. Figure 10 shows the reflection power spectrum in frequency domain. Figure 11 shows the digitized modulation of reflection power spectrum. Figure 12 shows the auto correlation magnitude with complex conjugate, in phase and random code sequence. These experiments result to be the symmetric high S/N ratio equivalent to the 32 chips code numbers with complex conjugate, and asymmetric middle level S/N ratio with in phase code sequence, and lower level S/N ratio with random code sequence. These results are seemed almost same characteristic to that of 3 reflectors as described above.

Further, Figure13 shows the experiment scene of vehicle. Figure 14 shows the reflection power spectrum in frequency domain. Figure 15 shows the digitized modulation of auto correlation magnitude. Figure 16 shows the auto correlation magnitude with complex conjugate, in phase and random code sequence. The experiments results to be almost same tendency similar to that of motor cycles.

Figure 9. Experiment Scene of Motorcycle

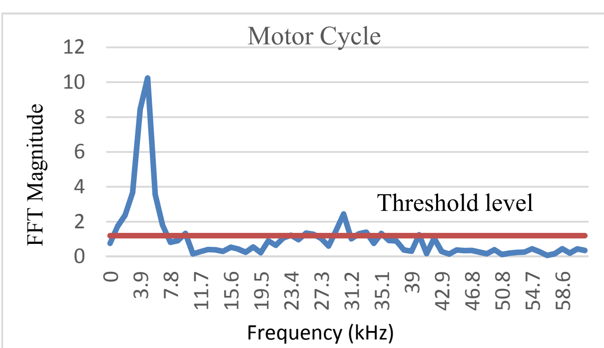

Figure 10. Reflection Power Spectrum

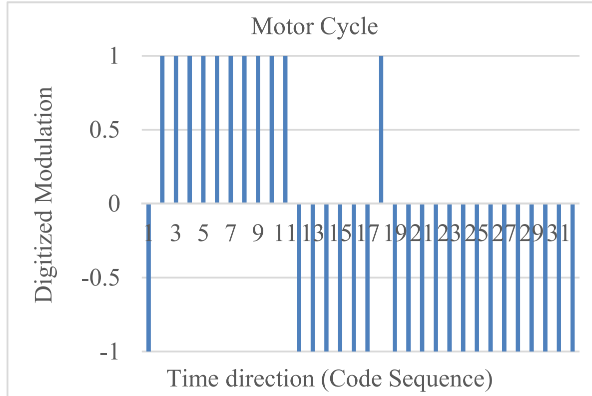

Figure 11. Digitized Modulation

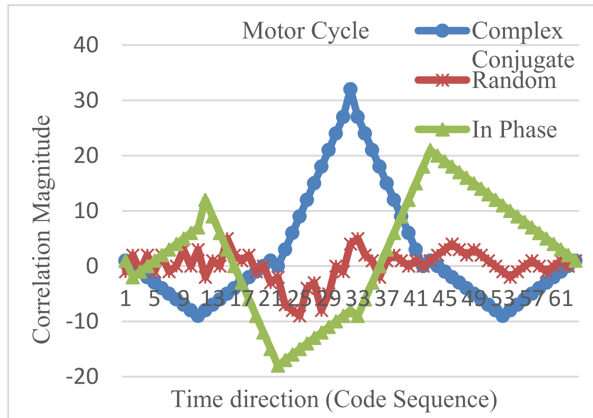

Figure 12. Auto Correlation Magnitude

Figure 13. Experiment Scene of Vehicle

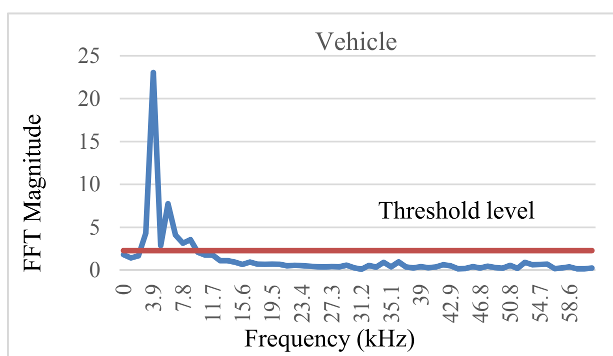

Figure 14. Reflection Power Spectrum

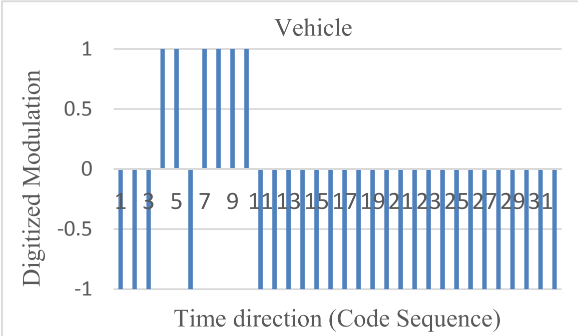

Figure 15. Digitized Modulation

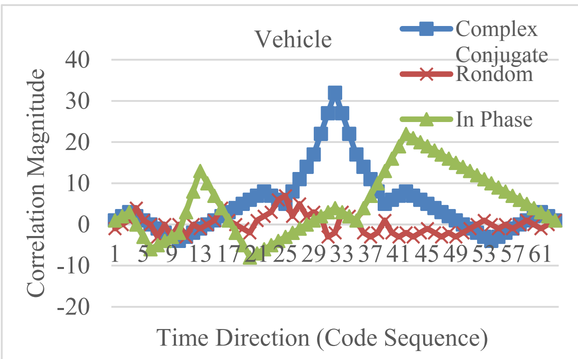

Figure 16. Auto Correlation Magnitude

D. Demonstration (2); Cross Correlation

Figure 17 shows the 32bit cross correlation magnitude with complex conjugate code sequence for a vehicle at a motor cycle. Figure 18 shows the 32bit cross correlation magnitude with complex conjugate code sequence for a motor cycle at a vehicle. These experiments result to be the asymmetric middle level S/N ratio with inadequate complex conjugate of other objects.

According to these experiments, the magnitude level of auto correlation is higher than that of cross correlation, as the results that the degradation ratio is 25bit/32bit=78%, and suppression ratio is 22% (=1-0.78) on the proposal identification procedures. In order to improve the identification performance, as a method of obtaining more improvement effects on the cross correlation effect, it is conceivable to extend the complicated code sequence length due to the reflection power spectrum.

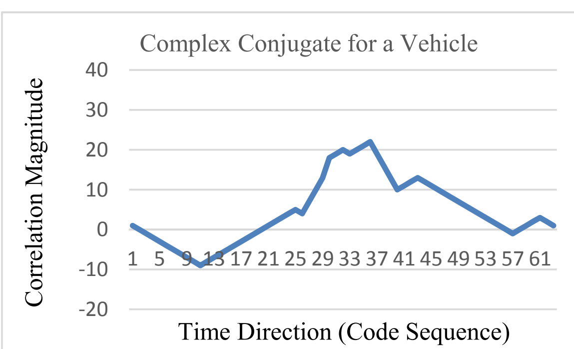

Figure 17. 32bit Cross Correlation Magnitude at a Motor Cycle

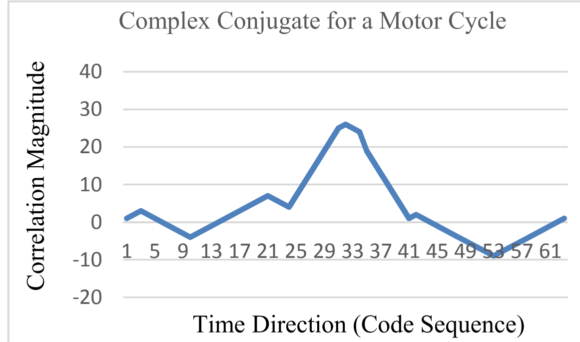

Figure 18. 32bit Cross Correlation Magnitude at Vehicle

E. Demonstration (3); Code Expansion Model

There prepared the actual target of a motor cycle and a vehicle on the grand. Figure 9 and Figure 13 shows that there are situated at the front of 24GHz FMCW radar respectively. Unique code sequence is expanded 32bit to 64bit in correlation calculation toward the fine range resolution owing to the wide frequency band width in higher millimetre waves; 60GHz, 76GHz and 79GHz [10] [11]. The 32-bit to 64-bit expansion method is assumed to be equivalent to the received signal when using a millimetre wave band wider than 24 GHz by doubling distance resolution and binarizing the reception signal within the same range bin.

Figure 19 shows the 64bit digitized code sequence due to the reflection power spectrum in time domain at a motor cycle. Figure 20 shows the auto correlation magnitude with complex conjugate code sequence and random code sequence at a motor cycle. Figure 21 shows the 64bit digitized code sequence due to the reflection power spectrum in time domain at a vehicle. Figure 22 shows the auto correlation magnitude with complex conjugate code sequence and random code sequence at a vehicle. These experiments result to be the symmetric high S/N ratio equivalent to the 64 chips code numbers with complex conjugate and lower level S/N ratio with random code sequence in Figure 20 and Figure 22.

Figure 23 shows the 64bit cross correlation magnitude with complex conjugate code sequence for a vehicle at a motor cycle. Figure 24 shows the 64bit cross correlation magnitude with complex conjugate code sequence for a motor cycle at a vehicle. These experiments result to be the asymmetric middle level S/N ratio with inadequate complex conjugate of other objects.

According to these experiments, the magnitude level of auto correlation is higher than that of cross correlation, as the results that the degradation ratio is 42bit/64bit=66%, and suppression ratio is 34% (=1-0.66) on the proposal identification procedures. 64bit is the auto correlation magnitude in Figure 20 and Figure 22, 42bit is the cross correlation magnitude in Figure 23 and Figure 24.

Therefore, the suppression effect of cross correlation by expansion of code sequence results to be +12% improvement from 22% to 34%. Hence, the improvement of effect can be determined that the correlation when using the code sequence of different vehicles is weak, it has been demonstrated.

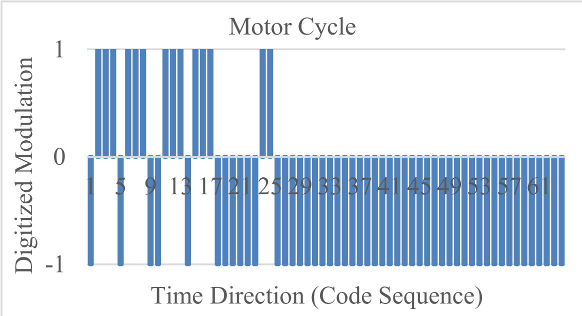

Figure 19. 64bit Digitized Code Sequence at Motor Cycle

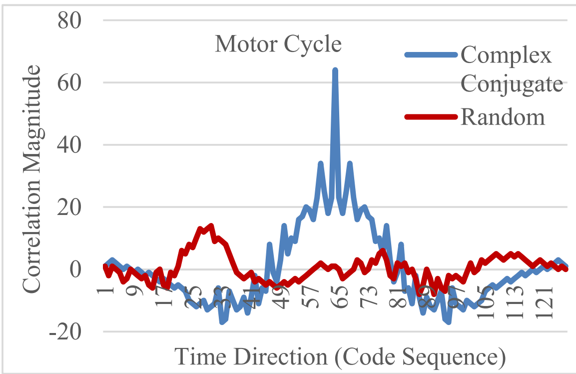

Figure 20. 64bit Auto Correlation Magnitude at Motor Cycle

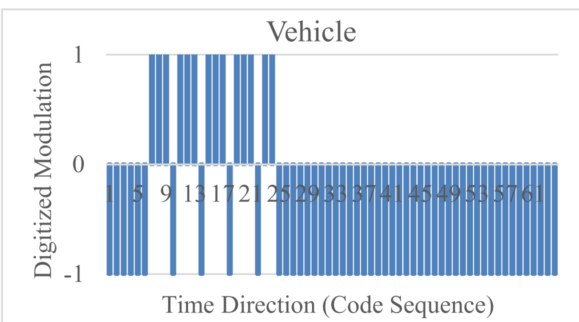

Figure 21. 64bit Digitized Code Sequence at Vehicle

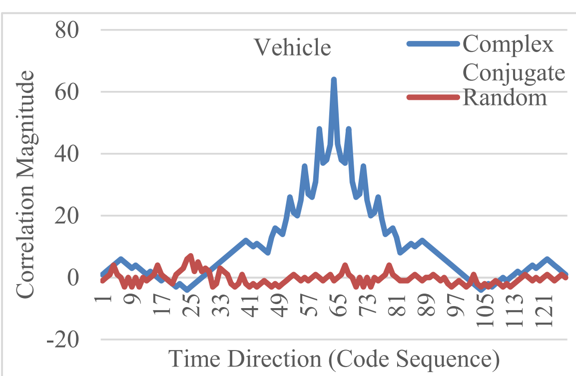

Figure 22. 64bit Auto Correlation Magnitude at Vehicle

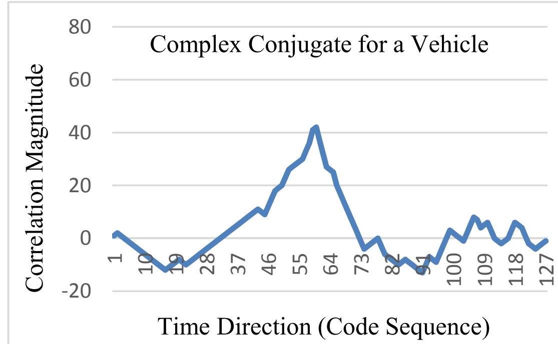

Figure 23. 64bit Cross Correlation Magnitude at Motor Cycle

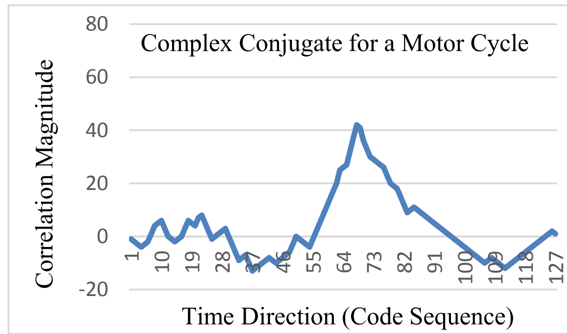

Figure 24. 64bit Cross Correlation Magnitude at a Vehicle

F. Demonstration (4); Error Correlation

There prepared one error bit into the 32bit code sequence of its own object due to the reflection signal. Figure 25 shows the 32bit auto correlation magnitude included one error bit in forward code sequence with complex conjugate code sequence at motor cycle. Figure 26 shows the auto correlation magnitude included one error bit in backward code sequence with complex conjugate code sequence at motor cycle. The both experiments result to be the asymmetric correlation magnitude, and 2bit (=+/- one bit) degradation of the magnitude. Therefore, the peak value of the auto correlation, because twice the error 1bit is lowered, in the case of 32bit code sequence is lowered at a ratio of 30/32=94%.

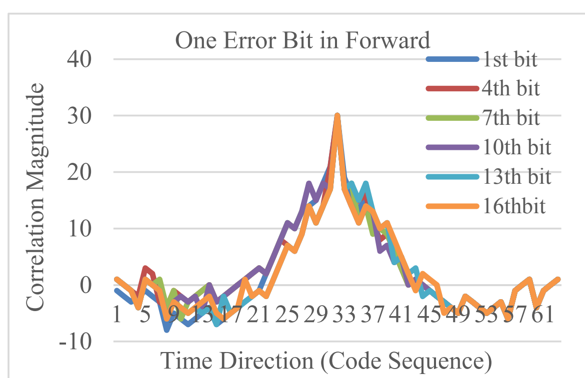

Figure 25. One Error Bit in Forward Code Sequence

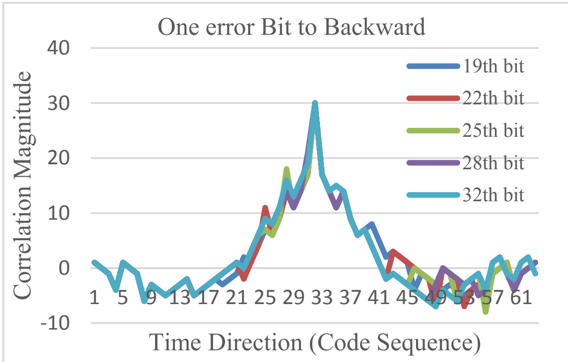

Figure 26. One Error Bit in Backward Code Sequence

Similarly, two error bits into the 32bit code sequence, 4bit (=+/- two bits) degradation of the magnitude, its ratio is 28/32=88%. Less going to decline as well.

Therefore, if there is an error bit in the code, there is no large suppression effect as a complete cross correlation characteristic, the cross correlation characteristics in accordance with the number of error bits is gradually lowered. Therefore, by using this, to prepare a pattern in which a plurality of error bits are present for the code sequence for identification, sequentially, to grasp the correlation characteristics the highest likelihood estimation method to extract a high sign of the most peak value, it is conceivable that the method of determining the identification is an object corresponding to it. This method, since there is no large difference in the code sequence in the vehicle of a similar shape, it is conceivable that it is possible to identify by extracting a high sign of the highest peak value from the pattern of a plurality of code sequences.

Figure 27 shows, a plurality of vehicles (A, B, C, D) in the case of a relationship where the error bit is present with respect to each other, a vehicle that corresponds to what the highest correlation characteristic of the peak value is obtained it shows how to determine.

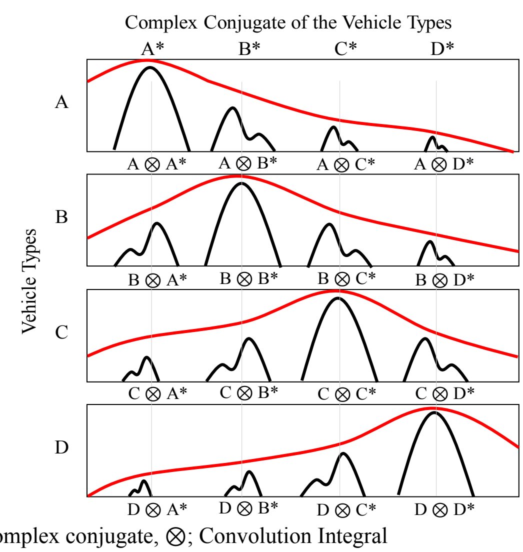

Figure 27. Vehicle Identification by Maximum Likelihood Estimation

V. Conclusion

We propose the identification procedures based on the utilizations of unique code sequence contained in the reflection signals from an object by millimetre wave radar for urban autonomous driving.

The demonstration experiments result to be as follows, the identification performance of the symmetric high S/N ratio equivalent to the unique code numbers of the vehicle's itself on auto correlation, and 34% suppression effect with the different vehicle code sequences on cross correlation, and degradation of the S/N ratio due to the error bit numbers in code sequence of its own object in auto correlation and appears the asymmetric form to the correlation magnitude.

The higher S/N ratio in the auto correlation is achieved. even though, the suppression ratio in cross correlation is insufficient to the absolute ratio. More complex unique code sequence is expected toward the fine range resolution owing to the wide frequency band width in higher millimetre waves.

Acknowledgment

This research was conducted with the support from joint research project with Keycom Co., Ltd. "The Fusion Research on Radar and Communication Devices ".

References

[1] Ministry of Information and Communications Council Information and Communication Technology Subcommittee Mobile Communications Systems Committee Report http://www.soumu.go.jp/main_content/000148569.pdf (2019/4/1 Access)

[2] Ohuchi Kazuo "Radar Fundamentals, from exploration radar to synthetic aperture radar", pp.184-186, Corona Corporation, Tokyo 2017

[3] Seki Akihito "In real time using a video image of a monocular camera 3D reconstruction Technology ", Toshiba Review, Vol.68, No.5, pp.40-43, 2013

[4] Sudou Wakana, Onoguchi Kazunori " A study on the sharpness of poor visibility image using the automotive image recognition LSI", D-12-54, IEICE General Conference, 2018

[5] Japan Automobile Research Institute of Japan "Strategic innovation of the Year Creation Program": Development and demonstration of all-weather white line identification technology ", METI JAPAN, 2015

[6] Nozawa Takuya "An Inter-Radar Interference Suppression Technique for Automotive Millimeter-wave FMCW Radar", A-14-5, IEICE General Conference, 2017

[7] G.M. Brooker, "Mutual interference of millimeter-wave radar systems," IEEE Transaction. Electromagnetic Compatibility, vol.49, No.1, pp.170-181, 2007

[8] M. Goppelt, H.–L. Blöcher, W. Menzel, "Automotive radar – investigation of mutual interference mechanisms", Advances in Radio Science., vol.8, 2010-1, pp.55-61

[9] Jung-Hwan Choi, Han-Byul Lee, Jiwon Choi, Seong-Cheol Kim, "Mutual Interference Suppression Using Clipping and Weighted-Envelope Normalization for Automotive FMCW Radar Systems", IEICE Transaction Communication, vol. E99-B, No.1, 2016-1, pp.280-287

[10] "60GHzBand Radio System Technical standards for", http://www.soumu.go.jp/main_content/000358265.pdf, MIC JAPAN (2019/4/1 Access)

[11] "76GHz Technical standards for low-power millimeter-wave radar", http://www.soumu.go.jp/main_content/000355601.pdf, MIC JAPAN (2019/4/1 Access)