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An Approach for Reducing Computational Time for Real-Time Autonomous Vehicle Tracking

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Abstract: Autonomous vehicles are familiar to public in daily life nowadays. For a recreational purpose, autonomous vehicles such as drones are commonly adopted for people. However with the easy accessibility, those autonomous vehicles can be a threat to anyone. Moreover, to detect and prevent those possible threats, real-time detection and tracking system is required. With the requirements, we propose a real-time communication between post-processing device and autonomous vehicle tracking sensor, which is a radar and a noise reduction method for post-processing. With the proposed method, a Frequency Modulated Continuous Wave (FMCW) radar can be utilized for real-time monitoring of autonomous vehicle. In this paper, we used an audio file recorded through a FMCW radar for distance tracking. The recorded audio data were processed by Inverse Fast Fourier Transformation (IFFT) and noise cancellation. We propose a data selection formula for faster IFFT processing and a noise reduction method in real-time communication. Also we propose a simple Android application to receive the processed data that sent to as distances of the target autonomous vehicle in time in real-time, so that a user can conveniently watch an autonomous vehicle near the radar.

Keywords: FMCW Radar, Detection and Tracking, Autonomous Vehicle, Signal Processing.

1. INTRODUCTION

After the unmanned aerial vehicles (UAVs) are introduced and populated to public in various uses such as for simple recreational fight to filming, various accidents, from drone crashing in a private backyard or an apartment to an empty seat in the first-base-side upper deck have been occurred [1]. With regard of the accidents, we can see that the unmanned vehicles could be a threat to a person or people in a public area such as baseball stadium. Moreover, the unmanned vehicles have been actively pursued for military purposes, and accidents have been happened within the military purposes.

As a safety countermeasure for such problems, radar is a proper sensor for watching unmanned vehicles because radar does not affect on weather or surrounding noises. Because of the reason, unmanned vehicle detection and tracking techniques using radar have been studied extensively. Usually, a detection and tracking radars are military purposed. Otherwise, frequency range of the radar was high such as S-band [2], because the purpose of the studies were overseeing a large area such as a city [3] or a military operating area [4]. Moreover the radar were not accessible for research, so that the post-processing or data fusion researches have been done virtually [5]. However a FMCW radar system designed at MIT [6] uses 2.4 GHz center frequency that can be operated in public area. Based on the radar, an accessible radar system has been proposed [7] for preventing accidents and threats exampled above. With the cost-efficient and accessible small radar, large number of radars can be deployed in a public place to surveillance the area [8]. The system can be deployed with audio to collect two different types of data including frequency of sound generated from propellers on rotor-type UAVs. Without audio tracking of drone, the radar can be utilized alone [9]. A drone can be detected and tracked with the radar system, however real-time data communication from the radar to the post-processing devices need to be established because the detection and tracking are much more useful when the detection and tracking data are shown to user in real-time. In additionally, the data collected from the radar and sent to a post-processing device need to be processed in real-time to show the distance of the drone to watch it to find out the purpose of its flight.

In this paper, a system to show distance of a target drone in real-time by using real-time communication between post-processing devices and android is performed. A FMCW radar is used to get data, and a raspberry-pi is utilized as a post-processing device. When the radar transmits data to the raspberry-pi, the raspberry-pi processes the data for each seconds. The processed data as shown in target distance is sent to an android device to visualize the target distance in a line plot. We used a pre-recorded wav file to simulate the proposed methods. The organization of this paper shows the configuration of the system in section 2. In section 3, a method for valid data searching and selection for fast data processing and a noise reduction method in real-time communication are proposed. In section 4, we show simulation and experiments. And in section 5, we discuss conclusions of this work and future plans.

2. CONFIGURATION OF THE SYSTEM

The radar we used for this research is shown in Fig.1. The radar system is proposed in [9]. The radar operates at a center frequency 2.5455 GHz. The radar uses a frequency band of about 21 MHz from 2.535 GHz to 2.556 GHz.

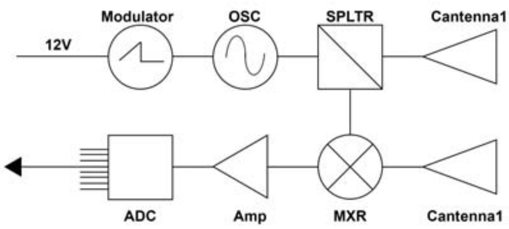

Fig. 1 Configuration of the radar.

Fig. 1 is configuration of radar, including modulator, oscillator, mixer (MXR), Analog to Digital Convert (ADC) and raspberry-pi. The radar uses a 12V and the ADC uses a 5V. So The radar is supplied with 12V power and the ADC is supplied with power converted from radar to 5V. The antenna shall face the same direction and the clearance between the two antennas is *0.5 m* to *1 m*. The MXR is connected to the amplifier, when the amplifier received data from the MXR, it is amplified 10 times and send to the ADC. The ADC has 16 bits of resolution and a sampling rate is 44100 Hz. Also the ADC must have at least 2 channels for sync data and data received.

The process of signal generation and transmission is as follows. First, the modulator generates sync signal with 52ms uptime. Fig. 2 shows the sync signal. It is send directly to the ADC. Second, the oscillator generates a transmission signal and TX antenna transmits the signal. Third, RX antenna receives a reflected signal and it is multiplied by transmission signal. This calculates the difference in power and phase of the two signals. The computed signal is sent to the ADC via the amplifier. The ADC converts the signal into a digital value and transmits it to the raspberry-pi. Finally, it is sent to Android applications after post-processing. Process the data received from the ADC in the raspberry-pi. The process is described in more detail in Section 3 and 4. The processed data is sent to the android application using the ZeroMQ library [11]. Android provides graphical visualization of incoming data.

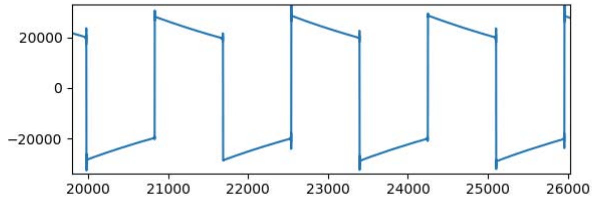

Fig. 2 Sync pulse generated by a modulator.

3. REDUCING COMPUTATIONAL TIME

3.1 Rising pulse search on sync signal

In the post-processing method that we are using for a research uses sync pulse as shown in Fig. 2, which is a sync signal generated by a modulator to sort out valid data from the receive radar signal.

Not all the values of signal received from the radar are needed for post-processing. The given processing used in previous radar experiments [7, 9] does not search for valid data among the received values, but uses all the data points. Because values when the sync signal is positive is required for post-processing, rising edge of sync signal is searched. Therefore by checking state of sync signal for each point first reduces the length of data to be processed dramatically.

Because the sync signal has fixed intervals in time, we can pick valid data corresponding to the intervals. In other words, if the first beginning of rising edge is found, then the next rising edge can be found easily. However, we do not know if the beginning of the recording of the sync signal starts from negative, zero, or positive states. Therefore, the first rising edge must be searched.

Let x be a length from the current rising edge to the next rising edge, and let n is an interval of values when the proposed method selects and checks if the value is on rising edge. We call x as a *period*, and n as a *step*. If n is *2*, then the proposed method selects values with two intervals, for example *1st, 3rd, 5th,* and so on values and checks if it is on rising edge. That is, with interval n, the proposed method picks 1th, $(1 + n)$th, $(1 + n + n)$th, and so on values as the starting points of a rising edge.

With a selected point $(i + n + 1)$, proposed method searches from $(1 + n + 1)$th to $(1 + n + n)$th values to find the edge where rising edge ends and flat positive sync signal begins. In the worst case, the maximum number of searching through the proposed method is equal as shown in Eq. (1). We assume that the average searching time through the proposed method is half of Eq. (1), so the maximum number of searching through the proposed method is equal as shown in Eq. (2).

$$\frac{x}{n} + n \tag{1}$$

$$\frac{x}{2n} + \frac{n}{2} \tag{2}$$

Through arithmetic-geometric mean as shown in Eq. (3), the relation between the period x and step n can be expressed as a perfect square expression.

$$\frac{x}{n} + \frac{n}{2} \quad \leq \quad 2\sqrt{\frac{x}{2}} \tag{3}$$

$$(n - \sqrt{\frac{x}{2}})^2 \quad \leq \quad 0 \tag{4}$$

Since the period x of the sync signal used in this study was about *1,700* and n is the optimal step, which is 58 according to the Eq. (4). We tested the proposed method to show if the optimal step is *58*. The performance of the method is measured in average time in second to find the first point of flat positive sync signal is started, and the test results are shown in table 1. With accordance of the table 1, 58 is the optimal step when the period is about 1,700.

3.2 Post-processing in real-time communication

To track target continuously by the radar, we process data through IFFT. Through IFFT, the received radar signal is converted into frequency and sound level in decibel on the frequency. After that, the frequency values are converted into distance. High sound level means that there is a target possibly. We assume that the target is coming inbound, so that we ignored a continuous signal on distance *2.5 m* generated due to hardware noise. Also we assume that if the data value larger than *2.5 m* and lasts more than 0.2 seconds, the value is the starting point of tracking. While tracking the target through the processed data, if the difference of two distance values exceeds the maximum speed we set, then we remove the second value that is regarded as noise.

We used the maximum speed of the target as *16 m/s* which is from the specification of DJI Phantom 3 SE[10], because DJI phantom drones are commonly used for recreational purpose. When a value is remove because it is considered as a noise value, an interpolation method is used to replace the value. However, interpolation is method of estimating and connecting the two points so it is not to be applied at the start or end point because the two points do not have linked points.

Table 1 Average time to find the point of end of rising edge depends on the length of the step.

Step	Average time (s)
1	3.5
2	1.77
3	1.23
4	0.93
5	0.725
10	0.42
20	0.23
30	0.22
40	0.165
50	0.16
58	0.157
70	0.163
80	0.17
100	0.22
120	0.22
150	0.24
200	0.32
300	0.42
400	0.57

4. SIMULATION

In the process of detecting the target using the radar, the data within the minimum detection distance of *2.5 m* was ignored due to the hardware noise. The sample data has a sampling frequency of 44100 Hz and the range representing the strength of the signal is 2^{16} from - 32768 to 32767.

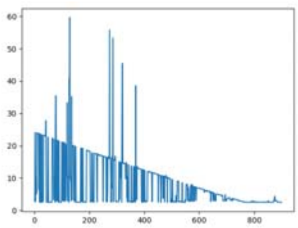

Fig. 3 Immediately data after IFFT.

Fig. 3 is a visualization of unprocessed data immediately after IFFT. If the hardware noise is stronger than the reflected signal, values close to zero are measured. In addition, if there is a strong external noise present, it is measured that is outside of an abnormally high value or target range of motion. The post-processing is applied to eliminate these abnormal data and to process them into user-recognizable data.

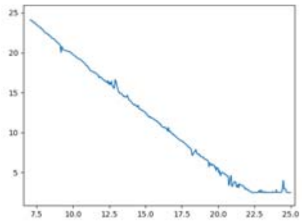

Fig. 4 Post-processed data after IFFT.

After Applying post-processing, we obtained result Fig. 4.

We conducted a simulation to measure real data and as expected we were able to obtain real-time data. However, due to the low resolution of the ADC used, it was unable to convert to a suitable digital signal and therefore the post-processing process failed. The future simulations aim for performing the post-processing and for real-time visualization on Android.

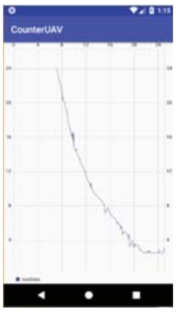

Fig. 5 Real time data visualization in Android.

Fig.5 shows the real time communication between Android application and rasberry pi.

5. CONCLUSION AND FUTURE WORK

This study uses the FMCW radar to detect objects such as UAV. We proposed applying IFFT to the data generated during the target detection process to convert from frequency domain data to time domain data. Also we show using interpolation on the data to reduce noise and obtain valid data for visualization. In Addition, a method of visualizing noise removed data by communicating with Android in real time was implemented.

Future work is to apply a Kalman filters instead of present interpolation to improve the efficiency of noise handling. We also intend to complete the installation of the equipment to obtain the actual data and apply the methods presented in this study to the data.

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REFERENCES

[1] (2018, Jun) Domestic drone accidents. [Online]. Available: http://rochester.nydatabases.com/map/domestic-drone-accidents.

[2] J. Suryana, M. Ridha, "Design and implementation of S-Band MIMO FMCW radar," *Telecommunication Systems Services and Applications (TSSA), 2016 10th International Conference on*, pp. 1-5, 2016.

[3] J.-F. Nouvel, S. Roques, and O. R. Du Plessis, "A low-cost imaging radar: drive on board onera motorglider," *IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2007*, pp.5306-5309, 2007.

[4] B. Yamauchi, "Daredevil: ultra-wideband radar sensing for small UGVs," *International Society for Optics and Photonics*, pp, 65 610B-65 61B.

[5] H. Byeon, S. Kim, S. Mun, and S. Lim, "Tracking relative angles by data fusing with RF sensor's data and SDIIR sensor's data in virtual reality," *The Korean Society for Aeronautical and Space Science* , pp. 1657-1660, 2015.

[6] G. L. Charvat, A. J. Fenn, and B. T. Perry, "The MIT IAP radar course: Build a small radar system capable of sensing range, doppler, and synthetic aperture (SAR) imaging," *IEEE Radar Conference (RADAR)*, pp. 0138-0144.

[7] S. Park, Y. Kim, E. T. Matson, and A. H. Smith, "Combination of radar and audio sensors for identification of rotor-type unmanned aerial vehicles (uavs),", *IEEE Sensors*, pp. 1-4, 2015.

[8] S. Shin, S. Park, Y. Kim, and E. T. Matson, "Design and analysis of cost-efficient sensor deployment for tracking small UAS with agent-based modeling," *Sensors*, Vol 16, No. 4, pp. 575-575.

[9] S. Park, Y. Kim, E. T. Matson, and A. H. Smith, "Accessible synthetic aperture radar system for autonomous vehicle sensing,", *Sensors Application Symposium (SAS) 2016 IEEE*, pp. 1-6, 2016.

[10] (2018, Jun) Phantom 3 SE. [Online]. Available: https://www.dji.com/phantom-3-se.

[11] (2018, Jun) ZeroMQ Library. [Online]. Available: https://www.zeromq.org.