True Ground Speed Measurement and Height Awareness of UAV by Radar Transceiver

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ABSTRACT

The goal of this project is to use radar transceiver to design a system, which could detect the velocity of Unmanned Aerial Vehicle (UAV) and its height. In this paper, the design of the system is displayed and some tests about the system are implemented to verify the feasibility of the system.

1. INTRODUCTION

With the development of automatic control of UAV, drones are widely used in different aspects, such as aerial photographing, rescuing and even delivery. But now the technology is not mature enough for business. One of the essential problems constraining the utilization of UAV is safety. And true ground speed and height are extremely important information for it. Although GPS was widely used to detect the speed and height of UAV, in some situations where GPS signal is lost, the speed and height of the UAV could only be measured by other methods. Stepped-Frequency Continuous Wave (SFCW) Radar and Doppler Radar are capable to do the measurement. Based on those methods, the speed and height of the UAV can be obtained through a radar system, built by mini radar transceiver and micro-controller. The spatial information from the radar system could assist emergency landing and automatic navigation system for UAV, and make it possible for business finally.

2. OBJECTIVE

- True ground speed measurement by radar for small UAVs
- Height awareness by radar for small UAVs

3. PRINCIPLE

3.1 Doppler Effect -- for True Ground Speed [1]

The Doppler effect is the change in frequency of a wave for an observer moving relative to its source. It can be described as: $f = \left(\frac{c+v_r}{c+v_s}\right) f_0$

Where f is observed frequency, f_0 is emitted frequency, c is the velocity of waves in the medium, v_r is the velocity of the receiver relative to the medium, v_s is the velocity of the source relative to the medium.

In radar system, because the Doppler shift affects the wave incident upon the target as well as the wave reflected back to the radar, the change in frequency observed by a radar is: $\Delta f = \frac{2\Delta v}{c} f_0$

Where Δf is Doppler shift frequency, Δv is the velocity of target relative to radar, is f_0 is emitted frequency, c is the velocity of waves in the medium.

3.2 Stepped-Frequency Continuous Wave -- for Height Awareness [2]

The frequency of radar has step changes over time. The received signal from radar will be a cosine function. The phase (Φ) changes of the function present the distance of object the radar senses.

$$\emptyset = \frac{4\pi f}{c} \cdot d$$

Where f is the frequency of transmitted radar wave, c is the speed of light, and d is the distance of object from radar.

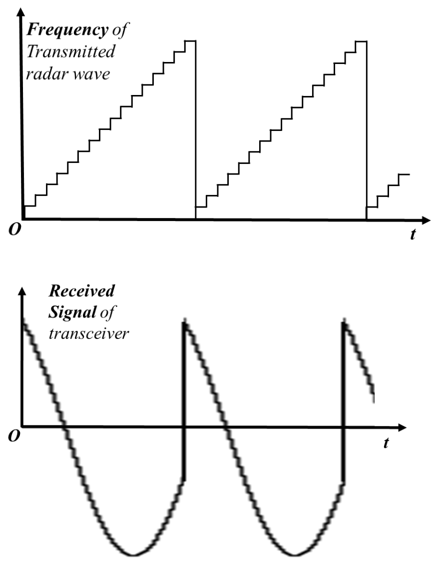

Fig.1 Principle of SFCW

Different phases (Φ) in the radar transceiver's output here can be an indication of distance and can be used for distance measurement.

4. IMPLEMENTATION

4.1 Radar Architecture

The transmitter (TX) on radar sends out radar wave with a constant frequency. This wave will be reflected by the object and be received by the radar receiver (RX) again. If the object is moving or the frequency of transmitted wave is varying, then the frequency of the received signal will change in the meantime. The final output of the radar is A•cos(2πΔft) or A•cos(Φ), which includes Δf (frequency difference between transmitted and received waves) or Φ (phase shift).

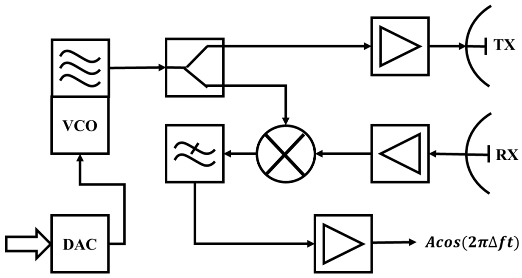

Fig.2 Radar Architecture

4.2 Block Diagram of Radar System

Radar transceiver (ViaSat) could send out and receive radar waves to obtain the frequency difference. In the meantime, micro-controller (Teensy 3.1) is used to control the frequency of the transmitted waves and receive the frequency difference signal (I/Q signals) form the transceiver. With the I/Q signals and spectral analysis, speed data can be calculated out and send to drone or computer by micro-controller.

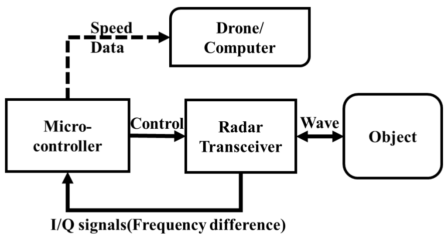

Fig.3 Block Diagram of Radar System

4.3 Hardware Development

Radar transceiver and microcontroller (Teensy 3.1) are connected, and some peripheral circuits are used to support the system.
SPI_ENB, SPI_DAT and SPI_CLK on the transceiver are connected to 3 digital output pins on Teensy; PLL_LOCK is connected to a digital input on Teensy; Q1, I1, Q2, I2, V_TUNE are connected to 5 analog input pins on Teensy [3]. One blue LED on the circuit board is designed to indicate if the PLL is locked: when it is locked, the blue LED will be lighted.

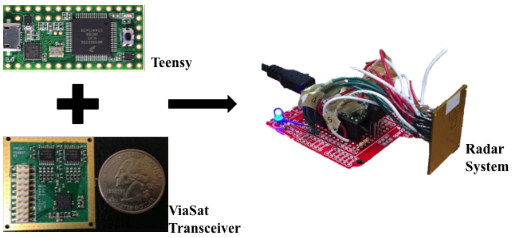

Fig.4 Hardware Construction

4.4 Software Development [4][5]

Programs on Teensy is developed to control the radar transceiver to work. The communication between transceiver and microcontroller is based on SPI (Serial Peripheral Interface).
Arduino libraries are developed to utilize different operations of radar transceiver, according to the Radar Transceiver MMIC Specification [6] by SPI. The core libraries are VS_EN, VS_PLL, PLL_CALI, and VS_VCO. For VS_EN, it could switch the transmitter, receiver and PLL system on or off, and it could also alter the gain of transmitter or receiver. For VS_PLL, it contains the functions of PLL operations, including enabling, A and B counter value; in the meantime, the tuning error output voltage can be obtained from the V_TUNE pin, which is connected to an analog input pin on Teensy. For PLL_CALI, it could automatically calibrate the frequencies and give out the corresponding coarse and fine tune values. And for VS_VCO, manipulating the frequencies that the transmitter sends out can be achieved, when different coarse and fine tune value are set.

5. Test and Result

5.1 Speed Measurement

Radar is mounted on a cart for speed measurement test.
In this case, the velocity calculated out from micro-controller is the velocity component perpendicular, v_{radar}, to the transceiver. Thus, take the tilt angle of radar transceiver, α, into consideration, the true ground speed $v = v_{radar}/\cos(\alpha)$.

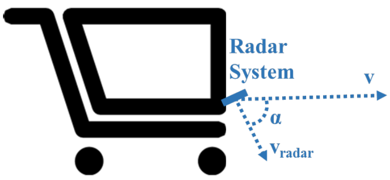

Fig.5 Mounting of Speed Measurement Test

Then Fast Fourier Transformation (FFT) is used to convert the time domain signal into frequency domain. The frequency disparity caused by the moving can make the frequency domain signal a shift towards higher frequency. From the *Fig. 6 Amplitude-Frequency,* the frequency shift is shown by the moving of the low-frequency-peak. The black points in figure are regarded as appearance of the Doppler shift frequencies.

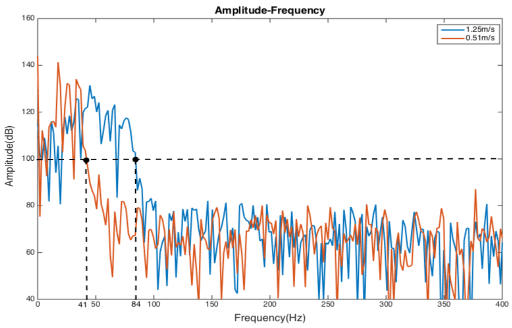

Fig.6 Amplitude-Frequency

For continuous-time measurement, *Fig.7 Time-Spectrum* presents the changes of spectrum during around 20s. At one certain time, darker color means lower amplitude in frequency domain, while the lighter color means higher amplitude. The Doppler frequency is around the edge of the frequency amplitude. The corresponding velocity can be obtained by this frequency and is shown in the *Fig.8 True Ground Speed - t*.

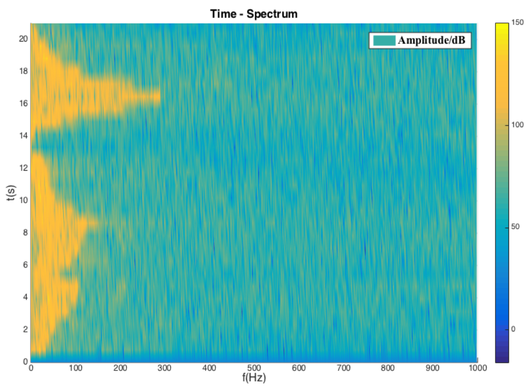

Fig.7 Time-Spectrum

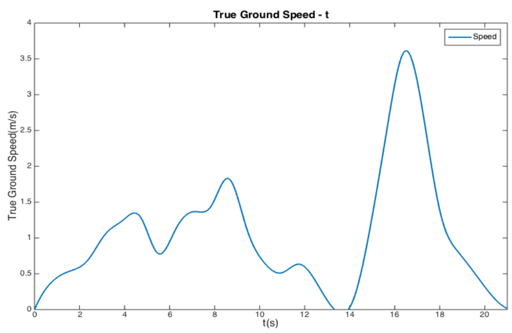

Fig.8 True Ground Speed - t

Since the radar beam is not just a single line, the Doppler frequency will spread over a range of values. In this paper's method, the speed value is obtained from the highest value in such range of frequency, which could be a little higher than the real speed.

5.2 Height (Distance) Awareness

Object is placed in front of radar at different distances, and different sets of I/Q signals is recorded. The results are shown in the following figure.

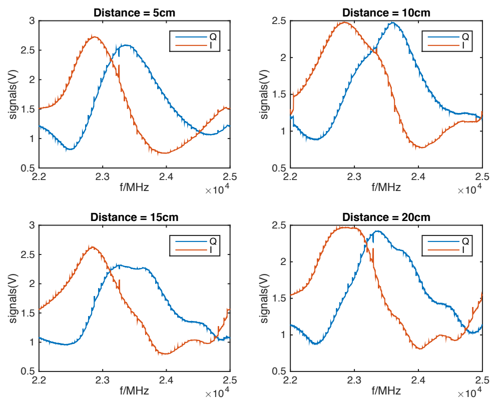

Fig.9 Original Signals from Transceiver

However, these signals are not distinctive with each other and cannot find much different in frequency domain. With some experiments and attempts, it is found that if non-object signal, which is the I/Q signals when there's nothing in front of the radar, is subtracted from the signals obtained in different distances, the results will be much more clear. The non-object signal could be regarded as an initial offset for the system. The processed signals are shown in the following figure.

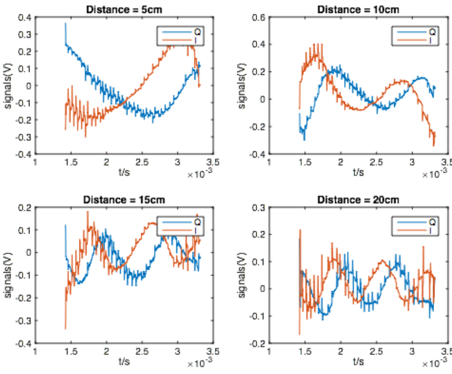

Fig.10 Processed Signals

The frequencies of this new results show that these frequencies are corresponded with the distances. The FFT of this new results also match the locations of the objects: object with farther distance mainly have higher peak frequency in the frequency domain, as shown in the following figure.

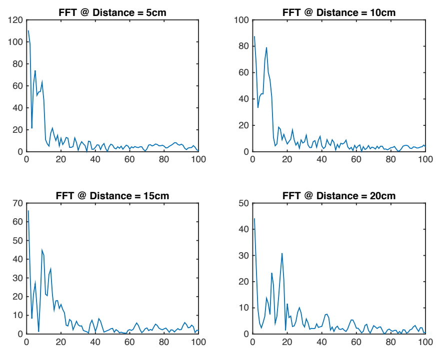

Fig.11 Frequency Spectrum of Processed Signals

The transceiver's output signal (I signal) is

$$\cos\emptyset = \cos\left(\frac{4\pi dk}{c}t\right),$$

where d is the distance of object from radar, k is the frequency change rate with time, t is time, and c is the speed of light. Thus, the higher peak frequency in the above figure means longer distance from the transceiver.

6. Conclusion and Future

The test of speed measurement shows that the radar transceiver can sense the Doppler shift frequency and output it in the final signal returning to the microcontroller. The speed result from the microcontroller matches the true ground speed. For the test of height awareness, the results show that using SFCW, the system can detect the object's distance. The disparity of the distance can be seen in the frequency change in the transceiver's output. Overall, the radar system has the ability and potential to detect the relative velocity or object distance using by Doppler effect or SFCW.

In the next step, more tests of the speed measurement, such as in different situations or with larger range of speed should be implemented. For height awareness, since the result is from one set of data with static object, more tests on height awareness and some modifications should be applied to make it more convincing. What is more, the system now was not amounted on UAV. To amount it, UART can be used for the communication between radar system and UAV. After amounts of testing, radar system could be applied on UAV eventually.

Acknowledgement

Mentor Prof. Xiaoguang "Leo" Liu, Juan Zeng and other fellow researchers in Leo's lab, Tingting Mao and my family

Reference

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