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Research Article

K Band Radar Drone Signatures

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ABSTRACT:

An experimental K-band radar setup has been developed using industrial radar board IVS-465 and NI MyRIO for control and data acquisition. This article presents results for drone reflected signals processing.

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Introduction

In recent years, the use of sensors with coherent signals, which use the changes of the reflected signal due to the Doppler Effect to identify the signatures of moving objects: machines, people, animals. The signature can be defined as a characteristic reflected signal-voltage, function of time and space, formed at the output of a receiving module generated by a radiating sensor: radar, laser, sonar. One advantage of coherent systems is the preservation of the phase of the reflected signal. In these systems, even a small vibration or rotation of the object causes a significant phase change. The term "micro-Doppler," first introduced in coherent laser systems, has become popular in the literature. The micro-Doppler effect was first studied systematically by Victor Chen using a radar sensor.[1] The micro-Doppler effect appears as Doppler frequency modulations in coherent laser or microwave radar systems induced by mechanical vibrations or rotations of a target or any part on the target. These Doppler modulations become a distinctive signature of a tar-get that incorporates vibrating or rotating structures, and provides evidence of the identity of the target with movement.

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The source of micromotion depends on the subject and can be a rotating propeller on a fixed-wing aircraft, the multiple spinning rotor blades of a helicopter, or an unmanned aerial vehicle (UAV); the vibrations of an engine shaking a vehicle; an antenna rotating on a ship; the flapping wings of birds; the swinging arms and legs of a walking person; and many other sources.[2]

Lately, the technology of Doppler radars for industrial applications and in the automotive field has been developing. There is a growing interest in the use of Doppler radars for drone detection.

The aim of the present study is to develop a K band radar experimental setup and evaluate its capabilities for drone detection, distance to it and its speed measurement, to study the radar signature of a drone in the K band.

K band radar experimental setup

One of the possibilities for realization of a coherent radar setup is the use of a widespread low-power radar module with industrial application. One of the conventional radar low power front ends -IVS-465 is used in 24 GHz K band.[3] This board has no preamplifier and custom conditioning board is used in the application. National Instruments data acquisition board MyRIO is used in the experiments.[4] Provide a description of the methods that is sufficiently complete, so that a reader is able understand and eventually reproduce the methods and processing steps without referring to associated publications.

The experiments were carried out in an enclosed space with drone motion in front of the radar antenna.

Principles of Doppler radar signal processing application

The radar circuit is built as an optimal receiver with coherent signal detection in a quadrature detector, which receives both part of the emitted and received

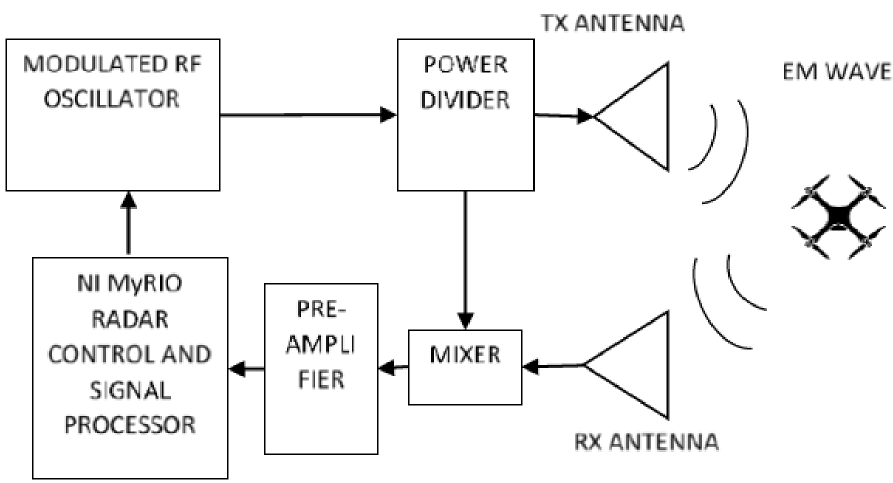

Figure 1: Block diagram of K band radar experimental setup.

Figure 2: Photos of drone and radar experimental setup.

signal. After multiplying the two signals in the detector, a low-frequency signal with difference frequency is formed. In continuous transmission on a single frequency, the difference frequency is proportional to the speed of the radar target.

The Doppler frequency as a difference between transmitted and received frequency due to target motion is given with the equation:

$$f_d = 2F_0 \frac{V_t \cos\theta}{c} \qquad (1)$$

Where F_0 is the frequency of the transmitted signal, Vt is radar target speed, θ is the angle between the target velocity vector and line of sight between transmitter and target, and c is the speed of electromagnetic wave.

This radar front end allows estimation also of the target range. The difference frequency is proportional to the distance to the radar target if a linear frequency modulated signal is used during the transmission. It is necessary to supply the voltage-controlled oscillator of the module with a saw-tooth voltage with a given slope. After receiving the reflected electromagnetic wave and mixing it with the transmitted wave, there is a beat frequency – f_b at the output which is linked with the target range:

$$f_b = \frac{2R.\Delta F}{c.T} \qquad (2)$$

where R is target range, c – speed of electromagnetic waves, T – time period of voltage modulation, ΔF is the frequency bandwidth of oscillator during the modulation process. Due to the Doppler Effect there is also change in the frequency, dependent on the target speed – expression (1).

MyRIO is the basic control and data storage unit of the radar system. It is a multiprocessor system characterized with:

- Xilinx Z-7010 processor 667 MHz (ARM Cortex A9 x 2 cores 28 nm process)

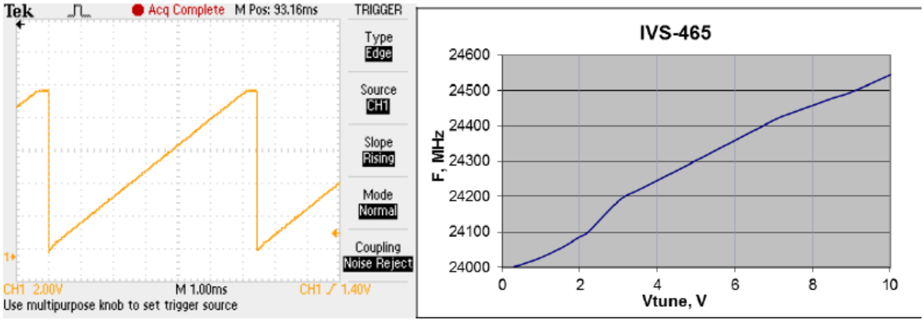

Figure 3: MyRIO FPGA saw tooth control voltage and radar VCO output frequency

- Memory: NV: 256 MB, DDR3 512MB, 533 MHz, 16 bits
- FPGA type same as processor

The control and data recording is done with designed host main application software on ARM processors together with FPGA application software. A LabVIEW virtual instruments were designed for FPGA signal generation for voltage-controlled oscillator frequency control and I/Q data read and recording on internal MyRIO flash system. After that the recorded files were processed.

Experimental results

The MyRIO system allows real-time operation. Recorded I/Q input signal, reflected from drone in real time without interruption, with a duration of 16.5 s, subject to processing are presented on Fig. 4.

On the following figures input CW I/Q signals from flying drone and Matlab short time furrier transform (STFT) processing results are presented.

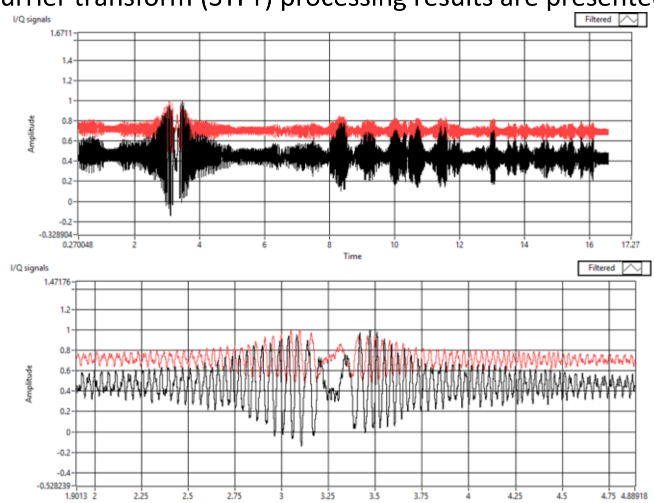

Figure 4: Drone I/Q signals in radar CW mode of operation.

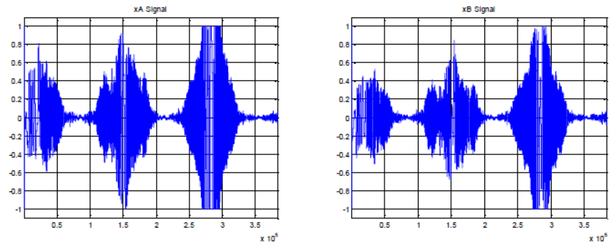

Figure 5: I/Q signals from flying drone.

On the following figures radar I/Q signals are presented in linear frequency modulation for drone distance estimation. The signal processing is done in Lab-VIEW.

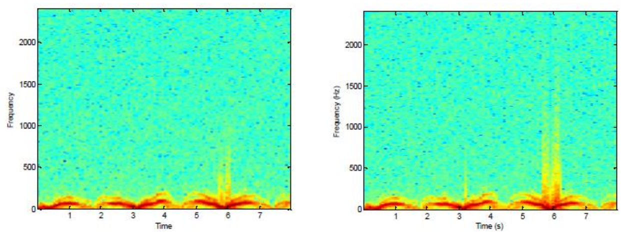

Figure 6: STFT spectrograms of signals from flying drone.

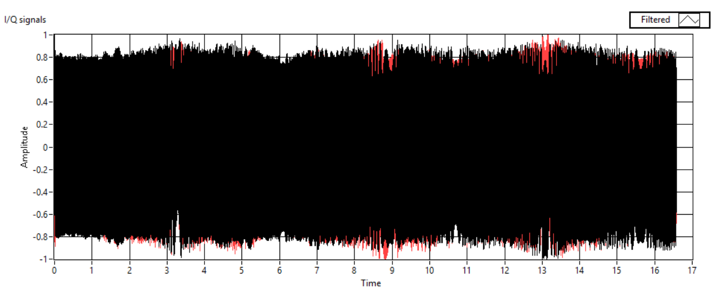

Figure 7: Recorded I/Q LFM signals with a duration of 16.5 s.

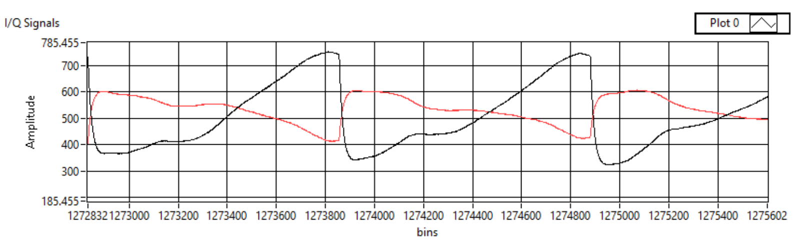

Figure 8: I/Q signals at the output of radar module, LFM transmission (frame 1243), representing data between bins 1272832 and 1273856.

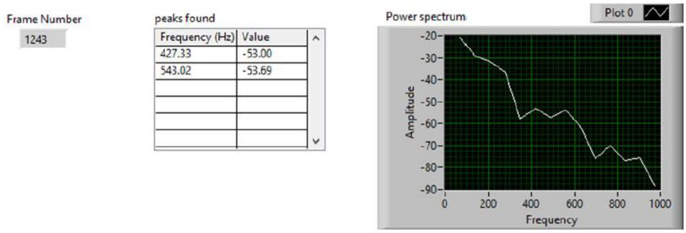

Figure 9: Results from FFT processing of flying drone beat frequency signal in frame 1243.

Conclusion

An experimental K band radar experimental setup has been developed with a low cost industrial module. Radar drone reflected signals are recorded in CW and LFM mode. CW spectrogram signals represent drone signatures in motion and may be used for drone identification. LFM mode is basic for drone distance estimation.

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