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Radar altimeter for ultralight aircraft

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Abstract
The main topic of this paper is a radar ranging for the use in an aircraft altitude measurement. This should help beginner pilots in practicing landing and take off.
To achieve this aim, we selected continuous-wave radars with frequency modulation (FMCW). Our solution is based on linear frequency modulation method using triangular modulation pattern. For data processing was used MATLAB, where will be produced an ideal algorithm. Afterwards, this algorithm will be implemented in C and used in an embedded device.
During the testing, it was found out that radars with 24 GHz transmit frequency and 180 MHz bandwidth have a range resolution from 1 meter upto 13 metres. This range is sufficient for use in training of takeoffs and landings, which is the main aim of this paper. Another good finding is that during take off and landing, there is minimal occurrence of doppler frequencies.
Meanwhile, results show that during practicing takeoffs and landings, it is possible to use radars for measuring altitude. This is very useful, mainly for inexperienced pilots, who cannot correctly estimate altitude for fully safe landing.

Keywords: Radar, Altimeter, FMCW, LFM, Ultralight, Signal processing, Radar ranging

Supplementary Material: *N/A*

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1. Introduction

[Motivation]This paper was made in order to create a system for height indication of ultra-light aircraft during takeoff and landing. This is essential, mainly for pilots in training who cannot safely estimate the height of aircraft while landing. This inability of height estimation could lead to damage of aircraft caused by fall from an unsafe height above the terrain or even to injuries of a aircraft crew.

The result of this work should be a system for height indication either visually or by sound.

[Problem definition] There are many solutions of radar ranging issue. The biggest problems which could arise are doppler frequency occurrences at high speed. Thanks to this effect, the measured frequency is shifted which leads to errors in evaluation of range.

The problem with the doppler shift was minimized using FMCW radar and linear frequency modulation (LFM) method using triangular modulation pattern. LFM method provides possibility of detecting doppler shift and even subsequent compensation.

Another problem is a necessity of data processing in real time. Therefore, an algorithm created for MATLAB, will be coded in *C*++ and loaded to a radar controlling device.

The device will be controlling radar module itself and it will be also processing data. In case of inability of real time processing, algorithms will be provided with selective data processing.

[Existing solutions] Today major part of planes are equipped with barometric altimeters. These altimeters are not ideal for accurate height measurement, because they are too dependent on actual meteorological conditions. Therefore, it is necessary to calibrate these altimeters before every flight. Another problem is that compared to radar type, barometric altimeters are not as accurate and they are measuring altitude above the sea. On the contrary, their advantage is a possibility of usage in great high altitudes.

Pulse radar altimeters are also very common. They are periodically emitting short pulses of electromagnetic waves and after each emission the radar is waiting for reflected signal. Height of aircraft is counted from roundtrip time of flight.

[Our solution] We have selected continuous-wave radar for height measurement. Radar is set up for frequency modulation. This radar is equipped by an antenna transmitting electromagnetic waves in 24 GHz band.

When a signal collides with some surface, signal is reflected back to the radar. Afterwards, the frequency of transmitted signal is subtracted from received signal frequency by mixing of both signals. Resultant frequency is essential for further computation of range. This is illustrated in Figure 1.

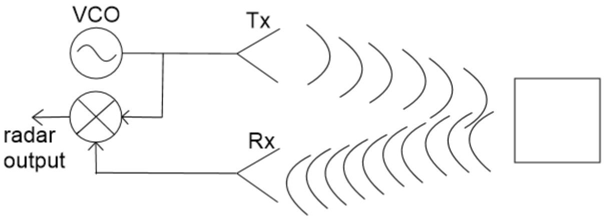

Figure 1. Simplified principle of radar detection

In order to measure range, it is necessary to insert some kind of timestamp into the signal. This timestamp is inserted by frequency modulation of transmitted signal. A signal frequency is continuously increasing and decreasing. Thanks to this frequency modulation, it is possible to calculate time of signal's flight and afterwards compute the range.

2. Signal processing

Radar output is differecne of transmitted and recieved signal. Radar used for our system provide two pairs of outputs. Each pair consist of recieved signal and signal shifted by $\frac{\pi}{2}$. One pair is amplified.

For range computation, it is necessary to know a beat frequency of transmitted and received signal. This frequency is obtained by a frequency analysis of a radar output signal. The result of this analysis is a spectrum. The spectrum is obtained by the Fourier transform of a radar output signal.

Signal is divided into small segments called **frames** which are processed by Fourier transform afterwards. The segmentation is done because an infintely periodical signal is needed for Fourier transform performance and if we used long signal, we would get too many frequencies in the spectrum [1]. Thanks to this reduction it is easier to locate required frequency. In our case, frames are selected according to a modulation pattern for the reason described in section 3.1.

Onward before application of Fourier's transformation there are **windowing functions** used. These functions are basically matrices, which are used to multiply frames. This is done because we need to form edges of frames, thus we achieve to get a better spectrum.

In our system, we are using **Hamming window**. This window is ideal for application with random signals. Using this window, we achieve suppression of lateral peaks [2].

After an application of Fourier's transformation and locating dominant frequency, we can advance to computation of range.

3. Frequency modulation

FM is a method which provides us a possibility of range measurement even by using continuous-wave radars. During signal transmission, we are modulating its frequency. This will represent timestamp in signal. Thanks to this, we can calculate signal flight time after its reception.

3.1 LFM

For our solution, we chose **linear frequency modulation** method. This method works on continuous steady rising and lowering of frequency of transmitted signal. Compared to **FSK** (**Frequency-shift keying**) method LFM is not dependent on motion and angle of observed target.

As an ideal modulation pattern for our purpose, we chose to use triangular (Figure 2). Using this pattern, it is possible not only for measure of range, but even detect the occurrence of **Doppler shift** and afterwards its compensation.

Doppler shift is caused by by moving the object towards or apart the radar [3]. This movement causes a change in receiving frequency, and it could cause change in result of range calculation which is undesirable.

In order to obtain beat frequency, we use as frames for Fourier transform parts of signal defined by up chirp and down chirp edges of triangular pattern.

Basic formula for range calculation is:

$$R = \frac{c\Delta t}{2} = \frac{cf_b}{2}\frac{T_M}{\Delta f} \tag{1}$$

Where R is range, c speed of light, Δt is unknown roundtrip time of flight, f_b is beat frequency, Δf is modulation depth and T_M is half of the period of the triangle.

For compensation of an eventual doppler shift, we have to substitute beat frequency with mean value of beat frequencies of up chirp and down chirp parts of the triangle. This is possible, because beat frequency is shifted up and down during modulation just as it is visible in Figure 2.

Formula is then:

$$R = \frac{c\Delta t}{2} = \frac{c}{2}\left(\frac{f_{bu}+f_{bd}}{2}\right)\frac{T_M}{\Delta f} \tag{2}$$

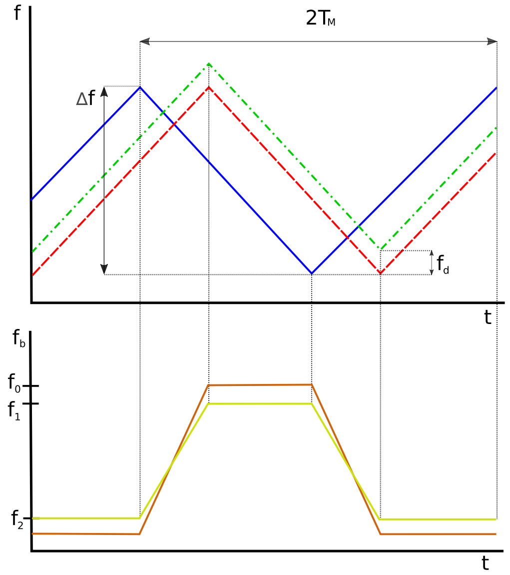

Figure 2. At top: triangular modulation pattern, down: beat frequency, blue: transmitted frequency, red: received frequency, green: received frequency including the doppler shift.

4. Real data results

Measurement takes place in Aeroprakt A-22 aircraft with radar placed between the back undercarriage.

For measurement, we decided to use K-MC1 radar, which works in 24 GHz band and provides modulation up to 180 MHz. Radar was set up on 24.069 GHz base frequency, modulation depth 173 MHz, sampling frequency 50 kHz, triangular modulation pattern consisting of 256 samples.

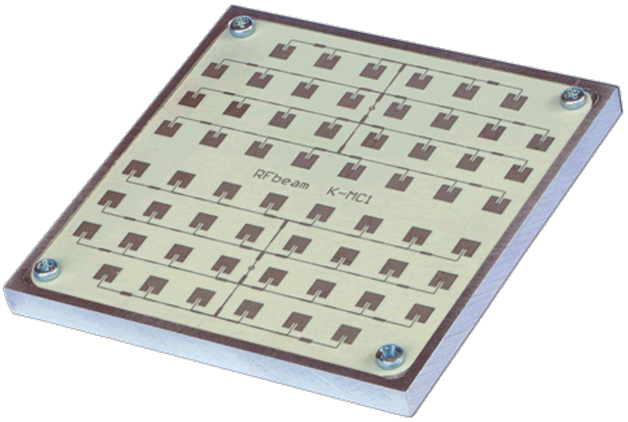

Figure 3. K-MC1 radar

We made two measurements with above-described setup. Output was processed in MATLAB. Before FFT usage, Hamming window was used and each signal was zero padded to length of 4096 samples. Next step was determination of the most significant peak in a spectrum. Currently depending on its surrounding the first or second highest peak is used (mostly second). Final steps are range calculation and filtering out of range values. Results are shown in the following table and in the Figures 4,5,6,7:

	maximal height	minimal height
1. takeoff	17.44 m	0.43 m
1. landing	24.60 m	0.46 m
2. takeoff	18.96 m	0.51 m
2. landing	26.31 m	0.43 m

Table 1

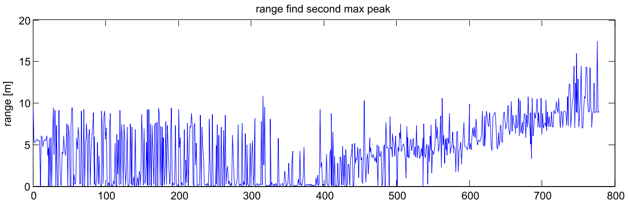

Figure 4. 1. takeoff

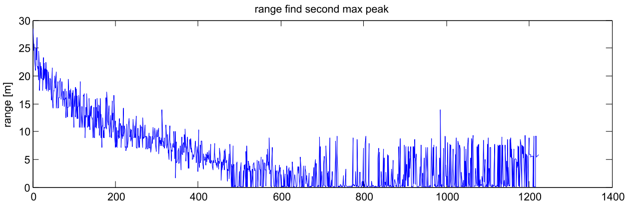

Figure 5. 1. landing

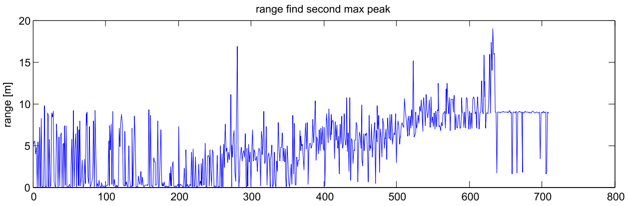

Figure 6. 2. takeoff

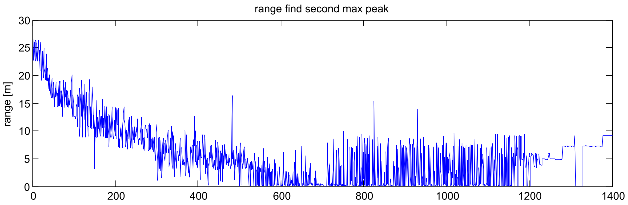

Figure 7. 2. landing

5. Conclusion

In this paper, we are handling problem of altitude measurement using radars. Our solution uses continuous-wave radar with linear frequency modulation using triangular pattern. By this method, we can effectively detect Doppler shift and afterwards compensate corresponding frequencies.

During the system testing, we discovered that by this method, we can measure range from 0.5 meter up to 26 metres.

Testing provides us with data, which shows that right now the calculated range fluctuates by 1 to 2 metres. This could be solved by alternating algorithm to take into account the neighboring values.

For computation, we are using MATLAB, which provide us with functions for easy FFT computation or finding peaks in spectrum and good support for work with vectors and matrices. Unfortunately, computations aren't as fast as desired. At the moment, calculation of range from one frame is taking an average of 0.0801s of which FFT computation lasts 0.0028s and peaks determination 2*0.0386s. Problem is that one frame takes 0.00512s to be recorded, so computation using MATLAB isn't suitable for real time processing. Therefore, the final algorithm will be coded in *C++*, this change should improve performance 10 to 100 times.

Main reason of this paper is to create a system, which could be used for support for pilot trainees. These trainees are generally unable to estimate a height of aircraft correctly. This inability could lead to damage of aircraft or injuries to an aircraft crew. Main idea is that our system should prevent these incidents.

In the future, we plan to improve limits of minimal and maximal measured heights. Furthermore, this system could be extended for recording of takeoff and landing curve for more detailed flight analysis.

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