



IMPLEMENTATION OF DOPPLER RADAR WITH OFDM WAVEFORM ON SDR PLATFORM

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ABSTRACT

A Doppler OFDM radar system is aimed at obtaining radial velocity and distance detection results from the target. This paper reports the implementation of a Doppler OFDM radar system on an SDR platform. The design of the radar system with math script is fed into LabVIEW Communication serving as processing software. The system uses USRP NI-2943R as a device for generating and receiving OFDM doppler radar signals that work in the S-Band. The test results show that to improve the detection result the number of sub carriers and OFDM symbols generated must be taken into account. From the test, relative errors of 5.6% for detection of radial rate and of 16.8% for detection distance are obtained with 40 MHz bandwidth. An increase in sample rate proportional to the value of OFDM signal bandwidth on USRP greatly affects the performance of systems.

Keywords: doppler radar, OFDM, OFDM radar, SDR.

1. INTRODUCTION

The current radar system has various functions in various fields, such as urban planning, military, and even medical fields as a technology for detecting breast cancer [1]. Radar is a system that can be used to detect a target to get information in the form of distance, position and radial velocity, based on the radio wave radiated or reflected by the target and received by the radar [2]. Signal waves on active radar can be modulated with various types as needed. Radar with SISO (Single Input Single Output) system can only detect radial distance and rate, and can not detect the angle of a target unless the antenna is used with narrow beamwidth and mechanical rotator.

To meet the needs of a more efficient radar, many researches on radar waveform has been conducted. Previous research about implementation of S-band radar using LFM waveform has been done in [3]. And nowadays, OFDM (Orthogonal Frequency Division Multiplexing) waveform has been a very potential candidate as radar waveform. It is superior compared to the LFM waveform because there is no coupling between the Doppler and delay profile [4]. The characteristic of OFDM radar waveform has been discussed in [5]. Doppler effect in radar comes from the reflection effect (echo) of a moving target which is detected, causing a shift in the waveform frequency. This paper reports the application of the Doppler concept on radar used to detect a moving target to obtain information of radial distance and velocity with the OFDM signal approach to optimize the use of signal waves [4]. This implementation utilizes SDR (Software Defined Radio), in this case NI USRP (Universal Software Radio Peripheral), and Labview as a user interface.

2. MODELING, DESIGN AND IMPLEMENTATION

A. System modeling

In the model of the radar system to be built, the first stage is generation of pseudonumeric integer bit information. A number of bits generated are then

modulated into several symbols by using QPSK modulation. The process is continued by changing the data form from serial to parallel required for the next stage. The next process uses the IFFT algorithm to form orthogonal subcarriers. The process is continued by adding CP (cyclic prefix) to prevent the occurrence of ISI and changing back from serial to parallel before being transmitted in the simulation. In the process of transmission through the channel, the target modeling process is done to get the distance and radial rate in the simulation is adjusted at the time of implementation. The block diagram is shown in Figure-1.

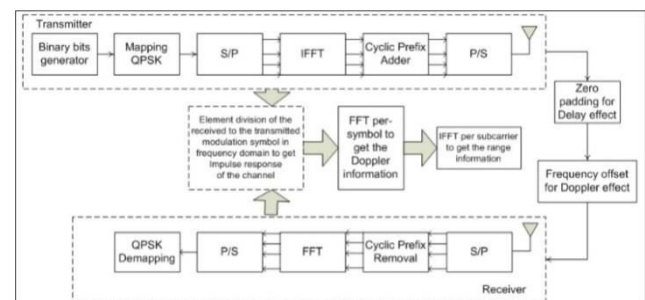


Figure-1. Block diagram of OFDM doppler radar system.

Target distance modeling is done by inserting a value of 0 or by using a zero pad that is proportional to the delay of the signal reflection to the target. On the other hand, the target radial velocity is modeled by adding an offset frequency on a channel proportional to the Doppler frequency and having a velocity relative to the wavelength of the signal. After the data are obtained from the target, the signal is captured at the receiver side serially and then converted into parallel for subsequent processing. CP deletion process is carried out, followed by FFT process. Acquisition of information about distance and radial velocity is done by correlation between received and transmitted waveforms.



B. System design by Matlab simulation

After the modeling is done and several parameters to be used in the system are defined, system is designed through simulation, which subsequently is implemented in the SDR device. The design simulation with MATLAB is done according to the Doppler Radar system block diagram. The results are tested to determine the radar capability when the predefined parameters are used.

After designing the system through OFDM Doppler radar system modeling and target modeling, the detected information is processed based on the generated symbol when transmitting OFDM signal. Information processing using a periodogram is also done to see the ambiguity of the detection result and produce a combined visualization between the speed and distance in a plot. The experiment was conducted by testing the simulation result by using working frequency of 2.1 GHz with 1024 subcarriers, 256 symbols, 40 MHz bandwidth, as well as radial velocity and target distance of 40 m/s and 40 m, respectively. The results in Figures 2 (a) and (b) show a radial rate estimate of 43.6 m/s and an estimated distance of 44.02 m. Thus, the detection result from the target model can be used because it has a relatively low error.

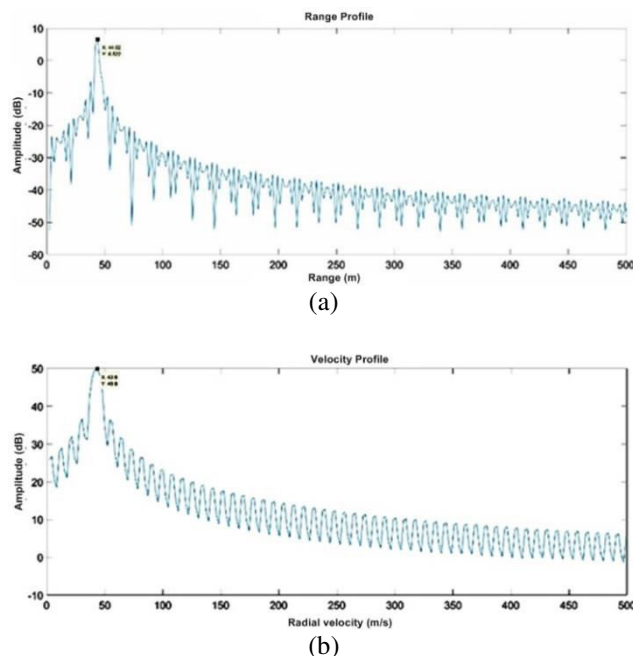


Figure-2. Detection result using Matlab (a) target distance, (b) radial velocity.

C. System design by simulation using LabVIEW communication

Simulation with LabVIEW Communication software aims to validate the system design results in Matlab simulation and also validate whether the mathscript program is appropriate and can be used in the test design program for further implementation and testing using USRP RIO device. Similar to the Matlab simulation, signal processing is done in a single stage that does not overload the computer.

The operation of LabVIEW Communication on the device for a program with high data rate can overload the computer. The use of mathscript in LabVIEW Communication is done to alleviate the load of the process when data processing is carried out. With mathscript as a signal generation and processing program, the simulation model can be done by modeling the target in real time. This means that radar simulation can be done for varying values of radial velocity and target range, where a target can be seen moving from location A to location B having different distance from the radar.

D. Design of measurement and testing

Prior to implementation of the Doppler OFDM radar system using USRP RIO, it is necessary to design the LabVIEW Communication to manage the configuration and synchronization of the required signal in the radar system. System design is done by applying the Matlab script on Labview Communication as a validation of the simulation program. The system design that has been done are then configured in accordance with Figure-3.

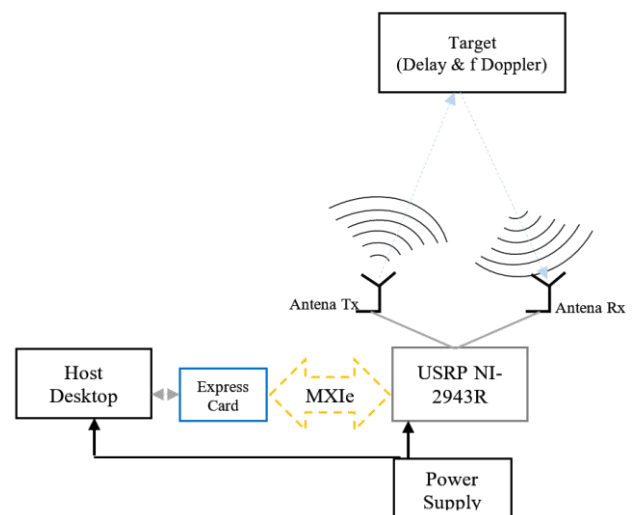


Figure-3. Configuration of the radar system hardware.

E. Testing

Testing is done by taking some actual values from the target radial velocity and distance to compare with the detection result. Data retrieval is performed multiple times with several different parameters. From the test, actual requirements of Doppler OFDM radar system can be learned with respect to bandwidth, the number of subcarrier and the number of symbols that need to be generated. The test configuration and the environmental situation are shown in Figure-4.



Figure-4. OFDM doppler radar testing configuration and environment.

Calibration of the system needs to be done to determine the zero reference point for radial velocity and distance as a comparator or indicator of the system that has been designed. The reference point calibration is done by connecting directly the transmitter to the receiver via cable and attenuator. This calibration method is performed to ensure that no signal delay occurs due to various devices used such as overflow or underflow on the data transmission process on the host computer and the process of transmission from the USRP RIO through the transmission medium.

3. RESULTS

A. Detection of target radial velocity and range in simulation

Based on the processing results, target detection and radial velocity resolution of the targets are shown in Table-1 for the 2.1 GHz carrier frequency system with 40 MHz bandwidth. Comparison of the detection result is done against target model which has constant and equal radial velocity of 20 m/s on each simulation result.

Table-1. Radial velocity detection from simulation.

Δf (Hz)	N_c	M_{sym}	Radial velocity resolution (m/s)	Detected radial velocity (m/s)
78125	512	64	77.505	26.16
78125	512	128	38.752	26.16
78125	512	256	19.376	26.16
78125	512	512	9.688	26.16
78125	512	1024	4.844	26.16
625000	64	512	77.707	558
312500	128	512	38.752	139.5
156250	256	512	19.376	69.75
78125	512	512	9.6881	26.16
3.9063	1024	512	4.844	21.8
1.9530	2048	512	3.75	20.95

From the table it can be observed that the larger number of symbols is used, the greater the resolution of the radial velocity of the detected targets, where the value of the smallest difference allowed of velocities is inversely proportional to the number of symbols. The resolution value does not significantly affect the readable detection result for a single target, but becomes important if there are multiple targets, where the resolution of the radial velocity determines the ability of the radar system to detect adjacent targets with different velocities.

The target distance detection results are closely related to the number of subcarriers because the smallest distance difference between two distinguishable targets is inversely proportional to OFDM signal bandwidth, where OFDM bandwidth is the product of subcarrier spacing and the number of subcarriers. Increased radar detection capabilities against target distances require a significant increase in bandwidth in addition to an increase in the number of subcarriers. According to Table-2, an increase in the number of subcarriers may increase the resolution of the target distance. Constant bandwidth with varying number of subcarriers changes the subcarrier spacing. However, the subcarrier spacing changes produce a relatively low value difference in distance resolution.

B. OFDM signal generation with USRP

The baseband OFDM signal is formed at the frequency domain and after modulation transmitted by the transmitting device. The OFDM signal coming out of the transmitter is read by a spectrum analyzer (SA) to determine the bandwidth and actual power of the transmitted signal. By adjusting the sample rate, i.e. the inverse of the sample spacing of the OFDM signal after the IFFT process, to 35 MS/s, a signal obtained with a bandwidth of about 35.224 MHz is shown in Figure-5. Experiments were performed several times for different sample rate and show that the bandwidth which appears on the SA is directly proportional to the size of the sample rate.

Table-2. Target range detection from simulation.

Δf (Hz)	N_c	M_{sym}	Range resolution (m)	Detected range (m)
625000	64	512	3.75	21.05
312500	128	512	3.75	20.96
156250	256	512	3.75	20.96
78125	512	512	3.75	20.96
3.9063	1024	512	3.75	20.96
1.9530	2048	512	3.75	20.95
78125	512	64	3.75	20.96
78125	512	128	3.75	20.96
78125	512	256	3.75	20.96
78125	512	512	3.75	20.96
78125	512	1024	3.75	20.96

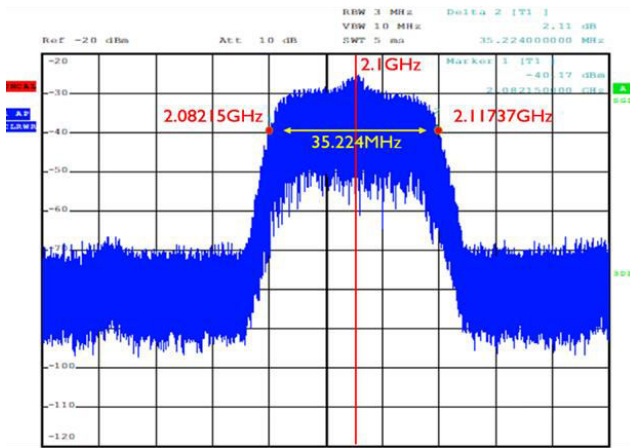


Figure-5. OFDM signal spectrum on spectrum analyzer.

To obtain a signal with the desired specifications adjustment to the configuration is required. The OFDM doppler radar system requires considerable bandwidth to get a sufficiently good detection result by increasing the sample rate. However, if the sample rate is enlarged, an overflow of data will result and cause the process to stop. In this case, bandwidth and data flow are trade offs that need to be considered and selected based on the needs of the radar system.

C. Radial velocity detection

The tests are performed using NI USRP RIO and LabVIEW Communication. Compared to the simulation designs in the previous sections, the implementation of the Doppler OFDM radar system on the USRP has many aspects to be taken into account to be able to transmit as desired. Configurations made on transmitter and receiver subsystems can affect the results of radar detection. One of the parameters that influence the signal generation is sample rate in LabVIEW which is used to transmit data on USRP RIO. In the previous discussion it is known that the value of the sample rate is proportional to the output signal bandwidth of USRP.

After the design of the OFDM doppler radar system the test results have been obtained with the pre-determined test scheme, using 1024 subcarriers and 256 symbols that also consider the symbol rate. The sample rate setting is minimized so that no data overflow can occur which may cause the radar system unable to work in real-time but with still considerable bandwidth. The bandwidth in the test follows the value of the sample rate, resulting in a bandwidth of 16.3 MHz. In the experiment, the first simulation is done to set the value of system parameters to enable target detection in order to get the resolution of radial velocity of 1.63 m/s. From the experiments conducted some data detection results are selected in Figure-6.

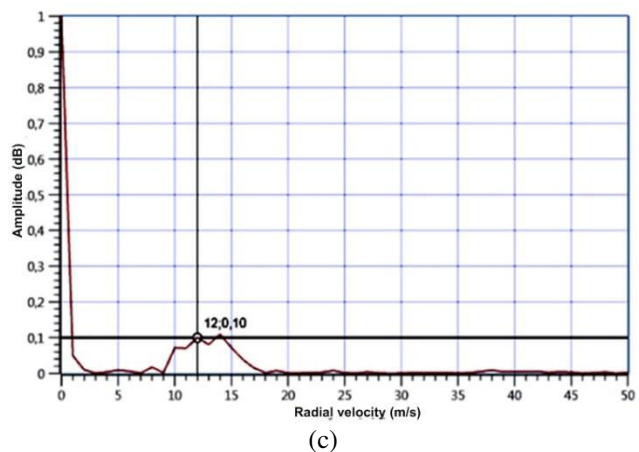
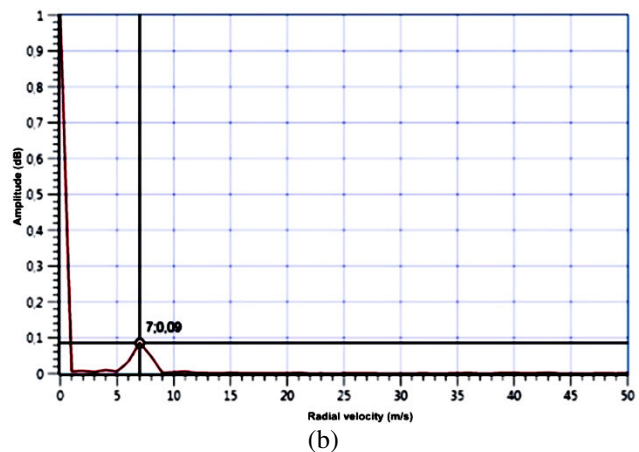
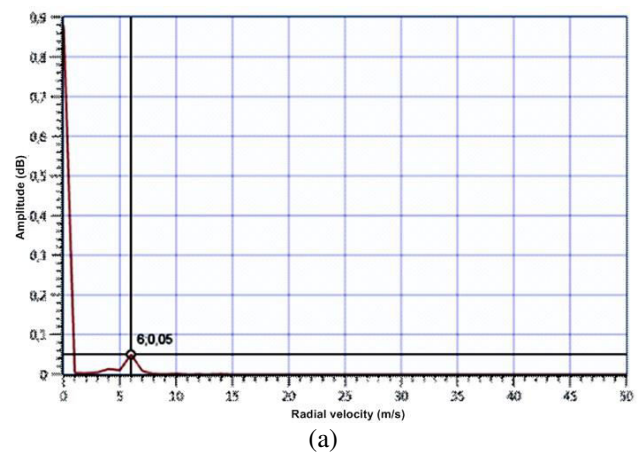


Figure-6. Radial velocity detection results:(a) 1sttarget, (b) 2ndtarget, and(c) 3rd target.

In Figure-6 (a) the actual target radial speed attached to a moving car is attempted to reach a value of about 20 km/h or 5.556 m/s with a vehicle speedometer as an indicator of the accuracy of the target radial rate. In Figure-6 (a) it appears that the detected target has low power after normalization, caused by an object detected at a radial velocity of 0 m/s at point 0 with high enough power which may be the clutter or incoming reflection via side lobe antenna with considerable power.



The relative error rate of the radial velocity detection results is quite good, which include test results of the 1st, 2nd and 3rd targets with an average relative error rate of 5.6%.

D. Range detection

Estimation of target distance takes into account the round trip delay. In this case, the radar system uses 1024 subcarriers and 256 symbols on the basis of subcarrier requirement to obtain a fairly good accuracy. In addition, the bandwidth used should be as much as possible by maximizing the capability of the device so that the processing of data flow on the transmitter and receiver can work properly. Sample rate is increased to 25 MS/s so that the actual bandwidth becomes 25 MHz with a trade off of higher noise level.

The first target is placed at a distance of 3 m from the transmitter so that by taking into account the round trip delay the total distance traversed by signal is obtained as far as 6 m. However, detection results on the radar indicate a total distance of 8 m. Deviations from the actual distance may be caused by the delay arising from the dominant indirect reflection. There is another signal with high enough power which can cause detection error of the target. The noise is due to the high sample rate adopted.

Subsequently, with target at 5 m range, the round trip delay signal is 10 m. Based on the experimental results, the peak power of the detected target is quite low and leads to an estimate error of the target distance. The received signal indicates a target with a 13 m round-trip range. The low signal power level happens because at the round-trip range the reflected signal has a power so low that it is close to the receive power threshold on the receiver.

The relative error rate of the detection result with a sufficiently varied target range should be taken into consideration in maximizing OFDM signal specification. From all experimental results, target distance detection provides an average relative error of 16.82%.

4. CONCLUSIONS

This paper reports the implementation of OFDM-based Doppler radar on the SDR platform. In this paper, USRP NI-2943R and LabView communication are used. The data transfer rate and the signal bandwidth can be adjusted by setting the sample rate value. Radial velocity and target range detection can be visualized on the graph plot or periodogram using processing based on the number of subcarriers and OFDM symbols generated. In the Doppler OFDM radar design the optimal number of subcarriers and OFDM symbols that can be used is 1024 and 256, adjusted to the sample rate on the USRP device.

To improve the target range detection, an increase in sample rate proportional to OFDM signal bandwidth is required. Meanwhile, to improve the detection of radial velocity of the target a lower sample rate is required so that the system can work in real-time. The average error rate of radial velocity detection is 5.6%, while the average error of range detection in the tests is 16.82%.

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REFERENCES

- [1] W. Werner, S. Leen, Y. Marwan, R. Tobias, K. Gerhard, M. Alberto. 2015. Radar 2020: The Future of Radar Systems. IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2015, Milan, Italy, 2015, 188-191.
- [2] Skolnik M.I. 2003. Introduction to Radar Systems, 3d ed., McGraw-Hill, New York.
- [3] N. Khakim, P. H. Mukti, D. Kuswidiastuti, G. Hendrantoro. 2015. Preliminary results on S-Band LFM Radar Development. International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA).
- [4] C. Sturm, E. Pancera, T. Zwick and W. Wiesbeck. 2009. A Novel Approach to OFDM Radar Processing. Proc. IEEE Radar Conference RadarCon09, Pasadena, CA, May 2009
- [5] D. Kuswidiastuti; P. Handayani; G. Hendrantoro; E. Widjiati; L. P. Ligthart. 2015. OFDM waveform design parameter for submarine radar. IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES).