Proceedings of the Asia-Pacific Microwave Conference 2016

Reconfigurable Doppler Radar Using Software Defined Radio Platform for Through-Wall Applications

Sangeeta Goyal, Shobha Sundar Ram, Vivek Ashok Bohara
sangeeta1472@iiitd.ac.in, shobha@iiitd.ac.in, vivek.b@iiitd.ac.in
IIIT-Delhi, New Delhi, India, 110020

***Abstract*- A reconfigurable Doppler radar is implemented on a software defined radio platform for detecting humans behind walls. Two types of configurations are tested – a continuous wave radar and an orthogonal frequency division multiplex (OFDM) radar. Both the configurations yield micro-Doppler signatures while the OFDM radar gives additional range information. Measurement results of single and two humans are presented in through wall scenario.**

I. Introduction

Through-wall radars have been researched and developed over the last decade for security and surveillance purposes [1-3]. Doppler radars, in particular, are useful for tracking moving humans since they suppress the background clutter from stationary objects [4]. Several types of Doppler radars have been developed with a variety of functional capabilities – one dimensional radars that track the micro-Doppler from the human, two and three-dimensional Doppler radars that are capable of locating multiple targets in azimuth and/or elevation [5]. In this work, a reconfigurable radar is presented that can be adapted to any of the above functionalities through software modifications.

Software defined radio (SDR) enables engineers to rapidly design and prototype wireless systems [6]. Physical layer functions, such as modulation, demodulation, sampling and filtering, are realized through software specifications. National Instrument's Universal software radio peripheral (USRP), is an SDR platform that was originally developed for the implementation of communication systems. More recently, radar systems based on USRP have gained popularity since the platform provides flexibility to change the radar waveform, carrier frequency, sampling rate etc. [7, 8]. Recently through-wall radars using wideband signals have been realized using SDR. In this work, we will focus on two Doppler radar implementations – continuous wave (CW) radar and orthogonal frequency division multiplexing (OFDM) radar.

Continuous wave radars provide radar users, micro-Doppler information of dynamic targets such as humans [2]. These micro-Doppler arise from the non-rigid swinging motion of the arms and legs. On the other hand, OFDM radars [9] use multiple orthogonal sub-carriers and hence allow for independent and unambiguous range-Doppler processing [10]. Radar systems implemented using OFDM [11] are robust, highly flexible and enable the fine tuning of system parameters for specific propagation channels [12]. This paper uses software modifications on the same hardware to implement both the CW and OFDM radar for the extraction of micro-Doppler signatures in through-wall conditions. The rest of the paper is organized as follows. Section II of this paper discusses the radar structure and algorithms for extracting the Doppler shift caused by the human movements. In section III, we discuss the experimental setup and the radar parameters for generating measurement data. Section IV presents the measurement results. Section V concludes the paper.

II. Theory

Micro-Doppler signature extraction in CW radars is straightforward and has been implemented in several works [4]. The time domain radar backscattered signal is amplified, down converted, digitized and the short time Fourier transform (STFT) is applied on the received signal to generate the micro-Doppler signatures.

In OFDM, a wideband signal is divided into parallel orthogonal narrowband subcarriers [15]. The time domain expression for the OFDM [13-15] is given in (1) by

$$x(t) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} D_{Tx}(mN+n)e^{(j2\pi f_n t)}, \quad 0 \le t \le T \qquad (1)$$

Where N represents the total number of orthogonal subcarriers, M the total number of symbols, $D_{Tx}(mN+n)$ are the complex modulation symbols modulated with discrete phase modulation technique, f_n is the individual subcarrier frequency and T is the total OFDM symbol duration. For maintaining the orthogonality of the OFDM symbols, and thereby reducing the interference between the subcarriers, the condition given in (2) has to be maintained. BW here represents the bandwidth of the OFDM symbol and Δf is the subcarrier spacing.

$$f_n = n\Delta f = \frac{n}{T} \; where, \Delta f = \frac{BW}{N} = \frac{1}{T} \qquad (2)$$

In the presence of the target moving with a velocity of *v m/s* (giving a Doppler shift of f_d) at a distance of R meters from the radar setup, the received OFDM symbol [11] is expressed in (3) by,

$$y(t) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} D_{Rx}(mN+n)e^{(j2\pi f_n t)} \qquad (3)$$

Where,

$$D_{Rx}(mN+n) = D_{Tx}(mN+n)e^{\left(-j2\pi f_n \frac{2R}{c}\right)}e^{(j2\pi m f_d t)} \qquad (4)$$

Here, c here is the speed of light. From (4), it can be seen that all the target information is contained in $D_{Rx}(mN+n)$,

978-1-5090-1592-4/16/$31.00 ©2016 IEEE

Authorized licensed use limited to: Indraprastha Institute of Information Technology. Downloaded on July 21,2021 at 13:52:49 UTC from IEEE Xplore. Restrictions apply.

complex received modulation symbols, which is received at the receiver and is available at the output of the demultiplexer. When element wise division [16] of the transmitted complex modulated symbol with the received symbol is performed, the channel transfer function is realized in the frequency domain.

$$h(m,n) = \frac{D_{Rx}(mN+n)}{D_{Tx}(mN+n)} \quad (5)$$

giving, $h(m,n) = e^{\left(-j2\pi f_n \frac{2R}{c}\right)} e^{(j2\pi m f_d t)}$ (6)

After getting the channel transfer function, the range-Doppler processing is carried out as follows:

A. Range processing

A target present at a distance of R causes a linear phase shift equivalent to $\frac{2R}{c}$ on each subcarrier of the reflected OFDM symbol. Therefore, the range can be estimated by carrying out the inverse discrete Fourier transform (IDFT) of the sub-carrier data.

B. Doppler processing

The Doppler shift experienced due to a target moving with velocity of *v m/s* is given in (7) by

$$f_d = 2v\frac{f_c}{c} \quad (7)$$

where f_d is the Doppler frequency and f_c is the carrier frequency.

This f_d causes a phase shift of $2\pi m f_d t$ on every subcarrier of symbol m of the OFDM symbol. Since the system bandwidth is much smaller compared to the carrier frequency, we assume that the Doppler affects all the subcarriers by the same amount. The Doppler shift is estimated by taking the fast Fourier transform (FFT) along the time axis. The above processing works on a single OFDM frame and hence does not provide micro-Doppler information.

For extracting the micro-Doppler, we consider the cell for which the range is zero. This results in *h(m,n)* to be $e^{(j2\pi m f_d t)}$ in (6). Then, different frames are combined so as to increase the total observation time [17]. Afterwards STFT is applied on the resultant time-domain signal to generate the joint time-frequency spectrogram.

III. Experimental Setup and System Parameterization

The experimental setup for carrying out the measurements is shown in Fig. 1. Two USRPs 2953R, from National Instruments, one working as a transmitter and the other as receiver are used. Both these platforms are configured using Labview. Both the USRPs were synchronized by feeding the clock of the transmitter USRP into the receiver USRP. Double-ridged horn antenna, HF907, having a wide operating frequency range of 0.8 GHz to 18 GHz with gain of 5 dBi to 14 dBi were used for transmission and reception. Both the USRPs were connected to the host computer using a 1 GB Ethernet cable. The same hardware was used for both implementing both the CW and the OFDM radars. Only the software configuration code on the platforms were modified for each of the cases. The software modified the transmitted waveform on the transmitter and the radar signal processing

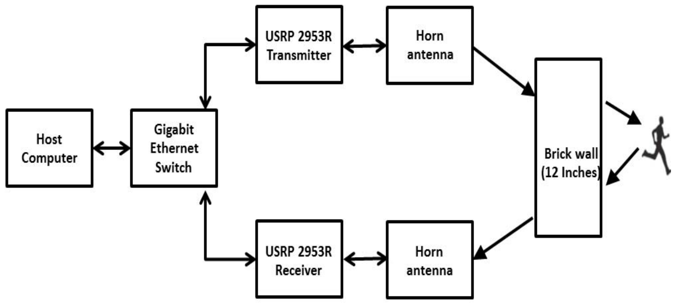

Figure 1. Block diagram of the experimental setup

algorithm on the receiver. The carrier frequency for both waveforms is 3 GHz.

Fig. 2 shows the floor geometry of the laboratory area where the experiments were performed. The walls are 12 inches thick and made of bricks. The distance between the radar system and the wall is 2 meters and the target was moving behind the wall for up to a maximum distance of 5 meters. Two cases have been considered. In the first case, a single human walks before the radar towards and then away from the radar. In the second case, two humans move simultaneously. While one moves towards the radar, the other human walks away and then they change directions.

For the extraction of micro-Doppler signatures of a moving target, a sampling rate of 400 KS/s is chosen for the receiver system of both radar configurations. For the OFDM radar, a subcarrier spacing of 6.250 KHz is selected. The subcarrier spacing is chosen to ensure that it is greater than ten times the maximum Doppler frequency of the moving target in order to ensure orthogonality. Since, humans are slow moving targets, this condition is easily satisfied with the choice of the subcarrier spacing.

The elementary OFDM symbol duration, *T*, equals to 0.16 ms. Also, no cyclic prefix has been used to save power. The Doppler resolution depends on the observation period, and is given by f_d = *1/(M*T)* which is equal to 10Hz giving a velocity resolution of 0.27 m/s. All the system parameters are summarized in table 1.

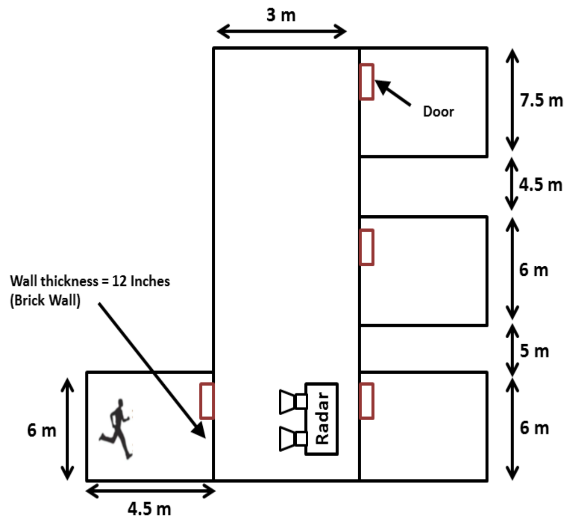

Figure 2. Floor geometry for through the wall experiments

Authorized licensed use limited to: Indraprastha Institute of Information Technology. Downloaded on July 21,2021 at 13:52:49 UTC from IEEE Xplore. Restrictions apply.

TABLE I
OFDM SYSTEM PARAMETERS

Symbol	Parameter	Value
F_c	Carrier frequency	3 GHz
N	Number of subcarriers	64
Δf	Subcarrier spacing	6.250 KHz
T	Elementary OFDM symbol duration	0.16 ms
B	Bandwidth	400 KHz
Δr	Range resolution	375 m
R_{max}	Maximum unambiguous range	24000 m
V_{max}	Maximum unambiguous velocity	$\pm$ 85.22 m/s
M	Number of evaluated symbols	625
Δv	Velocity resolution	0.27 m/s
Δf_d	Frequency resolution	9.84 Hz
F_{dmax}	Maximum Doppler frequency	$\pm$ 3.125 KHz

IV. Results

Experiments have been carried out showing the micro-Doppler signatures for CW radar and range-Doppler as well as micro-Doppler signatures using OFDM radar. For micro-Doppler signatures, STFT was applied on the time-domain data. Window size chosen for STFT was 0.1s. Fig. 3 shows the micro-Doppler signatures of single human using CW radar. Here the target approaches the radar from 0 to 3 seconds and then goes away from the radar from 3 to 7.5s. Movements of hands, legs and torso are seen clearly. Due to inherent I/Q imbalance in the data processing, we are able to observe some negative Dopplers even when the human is approaching the radar and vice versa. Fig. 4 shows the micro-Doppler signatures of two humans generated from the CW radar. Both the humans walk in opposite directions. Thus one shows positive torso Doppler and the other shows negative Doppler.
Fig. 5 and Fig. 6 show the range-Doppler profile of single and two humans generated using OFDM radar. Here, the radar is operated in a through-wall scenario where the targets walk behind the wall. Due to the low bandwidth, the range resolution is quite poor. Since the power is distributed equally throughout the bandwidth of the transmitted waveform, the received signal strength is lower as compared to that of the CW radar. The strong reflection shown in Fig. 5 (single human case) is due to the direct signal off the target and the wall. Here, both the returns are present in the same range bin.

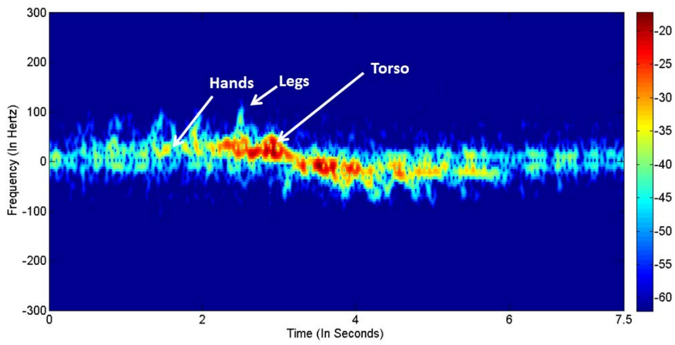

Figure 3. Micro-Doppler signatures of single human using CW radar

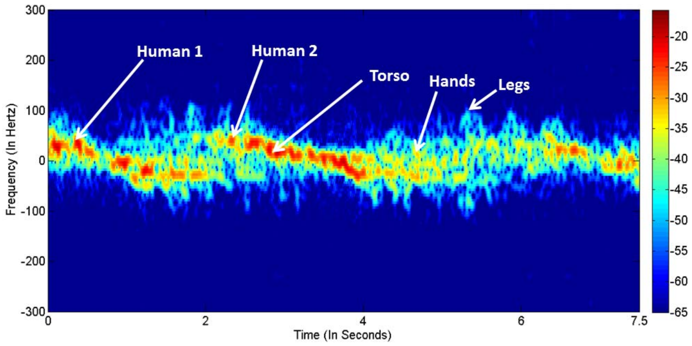

Figure 4. Micro-Doppler signatures of two human using CW radar

The Doppler spread is not due to Doppler ambiguity of conventional pulse Doppler radars. Instead, it is due to the micro-Dopplers of the body parts. In Fig. 6, we observe the micro-Doppler due to two humans. Again both the humans are in the same range bin due to the poor range resolution.

Fig. 7 and Fig. 8 show the micro-Doppler signatures of humans from the OFDM radar in through-wall scenarios. Fig. 7 shows the presence of single human while Fig. 8 shows the presence of two humans moving in opposite directions.

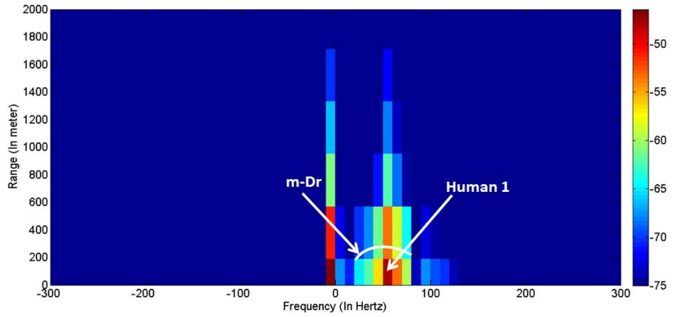

Figure 5. Range-Doppler profile of single human using OFDM

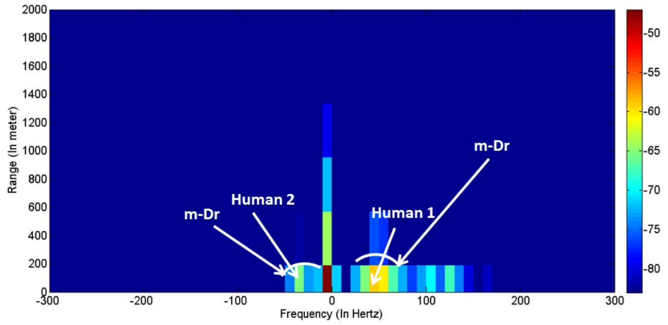

Figure 6. Range-Doppler profile of two human using OFDM

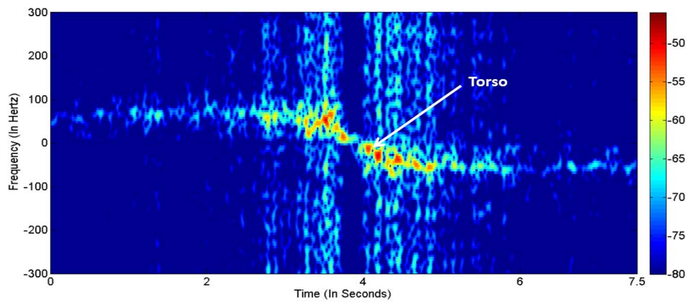

Figure 7. Micro-Doppler signatures of single human using OFDM radar

Authorized licensed use limited to: Indraprastha Institute of Information Technology. Downloaded on July 21,2021 at 13:52:49 UTC from IEEE Xplore. Restrictions apply.

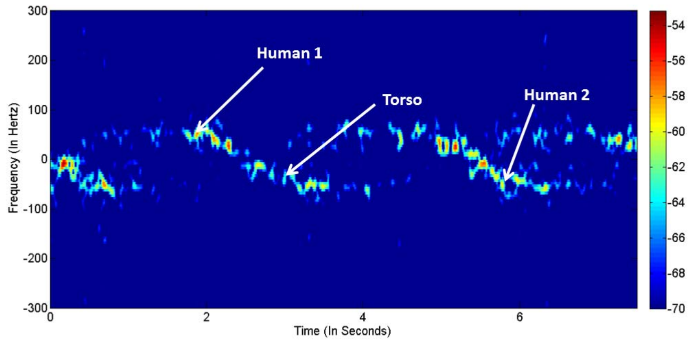

Figure 8. Micro-Doppler signatures of two human using OFDM radar

The walls introduce a signal attenuation of 10 dB. We see that due to the poor signal to noise ratio, we can only observe the micro-Dopplers due to the torso movement and Dopplers from the hands and legs are not easily seen. The reason for this being distribution of power caused by using OFDM.

V. Conclusion

CW and OFDM radar has been implemented using USRP. CW radar provides only micro-Doppler information while OFDM radar provides range-Doppler imaging as well as micro-Doppler extraction. The range resolution is poor due to the low bandwidth of the OFDM radar. The results were obtained for single human and two humans moving in opposite directions in free space and through-wall scenarios. .

References

[1] J. L. Geisheimer, W. S. Marshall, and E. Greneker, "A continuous-wave (CW) radar for gait analysis" *Thirty-Fifth Asilomar Conference on Signals, Systems and Computers, IEEE*, Vol. 1, 2001.

[2] M. G. Anderson and R. L. Rogers, "Micro-Doppler analysis of multiple frequency continuous wave radar signatures" *Defense and Security Symposium, International Society for Optics and Photonics*, 2007.

[3] J. E. Peabody, G. L. Charvat, J. Goodwin, and M. Tobias, "Through-wall imaging radar" *Lincoln Laboratory journal*, Vol. 19, No. 1, pp. 62-72, 2012.

[4] C. Clemente, A. Balleri, K. Woodbridge and J. J. Soraghan, "Developments in target micro-Doppler signatures analysis: radar imaging, ultrasound and through-the-wall radar" *EURASIP Journal on Advances in Signal Processing*, Vol. 1, No. 18, 2013.

[5] F. Adib and D. Katabi, "See through walls with wifi!" *ACM digital library*, Vol. 43, No. 4, pp. 75-86, 2013

[6] http://www.ni.com/sdr/usrp-rio/

[7] S. Costanzo, F. Spadafora, G. Di Massa, A. Borgia, A. Costanzo, G. Aloi, and O. H. Moreno, "Potentialities of USRP-based software defined radar systems", *Progress in Electromagnetics Research*, 2013.

[8] http://www.ni.com/labview/

[9] Z. Slimane, A. Abdelmalek, and M. Feham, "OFDM based UWB synthetic aperture through-wall imaging radar" *In IEEE, Third International Conference of Broadband Communications, Information Technology & Biomedical Applications*, 2008

[10] C. Sturm, T. Zwick, and W. Wiesbeck, "An OFDM System Concept for Joint Radar and Communications Operations" *VTC Spring*, 2009

[11] Y. Liu, G. Y. Liang, D. Garmatyuk, and Y. J. Morton, "USRP based OFDM radar systems for doorway detection" *IEEE Radar Conference*, 2014.

[12] C. Sturm, E. Pancera, T. Zwick, and W. Wiesbeck, "A novel approach to OFDM radar processing", *In IEEE Radar Conference*, 2009

[13] G. E. A. Franken, H. Nikookar, and P. V. Genderen, "Doppler tolerance of OFDM-coded radar signals" *European Radar Conference*, 2006

[14] Y. L. Sit, C. Sturm, L. Reichardt, W. Wiesbeck, and T. Zwick, "Verification of an OFDM-based range and Doppler estimation algorithm with ray-tracing" *IEEE- Antennas and Propagation in Wireless Communications (APWC)*, 2011

[15] Y. Leen, C. Sturm, L. Reichhardt, T. Zwick, and W. Wiesbeck, "The OFDM joint radar-communication system: An overview" *Third International Conference on Advances in Satellite and Space Communications*, Vol. 201, 2011.

[16] Y. L. Sit, C. Sturm and T. Zwick, "Doppler estimation in an ofdm joint radar and communication system" *IEEE German Microwave Conference*, 2011

[17] G. E. Smith, F. Ahmad, and M. G. Amin, "Micro-Doppler processing for ultra-wideband radar data" *In SPIE Defense, Security, and Sensing: International Society for Optics and Photonics*, 2012

Authorized licensed use limited to: Indraprastha Institute of Information Technology. Downloaded on July 21,2021 at 13:52:49 UTC from IEEE Xplore. Restrictions apply.