International Journal For Technological Research In Engineering
Volume 4, Issue 1, September-2016 *ISSN (Online): 2347 - 4718*

MICROWAVE DOPPLER RADAR TECHNOLOGY FOR NON-CONTACT TRAPPED VICTIM DETECTION AND VITAL MONITORING: A REVIEW

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Abstract: The precise and fast remote localization of the victims buried under the snow, collapsed buildings and debris is an emerging application of Non-Contact Doppler Radar sensing technology. In the last few decades, technological evaluation and new approaches have been proposed by many researchers to improve detection accuracy, precession, robustness and faster localization. The principle of Doppler Radar is the detection of shift in the frequency and phase induced due to breathing and heartbeat. This paper intends to review, the research accomplishments of Non-Contact Doppler Radar technology for detection of victims and vital signs as well as the future trends in the research and commercialization.
Keywords: Doppler Radar, Non-contact detection system, Microwave, Sensor, UWB Radar

I. INTRODUCTION

Recently, the Doppler radar based non-contact sensing technology has attracted the researchers for its novel applications like storm tracking, detection of trapped victims via vital signals, vehicle speed measurement etc. [1].The accurate and precise detection of trapped survival in the disasters, like collapsed building, earthquake and avalanches, is one of the most urgent first requirement to perform rescue activity/operation. The danger involved due to the instability of the collapsed structure raises the requirement to adopt non-contact and non-destructive detection method, which can be served by theDoppler radar sensing technology [2]. Microwave Doppler radar Non-contact life detection have wide applications in the healthcare and survivor rescue. In 1975, Prof. J.C.Lin hadreported first experiment to demonstrate the Non-contact vital sign detection and was able to detect respiration at a distance of 30 cm using radiometer [3]. Later, he conducted the experiment by replacing radiometer with vector voltmeter in which the detection of the heartbeat was possible but the simultaneous detection of heartbeat and respiration was not possible [4].In 1986, Prof. K.M. Chen et al. have reportedthe detection of heartbeat and respiration simultaneously at a distance of 30 m [5]. Later on,this technology attracted many researchers for detection of survivor after natural disasters. The most important task is to detect survivor and the time of detection is important because as the time of detection increases, chances of the survival decreases. For example, a subject buried under the rubble can live approximately 72 hours, depending on the local circumstances but the survival time for a subject buried under the snow is comparatively small. There are about 90 % chances of survival if a subject is rescued within 15 minute after an avalanche and the chances decreases to 30 % after an hour [2]. An avalanche victim can be detected using S-band microwave radar [6], a multi-frequency radar system [7] and frequency-modulated continuous-wave (FMCW) radar [8].The scanning of the avalanched area strip by strip using Microwave Doppler radar is a difficult task and time consuming because of the irregular surface and mixing of the snow with the heavy ice chunks. To overcome such problems, these radar systems are mounted on the aerial vehicles for the scanning of the area [9, 10]. On the other hand, people buried under the rubble are sometime able to move and sometimes not. Some subjects get unconscious due to injury and make detection process complicated. Microwave Doppler can detect even respiratory and heartbeat minute motion and can assist the search/rescue operation [11]. The major application of microwave Doppler radar technology can be in the healthcare monitoring e.g. baby monitoring for Sudden Infant Death Syndrome (SIDS), a major cause of infant death in developed countries [12, 13, 14],respiration & heartbeat monitoring of a seriously burned subject [15]. Microwave Doppler radar integrated with the baby monitor, detects small respiration motion and whenever no motion detected within 20 seconds, alarm stops for warning the parents [16]. Overnight sleep apnea monitoring is also possible using this technology without disturbing the normal sleep of the patient [17]. A wearable health monitoring system for a subject having exercise was proposed in 2015 by F. K. Wanget al. and experiments were conducted under various exercise conditions such as standing with fidgeting, deep breathing while walking, rapidly breathing while jogging and walking with gasping. The experimental results show a good validation of Bistatic self-injection-locked radar with machine learning algorithm using a moving average filter, for the wearable health monitoring. The table below shows the experimental results obtained [18].

Table 1 Comparison of different experimental results [18].

Experiment	Respiration rate (beats/minute)	Heart rate (beats/minute)	Step rate (steps/minute)	RMS amplitude (˚)
Standing	18.6	75	0	4.4

with Fidgeting				
Walking with Deep breathing	12.6	83.4	142.8	8.4
Jogging with Rapid breathing	21	92.4	277.8	20.1
Walking with Gasping	25.8	84 – 78	111.6	5.5

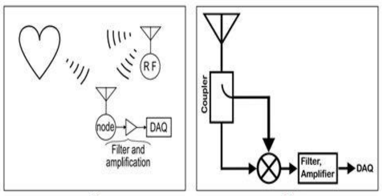
For the detection of multiple subject YanyunXuet al. [19] have proposed a method based on the SNCR (Signal to Noise and Clutter Ratio) for a complex and low SNCR situations, using ultra wide-band (UWB) radar. Since respiration and clutter have different energy level and frequency range, clutter can be removed efficiently.

Microwave Doppler radar based non-contact detection system is also helpful in the treatment of mobile cancer using linear accelerator[20, 21].

A non-contact method using the microwave is also useful for the detection of mobile cancer for treatment using linear accelerator [20, 21]. The presence of noise in the signal is also a problem for the accurate and precise detection of the survivor and vital monitoring. There are different type of noise are present in the signal such as random noise, stationary clutter, non-stationary clutter, internal noise etc. Thesenoise can be removed automatically by using a microprocessor-based system [22]. A self-calibrating Doppler radar was also proposed for accurate measurement of the vital sign [23] and different signal processing technique used for acquiring respiration and heartbeat detection such as arctangent demodulation, automatic clutter cancellation, DC offset compensation algorithm [24], complex signal demodulation [25, 26], Developed Adaptive Line Enhancer (DALE) [27], Differentiate and Cross Multiply (DACM) algorithm [28], autocorrelation algorithm, trace connection algorithm etc. Many researchers have designed and developed small microwave radar chip such as 5GHz CMOS radar, 60 GHz CMOS radar chip, DC coupled Doppler radar, MMW sensor etc. In the section 2 use of microwave Doppler radar for detection of vital sign and in section 3 various signal processing techniques are discussed. Following in section 4, various Doppler radar designed & developed are discussed. In section 5, some Hurdles in the commercialization of microwave Doppler detection system and in section 6 a conclusion of the paper is drawn.

II. NON-CONTACT LIFE DETECTION USING DOPPLER RADAR

There are different microwave Doppler radar which have been used in the healthcare monitoring some of them are discussed here. N. Hafner et al. have used a 2.4 GHz Doppler radar integrated in baby monitor for the detection of the heart rate using CW Doppler radar. A strong reference signal was acquired by placing receiver node, baby monitor and transmitter node very close to each other.And transmitter & receiver antenna placed at a distance of 1 meter from the subject as shown in Fig. 1 and 2. Experimental results show a very small difference of 0.29 bpm with respect to the reference heartbeat measured [16].



(a) (b)

Fig.1 Test setup for non-contact respiration monitoring of baby
(a) Setup for the baby monitor, subject, and node.
(b) Simplified electric diagram [16].

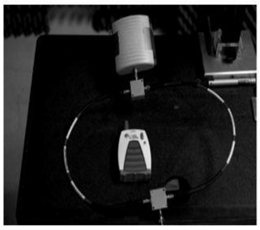


Fig.2 transmitter and receiver with baby monitor [16].

Machine Learning Approach is very useful for the detection of sleep apnea. An Impulse Radio ultra wide-band (IR-UWB) radar based on a Machine Learning Approach, was used under the mattress for the detection of the sleep apnea by A. Q. Javaid*et al*. Random body movements were removed from the signal by determiningthe upper and lower threshold for respiration signal. Since body movements cause a large change in signal amplitude, noise related to the body movements can be easily removed. Linear Discriminant Classifier (LDC) was used for the discrimination of normal respiration signal from the apnea signal. The system classifier accuracy was found to be about 70% and have no adverse effect on the normal sleep of the patient [29].

The conditions of a subject buried under the snow were simulated and Respiration & Heartbeat were detected using a 2.42GHz Doppler Radar.Thefrequency of respiration and heartbeat were found to be 0.24 Hz and 1.08 Hz respectively [11]. Detection of Respiration of a non-stationary subject is also using a microwave Doppler radar.Initially respiration of a stationary subject was detected and then unnecessary noise which are generated due to body movements were removed [30]. Respiration monitoring of a walking subject can be detected using a UWB radar and unnecessary noise can be removed using a STSSM (Short-Time State Space Method) [31]. Life detection at a distance of 2 m using a UWB radar operating at 400 MHz is highly efficient [27]. Two-dimensional respiration and heartbeat detection using a Doppler radar array showsimprovement in the detection sensitivity of the antenna array [32]. Life detection through the concrete wall using L-band and S-band Doppler radar [33], multiple subject detection [34] is also possible using microwave radar technology.

III. SIGNAL PROCESSING TECHNIQUES

Different signal processing techniques have been applied for the detection of the respiration and heartbeatsuch as Arctangent demodulation, complex signal demodulation, Signal to Noise Ratio (SNR) analysis, Digital Post Distortion

(DPoD) and Adaptive Line Enhancer (ALE) etc.

Arctangent Demodulation

For thecompensation of dc offset level and to reduce the problem of the null detection, arctangent demodulation can be used. Total Doppler phase can be calculated as given by equation (1).

$$\phi = \arctan\left[\frac{Q(t)}{I(t)}\right] \qquad (1)\ [24]$$

where Q(t) is the quadrature phase signal component and I(t) is the in-phase signal component. Total Doppler phase(ϕ) is directly related to the motion of the subject/object. And for the DC offset compensation final arctangent demodulation algorithm can be written as given in equation (2).

$$\varphi(t) = \frac{[Q(t)-Qdc]}{[I(t)-Idc]} - f \qquad (2)\ [24]$$

where f is a multiple of 180º. DC offset reduced in I(t) and Q(t) at a distance of 1 and 2 m from the reflector to 3, 3.4 mV and 0.6, 0.8 respectively [24].

Complex Signal Demodulation

Random body movements can also be eliminated using a complex signal demodulation technique. In this technique, both In-phase and quadrature-phase are combined with the baseband signal as shown in Fig. 3.

Complex signal can be written as

$$S(t) = I(t) + j \cdot Q(t) \qquad (3)\ [26]$$

where I(t) is the in-phase and Q(t) is quadrature-phase component.

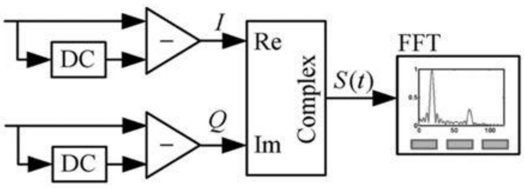


Fig.1 Complex signal demodulation [26]

Spectral analysis of the signal is done using Complex Fourier transform and important information components are always present in the frequency spectrum [26].

Signal to Noise Ratio (SNR) Analysis

SNR analysis of a Doppler radar signal is highly efficient for the detection of the heart rate and respiration rate. For the accurate heart rate and respiration monitoring, the strength of the signal for heartbeat and breathing should be greater than the noise in the signal. There are so many potential sources of the noise present in the signal such as direct coupling noise from the local oscillator, the additive noise of Gaussian nature, the noise related to the baseband circuit and mixer, antenna leakage noise, clutter noise etc.

The SNR can be written as

$$SNR = \frac{Si}{N1+N2+N3+N4+N5+N6} \qquad (4)\ [15]$$

where N1, N2, N3, N4, N5, N6 are direct coupling noise from LO, additive white Gaussian noise, noise related to the mixer and baseband circuit, antenna leakage, mixer leakage, clutter noise respectively. Thus by knowing about various type of noise present in the signal and filtering these noise, one can calculate the SNR of the Doppler radar for the detection of the heart rate and respiration [15].

Adaptive Line Enhancer

C. Li et al. have proposed a method for the noise removal using Adaptive Line Enhancer (ALE) and improving SNR for outdoor application. The LMS algorithm was used for the adaptive noise cancellation and real-time application. A system block diagram represented in Fig 4.

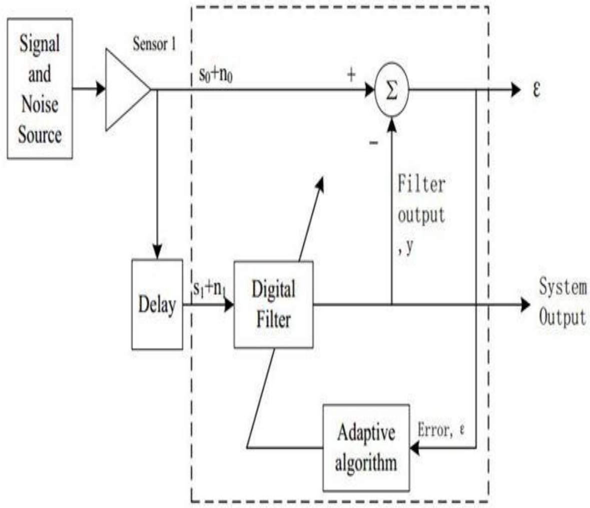


Fig.2 Block diagram of the system using ALE [35].

One sensor is sufficient for acquisition of reference as well as desired signal. In this system s0+n0 is the desired signal and after delay signal s1+n1 is the reference signal. Now as the desired signal is periodic in nature, s0 and s1 are correlated but noise components n0 and n1 are uncorrelated with each other. Thus, a periodic target signal results in target signal i.e. system response will be the target signal [35].Another signal processing approach is using FFT estimation and threshold detection algorithm for the accurate measurement of the respiration and heartbeat have also been applied [36].

Digital Post Distortion Technique(DPoD)

The distortion of the signal caused by AC coupling can be removed using DPoD (Digital Post Distortion) technique and slow periodic motions such as mechanical vibration and physiological motions which are near to DC can be detected. This can be done using software commands and donot add any extra hardware cost. The experiments were conducted by C. Guet.al. shows a very high accuracy of the proposed method [37].

IV. DESIGN CONCEPTS

Different design architectures have been used for the designing and development of the Doppler radar for non-contact detection of the respiration and heartbeat.Since 2000, there are various small size direct conversion Doppler radar have been demonstrated [38-41]. First CMOS process based micro radar shown in Fig. 5 was implemented in 2001. This chip was able to deliver an amount of 2 mW RF energy and dissipate 180 mW from DC source [40]. For removing the null point detection problem a 2.4 GHz radar [41] and improving the system accuracya 1.6 GHz radar were designed [38, 39].

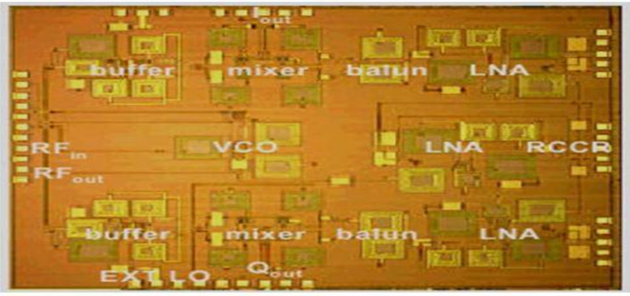
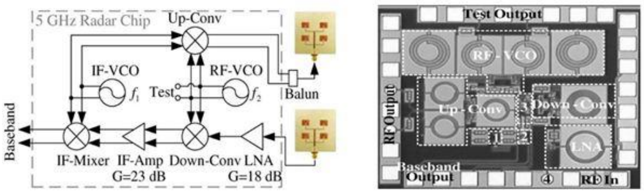


Fig.3 Sensor chip for the non-contact vital detection [38]

The implementation of the first CMOS chip radar hasled to the development of other small size non-contact vital detection radar. There are different CMOS process based radar chips were implemented [42, 15, 43, 44]. In 2008, a 5GHz CMOS differential architecture based radar chip was designed and fabricated. It has a wide range of tuning over 1 GHz and low LO leakage, block diagram and photograph are shown in Fig. 6 (a) and 6 (b). It has two different VCO for the generation of the intermediate frequency (IF) operating 60 MHz to 520 MHz and other for radio frequency (RF) operating in the 4.6 to 5.7 GHz [42].



(a) (b)

Fig.4 Block diagram of a 5 GHz radar chip.
f1 = 60~520 MHz and f2 = 4.6~5.7 GHz [42].

An another Bio-radar operating at a frequency of 2.4 GHz was designed and implemented, shown in Fig 7. The total dimension of the PCB was 90 mm x 50 mm and operating voltage is 5 Vdc. The radar was able to detect respiration and heartbeat at a distance of 50 cm [15]. In 2010, a 5.8 GHz Doppler radar was designed and implemented, having a bandwidth of about 1GHz and can be configured in software. Detection sensitivity was high up to -110 dBm without random body movements and radar system was powered by 1.5V-AA battery. Radar chip is shown in Fig.8 and the chip radar was able to detect heartbeat and respiration from a distance of up to 3m.

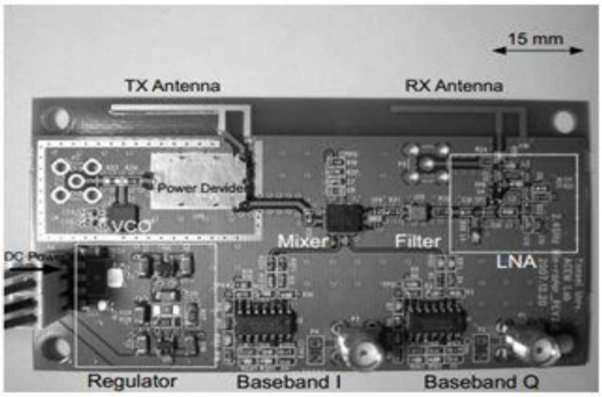


Fig. 7 A 2.4 GHz Bio-radar [15]

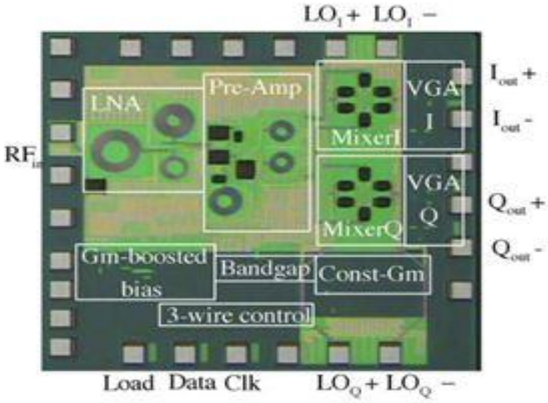


Fig. 8 Direct conversion 5.8 GHz CMOS radar chip [43].

Respiration and heartbeat are found to be 14 breath/minute and 70 beats/minute respectively [43]. Heartbeat detection is rather more difficult because of the small motion caused by beating heart. Thus, for the detection of motion caused by beating heart, a flip-chip package based CMOS micro-radar sensor operating frequency of 60 GHz was designed and fabricated. All the system components such as CMOS chip, transmitter & receiver antenna, DC power supply and bypass capacitor integrated into a 45mm X 31.3mm PCB having weight 5 grams, as shown below in Fig.9.

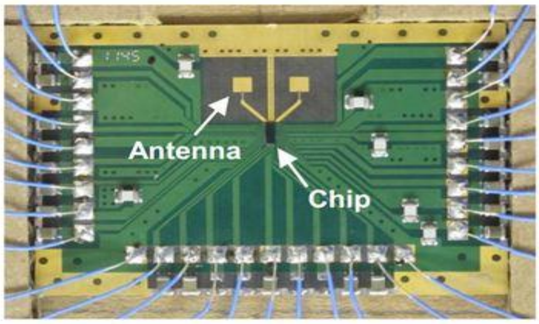


Fig. 9 Integrated radar on a single PCB of dimension of 45mm X 31.3mm [44].

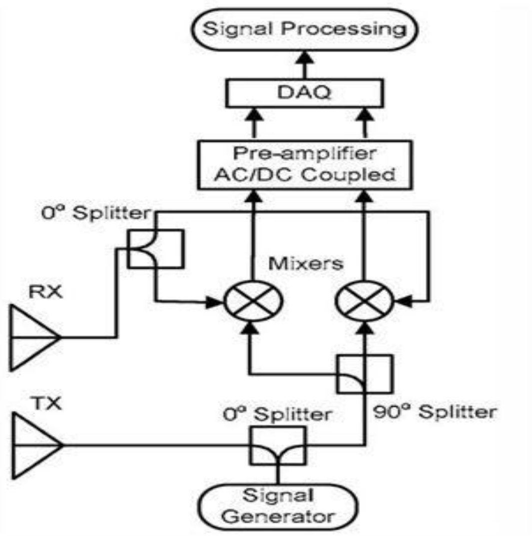


Fig.10 Block diagram of the direct conversion AC coupled Doppler radar [45]

This system has a power consumption of 377 mW at a supply of 1.2 Vdc [43, 45]. Another DC coupled microwave Doppler radar was designed and fabricated in 2011, have low signal distortion as compared to AC coupled Doppler radar and a very good accuracy for rate measurement [47]. There are other improvements in the non-contact life detection such as compact millimeter microwave Doppler radar [48].Calibration of the AC coupled Doppler radar is very important for the accurate measurement. A method for the calibration of the AC coupled Doppler radar for the elimination of the DC coupling and to simplify the system architecture, was proposed by X. Gao and O. B. Lubeckein 2015. A block diagram of the system architecture is shown in Fig. 10. The system composed of a signal generator, transmitter and receiver antenna, signal mixer, a signal splitter and a pre-amplification circuit having AC/DC coupling mode. By using AC coupling a very high SNR is obtained and physiological parameters such as respiration and heartbeat detection become easy [43]. The relative motion of the human target and radar itself is a great problem which can be overcome by using an RF tag. A method for the adaptive noise cancellation using an RF tag was proposed by A. Rahman et al. and the experiment was conducted using a programmable platform in two situations. First, the platform was programmed with a displacement of 8mm at 1.2 Hz and then using a square wave motion with a displacement of 12mm. The experimental results were compared with a reference respiration signal obtained from the chest belt. The experimental results show that using an RF tag a good accuracy can be achieved for the removal of the noise caused by the relative motion of the target subject and Doppler radar [49].

V. HURDLES FOR THE COMMERCIALIZATION OF NON-CONTACT VITAL DETECTION

About 40 years back, non-contact vital detection technique was demonstrated but there are no commercial product available which are based on this technology. C. Li *et al.* have purposed and demonstrated a microwave based baby monitor which give the alarm if respiration or other body movements were detected for 20 seconds [50]. This can be helpful in preventing the SIDS (Sudden Infant Death Syndrome), which is a major cause of infant mortality in developed countries. People want this type of technology in the market, but there are some technical problems such as the vital detection for a thin person cannot detect vital sign for a fat person because of the variation in the chest wall due to breathing or due to heartbeat. Another problem is random body movements. In 2008, Li and Lin have purposed a method to overcome this problem, using two radar and resulting an accurate vital detection [25]. For the detection of accurate heartbeat and respiration of a person running on a treadmill with body movements limited within 10 cm, was done in 2011 by Wang *et al.* [51]. Many experimental results show a weaker vital sign by a non-contact method for exercise condition because of the small movements of the chest or the skin having smaller reflection coefficient. Another major problem is the FDA approval. These microwave Doppler radar have very low energy emission and are not harmful to the human body but the approval takes a very long time and many inventors have this concern.

VI. CONCLUSION

In last fewdecades, there are a lot of advancements in the non-contact vital detection using Microwave Doppler radar system because this technology can address the issues of lower time consumption for victim detection with accuracy and precision. In the modern era with the advancement of VLSI technology the whole system can be developed on a microchip.Small chip based microwave Doppler radar have very low power consumption, portable and have very high detection sensitivity, making this area of research more fascinating. Though, the much work has already been done by the various research groups for developing the efficient microwave Doppler radar system for various applications in natural and war disasters but still a lot of futuristic research is required to be carried out do develop the radar based non-contact detection systems with betterdetection range, sensitivity and efficient signal processing techniques with capability of omitting of clutter and noise.

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