SIGNAL ANALYSIS BASED RADAR IMAGING USING RADAR SENSOR

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Abstract: ***Imaging Radars are gaining attention as it has advantages like medical imaging, sensing humans in through-wall scenarios. But Radar images are unlike optic images and are of very low resolution since they are limited by the carrier frequency, size of the radar aperture, Doppler and clutter. This work proposes a close measuring device answer that could be a privacy secure and dark surroundings resistant system. In this resolution, we use a low power, Frequency Modulated Continuous Wave (FMCW) radar array to capture the reflected signals and then construct to 2D & 3D image frames. This resolution styles a knowledge pre-processing mechanism to get a grid of background static reflection, second an indication process mechanism to transfer received complicated measuring device signals to a matrix contains special information, and a Deep Learning scheme to filter broken frame which caused by the rough surface of human's body.***

Keywords— ***Through-wall imaging radar (TWI), Micro Doppler radars, Frequency modulated continuous wave (FMCW), Short-time Fourier Transform (STFT)***

I. INTRODUCTION

In thru-wall imaging (TWI) radar, the sign transmitted experiences huge constriction because of misfortune in free area, unfold within the air–divider interface (impedance mismatch), misfortune in divider, and scattering on various items. In TWI programs, excessive microwave radar goals with most flag entrance region unit interesting points. Electrically huge openings involving many cluster components are required to get high goals pictures. Such a radar framework with different receiving wire components each with a related information obtaining channel is both expensive and complex to execute. Diverse moving pieces of a human body offer ascent to unmistakable small scale Doppler's. This extra Doppler measurement empowers the unwinding of the goals as far as the transporter recurrence and the quantity of cluster components over different measurements [1].

Moreover, identifying the objective within the sight of solid clutter represents another extraordinary point. Clutter happens because of coupling among transmitter and receptor receiving wires, just as because of flag mirror image lying on the outside and internal partitions and near-by the things. The basic strategy is to diminish the messiness includes subtracting the reference mess reliant on information acquired within the sight of the objective. Increasingly modern strategies depend on methods dependent on flag preparing insights, for example, blind source detachment [1].

Continuous wave Doppler radars are characteristically proper for imaging moving people for different reasons. In the first place, stationary foundation clutter is smothered while utilizing continuous wave signals. Second, Doppler signals are definitely progressively powerful to multi-path brought about by walls and floors than wide-band wave forms. This paper proposes to join Doppler handling with two-dimensional cluster preparing to powerfully resolve the diverse dissipates on the human body in three measurements dependent on their distant Doppler's, azimuth and elevation positions. The diverse body parts are first settled dependent on their Doppler's. At that point the azimuth and elevation position of each body part with an distant Doppler is evaluated utilizing two-dimensional array processing..

II. BACKGROUND

Generally, restricted band radars are intended for TWI with low objectives. To improve the objectives, millimeter waves can be utilized to enter through clothing or else packaging. By the by, this methodology can't be utilized in applications, for example, infiltration thru walls of thick substances (wood, mortar, blocks, also solid squares), as a result of strong signal attenuation. Along these lines, ultra-wideband (UWB) microwave radar acts like a legit decision to understand the TWI disadvantage on the grounds that UWB system makes up for the decrease in the inside recurrence with the aid of boosting the information transmission that converts into fine vary goals [5].Moreover, UWB framework gives higher invulnerability in opposition to impedances in like manner as lower capture likelihood alluring qualities for the barrier territory. TWI system utilizing UWB radars wound up entrancing alternatives in common and Defense applications like salvage missions in torrential slides, avalanches in structure destinations, target location through walls, reconnaissance, acknowledgment, and investigation. In the previous couple of years, achievements inside the systems and gadgets used for age and display of highly small heartbeats contain invigorated the exploration on excessive-accuracy UWB radars, along the 2002 Federal Communications Commission endorsement of the 3.1 to 10.6 GHz band. In any case, the business accessibility of TWI structures utilizing UWB radars are restricted to the current minute due to the complexity known with the advancement of those frameworks. A few models of these systems utilizing UWB radars are created [6– 8]. They offer nice goals and display great execution within explicit situations; in any case, they are as yet insufficient for general purposes.

III. FMCW RADAR

FMCW (Frequency Modulated Continuous Wave) radar differs from pulsed radar in that an electromagnetic signal is continuously transmitted. The frequency of this signal changes over time, generally in a sweep across a set bandwidth. The difference in frequency between the transmitted and received (reflected) signal is determined by mixing the two signals, producing a new signal which can be measured to determine distance or velocity. The functional Diagram of FMCW Radar

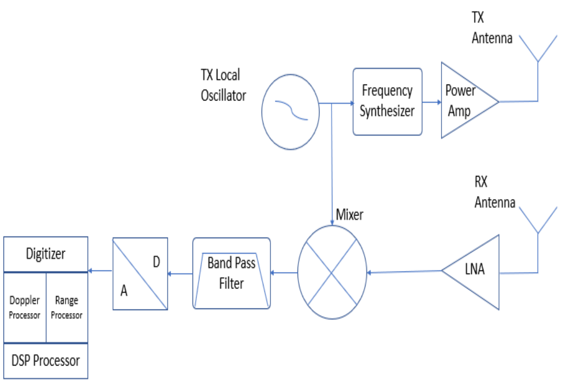

Figure 1 Functional Diagram of FMCW Radar

A. *Range & Doppler Measurements*

FMCW microwave radar emits an RF signal that is typically swept linearly in frequency. The received signal is then mixed with the emitted signal and due to the delay caused by the time of flight for the reflected signal; there will be a frequency distinction that may be detected as a signal within the low frequency range.

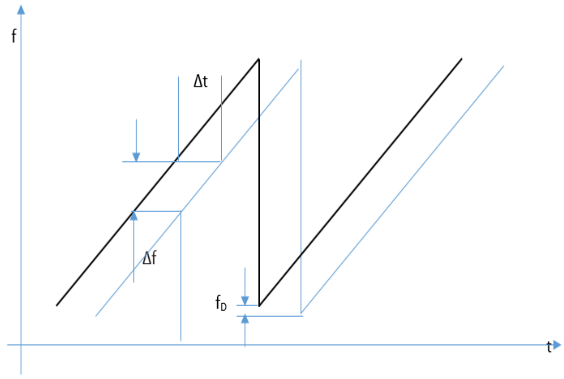

Figure 2: Range and Doppler Measurements analysis

Principle of dimension characteristics of FMCW radar is: the space measure is executed by using comparison of the frequency of the acquired signal to a reference (commonly immediately the transmission sign).

The length of the transmitted waveform T is notably more than the desired receiving time for the mounted distance measuring variety. the distance R to the reflecting item can be determined by means of the subsequent relations:

$$R = c*|\Delta t| /2$$

$$= c*|\Delta f| /2 *(\delta(f) /\delta(t))$$

where c is speed of mild = 3*10^eight m/s

Δt is delay time (s)

Δf is measured frequency difference (Hz)

R is distance among antenna and the reflecting object

δ(f)/ δ(t) is the frequency shift in keeping with unit time

B. *Maximum Range and Range Decision*

By using suitable choice of the frequency deviation in step with unit of time may be decided the radar resolution, and by means of choice of the length of the increasing of the frequency (the longer fringe of the formidable noticed tooth in figure 2), can be determined the maximum non-ambiguous variety. The resolution of the FMCW radar is decided by way of the frequency trade that takes place inside this time limit.

$\Delta fFFT=1/T$
$=\delta(f)/\delta(t)*(fUP-fDWN)$
Where, ΔfFFT is put off time (s)
fUP is higher frequency of the sweep
fDWN is decrease frequency of the sweeps
δ(f)/δ(t) is the steepness of the frequency deviation

C. *Joint Doppler Processing*

Humans are non-rigid targets.When a human move, different moving parts offer ascent to particular small scale Doppler segments which are best spoken to in joint time recurrence space utilizing brief time Fourier change (STFT),as shown in

$$\chi(f,t)=\int Y(\tau)h(t-\tau)\, e{-}j2\pi f\tau d\tau \quad (1)$$

Where, χ (*f*, *t*) is a matrix of size [*N* × *N*] that comprises of the joint time-frequency illustration of the deliberate information at the array and *h*(*t*) is a moving time window with fixed width. Array processing or two-dimensional beam forming is carried out for each Doppler frequency, as shown in

$$W_{\Theta,\phi}(f,t)=F{-}1\,\chi(f,t) \qquad (2)$$

Accordingly, the estimation information have been adequately settled in three measurements: Doppler (f), height and azimuth for each time interval. This additional Doppler information helps in relaxing resolution regarding to carrier frequency and number of elements requirements.

D. HARDWARE SETUP

The discussion in the previous sections demonstrated that joint Doppler and array processing can potentially reduce the hardware complexity required to generate frontal images of humans. However, all the results were based on simulation data. In order to truly demonstrate the effectiveness of the solution, similar results need to be obtained from measurement data. Hence, we need a hardware operating in microwave frequency range below 10GHz. We propose using the Walabot, an RF imaging sensor, to transmit radio waves and will apply joint Doppler processing and array processing on the returned signal to get Doppler, azimuth and elevation positions of the different body parts of a moving human.

IV. IMAGING RADAR SENSOR

WALABOT: It transmits FMCW chirps and collect received signals by 2D antenna array, there is an off-the shelf radar sensor called Walabot. It is a programmable 3D sensor that looks in to objects, using radio frequency technology. Walabot operates in the frequency range of 3.3 – 10.3 GHz proving a huge bandwidth of 7GHz. Walabot uses an antenna array to illuminate the area in front of it and sense the returning signals. The signals are produced and recorded by VYYR2401 A3 System-on-Chip integrated circuit. The data is communicated to a host device using a USB interface, which is implemented using Cypress controller. Walabot operates over an ultra-wideband (UWB) range of frequencies corresponding to the regulatory domain of the model. The US/FCC models operate over 3.3-10.3 GHz range which is good enough to detect direct distance within 10 meters range based on gradient of FMCW chirp. It also contains 18 pair of antennas, which are arranged to 2D antenna array. The European/CE models operate over 6.3-8.3GHz range. The average transmit power of both models is about -16 dBm (25 microwatts). These power levels do not have any health issues whatsoever.

Figure 3: Board level Image of Walabot

Walabot senses the environment by transmitting, receiving and recording signals from multiple antennas. The broadband recordings from multiple transmit-receive antenna pairs are analyzed to reconstruct a three-dimensional image of the environment. Walabot is capable of short-range imaging into dielectric environments, such as drywall and concrete.

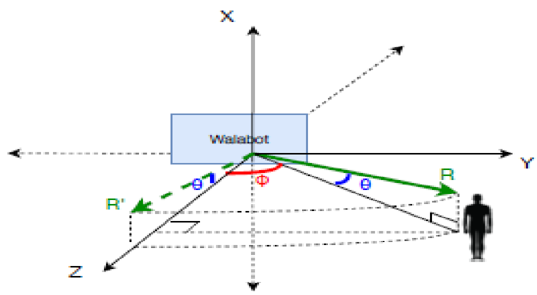

Figure 4: Scanned 3D Axis of Walabot

Walabot emits FMCW chirps to scan in horizontal direction and in vertical direction. The scanned area of Walabot can be present as figure 4

Where ϴ is Elevation angle to detect the height of human, and φ is Wide angle to capture the width of human. R is FMCW signals travel distance from transmit antenna to human's head, and R0 is hypotenuse of triangle whose angle is ϴ and hypotenuse R rotate φ degree; the scan range is the sector which triangle passed. In our case, ϴ is from -45to 45and φ is from -90 to 90.

Since Walabot antenna array collects RF-signals, which is complex signals, they can be represented by amplitude and phase as follows:

$$S_t = A_{t*} e^{-j2\pi(r/\lambda)*t} \quad (3)$$

Where S_t is signals received at t moment. A_t is amplitude of signal at time t, r is travel distance of signal and λ is signal's wavelength. Since received phase has linear function with travel distance, so 2π(r/λ) t is the signal phase when it reach to receive antenna at moment t_n^{th} antenna number, and $S_{n,t}$ is signals received by antenna n at moment t.

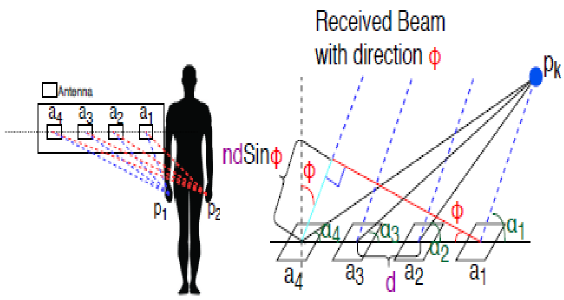

Figure 5: 2D Scenario scanning Multiple Point

Another parameter needs to be clarified is r. Since human body is a surface rather than a point, it reflects signals from different directions to all antennas, the received signals at moment t of one antenna contains more than one points' reflection, thus r varies from multiple reflect points. Figure 5 shows when antenna array scans human body, his left hand p_1 reflects to antenna a1; a2; a3; a4 as blue dot line, his right hand p_2 reflects to antenna array as red dot line. Based on above description, equation 4 is designated as follow:

$$S_{n,t} = A_{n,t*} e^{-j2\pi(r_{n,k}/\lambda)*t} \quad (4)$$

$$r_{n,k} = \text{travel}(p_k, a_n)$$

Suppose pk is kth points on the detected object, then K is number of points being scanned, $r_{n,k}$ is signal travel from p_k to antenna a_n.

A. *Directional Power*

Based on equation 3 and 4, the problem can be declared as: known signals $s_{n,t}$ received by antenna an at moment t, then compute reflection power of every scanned points. Because both angles and distance property can be reflected to phase of received signal. More specifically, the power of specific angle φ,ϴ can be referred by antenna array property, while the power of specific distance 'r' can be calculated by FMCW feature. Revisit to figure 5 and change antenna array panel to a plane figure, antenna a1; a2; a3; a4 receive reflection from pk, the coming direction of beam is φ as shown in figure 5. While a1, a2, a3, a4 are angles between antenna to p_k, and 'd' is distance between two antennas. Thus, power of direction φ can be presented as P (φ) in equation 5

$$P(\varphi) = \sum_{n=1}^{N} (Sn,te^{-j2\Pi(nd\sin\varphi)}/\lambda) \quad (5)$$

Where 'N' is how many antennas in the dimension. Because $s_{n,t}$ travel different distance for each antenna, and the difference can be represented by 'nd sin φ' as depicting with light blue colour. Thus, their phase change of antenna n is $2\pi(nd\ sin\varphi/\lambda)$ is signal wavelength.

B. *Power Received from Distance*

The travel distance of signals also related to the direct distance from point pk to antenna and Frequency Modulated Continuous Wave measures reflection depth by calculating frequency shift between transmits and receive chirp. Equation 1 shows the FMCW feature. We define 'v' is slope of frequency chirp versus time, where 'v' is equal to df/dt in figure 3. So the power of distance r_k can be calculated by phase change of $s_{t,n}$ as shown below in equation 6:

$$P(r_k) = \left| \sum_{n=1}^{N} \sum_{t=1}^{T} s_{n,t} e^{-j2\Pi \frac{vT_{n,k}}{c} t} \right| \quad (6)$$

Where r_k is signal travel distance from point k. T is the duration of each chirp. Because f = vt and r/c = t_{travel}, we can easily get the phase change is $2\pi f t_{travel}$, thus power of r_k is summation over duration T and total antenna number N.

C. *Image Construction*

Remove Background Reflection: To get rid of environment reflections such as desks or walls, Walabot starts a sensing process before capture humans, name as calibration. Since background reflection is static and the reflection power is fixed, so that calibration sensing, calculating and recording the background reflection power of any voxel, after that, when Walabot starts human image capturing task, it subtracts the static background reflection power from the real-time reflection power. We need to make sure there is no human enters the lab during calibration period.

Once Walabot calculates the power of every voxel and removes background reflection power, it gets a 3D matrix M with the dimension of (sizeX; sizeY; sizeZ),

Where sizeX; sizeY; sizeZ can be referred from equation 2. Since a 2D image is related to either (R, Θ), (R,φ) or even (Θ, φ). To make 2D image has a clear meaning, we choose to construct 2D image with distance and wide angle (R, φ). At first, we find the highest power from M, suppose the highest reflection power is from point at (R_a, $Θ_b$, φc), then M (R_a,$Θ_b$,$φ_c$) is the highest value in M, and M(R_a, $Θ_b$, $φ_c$) is a 2D array because parameter Θ is fixed as Θb. Thus we draw a 2D heat map image based on M(R_a,$Θ_b$,$φ_c$),where the

colour shows reflection power intensity, the darker colour means the higher reflection power at (R_a,$Θ_b$,$φ_c$). Figure7a shows 2D image capturing scenario and its corresponding heat map. As can be seen from figure 7a, the range of φ is from -60° to 60°, where φ is the angle from dash blue line to human, in this case, dash blue line is the base line in the middle of Walabot, thus φ is wide angle from baseline to object.

After processing Walabot displays the image in 3 modes, Intensity Graph which indicates the Time Vs Intensity & Doppler, PPI Radar display and a time domain display of the signal received.

The following image displays the human detection by the Walabot.

V. WALABOT SPECIFICATIONS:

RADAR TYPE	FMCW RADAR
Model	Walabot Pro
Number of antennas	18
External power supply	5v
Current consumption	0.4-0.9A
Average transmitted power	41dBm/MHz
Frequency range	3.3-10GHz
Software API	C#/VB/C++/PYTHON
Communication protocol	USB 2.0 480Mbit
Measurement distance	0 to 10meters
Operating systems	Windows/Linux

Table 1: Walabot Radar specifications

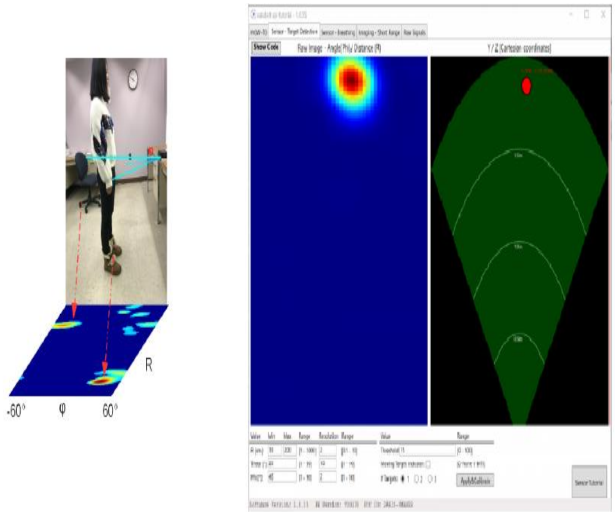

Figure 6: 2D Image Heat map

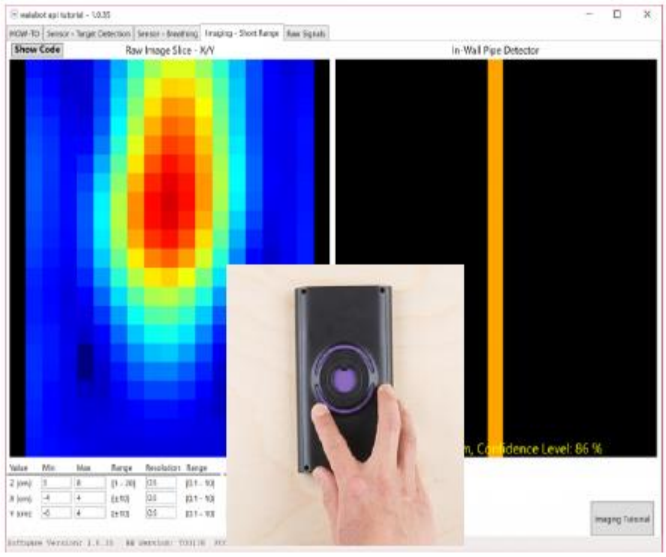

Figure 7 Through Wall Image of the PIPE

Fig 7 depicts the image of a pipe inside the wall. It can be detected by placing the Walabot.

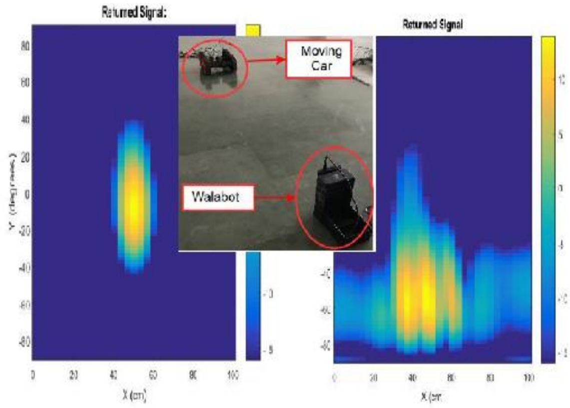

Figure 8 Radar Image of stationary car and moving car

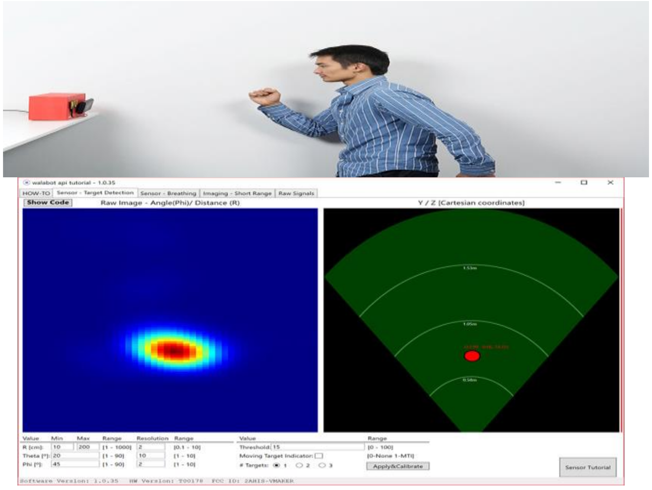

FIGURE 9:DISPLAYS THE SENSOR TARGET DETECTION

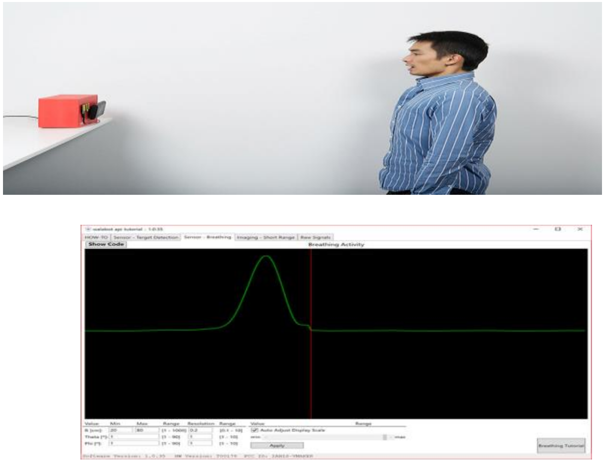

Figure 10:Displays the sensor breathing

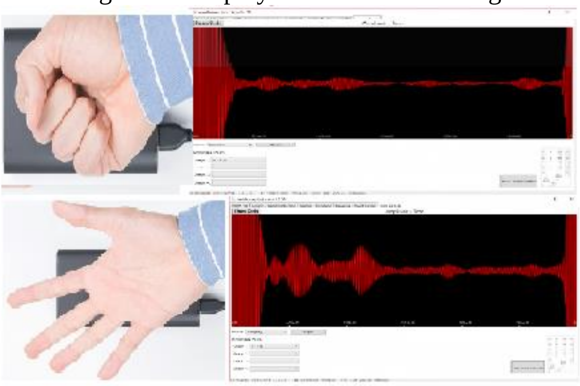

Figure 11: Time domain display response of a hand

VI. CONCLUSION

We have simulated and tested the imaging radar which can detect the human motion and objects through the wall. For radar packages of TWI, the overall presentation of the machine relies upon totally on standards. Initially, the selection of an ideal bandwidth for the procedure on a particular application. Secondary, the selection of the UWB antennas with a excellent standard overall performance on the selected operation band. On this have a look at, UWB for TWI radar come to be designed thinking about such requirements. We may not be reconstructing the clear image of the human using this sensor, but further processing and statistical analysis and clutter removal can bring out a better picture.

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