FMCW Radar-Enabled Smart Home for Contactless Elderly Health Monitoring: Vital Sign Tracking and Fall Detection A Privacy-Friendly Alternative to Video Surveillance.

Introduction & Literature Review:

The emergence of ubiquitous sensing technologies has paved the way for millimeter-wave frequency-modulated continuous wave (FMCW) radar systems, enabling precise measurement of range, velocity, and angle of arrival of objects. This advanced radar technology is increasingly finding applications in healthcare, particularly for contactless monitoring of vital signs and fall detection. Accurate tracking of the four primary vital signs—body temperature, blood pressure, respiratory rate, and heart rate—is critical for early identification of health issues and timely medical intervention. Simultaneously, falls, particularly among the elderly, pose a significant public health concern, necessitating effective detection systems to ensure prompt response and assistance. This study proposes a novel smart home system leveraging 60 GHz FMCW radar to address these challenges, offering a privacy-friendly and non-intrusive alternative to traditional monitoring solutions. Unlike conventional methods that rely on wearable probes or video surveillance, the proposed system prioritizes user comfort and privacy while delivering robust functionality. Inspired by the healthcare challenges faced during the COVID-19 pandemic, this contactless approach eliminates the discomfort associated with physical sensors and mitigates the risk of pathogen transmission. The proposed system integrates multiple functionalities, including vital sign tracking, fall detection, and presence and movement detection, into a cohesive smart home framework. Designed for ease of installation, radar devices can be strategically mounted on ceilings, walls, or tables to provide comprehensive coverage throughout a home. By combining advanced radar sensing capabilities with efficient processing units and low-power autonomous operation, the system ensures reliable and energy-efficient performance. This innovative approach aims to enhance the quality of life for elderly individuals and patients with chronic conditions by enabling continuous health monitoring in the comfort of their home. Fadel Adib et al.[1] tested radar transmitting signals sweeping from 5.46 GHz to 7.25 GHz every 2.5 milliseconds. the device demonstrated a median accuracy of 99% for breathing and heart rate monitoring and also can monitor vital signs from up to 8 meters or even from behind a wall. Alizdeh et al.[2] investigated the respiratory rate and heart rate by 77 GHz After collecting data found 94 % accuracy was found for breathing and 80 % for heart rate. Wang et al.[3] used a 77 GHz mm-wave FMCW radar for heart rate and breathing rate measurement and found 93% accurate. Giulia Sacco et al.[4] proposed a system working in the 5.8 GHz ISM band. The experimental results show the accuracy of heart rate independently with maximum error in terms of BPM is 0.8 BPM and 3.1 BPM for the respiratory and heart rate, accordingly. Leem et al.[5] developed a 6.8 GHz IR-UWB radar-based system using the NVA6201 transceiver to monitor vital signs and detect mobile phone use for car crash prevention. Placed under the steering wheel, the system achieved nearly 100% accuracy in detecting phone usage, even during stationary, general movement, and driving conditions. Fuchuan Du et al.[6]developed an algorithm for multi-target vital sign extraction using a 60 GHz FMCW radar. The approach includes noise filtering with the DC offset method, separation of breathing and heartbeat using Empirical Mode Decomposition, and multi-target monitoring via an L-shaped antenna. However, limitations in detection range, transmission power, and antenna count challenge the algorithm's ability to accurately position and distinguish between multiple individuals. Yaokun

Hu et al.[7] monitors vital signs of multiple moving targets for heart rate estimation was 4.09 bpm, with an accuracy of 95.88%. Xiang et al.[8] proposed a system with 77 GHz radar and found 98.67% accuracy for respiratory rate and 98.04% for heart rate. Choi et al.[9] proposed a method to improve the heart rate measurement efficiency by FMCW radar. The authors used temporal phase coherency with the gathered data. Arsalan et al.[10] enhanced contactless heartbeat estimation using a 60 GHz BGT60TR13C radar and a Kalman Filter Tracking method, achieving root-mean-square errors of 5.3 bpm and 7.0 bpm, significantly reducing errors by a factor of 3 compared to previous methods (17.6 bpm and 21.3 bpm). The proposed method had the lowest MD, -1.02 BPM with a 95% confidence interval of -8.33/6.30 BPM whereas other methods have around comparable mean differences but with wider confidence intervals, indicating greater variability in their results. Zisheng Li et al[11] . resents a deep learning framework, ResTCN, combining ResNet and TCN to classify sleep postures using FMCW radar. It incorporates statistical motion features for micro-movement detection and uses data augmentation to enhance performance. The model achieved 82.74% accuracy, outperforming state-of-the-art methods. Limitations include a small dataset and lack of Obstructive Sleep Apnea (OSA) data. Future work involves dataset expansion and exploring additional scenarios. Turppa et al. [12]evaluates a 24 GHz FMCW radar for monitoring respiration and heart rate during sleep. The radar showed high reliability, with correlation coefficients above 86% for heart rate and 91% for respiration rate, comparable to clinical devices. It highlights the radar's ability to analyze stress and sleep disorders through heart rate variability (HRV). Limitations include a small sample size and static conditions. Future work suggests real-time applications and exploring advanced radar systems. Yoo et al. [13]proposes an unsupervised method for detecting wake, REM, and non-REM sleep stages using a 61 GHz FMCW radar. It achieved an average accuracy of 68.91%, validated against polysomnography (PSG). Though less accurate than machine learning methods, it introduces a non-contact alternative for sleep stage detection. Future enhancements include combining radar with EEG for comprehensive sleep analysis. Radar technology has proven effective for human activity monitoring due to its ability to operate in all weather conditions and preserve privacy, making it ideal for sensitive environments like bathrooms and bedrooms [14]. Millimeter-wave frequency-modulated continuous-wave (FMCW) radar leverages precise short wavelengths to detect motions through Doppler and micro-Doppler effects, aiding fall detection and gait analysis [13] [14]. Recent studies highlight the development of non-invasive fall detection systems, especially for the elderly. Techniques involve feature extraction from range-Doppler and time-frequency domains using transformations like STFT, Wavelet Transform, and machine learning classifiers[17], [18]. Simulated datasets, k-band CW Doppler radars, and prototypes using Texas Instruments boards (e.g., IWR6843ISK) have demonstrated high accuracy in fall detection and mobility monitoring[19], [20].Applications extend to daily activity tracking, bathroom safety, and gait analysis, where radar systems detect fall risks and mobility changes without cameras, ensuring privacy [21], [22]. Emerging innovations like knock-based security systems and biometric locks further showcase radar's potential across healthcare and security domains[23], [24]. These advancements highlight radar's promise in creating accurate, privacy-conscious monitoring solutions. This smart home solution combines the advanced sensing capabilities of FMCW radar with efficient processing units, like Arduino boards, to deliver real-time results wirelessly. The system also incorporates a digital interface for seamless configuration and radar data acquisition. Optimized power modes and an integrated state machine allow for low-power, autonomous operation, making the solution both reliable and energy-efficient. While the technology offers numerous benefits, challenges remain, particularly in distinguishing vital signs in environments with multiple targets or individuals. The presence of nearby objects or people may interfere with the radar's ability to isolate specific heart and respiratory rates. Addressing these challenges is a key focus of our development process our project aims to revolutionize healthcare monitoring by offering a versatile, contactless solution that eliminates the discomfort of probes and the privacy concerns of video surveillance. This system promises to enhance the well-being of elderly individuals, newborns, and patients with chronic conditions, such as arrhythmia, by providing accurate, efficient, and non-intrusive monitoring in the comfort of their homes.

Proposed System:

The FMCW radar-based smart home system comprises three distinct devices, each utilizing a 60 GHz FMCW radar sensor. These devices are designated as follows: Contactless Vital Sign Monitoring (CVSM), Contactless Fall Detection System (CFDS), and Contactless Sleep, Presence and Movement Detection System (CSPMDS). Each device is designed for specific applications and can be installed in various parts of a home. For instance, the radar system can be mounted on the ceiling to monitor a person's respiration, heart rate, and sleep quality while lying on a bed. In the case of the fall detection system, installing the radar in a bathroom ceiling enables it to monitor vital signs despite body and arm movements during a fall, making it well-suited for applications like sleep monitoring and fall detection. For presence and movement detection, the radar can be mounted on a wall in a hallway or room to track movement. It can also support additional applications, such as automatically turning on lights in a hallway or room when the presence of a person is detected. For elderly health monitoring, the radar device can simply be placed on a table. When the person sits in front of it, the system can measure primary vital signs like heart rate, respiratory rate, and skin temperature. Notably, skin temperature is measured using a separate sensor, not the radar.

A smart home layout has been designed to illustrate the potential installation locations for these radar devices, providing a clear understanding of their optimal placement for effective operation.

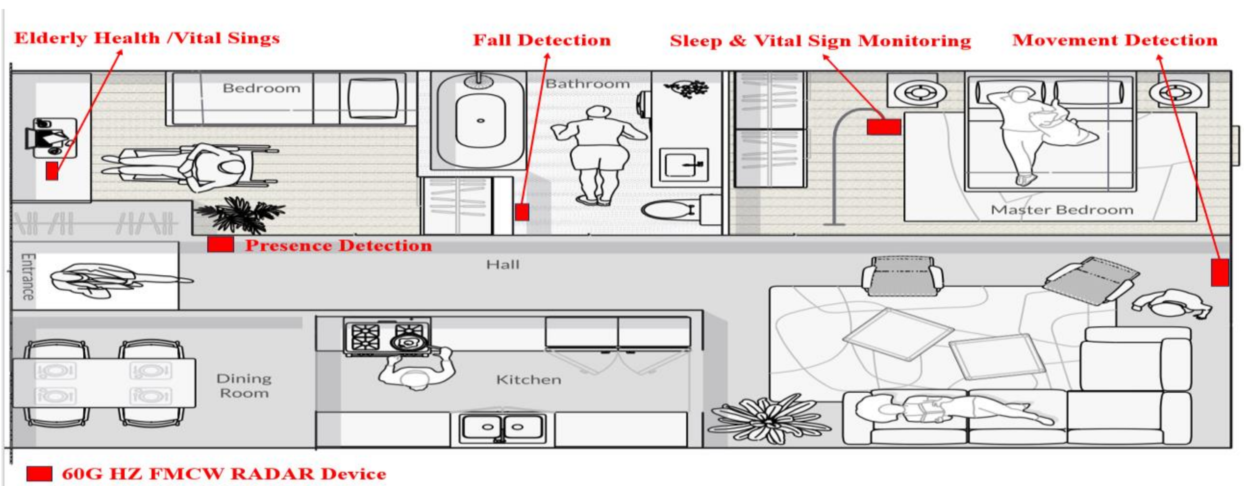


Figure 1: Layout of FMCW based Smart Home for Contactless Elderly Health Monitoring System

Methodology:

1. **Analysis of FMCW Radar Systems Using MATLAB**: **[Needs Sirs suggestions regarding making it short]**

The performance of an FMCW radar system was analyzed through a MATLAB simulation, where the transmitted (Tx) and received (Rx) signals were processed to obtain the intermediate frequency (IF) signal. The results, including spectrograms and other visualizations, were generated to provide insights into radar signal behavior under various scenarios. These visualizations were utilized to understand signal dynamics and facilitate the extraction of critical information such as target distance and velocity. The FMCW radar system's performance was analyzed by initializing key parameters that define its operational characteristics, such as maximum range, range resolution, and carrier frequency. Using these parameters, the transmitted signal was modeled as a linear frequency-modulated cosine wave, while the received signal accounted for the propagation delay caused by the target's distance and velocity. The intermediate frequency (IF) signal, derived from the difference between the transmitted and received signals, was processed to extract critical information, including target range and Doppler shifts. FFT analysis of the IF signal provided frequency components, enabling the calculation of the target's range, while spectrogram analysis revealed time-varying frequency behavior, assisting in detecting small displacements and velocity changes. This comprehensive signal modeling and processing framework ensures precise detection and visualization of radar signal dynamics.

Step_1: Radar parameters setting

This step will set the basic parameters in a radar system,

Table 1 Important Radar Signal Processing Parameters

Parameter	Name	Value
Maximum range	Max R	200 m
Range resolution	Range Res	1 m
Maximum speed	Max V	70 m/s
Carrier frequency	fc	60 GHz (60 × 10^9 Hz)
Speed of light	c	3 × 10^8 m/s

Target initial distance	r_0	100 m
Target speed	v_0	70 m/s
Bandwidth	B	150 MHz (150 × 10^6 Hz)
Chirp time	T_{chirp}	7.33 µs (7.33 × 10^-6 s)
Time delay	t_d	(2 × r0) / c
Range	range	frequency × c / (2 × slope)

Bandwidth(B):

$$B = \frac{c}{2.range\ Res} \tag{1}$$

The bandwidth B is calculated based on the desired range resolution range Res. A higher bandwidth allows for finer range resolution. The speed of light c is divided by twice the range resolution to determine the required bandwidth.

Chirp time (Tchirp):

$$T = 5.5\frac{2maxR}{c} \tag{2}$$

The chirp time is based on the maximum range max R that the radar should detect. The factor 5.5 is a design parameter ensuring the chirp time accommodates the round-trip time for the signal to travel to the maximum range and back.

Chirp slope:

$$slope = \frac{B}{T_{chirp}} \tag{3}$$

The chirp slope is the rate of change of frequency over time. It is calculated as the bandwidth B divided by the chirp time T_{chirp}

Maximum Intermediate Frequency (f_{IFmax}):

$$f_{IF_{max}} = \frac{slope.2.maxR}{c} \tag{4}$$

The maximum intermediate frequency IF max is the beat frequency corresponding to the maximum range maxR. It is calculated using the chirp slope, the maximum range, and the speed of light.

Current Intermediate Frequency (f_{IF}):

$$f_{IF} = \frac{slope.2.r_0}{c} \tag{5}$$

Similar to IF_{max} this is the beat frequency corresponding to the current target range r_0

Speed resolution (vres):

$$v_{res} = \frac{\frac{c}{f_c}}{2.N_d(T_{chirp}+endl_{time})} \tag{6}$$

The speed resolution v_{res} determines the smallest detectable change in velocity. It depends on the speed of light carrier frequency, number of chirps, chirp time and a parameter end time.

Sampling rate (F_s):

$$F_s = \frac{N_r}{T_{chirp}} \tag{7}$$

The sampling rate is the rate at which the ADC samples the received signal. It is determined by the number of ADC samples divided by the chirp time T_{chirp}.

Step_2: Signal of Tx:

Assuming that the Tx signal is a cosine signal whose frequency varies linearly with time,

Tx waveform angular frequency ($angle_{freq}$):

$$angle_{freq} = f_c\,.\,t + \frac{slope.t^2}{2} \tag{8}$$

This represents the angular frequency of the transmitted signal, incorporating the carrier frequency and the frequency modulation over time due to the chirp slope.

Tx waveform (Tx):

$$Tx = \cos(2\pi . angle_{freq}) \tag{9}$$

The transmitted signal Tx is a cosine wave with the calculated angular frequency.

Step_3: Signal of Rx:

The Rx waveform can be calculated from the Tx waveform and the delay time,

Target Distance(r_0):

$$r_0 = r_0 + v_0 . t \tag{10}$$

The target distance r0 is updated over time as the target moves with velocity v0

Time delay(td)

$$t_d = \frac{2.r_0}{c} \tag{11}$$

The time delay td is the round-trip time for radar signal to travel the target and back, calculated using current target distance r_0.

Rx wave form frequency:

$$freqRx = f_c + slope.t \tag{12}$$

Similar to the transmitted signal the frequency of the received signal increase linearly over time due to the slope.

Rx Wave form:

$$Rx = \cos(2\pi \left(f_c(t - t_d) + \frac{slope(t-t_d)^2}{2}\right)) \tag{13}$$

The received signal Rx is a cosine wave with the angular frequency considering the time delay td.

Step_4: IF signal

According to the processing, assuming the IF signal can be represented by cos((2*pi*wt*t-2*pi*wr*t)),

Intermediate Frequency (IF) signal angular frequency

$$IFangle_{freq} = f_c\,.t + \frac{slope\,.t^2}{2} - (f_c.(t - t_d) + \frac{slope\,.(t-t_d)^2}{2} \quad (14)$$

The equations are representing the angular frequency difference between the transmitted the received signal which corresponds to the beat frequency.

IF wave form

$$IFx = \cos(-2\pi(f_c(t - t_d) + \frac{slope(t - t_d)^2}{2} 2\pi.angle_{freq}) \quad (15)$$

The IF signal IFx is difference between the transmitted and received signals resulting in a beat frequency

IF signal frequency

$$freqIF = slope.t_d \quad (16)$$

The frequency of the intermediate frequency (IF) signal is determined by the product of the chirp slope and time delay td

Step_5: FFT of IF signal

In this step, we calculate the frequency of IF signal by the FFT of IF signal,

Doppler Signal:

$$doppler = 10.\log_{10}(|fft.\left(IFx(1{:}\,1024)\right)|) \quad (17)$$

The Doppler signal is obtaining by taking the fft of the IF signal and converting it to a logarithmic scale to analyze the frequency components

$$frequency = fftshift(\left(\frac{-N_r}{2}:\frac{N_r}{2}-1\right).\left(\frac{F_s}{N_r}\right)) \tag{18}$$

The equations generate the frequency axis for the FFT result shifted to center around zero

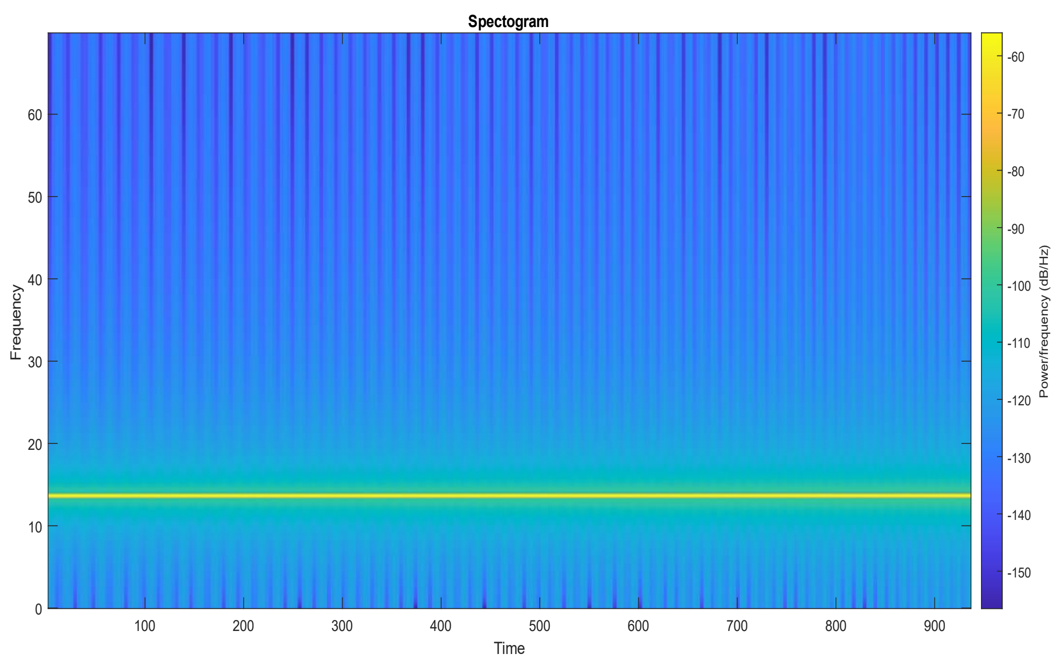
Range

$$range = frequency\ .\frac{c}{2.slope} \tag{19}$$

The range is calculated form the frequency axis of the FFT result, using the speed of light and the chirp slope which translates the frequency components into distance measurements.

Step_6: Spectrogram with time

In this step, Spectrogram with time change will be calculated.



We can see that the IF signal frequency change due to target displacement within a single FRAME cycle is difficult to distinguish within the spectrogram, so we need to detect small displacements and velocities by phase changes.

2. Contactless Vital Sign Monitoring (CVSM):

The main component of the project is 60G band millimeter wave FMCW radar. Our particular radar has transmitter antenna and two receiving antennas. The transmitter transmits a 60G band millimeter wave signal and the measured target reflects the electromagnetic wave signal and demodulated the transmitted signal and process it through amplification, filtering and phase of the eco signal data. Then the data is sent to microcontroller unit in short MCU unit. In our case for measuring breathing and heart rate the system relies on the observation that when an individual inhale, their chest expands, bringing it closer to the antenna. Conversely, during exhalation, the person's chest contracts, moving away from the antenna, which increases the distance between the chest and the antenna and prolongs the reflection time. The MCU unit then calculate the amplitude, frequency and phase of the eco signal and measured the targeted parameter heart rhythm and respiratory rate. To measure body temperature, an IR thermal camera module (Model no. AMG8833) is connected to a microcontroller unit (MCU). This setup allows for the accurate measurement of human body temperature

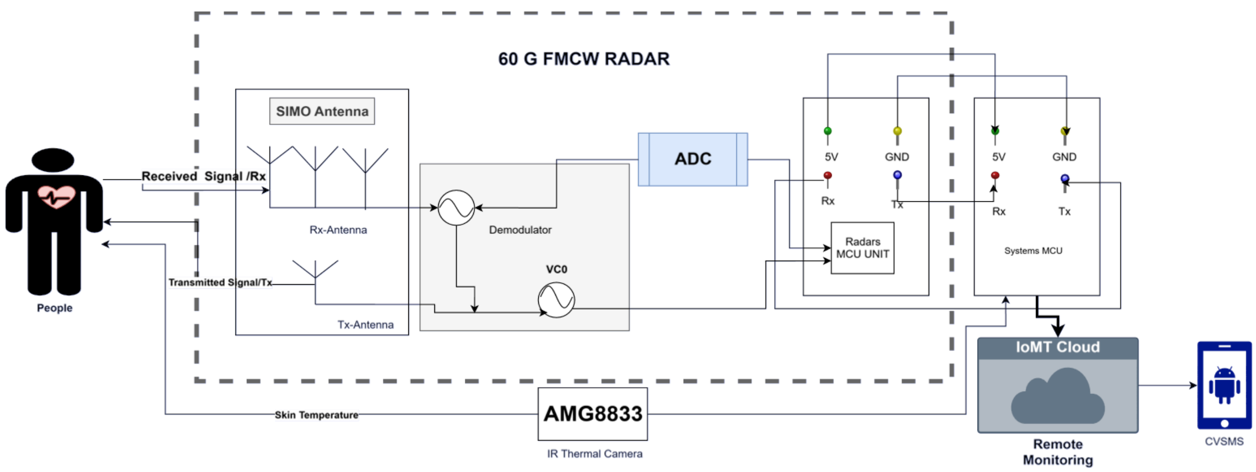


Figure 2: Working principal diagram of the of the contactless vital signs monitoring system.

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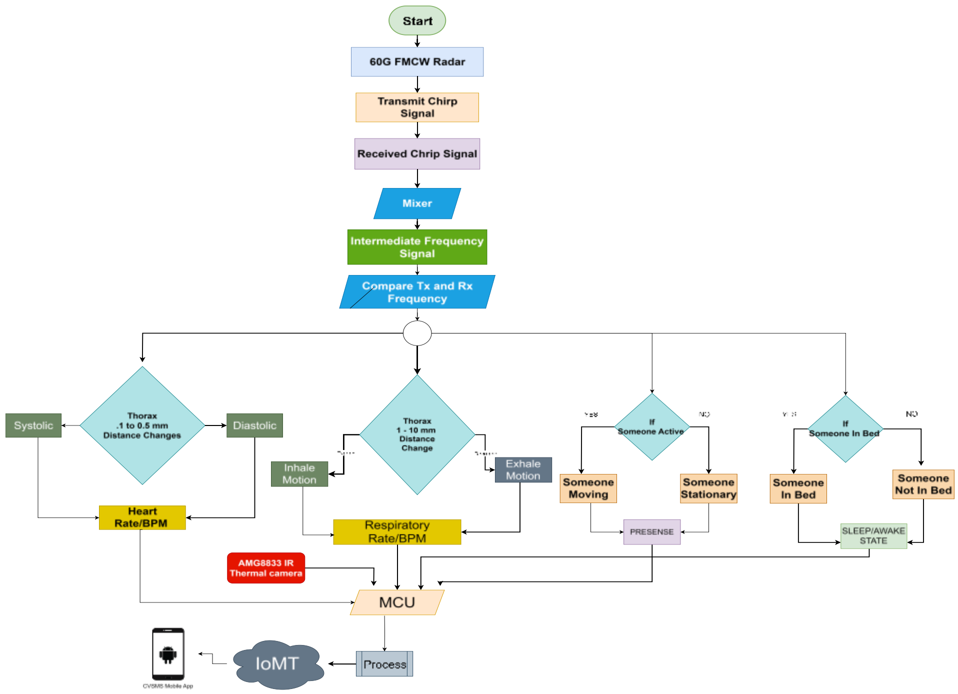


Figure 2: Flowchart of the contactless vital signs monitoring system.

The system tracks human vital signs like heart rate, respiratory rate, movement, and human presence using an FMCW radar. The synthesizer emits a chirping signal that transmits outside and is reflected by everything in its path. The original signal is combined with this reflected signal to produce an IF signal that contains a pack of environmental data. From this IF signal, the MCU extracts important information like angle, velocity, and range, and compares it to predetermined thresholds and successfully delivers the heart rate and respiratory rate. To measure body temperature, an IR thermal camera module (Model no. AMG8833) is connected to a microcontroller unit (MCU). This setup allows for the accurate measurement of human body temperature. Once the vital signs are successfully measured, the MCU unit of the system sends the data to the IoMT (Internet of Medical Things) environment. From there, the system displays the data in real-time on our developed Android application named CVSMS, providing graphical analysis alongside.

Figure 2: Experimental setup of the contactless vital signs monitoring system.

In experimental setup, the mmWave radar device is utilized to measure heart rate and respiratory rate. To validate the radar's data, we employed conventional measurement methods for comparison. Respiratory rate was measured using the ADS1292R respiration module, a 3-lead ECG system that estimates respiratory rate by analyzing impedance variations caused by thoracic expansion and contraction during breathing. The RA (Right Arm) probe was connected to the right arm, the LA (Left Arm) probe to the left arm, and the RLD (Right Leg) electrode was positioned below the pectoral muscles on the left side. Heart rate data was obtained using an FDA-approved pulse oximeter (model: Jumper 500D). These reference measurements were then compared against the data collected by the radar to evaluate its accuracy and reliability.

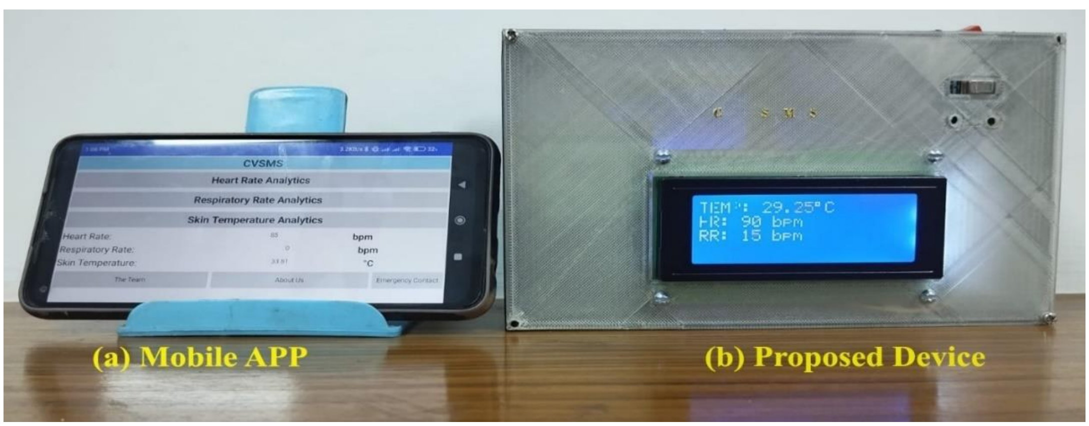


Figure 3: Hardware Model: Outer view of the device

The 60 GHZ radar and the AMG8833 thermal sensor is connected to ESP 8266 Node MCU. The RX pin of radar sensor is connected to TX pin of Node MCU and Tx of radar is connected with Rx pin of MCU and ESP 8266 is sending data to MATLAB's cloud service ThingSpeak also showing the data on the screen to D1 and D2 screen. From the cloud server the real time data is directly shown to developed android app called (CVSMS) the app was developed using MIT app inventor. The AMG 8266 is also connected with D1 and D2 pin of the node-MCU. The radar, Screen and thermal sensor is powering from ESP 8266 and a

9V adapter. The system should keep aligned with the chest of the patient for more accurate data collection. For lying patients, the system can be set in a PVC pipe structure and aligned with the chest. The radar will collect data of the patient and show it. Also send it to the attendant or nurse through thing speak and firebase. By which the attendant can monitor the patient. To power the entire system, a battery pack with a BMS is used. The battery pack ensures portability of the system. The sensor setup to be deployed in various locations without relying on a constant external power source.

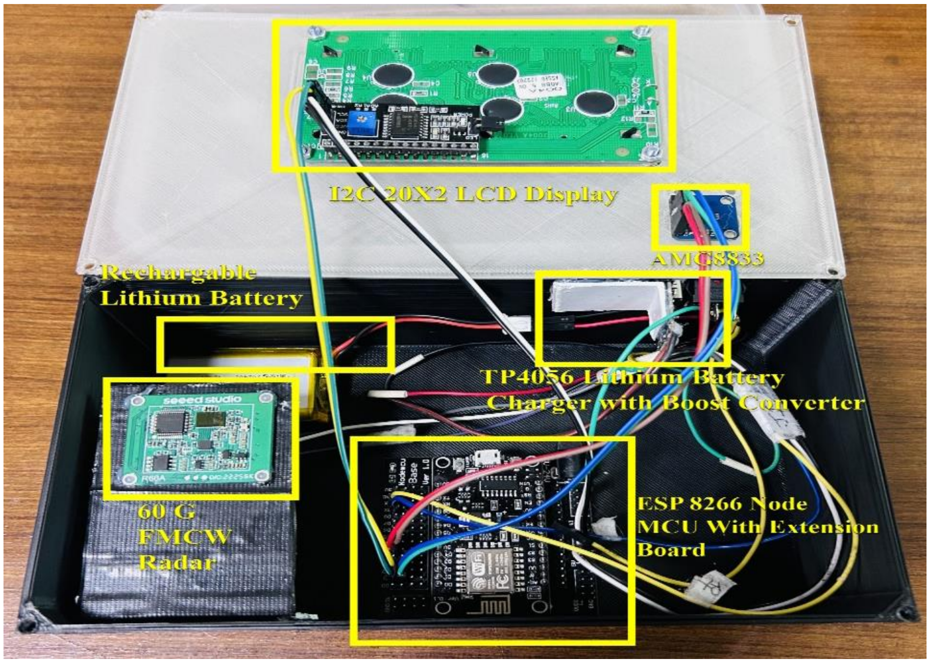


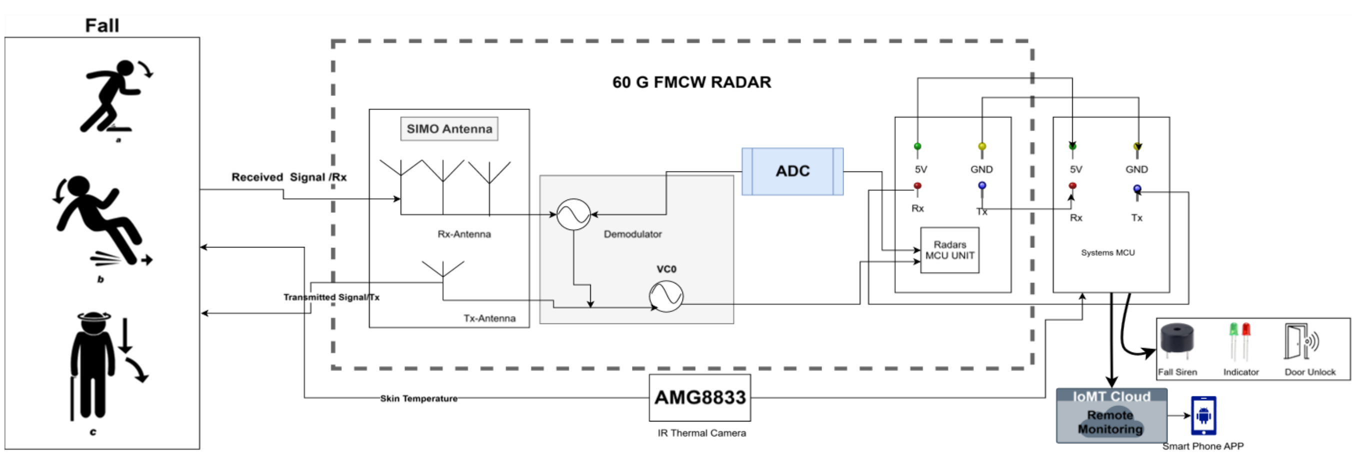
Figure 4: Hardware Model: Inside View of the device.

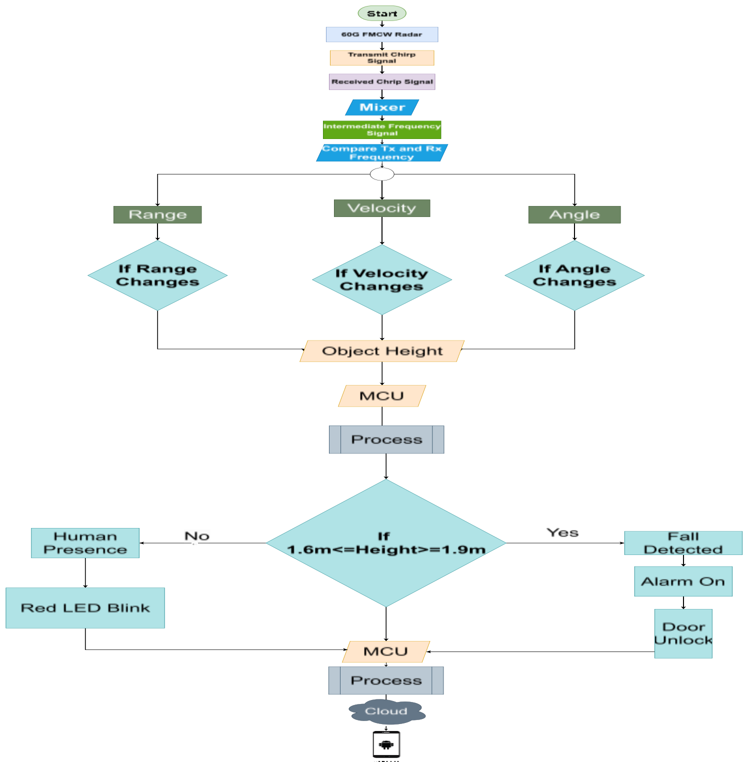
Table 2 Connection Table of CVSMS

ESP 8266	Equipment
Radar	
Vin	VCC
G	GND
Rx	Tx
Tx	Rx
AMG 8266	
3.3 V	Vin
G	GND
D1	SCL
D2	SDA
I2C LCD Display	
G	GND
Vin	VCC
D2	SDA
D1	SCL

3. Contactless Fall Detection System (CFDS):

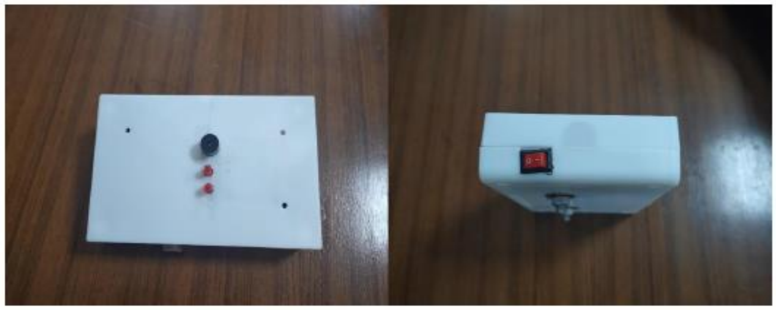
The fall detection system is designed using Frequency-Modulated Continuous Wave (FMCW) radar, leveraging its capability to monitor human motion accurately while preserving privacy. The system works by transmitting continuous chirp signals, which are sinusoidal waves with linearly modulated frequencies. These signals reflect off moving objects, and the radar receiver captures the returned waves. The frequency difference between the transmitted and received signals, known as the Doppler shift, reveals the velocity of the object. Additionally, the motion of smaller body parts, such as arms or legs, generates unique micro-Doppler signatures, while larger movements like falling produce distinct Doppler shifts. These characteristics are processed to differentiate between falls and non-fall activities. The received radar signals are converted into intermediate frequency (IF) signals, which undergo signal processing using techniques like Short-Time Fourier Transform (STFT) or Wavelet Transform to extract time-frequency features. These features are classified using pre-defined fall detection algorithms, which are pre-trained to identify fall-specific patterns such as rapid descents followed by inactivity. The system integrates a high-frequency millimeter-wave radar module, such as the MR60FDA1, with an Arduino Uno R3 microcontroller for signal processing and decision-making. A servomotor is included to unlock doors during emergencies, addressing scenarios where a fall occurs behind a locked door. Furthermore, a SIM800L GSM module is used to send alerts to caregivers or emergency contacts in real-time, ensuring prompt assistance. This fall detection system is equipped to operate in real-time, providing immediate responses to emergencies. It ensures privacy and non-intrusiveness, making it suitable for sensitive environments like bathrooms or bedrooms where traditional camera-based systems may not be feasible. By combining radar technology with advanced signal processing, the system offers an effective and reliable solution for fall detection and safety monitoring, particularly for elderly individuals.



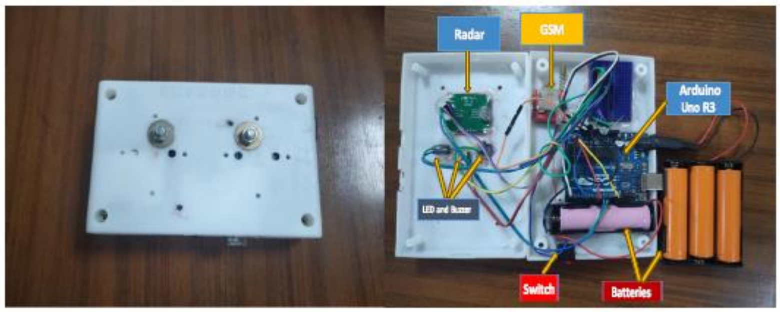


The fall detection system utilizes Frequency-Modulated Continuous Wave (FMCW) radar to monitor human motion and detect falls. A synthesizer within the radar emits a "chirp" signal, which is a frequency-modulated waveform that fluctuates over time. This signal is transmitted via an antenna and reflects back when it encounters an object, such as a person. The reflected signal is combined with the original transmitted signal in a mixer block, producing a beat frequency signal. This beat frequency, proportional to the difference between the transmitted and reflected frequencies, carries crucial data about the object's range and velocity. The Doppler effect influences the beat frequency, with objects moving toward the radar causing a higher frequency shift compared to stationary or receding objects.

The radar system processes the beat frequency through a low-pass filter, and the output is analyzed by a microcontroller to calculate the object's range and velocity. Range is determined by measuring the signal's time-of-flight, while the Doppler shift provides velocity information. The microcontroller executes a fall detection algorithm, identifying patterns indicative of falls, such as a sudden change in range followed by inactivity. If a fall is detected, the system triggers several responses. A red LED lights up, and a buzzer sounds for one minute, signaling an alert. Simultaneously, the system engages a servomotor to unlock a door after one minute, facilitating emergency access. Additionally, the GSM module sends an alert message to a predefined phone number.



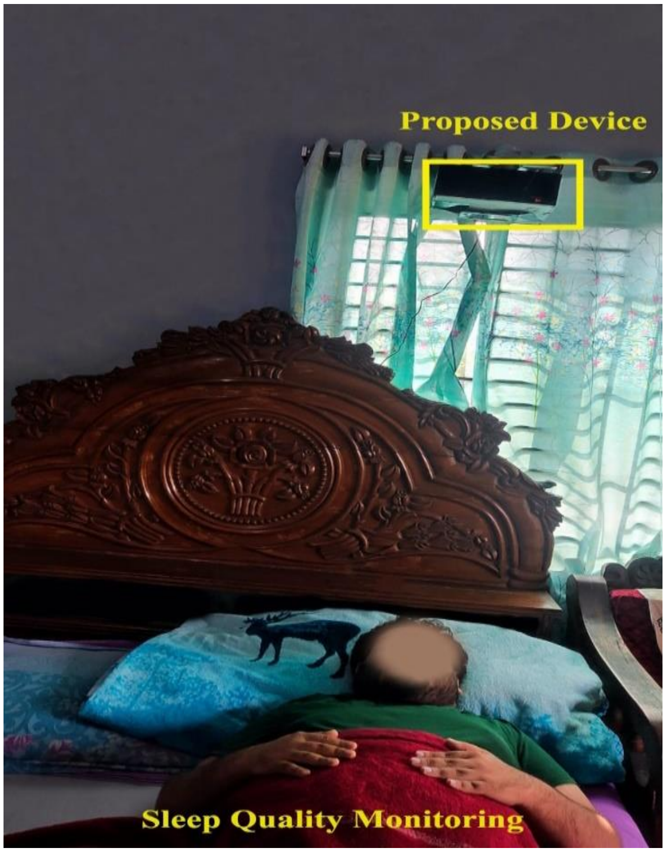
(a)Top View (b) Side View



(c) Bottom View (d) Inside View

The hardware implementation includes the MR60FDA1 mmWave radar sensor operating at 60 GHz, an Arduino Uno R3 microcontroller, a GSM module, a servomotor, LEDs, a buzzer, and batteries. The radar sensor, with a range of 3 meters, measures an object's angle, velocity, and range. Signals processed by the Arduino Uno R3 are used to execute the fall detection algorithm, while the GSM module ensures remote communication. A plastic case houses all components, with a dedicated 3.7V battery powering the GSM module, which activates after the one-minute alert period to send a message. The setup includes LEDs to indicate human detection and falls, with human motion causing a blinking light, and fall detection triggering the LED to remain on for one minute. The radar signal's reflection and processing are continuous, enabling real-time monitoring of movement patterns.

4. **Sleep Quality Monitoring:**



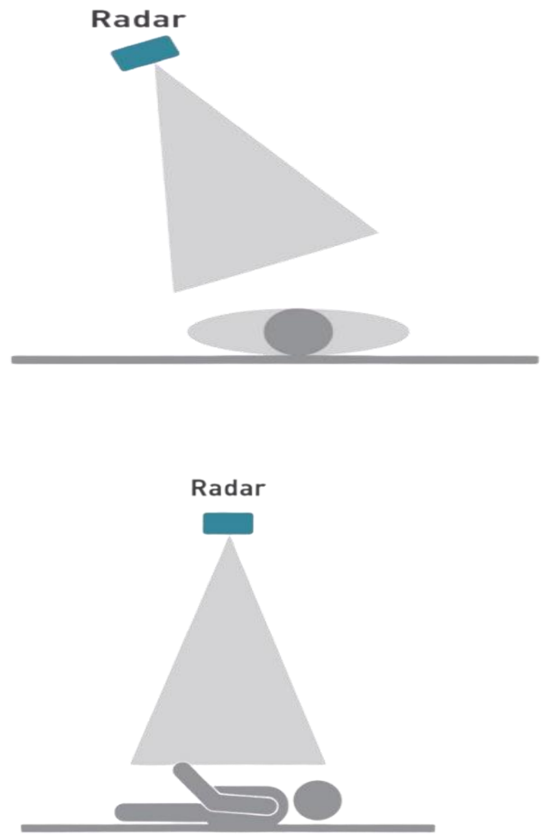


Figure: Sleep Quality monitoring device alignment

The mmWave Sleep Breathing Monitoring Sensor uses advanced radar technology to measure sleep quality and vital signs with remarkable precision. It emits low-power radio waves that reflect off the body, capturing minute movements caused by breathing and heartbeats. The device's built-in algorithm analyzes these signals to monitor breathing rates, detect sleep apnea, record sleep duration, and evaluate sleep quality, including metrics like tossing and turning, as well as light and deep sleep stages. Operating in an area of up to 9m², it achieves over 95% accuracy. The sensor can differentiate between awake and sleeping states and provides apnea alerts, making it a reliable tool for sleep analysis. Unlike traditional devices requiring contact or wearables, this sensor is entirely contactless, offering unmatched convenience and privacy. Priced at around $28, it outperforms expensive alternatives like Tempur-Pedic Sleep Tracker ($299) and Sleepon Go2sleep Tracker ($129) in terms of cost and user experience. Suitable for bedrooms, nursing homes, and other environments where sleep quality is essential, the sensor ensures effective monitoring with optimal comfort for users.

5. **IoMT Based App Development:**

The CVSMS Android app was created using the MIT App Inventor platform, a high-level, block-based visual programming language. Initially developed by Google and now managed by the Massachusetts Institute of Technology, this platform enables beginners to build applications for both Android and iOS. The app consists of multiple screens, each with various buttons and visual logic blocks to display real-time data. To achieve this, MATLAB's cloud-based service, ThingSpeak, was utilized. The system's MCU unit, specifically the Node MCU 8266, first collects heart rate and respiratory rate data from the 60G band radar sensor, and temperature data from the AMG8833 sensor. It then sends this data to the ThingSpeak server, where three different graphs are generated. These graphs are subsequently linked to our CVSMS app, enabling users to remotely access patient data. The following images illustrate the process of developing the Android app.

Figure 7: MIT app inventor high level block based visual interface

Results Analysis: [Nihal’s Part]

Maintain sequence 1. vital 2 fall 3 sleep in results sections

Range	Average Time(Each Fall Test)	Average BMI (Among 5 People)	Average Fall Test	Accurate Fall Detection	MAPE
Origin	11.58	12.19	10	10	0
Origin -2 Feet	12.75	12.19	10	9	10%
2-3 Feet	0	12.19	10	0	100%

The table shows the fall detection accuracy for different rage. The origin means just under the radar. Ad there is 100% accuracy. From origin to 2 feet it ca detect 9 falls out of 10 falls so it gets the accuracy of 90%. The results suggest that the system performs well in the baseline scenario but accuracy decreases as the fall distance increases. And after 3 feet the radar cannot detect the fault. So this radar has a range of 2 Feet.

Model	Cost	Fall detection Accuracy	MIMO Config	Freq.	Ref.
IWR1443 BOOST	$299	92.34 %	4Rx & 3Tx	76-81GHz	
AWR1642 BOOST	$299	96%	6Rx & 2Tx	76-81GHz	
IWR6843 BOOST	$175	98%	4Rx & 3Tx	60-64GHz	
AWR1443 BOOST	$299	98%	4Rx & 3Tx	76-81GHz	
MR60FDA1	$37	≥90%	3Rx & 1Tx	58-63.5GHz	

Aspect of Comparison	FMCW Radar	IP camera	PIR Sensor
Privacy protection	Does not capture images or video	Captures images or video	Does not capture images or video
Low-light operation	Effective in no-light condition	Requires adequate light	Works with IR sensor
Detection range	Short; indoor area	Short to long	Short to medium
Stationary object detection result	Can detect	Only when it starts moving	Cannot detect
Environmental conditions	Resilient to weather	Affected by weather conditions	Affected by weather conditions
Multi Targets	Can detect	Need higher processor	Cannot differentiate

The comparison of FMCW radars, IP cameras, and PIR sensors highlights their features and limitations for fall detection and movement detection. FMCW radars and PIR sensors do not capture images or videos whereas IP cameras that record visual data. So video recording in home can lead the privacy issue of the house. In low-light conditions, FMCW radars perform the best as they do not require light, while PIR sensors rely on infrared signals, and IP cameras need adequate lighting. For detection range, FMCW radars are suitable for short-range indoor use, IP cameras can cover a wide range based on their setup, and PIR sensors are effective within short to medium ranges. FMCW radars are weather-resistant, whereas IP cameras and PIR sensors can be affected by environmental conditions. Lastly, FMCW radars can detect multiple targets simultaneously, IP cameras can do so with high processing power, but PIR sensors cannot differentiate between multiple objects. As home is the safe and private place for everyone so the FMCW radar is the best suggestion for smart home system considering its high privacy and fall detection feature.

The result comparison shows that implemented device is the cheapest solution for contactless monitoring of the vital sign. The system gives the solution about 22.61% cost effective then other device. According to comparative analysis the features that an expensive radar can give we can provide the same service at very low cost. The accuracy rate is also comparable with the other device. The accuracy of the system is also good according to the cost of the project.

When a human present in front of radar the Yellow LED turned on. The Heart-rate and Respiratory rate and the temperature showed in the screen and the app. The radar simultaneously measures the parameters and show the result in the screen. 5 data for every person was taken to validate the data and further medical analysis.

The table represents 5 males and 5 female 22-to-25-year person data. The Age, height, weight is collected first from the volunteers of the project. Then the BMI was calculated,

$$\text{BMI}=\frac{Weight\ (KG)}{Height^2(m)} \tag{20}$$

Five male and five female volunteers took part in the system's development to collect data. Five sets of data were taken from each participant. Total fifty data samples were collected for analysis. Heart beat and respiratory rates were measured. The heart rate was compared with FDA approved Pulse Oximeter (Jumper -JPD 500D). Three techniques were used to measure the respiratory rate. Volunteers initially counted their respiration rate. To obtain additional respiratory rate data, a 24GHz mm Wave radar sensor and an ADS1292R ECG/respiration Module were used simultaneously. Following that, a comprehensive analysis was conducted on the gathered datasets. From table we calculated Mean Absolute Percentage Error

$$\text{MAPE}=\frac{1}{n}\sum_{l=1}^{n}\left|\frac{A_t-F_t}{A_t}\right| \tag{21}$$

Table5.2.1 Data table for 22 to 25 age

Subject	Gender	Age	BMI	Heart Rate (PO)	Heart Rate (Radar R60A)	MAPE(Individual)	MAPE(OVERALL)	RR (Calculated)	RR (Radar R60A)	MAPE(Indivual)	MAPE (Overall)
Person 1	M	25	33.15	80	76	3.43	7.89	17	16	5.43	10.12
				79	78			17	16		
				84	81			15	15		
				80	76			16	16		
				87	85			13	11		
Person 2	F	24	19.57	96	87	6.82		20	18	8.22	
				78	74			12	12		
				79	74			17	17		
				85	80			10	12		
				95	88			18	16		
Person 3	M	24	24.81	93	83	11.42		12	11	11.60	
				83	77			13	14		
				90	81			14	11		
				94	78			16	15		
				91	80			14	16		
Person 4	F	22	26.21	61	75	9.01		16	14	9.17	
				64	70			17	15		
				60	64			16	14		
				63	63			12	12		
				66	70			11	12		
Person 5	M	24	29.50	84	80	11.01		17	14	8.97	
				85	78			15	15		
				90	70			16	15		
				83	74			15	14		
				78	71			14	12		
Person 6	F	24	32.17	74	73	5.70		10	11	12.15	
				76	73			9	12		
				79	76			11	12		
				83	82			13	13		
				77	63			12	11		
Person 7	M	24	25.55	91	74	11.48		12	12	14.27	
				88	77			14	16		
				90	80			12	17		
				88	77			13	15		
				77	75			15	15		
Person 8	F	23	24.16	87	79	6.53		13	17	12.94	
				85	75			14	12		
				85	79			14	13		
				86	83			14	14		
				87	86			16	14		
Person 9	M	22	21.19	67	65	4.64		17	16	8.13	
				73	76			14	15		
				69	71			20	22		

				68	76			17	16		
				70	69			17	15		
Person 10	F	22	19.68	85	77	8.91		12	11	10.33	
				81	77			14	13		
				79	69			13	12		
				85	77			16	15		
				86	79			9	11		

Table 1 consists of 10 volunteers heart rate and respiratory rate taken from radar and their reference values by conventional elements. The MAPE percentage of each individual participant and for all the percipients are also presented on the table. The MAPE of heart rate is 6.67 % and the respiratory rate is 10.12% and 12.19% respectively. This error is comparatively higher. The respiration rate accuracy is 89.88% and 87. 81%. Respiratory rate accuracy is lower as the fractional values of respiration were not counted properly with fractional values.

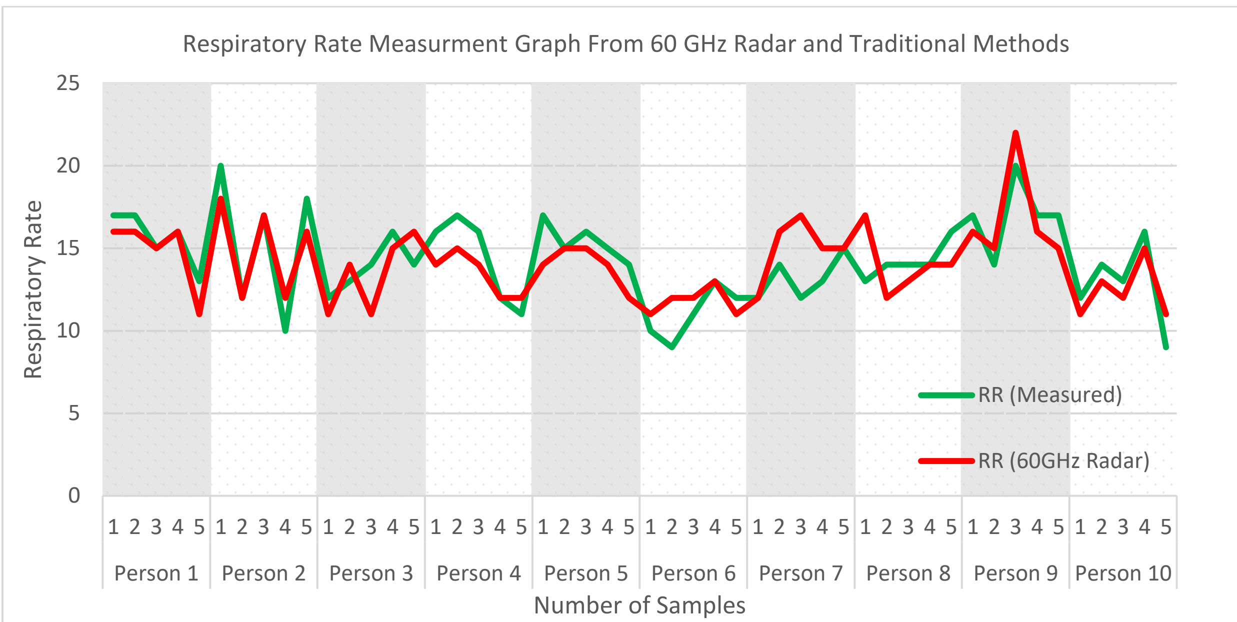


Figure 5.2.1 Respiratory rate data for measured and radar data

The respiratory rate graph analysis of reference material measurement data, 60 GHz radar data. As 60 GHz radar has the shorter wave signal and 24 GHz radar has the longer wave signal. The heart rate data graph analyzes the data between pulse oximeter and 60 GHz radar data. The radar data is nearly accurate with an accuracy of 93.34%. Heart rate values vary every time, but the radar can give data with very good accuracy. The average difference between reference values and radar data is 5.90 for heart rate and for respiratory rate it is 1.60.

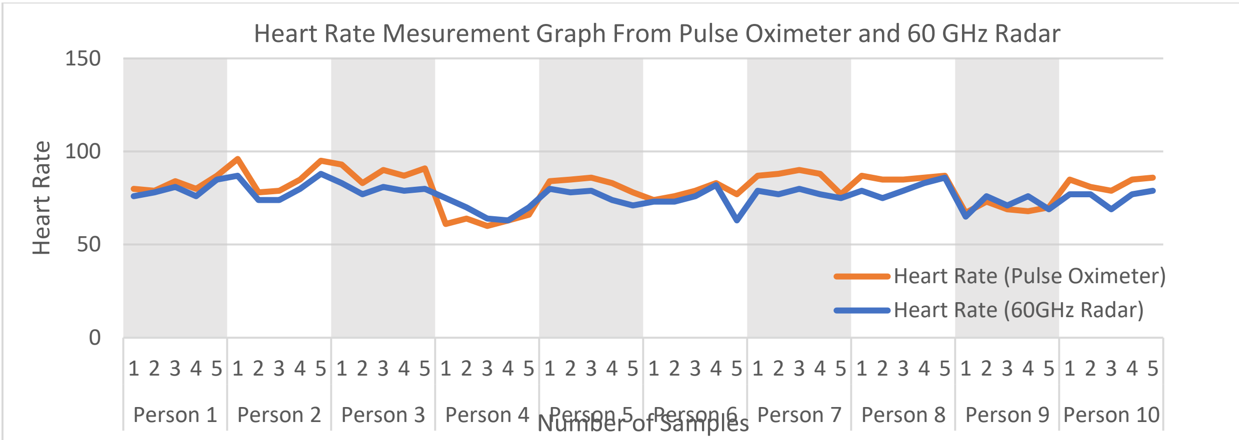


Figure 5.2.2: Heart rate data for measured and radar data

For aged people a new data table is created for comparing the data's:

Table 5.2.2 Data table for 45 to 79 ages

Subject	SEX	Age	BMI	Heart Rate (PO)	Heart Rate (Radar R60A)	MAPE(Individual)	MAPE(OVERALL)	RR (Calculated)	RR (Radar R60A)	MAPE(Individual)	MAPE (Overall)
Person 1	F	50	27.68	88	90	1.61	4.29	20	20	7.44	6.86
				88	90			22	20		
				84	85			18	19		
				87	86			17	17		
				84	85			18	17		
Person 2	F	62	23.36	71	73	0.81		16	15	5.78	
				73	73			12	12		
				80	79			13	14		
				77	77			12	13		
				76	76			15	14		
Person 3	M	79	25.03	69	64	8.06		12	11	5.52	
				64	62			13	14		
				72	62			12	11		
				68	63			16	15		
				69	63			14	16		
Person 4	F	51	21.28	76	77	4.01		13	15	14.47	
				74	77			13	14		
				73	74			14	16		
				73	77			16	15		
				77	71			16	15		
Person 5	M	56	26.28	79	75	4.18		20	18	9.15	
				82	90			21	21		
				78	79			21	20		
				83	81			21	20		
				83	81			19	19		

Person 6	M		32.17	82	78	4.07		10	11	8.12	
				82	79			9	11		
				78	82			11	12		
				75	78			13	13		
		45		75	77			12	11		
Person 7	M	56	26.28	91	85	8.12		20	18	8.60	
				93	85			21	21		
				90	82			20	17		
				90	83			21	20		
				89	84			19	19		
Person 8	M		27.04	82	78	1.61		15	14	7.44	
				82	79			16	15		
				78	82			13	12		
				75	78			12	12		
		45		75	77			11	11		

Table 2 consists of 8-person data age range 40 to 79. From the data table The MAPE for individual measurements usually looks low, with most values below 10%. This shows that the Radar R60A measurements are roughly the same as the PO readings. The overall MAPE for each individual is similarly relatively low, ranging from 4.29% to 20%. Each person's heart rate results vary slightly depending on the measurement. This could be related to a number of variables, including exercise level, stress, or time of day. From 2 data table analysis it can be said that the device is more effective for aged people. As the heart rate is comparatively low for the aged people so comparing with young people so the device can detect the measurement easily. The breathing rate MAPE is also low comparing with young people. So the device is more compatible for elderly people.

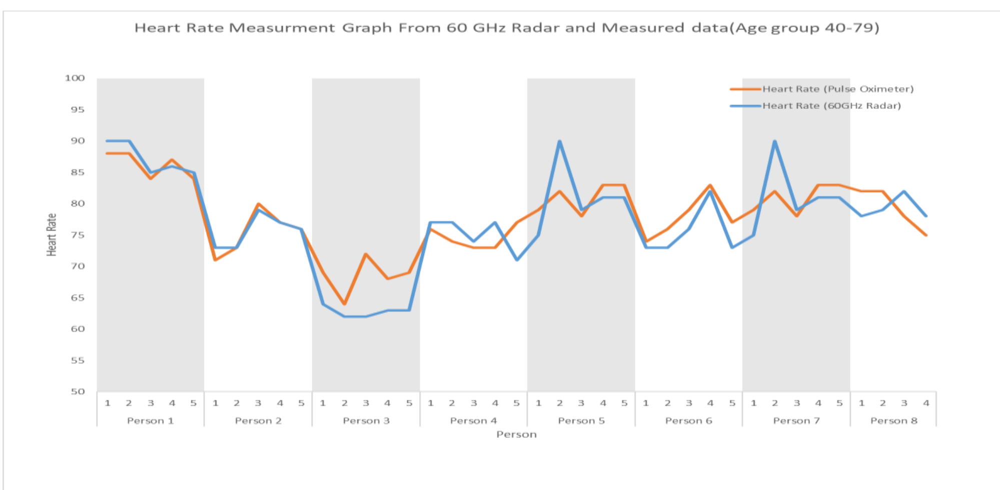


Figure 5.2.3: Heart rate data for measured and radar data for aged people

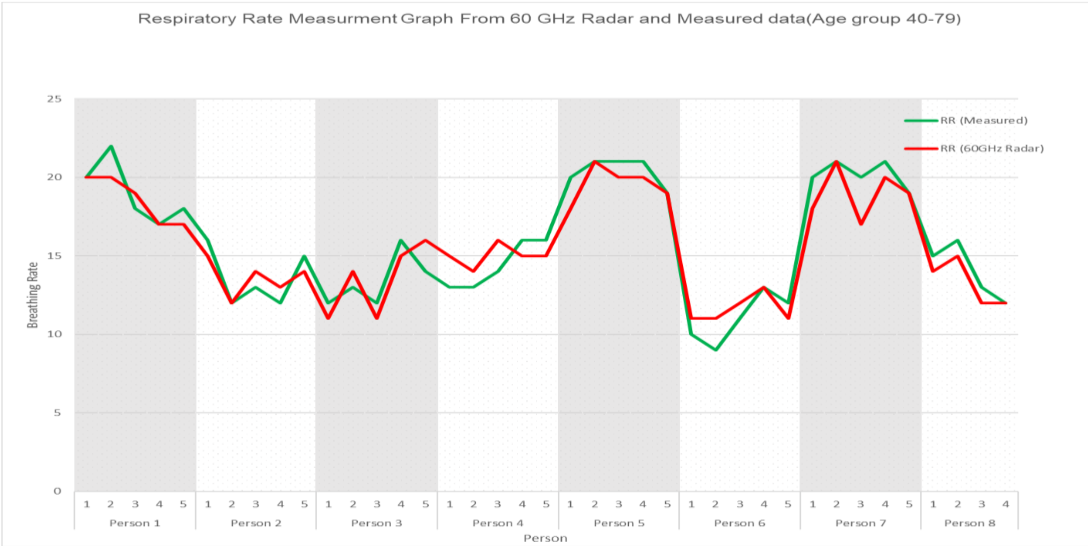


Figure 5.2.3: Respiratory rate data for measured and radar data for aged people

Comparison of Results

Table 5.3.1 Comparison with other system

Author	Radar Frequency	Accuracy Rate		Radar & Baseboard Price
		Respiratory rate	Heart Rate	
Project Device	60 GHz	89.88%	92.11%	5000
Fadel Adib et al.[25]	5.46 GHz to 7.25 GHz	99%	99%	Own developed
Alizdeh et al.[26]	77GHz AWR1443	94%	80%	73500
Wang et al.[27]	77 GHz AWR 1642	93%	93%	73000
G. Sacco, et al[28]	5.8 GHz ISM band	93.34%	96%	
Fuchuan Du et al.[29]	Infineon BGT60TR13C shield 60 GHz	91.25%		23000
Turppa et al[30]	24 GHz	91%	96%	

Xiang et al[31]	77 GHz AWR1642 from Texas Instruments	98.67%	98.04%	73000
Xue et al[32]	77 GHz Texas Instruments (TI) IWR1443	94.2%	95.1%	72000
Wang et al[33]	77 GHz AWR1642 from Texas Instruments	87%	85%	73000

The result comparison shows that implemented device is the cheapest solution for contactless monitoring of the vital sign. The system gives the solution about 22.61% cost effective then other device. According to comparative analysis the features that an expensive radar can give we can provide the same service at very low cost. The accuracy rate is also comparable with the other device. The accuracy of the system is also good according to the cost of the project.

Components	Quantity	Projected Price (Tk)	Total Price (Tk)
60 GHz Radar	1	5500	5000
Thermal Sensor	1	6500	6700
ESP 8266 Node MCU	1	400	420
BMS Circuit	1	300	220
LCD Display with I2C module	1	600	550
Battery	1	400	350
ESP 8266 Node MCU Extension Base Board	1	250	260
Battery Adapter	1	350	350
3D printing		2000	1000

Miscellaneous		500	400
Total		16800	15250

Total Estimated Project Cost = BDT. 16,800/-

Total Actual Cost of Project = BDT. 15,250/-

% of Error in Cost Estimation = (16800−15250)/15250∗100 %

% of Error = 10.16 %

Conclusions: [Not Modified]

The 60GHz FMCW radar-based contactless vital sign monitoring system offers a transformative solution for healthcare by enabling non-intrusive measurement of vital signs like heart rate and respiratory rate. Designed with portability and user-friendliness, the system is complemented by a personalized Android app for real-time monitoring, data visualization, and remote access for patients and healthcare professionals. It addresses challenges such as privacy concerns, reduced infection risk, and the discomfort associated with traditional probes. Despite its current limitations, such as single-user functionality and susceptibility to signal interference, the system's future scope includes improved accuracy, multi-person tracking, and integration with other sensors for enhanced diagnostics. Culturally tailored for Bangladeshi privacy sensitivities, the system is economically viable, environmentally sustainable, and built with recycled materials, supporting job creation in the biomedical sector. By aligning with ethical guidelines and prioritizing sustainability, this innovation promises to revolutionize healthcare, particularly in resource-constrained settings, while ensuring affordability, accessibility, and cultural relevance.

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