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

Shilamoni shaha Neir
[a] *Department of Electrical and Electronic Engineering*
[b] *Center for Biomedical Research (CBR), D2A2I*
[1]*American International University-Bangladesh, Dhaka 1229, Bangladesh*

Abstract

In this work we demonstrate a_b the formation Y_1 of a new type of polariton on the interface between a cuprous oxide slab and a polystyrene micro-sphere placed on the slab. The evanescent field of the resonant whispering gallery mode (WGM) of the micro sphere has a substantial gradient, and therefore effectively couples with the quadrupole 1*S* excitons in cuprous oxide. This evanescent polariton has a long life-time, which is determined only by its excitonic and WGM component. The polariton lower branch has a well pronounced minimum. This suggests that this excitation is localized and can be utilized for possible BEC. The spatial coherence of the polariton can be improved by assembling the micro-spheres into a linear chain.

Keywords: Vital Sign, Fall detection, Sleep Quality Monitoring, FMCW radar Smart Home, IoMT

---

1. Introduction

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 homes. 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.

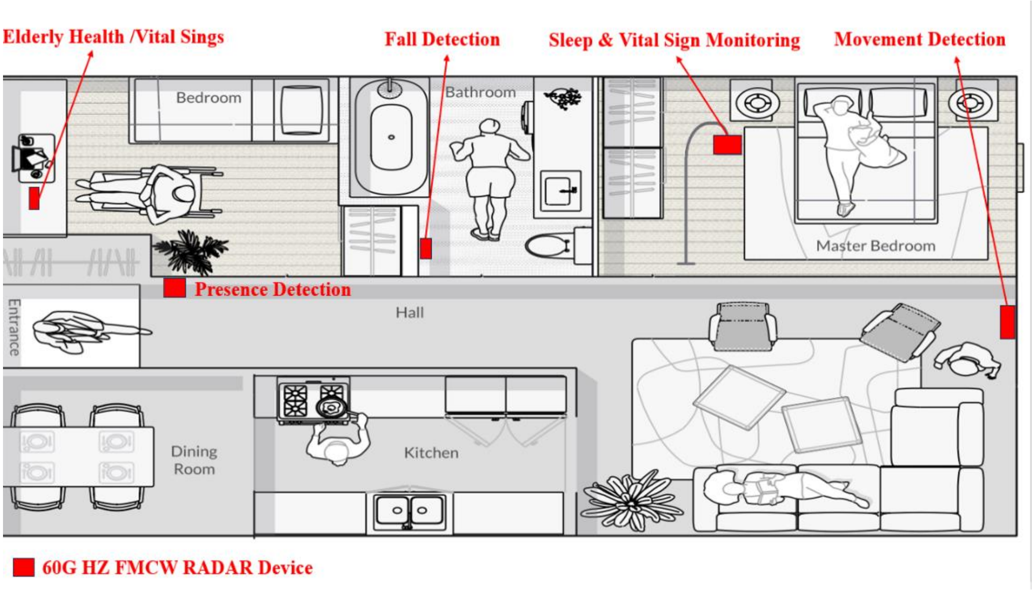


Figure 1: Layout of FMCW based Smart Home for Contactless Elderly Health Monitoring.

[x]This document is the results of the research project funded by the National Science Foundation.

[xx]The second title footnote which is a longer text matter to fill through the whole text width and overflow into another line in the footnotes area of the first page.

*Corresponding author

Email addresses: jkk@example.in (J.K. Krishnan), han@different.edu (Han Thane)

URL: www.nowhere.com (T. Rafeeq)

[1]This is the first author footnote.

[2]Another author footnote, this is a very long footnote and it should be a really long footnote. But this footnote is not yet sufficiently long enough to make two lines of footnote text.

[3]Yet another author footnote.

2. Methodology

2.1 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):

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

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):

$$r_0 = r_0 + v_0 . t \quad (10)$$

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

Time delay(td)

$$t_d = \frac{2. r_0}{c} \quad (11)$$

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:

$$freqRx = f_c + slope. t \quad (12)$$

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

Rx Wave form:

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

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:

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

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.

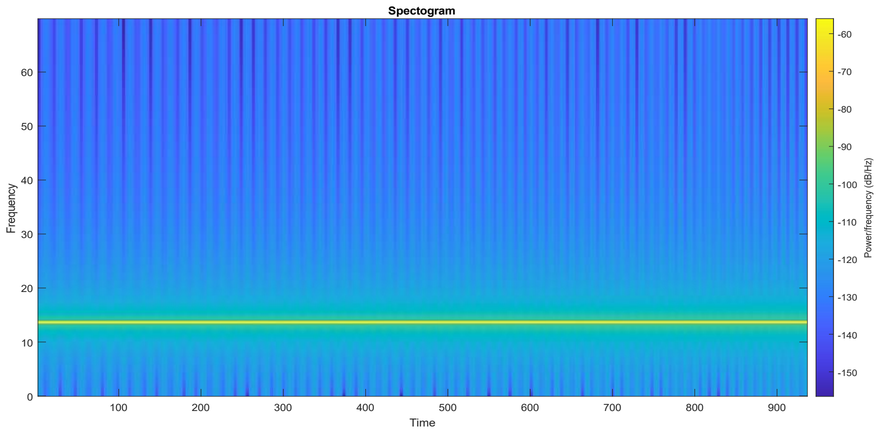


Figure 2: Spectogram of FMCW the MATLAB Simulation

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.

2.2 FMCW Radar based 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.

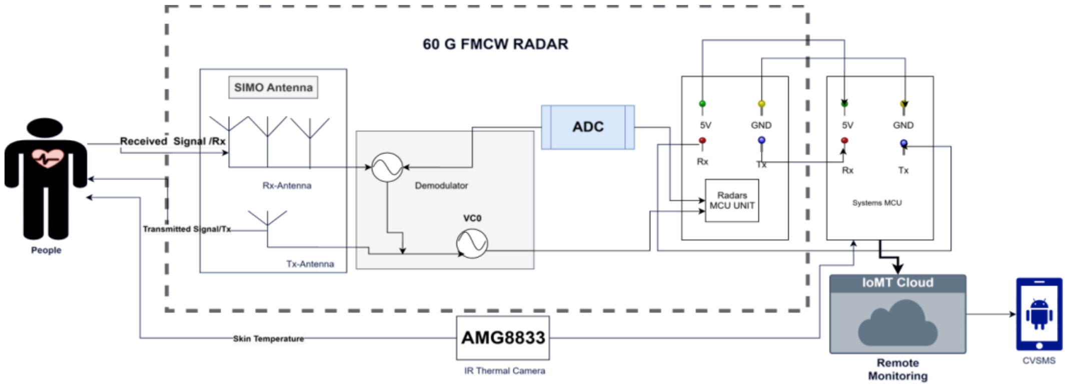
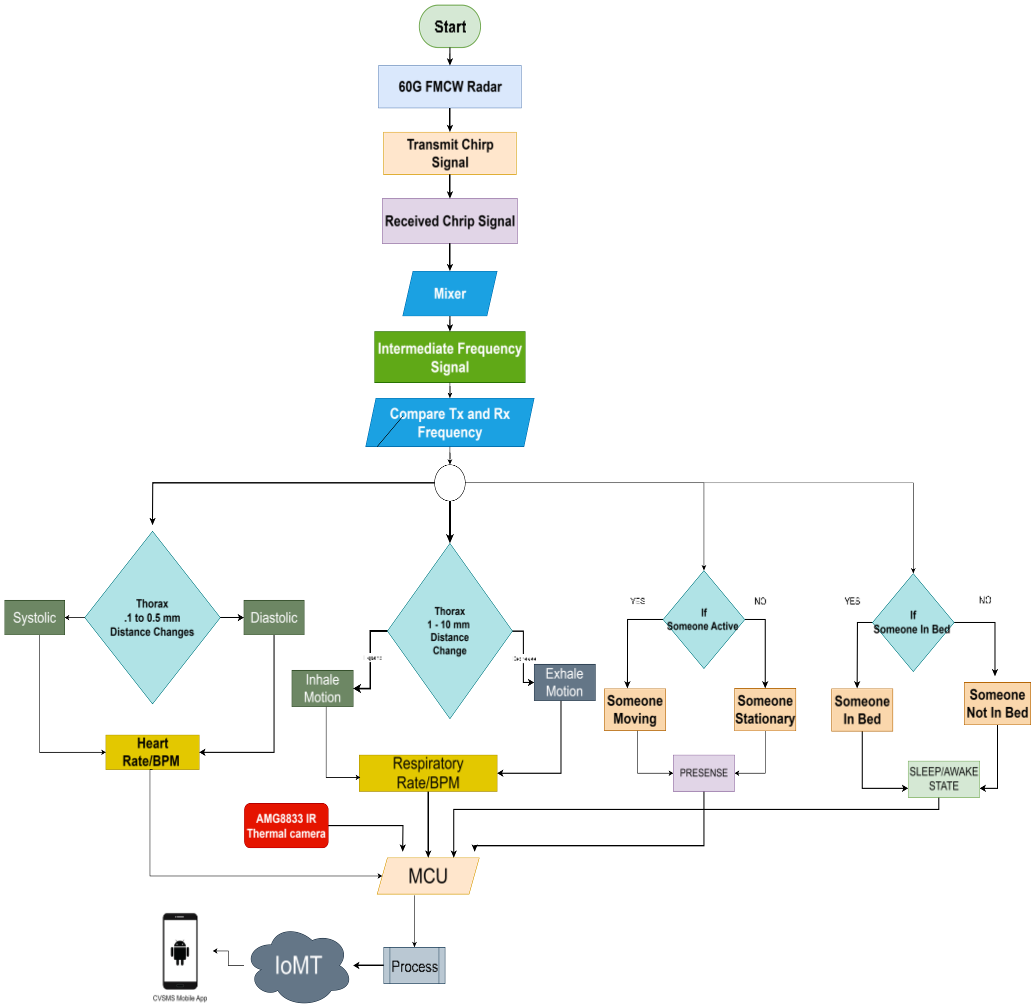


Figure 3: The working principal diagram Of FMCW radar based vital sign monitoring system.



.

Figure 4: Flowchart of the FMCW Radar based 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.

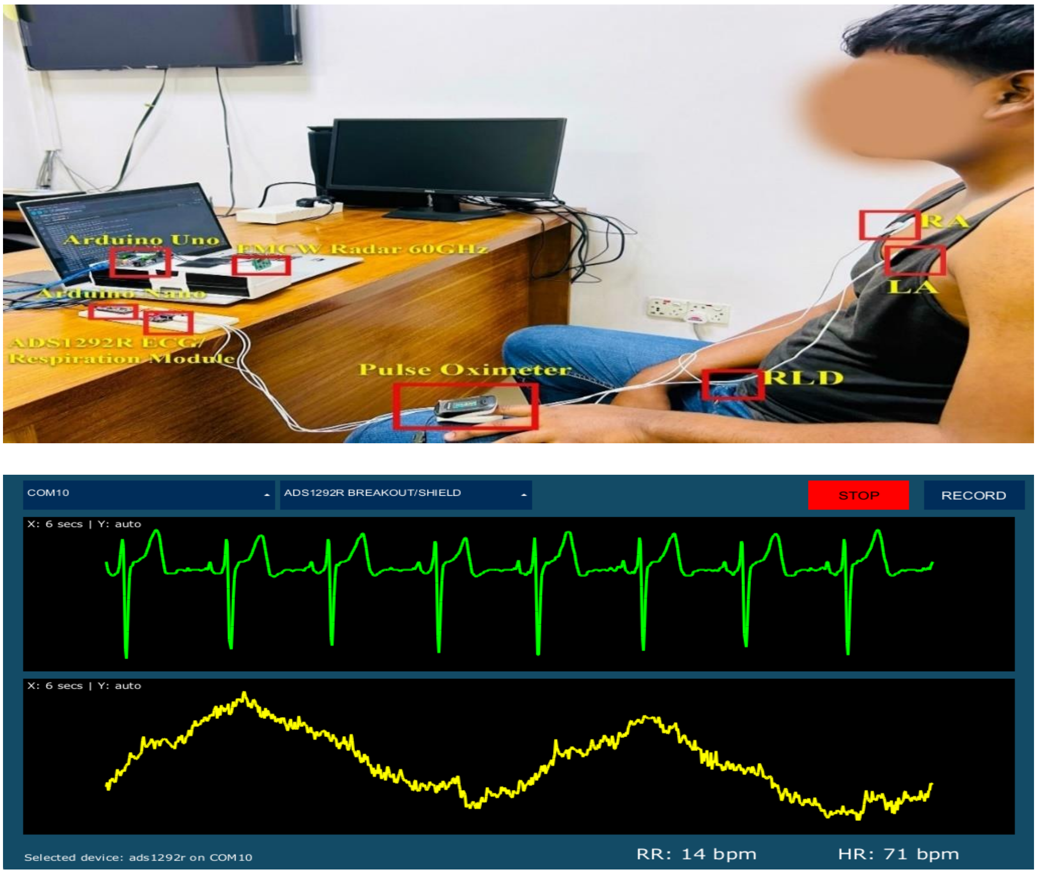


Figure 5: Experimental setup of the FMCW Radar based vital signs monitoring system.

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 6: Hardware model of the FMCW radar based vital sign monitoring 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.

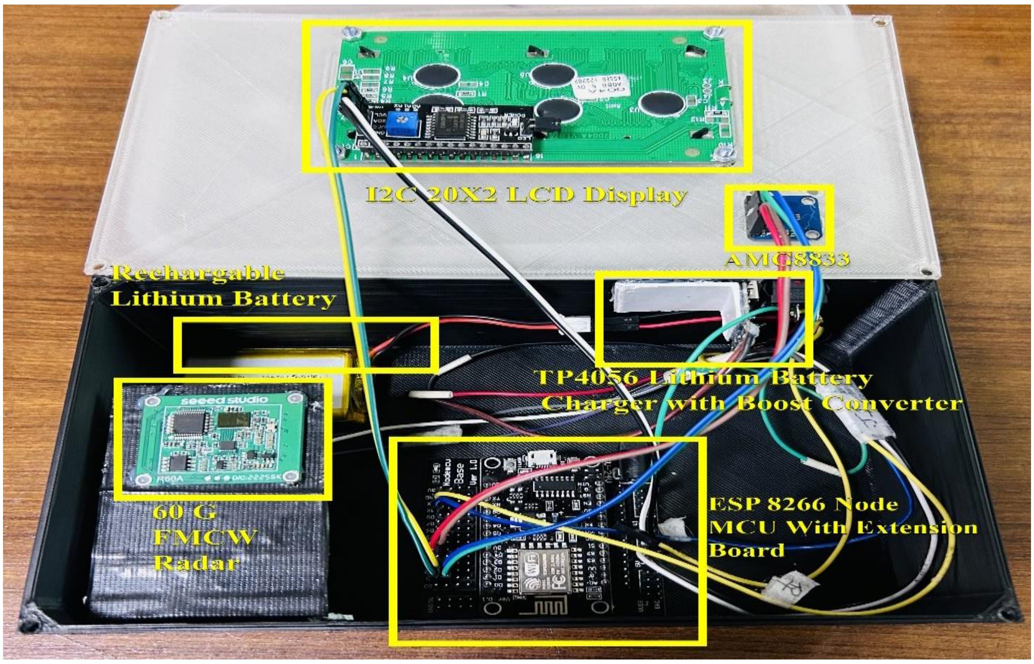


Figure 7: Hardware Model: Inside View of the of the FMCW radar based vital sign monitoring device.

.

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

2.3 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.

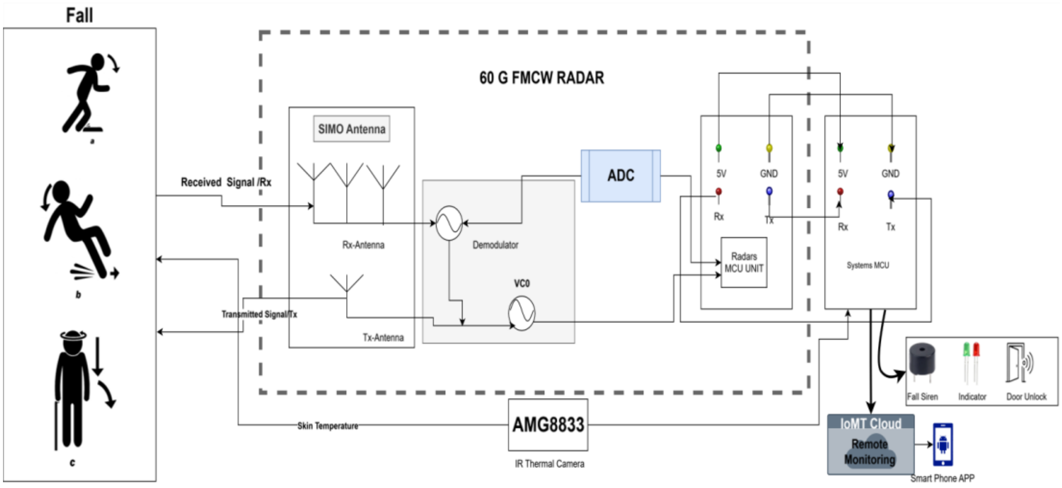


Figure 8: Working Principal diagram of FMCW radar-based fall detection system.

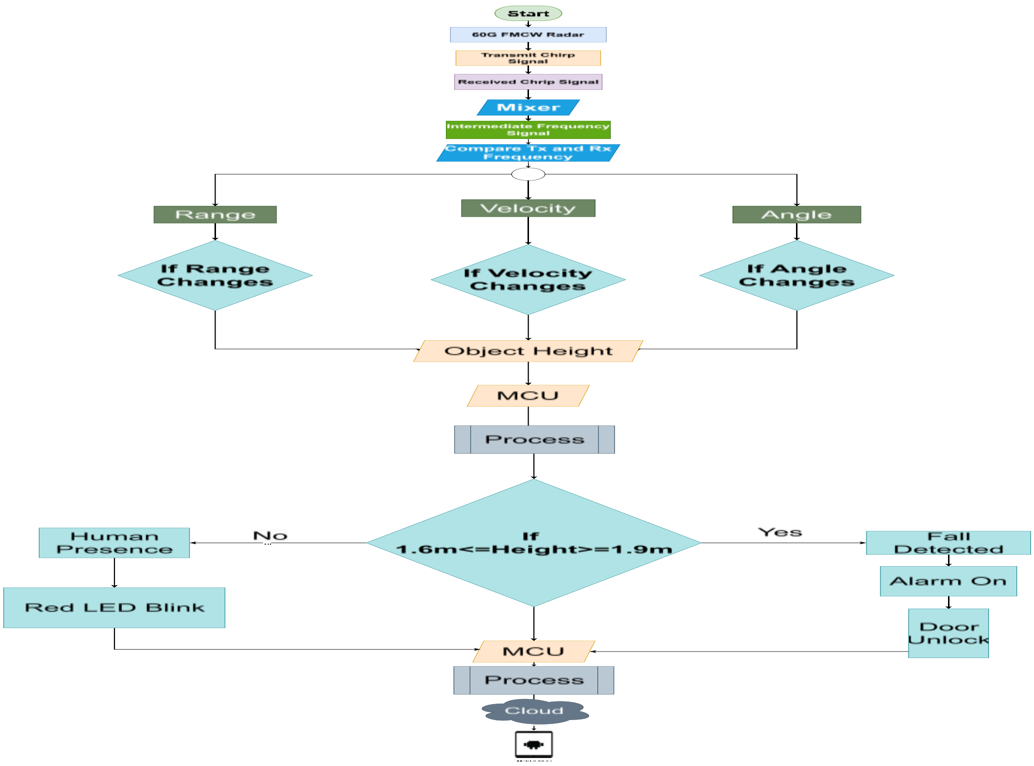


Figure 9: Flowchart of the FMCW Radar based fall detection and automatic door opening system.

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.

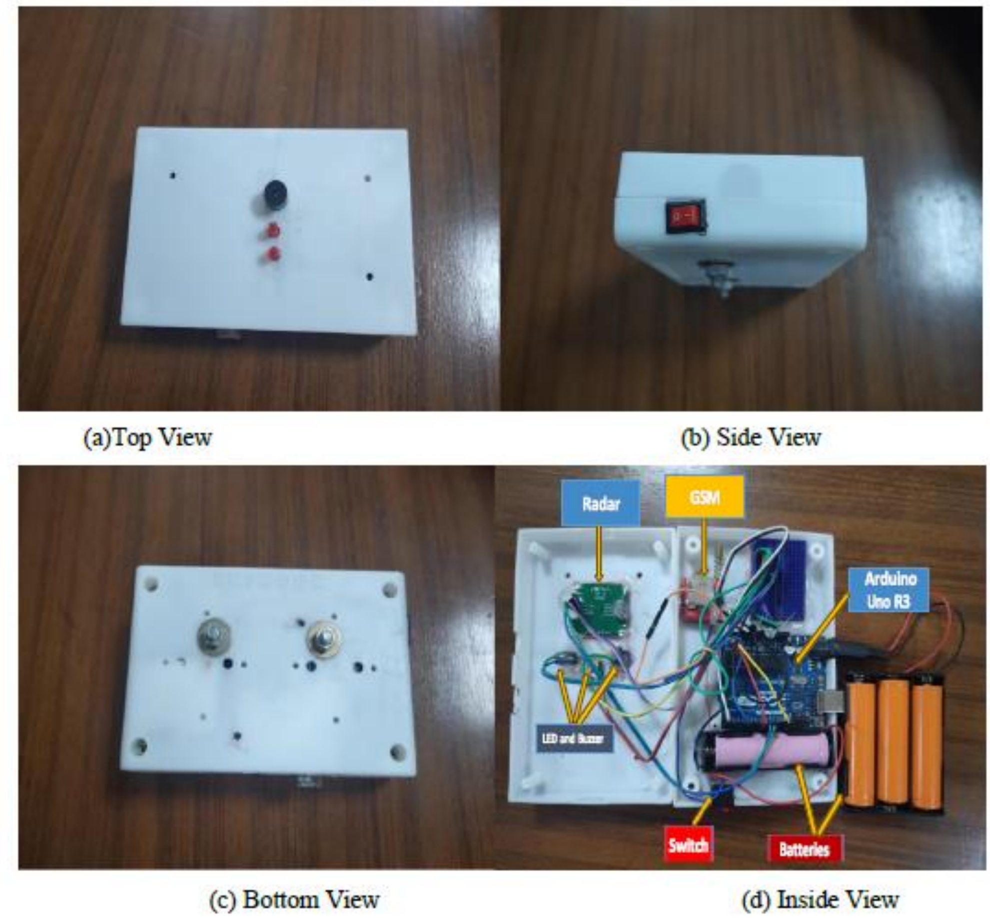


Figure 10: Hardware model of FMCW radar-based fall detection and door opening system.

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.

2.4 Sleep Quality Monitoring:

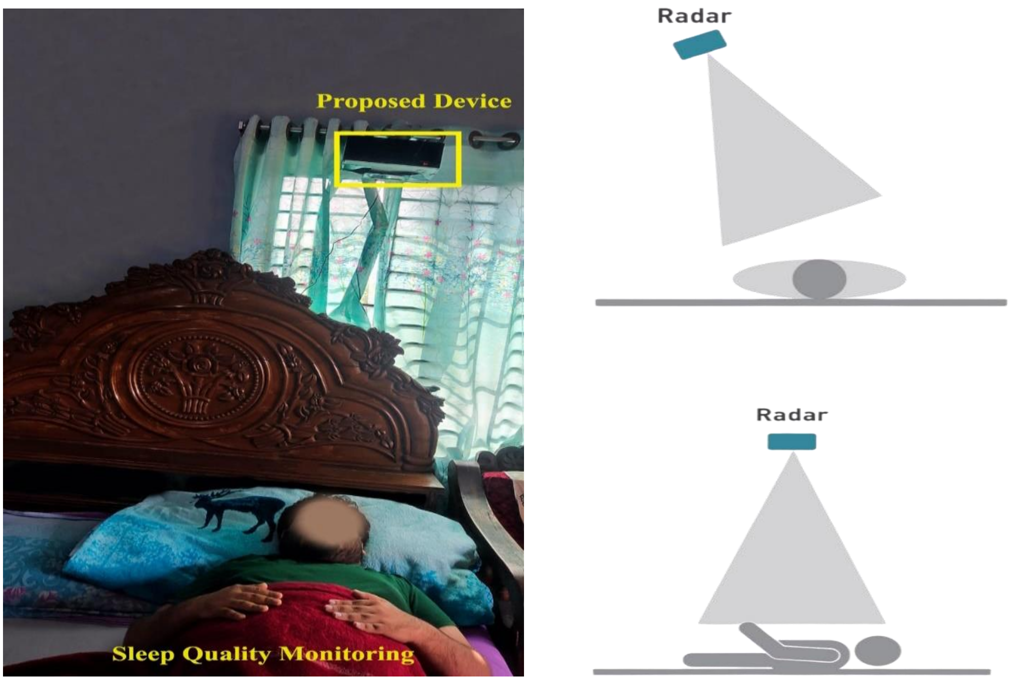


Figure 11: Sleep quality monitoring with FMCW radar-based device. The device can monitor   given in the diagram different sleeping positions.

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.

2.5 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 12: MIT app inventor high level block based visual interface developing the android app for remote monitoring system.

[4]WGM occur at particular resonant wavelengths of light for a given dielectric sphere size. At these wavelengths, the light undergoes total internal reflection at the sphere surface and becomes trapped within the particle for timescales of the order of *ns*.

[5]comparing to the evanescent field penetration depth

3 Results and discussion [NIHAL'S PART]

3.1 FMCW Radar based vital sign monitoring system

3.2 FMCW Radar based fall detection system with automatic door opening system

3.3 FMCW Radar based presence, movement and sleep quality monitoring system

4 Conclusion

5 Appendix

References

[1] F. Adib, H. Mao, Z. Kabelac, D. Katabi, and R. C. Miller, “Smart Homes that Monitor Breathing and Heart Rate,” in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, Seoul Republic of Korea: ACM, Apr. 2015, pp. 837–846. doi: 10.1145/2702123.2702200.

[2] M. Alizadeh, G. Shaker, J. C. M. D. Almeida, P. P. Morita, and S. Safavi-Naeini, “Remote Monitoring of Human Vital Signs Using mm-Wave FMCW Radar,” *IEEE Access*, vol. 7, pp. 54958–54968, 2019, doi: 10.1109/ACCESS.2019.2912956.

[3] Y. Wang, W. Wang, M. Zhou, A. Ren, and Z. Tian, “Remote Monitoring of Human Vital Signs Based on 77-GHz mm-Wave FMCW Radar,” *Sensors*, vol. 20, no. 10, Art. no. 10, Jan. 2020, doi: 10.3390/s20102999.

[4] G. Sacco, E. Piuzzi, E. Pittella, and S. Pisa, “An FMCW Radar for Localization and Vital Signs Measurement for Different Chest Orientations,” *Sensors*, vol. 20, no. 12, Art. no. 12, Jan. 2020, doi: 10.3390/s20123489.

[5] S. K. Leem, F. Khan, and S. H. Cho, “Vital sign monitoring and mobile phone usage detection using IR-UWB radar for intended use in car crash prevention,” *Sensors*, vol. 17, no. 6, p. 1240, 2017.

[6] F. Du, H. Wang, H. Zhu, and Q. Cao, “Vital Sign Signal Extraction Based on mmWave Radar,” *J. Comput. Commun.*, vol. 10, no. 3, Art. no. 3, Mar. 2022, doi: 10.4236/jcc.2022.103009.

[7] Y. Hu and T. Toda, “Remote Vital Signs Measurement of Indoor Walking Persons Using mm-Wave FMCW Radar,” *IEEE Access*, vol. 10, pp. 78219–78230, 2022, doi: 10.1109/ACCESS.2022.3193789.

[8] M. Xiang, W. Ren, W. Li, Z. Xue, and X. Jiang, “High-Precision Vital Signs Monitoring Method Using a FMCW Millimeter-Wave Sensor,” *Sensors*, vol. 22, no. 19, Art. no. 19, Jan. 2022, doi: 10.3390/s22197543.

[9] “Improved Heartbeat Detection by Exploiting Temporal Phase Coherency in FMCW Radar | IEEE Journals & Magazine | IEEE Xplore.” Accessed: Nov. 11, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9635781

[10] M. Arsalan, A. Santra, and C. Will, “Improved Contactless Heartbeat Estimation in FMCW Radar via Kalman Filter Tracking,” *IEEE Sens. Lett.*, vol. 4, no. 5, pp. 1–4, May 2020, doi: 10.1109/LSENS.2020.2983706.

[11] Z. Li, K. Chen, and Y. Xie, “A Deep Learning Method for Human Sleeping Pose Estimation with Millimeter Wave Radar,” *Sensors*, vol. 24, no. 18, p. 5900, Sep. 2024, doi: 10.3390/s24185900.

[12] E. Turppa, J. M. Kortelainen, O. Antropov, and T. Kiuru, “Vital Sign Monitoring Using FMCW Radar in Various Sleeping Scenarios,” *Sensors*, vol. 20, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/s20226505.

[13] Y.-K. Yoo, C.-W. Jung, and H.-C. Shin, “Unsupervised Detection of Multiple Sleep Stages Using a Single FMCW Radar,” *Appl. Sci.*, vol. 13, no. 7, Art. no. 7, Jan. 2023, doi: 10.3390/app13074468.

[14] T. Yang, J. Cao, and Y. Guo, “Placement selection of millimeter wave FMCW radar for indoor fall detection,” in *2018 IEEE MTT-S International Wireless Symposium (IWS)*, May 2018, pp. 1–3. doi: 10.1109/IEEE-IWS.2018.8400812.

[15] M. G. Amin, Y. D. Zhang, F. Ahmad, and K. C. D. Ho, “Radar Signal Processing for Elderly Fall Detection: The future for in-home monitoring,” *IEEE Signal Process. Mag.*, vol. 33, no. 2, pp. 71–80, Mar. 2016, doi: 10.1109/MSP.2015.2502784.

[16] C. Lovescu and S. Rao, “The fundamentals of millimeter wave radar sensors,” *Tex. Instrum. Julio*, 2020.
[17] E. Cippitelli, F. Fioranelli, E. Gambi, and S. Spinsante, “Radar and RGB-Depth Sensors for Fall Detection: A Review,” *IEEE Sens. J.*, vol. 17, no. 12, pp. 3585–3604, Jun. 2017, doi: 10.1109/JSEN.2017.2697077.
[18] C. Ding, Y. Zou, L. Sun, H. Hong, X. Zhu, and C. Li, “Fall detection with multi-domain features by a portable FMCW radar,” in *2019 IEEE MTT-S International Wireless Symposium (IWS)*, May 2019, pp. 1–3. doi: 10.1109/IEEE-IWS.2019.8804036.
[19] K. Hanifi and M. E. Karsligil, “Elderly Fall Detection With Vital Signs Monitoring Using CW Doppler Radar,” *IEEE Sens. J.*, vol. 21, no. 15, pp. 16969–16978, Aug. 2021, doi: 10.1109/JSEN.2021.3079835.
[20] “State-of-the-Art Wearable Sensors and Possibilities for Radar in Fall Prevention.” Accessed: Dec. 24, 2024. [Online]. Available: https://www.mdpi.com/1424-8220/21/20/6836
[21] “Walking Step Monitoring with a Millimeter-Wave Radar in Real-Life Environment for Disease and Fall Prevention for the Elderly.” Accessed: Dec. 24, 2024. [Online]. Available: https://www.mdpi.com/1424-8220/22/24/9901
[22] S. Matsuguma and A. Kajiwara, “Bathroom accident detection with 79GHz-band millimeter wave sensor,” in *2019 IEEE Sensors Applications Symposium (SAS)*, Mar. 2019, pp. 1–5. doi: 10.1109/SAS.2019.8706084.
[23] D. A. Preethi, R. Nagarajan, and S. Kannadhasan, “SOUND BASED DOOR LOCKING SYSTEM USING ARDUINO”, Accessed: Dec. 24, 2024. [Online]. Available: https://www.researchgate.net/profile/Kannadhasan-Suriyan/publication/355484226_SOUND_BASED_DOOR_LOCKING_SYSTEM_USING_ARDUINO/links/61745b88eef53e51e1d636fb/SOUND-BASED-DOOR-LOCKING-SYSTEM-USING-ARDUINO.pdf
[24] K. A. Patil, N. Vittalkar, P. Hiremath, and M. A. Murthy, “Smart door locking system using IoT,” *Int. Res. J. EngTechnol IRJET*, pp. 3090–3094, 2020.