

Design and Implementation of a Non-contact Intelligent Health Monitoring System Based on STM32F407 and Millimeter-Wave Radar

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Abstract

This paper designs a non-contact intelligent health monitoring home system with a millimeter-wave radar module as the core sensing unit and an STM32F407 microcontroller as the main control core. The system integrates photosensitive sensing, inertial measurement units (IMU), and wireless communication technologies to construct an integrated solution for non-intrusive health monitoring and smart home control. The system achieves continuous non-contact monitoring of vital signs, including respiration and heart rate, through millimeter-wave radar. It implements high-precision fall detection using multi-modal judgment logic combining radar and IMU data. Simultaneously, it integrates human positioning and photosensitive sensing to achieve energy-saving lighting control characterized by “lights on when people arrive, and dimming when people leave.” When abnormal vital signs or fall events are detected, the system can link with smart devices to perform environmental intervention and push alarm information to preset contacts via the cloud. The system adopts an edge computing design, where core vital sign calculation, behavior recognition, and intelligent judgment logic are all completed at the edge. Only statistical data and abnormal event information are uploaded to the cloud, effectively reducing transmission latency and enhancing data privacy, which aligns with the trend of edge intelligence in Internet of Things (IoT) medical systems. Experimental results show that within a detection range of 0.5 to 5m, the respiration rate detection accuracy is ± 1 breath/minute, the heart rate detection accuracy is ± 2 beats/minute, and the fall recognition accuracy is 98%. All functions are stably implemented, providing a privacy-friendly and highly reliable intelligent solution for home-based elderly care and monitoring of special populations.

Full Text

Design of a Non-Contact Intelligent Health Monitoring System Based on STM32F407 and Millimeter-Wave Radar

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Abstract

With the increasing demand for continuous health monitoring in aging populations and smart home environments, non-contact physiological signal sensing has become a critical research direction. This paper presents the design and implementation of an intelligent health monitoring system utilizing the STM32F407 microcontroller and frequency-modulated continuous wave (FMCW) millimeter-wave (mmWave) radar. The system leverages the high-precision displacement sensing capabilities of mmWave radar to capture micro-motions of the human chest wall. By implementing advanced signal processing algorithms, including Fast Fourier Transform (FFT) and digital filtering, the system extracts heart rate and respiratory rate in real-time without physical contact.

Furthermore, the system employs multi-modal decision logic to achieve high-precision fall detection. The integration of human positioning and photosensitive sensing enables energy-efficient lighting control, such as “lights on when present, lights off when absent.” In the event of detected vital sign abnormalities or fall incidents, the system triggers smart device linkages for environmental intervention and pushes alarm notifications to preset contacts via the cloud. Adopting an edge computing architecture, the core vital sign calculations, behavior recognition, and intelligent decision-making logic are processed at the edge, effectively reducing latency and enhancing privacy. Experimental results demonstrate that within a detection range of 0.5–5m, the system achieves high accuracy for respiratory and heart rate monitoring alongside robust fall detection, providing a reliable solution for long-term, non-invasive health management.

Keywords

STM32F407; Millimeter-wave radar; Vital signs monitoring; Fall detection; Smart home; Health monitoring; Edge computing; Multi-sensor fusion

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1. Introduction

1.1 Research Background and Significance

As the global aging process accelerates, the home health safety and emergency rescue of elderly individuals living alone have become critical social issues. Ac-

Figure 1

Figure 1: Figure 1

According to the World Health Organization, the annual incidence of falls among the elderly over 65 is as high as 28% to 35%, making falls the second leading cause of accidental injury and death. Furthermore, the early home screening of chronic conditions such as cardiovascular diseases and sleep apnea syndrome has created an urgent demand for long-term, non-intrusive vital signs monitoring.

Traditional monitoring solutions possess significant limitations. Wearable devices often lead to poor compliance due to skin discomfort and battery life issues. Camera-based systems pose serious privacy risks and are sensitive to lighting conditions. In contrast, millimeter-wave (mmWave) radar technology is non-contact, privacy-friendly, and resistant to environmental interference. It can penetrate clothing to accurately capture sub-millimeter chest movements caused by respiration and heartbeat while identifying abnormal behaviors like falls through the Doppler effect.

1.2 Current Research Status

In the field of mmWave radar vital signs monitoring, international scholars such as Vinci et al. pioneered technical validation using six-port radar architectures. Domestic research has focused on optimizing signal processing in complex scenarios, proposing adaptive filtering to address human motion noise. In fall detection, early rule-based methods were prone to false alarms. Recent advancements, such as the Line Kernel Convolutional Neural Network [?] and the mmFall detection scheme based on Hybrid Variational Autoencoders [?], have significantly improved recognition accuracy. However, most existing studies rely on high-performance computing platforms. There remains significant room for optimization in lightweight edge-side deployment for embedded terminals like the STM32 to meet the practical requirements of low cost and low power consumption.

2. System Architecture

The system consists of four primary components: the terminal sensing unit, the main control processing unit (STM32F407), the communication and execution unit, and the cloud/user interface.

2.1 System Core Functions

1. **Non-contact Vital Sign Monitoring:** Real-time monitoring of respiratory and heart rates. Anomalies trigger automatic ventilation via smart windows and push alerts to mobile devices.
2. **Multimodal Fall Detection:** Integrates mmWave radar and IMU data

to differentiate between falls and daily activities (sitting/squatting), triggering local and remote alarms upon confirmation.

3. **Energy-Efficient Lighting:** Fuses light intensity data with radar positioning for “lights on when present” functionality.
4. **Regional Presence Sensing:** Perceives personnel location to manage air conditioning or fresh air systems.
5. **Data Visualization:** A mobile application provides real-time data, health trends, and threshold configuration.

3. Hardware Design

3.1 Overall Architecture

The hardware utilizes the STM32F407VGT6 core board as the central hub, supported by a mmWave radar module, auxiliary sensors (BH1750 light sensor, 6-axis IMU, temperature/humidity sensors), a Wi-Fi module (ESP8266/ESP32), and relay control modules.

3.2 Core Module Selection

- **Main Control Unit:** The STM32F407VGT6 (Cortex-M4, 168MHz) provides the FPU and memory required for real-time radar signal processing.
- **Millimeter-Wave Radar:** The IWR6843 60GHz module is used for its high sensitivity to micro-displacements and ability to output point cloud information.
- **Communication:** The MQTT protocol is employed for low-overhead, reliable data interaction between the terminal and the cloud.

4. Software and Algorithm Implementation

4.1 Vital Signs Extraction Algorithm

The algorithm involves: 1. **Signal Pre-processing:** Removing DC offsets and suppressing static clutter. 2. **Target Locking:** Using FFT to identify the range bin of the human subject. 3. **Separation and Calculation:** Digital filters isolate respiration and heartbeat signals. FFT analysis identifies frequency peaks to calculate rates within physiological ranges.

4.2 Multi-modal Fall Detection

The system extracts features such as range, velocity, micro-Doppler spectra, and centroid height variations [?, ?]. By fusing radar data with IMU-calibrated device status, the system distinguishes falls from daily activities like squatting, reducing false alarms.

4.3 Intelligent Linkage Logic

The system implements adaptive lighting based on occupancy and ambient light. For emergencies, it triggers relay-driven windows for ventilation and initiates multi-channel alerts (App push, SMS, and voice calls) via the cloud.

5. Experimental Results and Analysis

5.1 Performance Testing

Tests were conducted in a residential environment. Core performance metrics are summarized in .

- **Vital Signs:** Respiratory rate detection range is 10 ~ 40 breaths/min; heart rate range is 50 ~ 120 beats/min.
- **Environmental Sensing:** Temperature range $-40^{\circ}\text{C} \sim 80^{\circ}\text{C}$; humidity 20%RH-90%RH.
- **Response Time:** Local alarms trigger immediately; emergency cloud notifications are delivered in ≤ 5 seconds.

5.2 Stability Verification

During long-term testing, the system exhibited no data loss or functional anomalies. The non-contact monitoring and fall recognition functions operated stably within a 0.5-5m range, meeting the requirements for home-based elderly care.

6. Future Outlook and Conclusion

Future work will focus on introducing lightweight deep learning models to enhance performance in complex scenarios and expanding to multi-node radar deployment for full-home coverage.

In conclusion, this system successfully integrates STM32F407 and mmWave radar to provide a non-contact, privacy-preserving health monitoring solution. By combining vital sign extraction, fall detection, and smart home linkage through an edge computing architecture, it offers a highly reliable and low-cost alternative to traditional wearable or camera-based monitoring systems.

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