PRIVACY-PROTECTED ELDERLY MONITORING SYSTEM: WI-FI AND WEARABLE SENSORS

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Contents

1 Introduction

1.1 Problem

China is facing a significant demographic transformation as it moves toward becoming an aging society, with projections showing that by 2050, nearly a third of its population will be over 60 years old. Already, over 264 million Chinese citizens are aged 60 and above, making up approximately 18.7% of the nation's total population. [1] This demographic shift has led to an increased demand for elderly care services, placing Elderly Care Centers at the forefront of providing essential care and safety for this vulnerable group. Yet, these centers face substantial challenges in monitoring and responding to emergencies, such as falls or medical crises, without compromising the privacy and dignity of the elderly, as traditional surveillance methods are both resource-intensive and ethically problematic.[2]

Addressing the limitations of current emergency detection systems in these care centers has become increasingly critical, especially considering China's growing elderly population. A survey among Elderly Care Centers in China revealed a significant lack of advanced mechanisms for detecting emergencies while preserving privacy.[3] This inadequacy in care provision highlights an urgent need for innovative solutions that balance efficient emergency detection with the preservation of privacy and dignity. [4] Developing such systems is essential not only for enhancing elderly care but also for adapting to China's changing demographic landscape, making it imperative to invest in technologies that ensure safety and respect for the elderly simultaneously.[5]

1.2 Solution

To bridge this gap, we propose the development of an Emergency Detection System specifically designed for elderly individuals. This system combines two innovative components to ensure both efficacy and privacy. The first one is Wi-Fi Emergency System: Utilizing advanced signal processing and deep learning techniques, this system interprets Wi-Fi signal disruptions caused by human movement within its coverage area. By analyzing these disruptions, the system can identify unusual patterns indicative of falls or other emergencies without the need for visual surveillance, thereby maintaining privacy. [3]

While Wearable Devices complementing the Wi-Fi Emergency System. These devices are equipped with motion and health sensors. They are designed to be lightweight, unobtrusive, and capable of providing real-time data on the wearer's physical state. In the event of an abnormality, the device can trigger an immediate alert to caregivers for prompt response.

1.3 Visual Aid

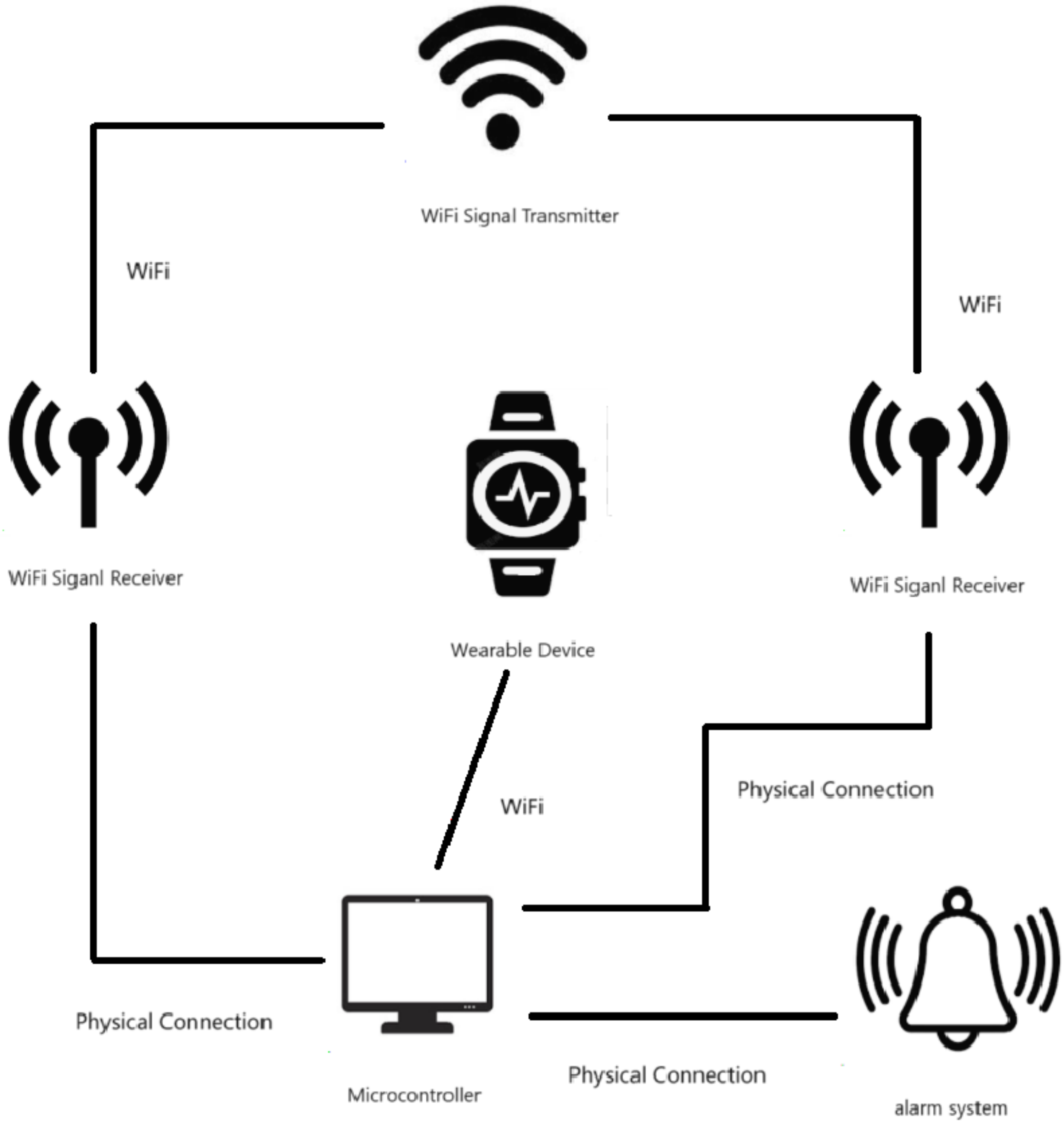

Figure 1: Visual Aid

1.4 High-level Requirements Lists

- For the recognition of the action of falling, the correct rate should be more than 90%, the probability of false alarms should be maintained at less than 20%, and the probability of miss should be maintained at least at less than 5% and 0 miss should be the target.
- The complete system should be able to operate in a 50 square meter scenario and maintain above recognition accuracy. Real-time signal monitoring should be maintained within this area
- The system alarm should be triggered within 500ms after the falling action.

2 Design

2.1 Block Diagram

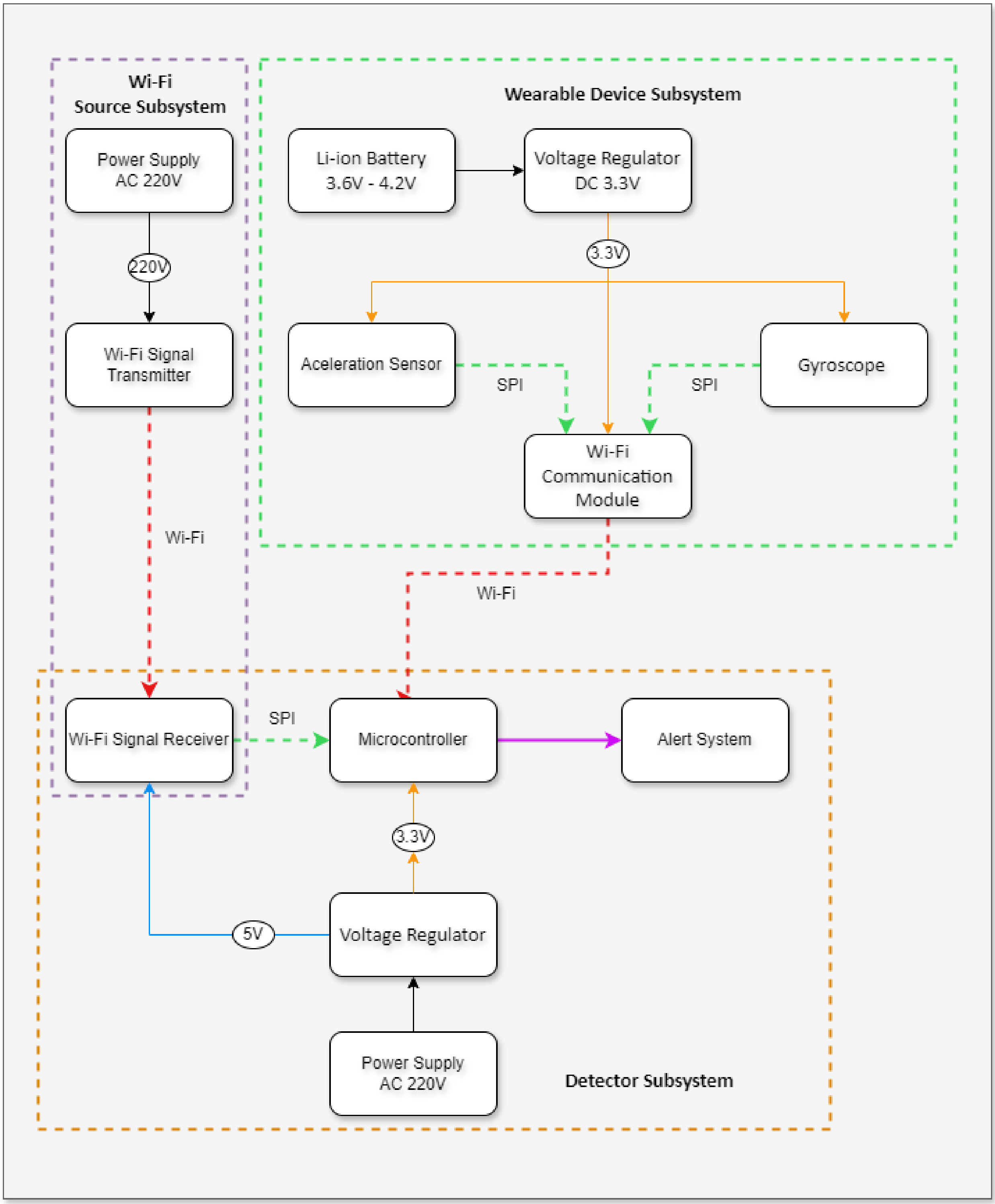

Figure 2: Block Diagram

2.2 Subsystem Overview

The Wi-Fi Source Subsystem will be a high-performance Wi-Fi router capable of dual-band signaling (2.4GHz and 5GHz), providing extensive coverage and penetration through various obstacles commonly found in residential settings. It should be capable of sustaining multiple device connections simultaneously without degradation of service quality. The router will have high-gain antennas to ensure the signal's strength is maintained even at the edges of the coverage area. The Wi-Fi signal will be received by the Detector Subsystem and used to determine the current movement of the tester.

The Wearable Device Subsystem is designed to collect acceleration as well as angle information while being worn on the tester's wrist and send it to the software processing section. The subsystem needs to consist of at least one acceleration sensor module and one gyroscope module to collect enough information. The information is sent to the software processing section via a transmission module. The entire subsystem should be powered by a separate power supply module that can provide 3-5V voltage. Similarly, the acceleration and angular data collected by the sensors in three dimensions will be received by the Detector Subsystem and used to determine the current movement of the tester.

The Detector Subsystem is a standalone module with its own dedicated casing, designed to be lightweight and compact, potentially the size of a small router or a large smartphone to be placed within the living space of the elderly person. It requires a stable power source, typically 5V supplied via a USB connection or wall adapter, and must have an internal voltage regulator to provide a clean 3.3V power supply for its internal electronics, with at least 500mA current capacity to support its operation.

The core of this subsystem is a high-performance microcontroller or a microprocessor with a fast clock speed, sufficient to process data from both the wearable sensors and the Wi-Fi signal strength information. It should possess robust communication interfaces like SPI and I2C to interface with the Wi-Fi module and possibly additional UART interfaces for debugging and future expansions.

The Wi-Fi module should be capable of operating in dual-band (2.4GHz and 5GHz) to ensure comprehensive coverage and the ability to analyze signal strength with a high degree of accuracy. The SPI or UART interface with the microcontroller must support high data rate transfer to prevent any data bottleneck.

Moreover, the Detector Subsystem should feature onboard memory (RAM and flash) to log events and store the necessary analysis algorithms, ensuring that a transient loss in connectivity does not result in data loss. The received Wi-Fi signal and sensor data will be used in this sub-system to determine the tester's movements and cross validate for improved accuracy.

2.3 Wi-Fi Source Subsystem Requirement

2.3.1 Power Supply Module

Common Wi-Fi signal transmitters use 220V AC for power supply. A backup battery power supply should be available for emergencies.

Requirement: Should operate on a standard 220V supply with a built-in uninterrupted power supply (UPS) system to ensure that the Wi-Fi signal is maintained even during power outages, with a battery life capable of running for at least four hours autonomously.

2.3.2 Wi-Fi Signal Transmitter Module

The Wi-Fi signal transmitter should be capable of continuously transmitting a substantially blind Wi-Fi signal that covers at least the normal area of the usage scenario to ensure monitoring accuracy. The signal is received by the Wi-Fi signal receiver and transmitted to the detector subsystem for processing.

Requirement:

- Must support the latest Wi-Fi standards (at least IEEE 802.11ac or better) to ensure compatibility with the Detector Subsystem. It should feature advanced MIMO (Multiple Input Multiple Output) technology to maximize throughput and signal fidelity.
- Must have a range that covers at least 150 square meters with the ability to penetrate through walls and floors, ensuring no dead zones within the home.
- Prioritize the Detector Subsystem's data traffic, ensuring the fall detection and alerting algorithms receive real-time data without delay.

2.4 Wearable Device Subsystem Requirement

2.4.1 Acceleration Sensor Module

The acceleration sensor module measures the acceleration values in three dimensions and transmits them to the data transmission module via I2C or SPI.

Requirement: The measuring range of the acceleration sensor should be at least ±2g with an acceptable margin of error, taking into account the actual situation.

2.4.2 Gyroscope Module

The gyroscope module measures the angular velocity in three dimensions and transmits the data to the data transmission module via I2C or SPI.

Requirement: Considering the actual situation, not less than ±360°/sec should be a reasonable range requirement and should have an acceptable range of error.

2.4.3 Power Module

The power supply module should provide the right voltage for the acceleration module, the gyroscope module and the transmission module.

Requirement: The power supply module should provide a voltage of 3.3V with a fluctuation of ±5% and a current of no more than 10mA to meet the supply voltage and energy consumption of other modules.

2.4.4 Wi-Fi Communication Module

The data transfer module receives the data collected by the acceleration sensor and gyroscope via I2C or SPI and sends it in real time to the software processing subsystem on the PC in range.

Requirement: it should at least support the standard IEEE 802.11b/g/n Wi-Fi protocol, and is able to connect with the wireless network. In addition, it should have low enough power consumption to take on real-time data transmission.

2.5 Detector Subsystem Requirement

2.5.1 Power Module

This module will provide a stable power supply to the receiver and processor modules and minimise power consumption

Requirement: It requires a stable power source, typically 5V supplied via a USB connection or wall adapter, and must have an internal voltage regulator to provide a clean 3.3V power supply for its internal electronics, with at least 500mA current capacity to support its operation.

2.5.2 Wi-Fi Signal Receiver Module

This module will be used to receive the Wi-Fi signals emitted by the Wi-Fi Source subsystem and transmit them to the processor.

Requirement: The module should support IEEE 802.11ac or better to detect dual-band Wi-Fi signals and must interface with the microcontroller via a high-speed SPI or UART connection.

2.5.3 Microcontroller

This module receives data from the Wi-Fi Source subsystem and the wearable device subsystem via SPI and Wi-Fi and performs data processing such as noise cancellation. The processed data is then used by algorithms to recognize the current movements of the tester and send commands to the alarm system as appropriate.

Requirement:

- The microcontroller must have high computational capabilities, like an ARM Cortex-A series, to handle real-time analysis of data streams from both the Wi-Fi and wearable sensor module.
- Real-time processing of sensor data from the wearable unit and Wi-Fi signal with the capacity to run complex algorithms for detecting patterns that indicate a fall.
- Must include at least 1GB of RAM for effective multitasking and 4GB of flash memory for robust data logging and algorithm storage.
- Should be housed in a non-obtrusive, sturdy enclosure that can be mounted on a wall or placed on a shelf, with dimensions not exceeding 20x10x5 cm.
- The fall detection algorithm must execute within a maximum processing time of 500 milliseconds from data reception to sending an alert.

2.5.4 Alert System

This module is a mobile phone or computer program that receives data sent from the microcontroller. It sends alerts if the tester is judged to have fallen.

Requirement: This modules should provide clear, quantifiable interfaces for power inputs, sensor data inputs, and alarm outputs, with redundancy to ensure reliability. In addition, the module should be able to receive and display real-time data from multiple testers simultaneously

2.6 Tolerance Analysis

2.6.1 Wi-Fi Source Subsystem Analysis

The subsystem must sustain a consistent signal strength with a variance not exceeding ±2 dBm to ensure the Detector Subsystem can accurately assess Wi-Fi signal strength. It should also feature adaptive channel selection to avoid congestion and interference with other household devices, maintaining a signal-to-noise ratio (SNR) above 25 dB for optimal performance.

Security measures will be tested to ensure compliance with current standards, and the UPS will undergo rigorous testing to validate its 24-hour minimum operational capacity.

As the risk of this subsystem ceasing to function due to equipment damage could result in a complete loss of the Wi-Fi signal, it was considered that this tolerance could be consolidated into the processor and alarm system to be handled centrally.

2.6.2 Wearable Device Subsystem Analysis

The accuracy of the data collected and the miniaturization and robustness of the device structure are priorities for the wearable device subsystem. Given that the errors of existing sensors are negligible compared to the magnitude of the test movements, the tolerance analysis will focus on ensuring that the wearable device minimizes the impact on daily movements when worn on the wrist. Additionally, it must remain fixed and maintain normal function during more amplified test movements. During the initial testing of the wearable, the body will be confined and secured in a closed box no larger than twice the size of a normal watch. The device is then worn by a tester in a series of larger test motions to assess its size and robustness.

2.6.3 Detector Subsystem Analysis

For the Detector Subsystem, accurate fall detection is critical and dependent on the precision and reliability of the received data. The tolerance analysis will focus on ensuring the processing latency and the integrity of the data. For instance, the subsystem must be able to handle potential data transmission errors, which can be mitigated through cyclic redundancy checks (CRC) or similar error-detection schemes.

The voltage regulation must have a tolerance of ±5%, ensuring the microcontroller and associated electronics function optimally even with fluctuations in power supply. The Wi-Fi module's sensitivity should be high enough to discern signal strength variations corresponding to different locations within the home, with a minimum detectable signal change of -3 dBm to ensure spatial resolution.

To ensure robust operation, the subsystem's design must include electromagnetic compatibility (EMC) considerations to minimize the impact of noise on the signal integrity. The EMC tests should verify that the subsystem is compliant with regulatory standards, indicating a high tolerance to potential interference.

Through rigorous testing and simulation, we can establish the operational tolerances for each component within the Detector Subsystem to ensure reliable and accurate performance in the context of elderly fall detection.

3. Ethics & Safety

Our Emergency Detection System for Elderly Care is designed with a strong commitment to ethical standards and safety, drawing guidance from the IEEE Code of Ethics and the ACM Code of Ethics. Key ethical considerations include the protection of privacy and confidentiality, as outlined in the ACM Code, and the imperative to avoid harm, a fundamental aspect of the IEEE Code.[6] We prioritize these ethical principles by implementing data encryption, anonymization, and employing system designs that minimize the risk of false alarms and missed emergencies.

Proactive measures to avoid ethical breaches include regular reviews by an ethics board, comprehensive team training on ethical conduct, and strict data protection measures. Potential safety concerns, such as device malfunction and data breaches, will be mitigated through rigorous testing, the development of clear emergency response protocols, and advanced cybersecurity measures.

Our approach ensures that the Emergency Detection System not only enhances the safety and care of the elderly in care facilities but does so with utmost respect for their dignity and privacy, embodying the principles of ethical responsibility and safety compliance.

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