ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Design Document for ECE445:

Intelligent Home Security System

Team #13

DANYU SUN

(danyu3@illinois.edu)

GE SHAO

(geshao2@2puksibd)

JIAXUAN ZHANG

(jz122@illinois.edu)

YUXIN XIE

(yuxinx7@illinois.edu)

TA: Jingzhou Li

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Abstract

As the population ages, an increasing number of the elderly cannot receive timely intervention after a fall. Delayed assistance may threaten the safety of them. Therefore, the project aims to develop an intelligent home monitoring and alert system that utilizes a mobile robot to monitor the activities of the elderly in real time. The key features of the system consists of autonomous trace, human detection, and fall motion detection. The robot carrying the whole system will adapt to various home environments to avoid ob-stacles, follow the elderly, and monitor the activities of the elderly. The system has several advantages, such as reducing response time to fall events and minimizing medical risks. Although the system is still facing risks and challenges, it will continue to update to im-plement more features, such as heart rate monitoring and voice interaction. Overall, by mixing real-time monitoring and instant alerts, the system can help the elderly receive timely intervention, which can improve their safety and quality of life.

Contents

1 Introduction

With the development of an aging society, the problem of elderly people not being able to get timely assistance after falling is becoming more common. This project aims to develop an intelligent home security system that collects environmental data through a movable robot and uses a central control unit to detect fall accidents in real time, and once a fall is detected, the system will automatically trigger an alarm to protect the safety of the elderly.

1.1 Objective and Background

1.1.1 Goals

Our goal is to monitor the activities of the elderly in real time and recognize if a fall accident occurs. Currently, many elderly people find it difficult to be recognized and get help in time after a fall, leading to serious consequences. Through intelligent recognition and tracking, we can send out an alert at the first time when a fall occurs to ensure the safety of the elderly.

1.1.2 Functions

- **Human Detection**: The system detects the presence of a human in the environment using a deep learning algorithm, distinguishing human figures from other objects.
- **Autonomous Trace**: The robot moves independently, avoiding obstacles and following the moving person.
- **Multi-Angle Vision**: The camera can rotate at different angles and collect real-time visual data.
- **Fall Detection**: The control unit distinguishes between falls and normal activities through deep learning algorithms in real time.
- **Automatic Alert System**: The system automatically triggers an LED light and speaker alarm when it detects a fall.

1.1.4 Features

- **Autonomous Mobility and Environmental Adaptation**: The robot can navigate autonomously, avoid obstacles to follow the elderly, and flexibly adjust its path ac-cording to different home layouts to ensure efficient operation.
- **Multi-angle Visualization and Data Analysis**: The robot is equipped with a rotat-able camera that collects video data from multiple angles in real time and combines it with historical data analysis to improve fall detection accuracy.
- **Intelligent Warning and Remote Notification**: The system will automatically acti-vate LED lights and speakers upon detecting a fall event, and autonomously sends a text message to an emergency contact within 5 seconds to quickly signal for help, enabling a fully automated emergency response.

1.2 High-level Requirements List

- **Remote Notification Function:** The system should be able to send SMS alerts to emergency contacts within 5 seconds to ensure timely notification. Through this rapid response mechanism, the rescue time can be greatly shortened to improve the efficiency of saving the elderly after a fall, and ensure that the rescue response is obtained in the shortest possible time, thus effectively reducing the medical risk.
- **Power Consumption Optimization:** The system should adopt an energy-saving strategy to reduce energy consumption by at least 30% by entering a low-power mode when there is no activity, in order to improve runtime and stability.
- **Adaptable Design:** The system should have a modular design that allows for the integration of additional functions, e.g. heart rate monitoring, voice interaction, in the future to adapt to different user needs.

2 Design

2.1 Block Diagram

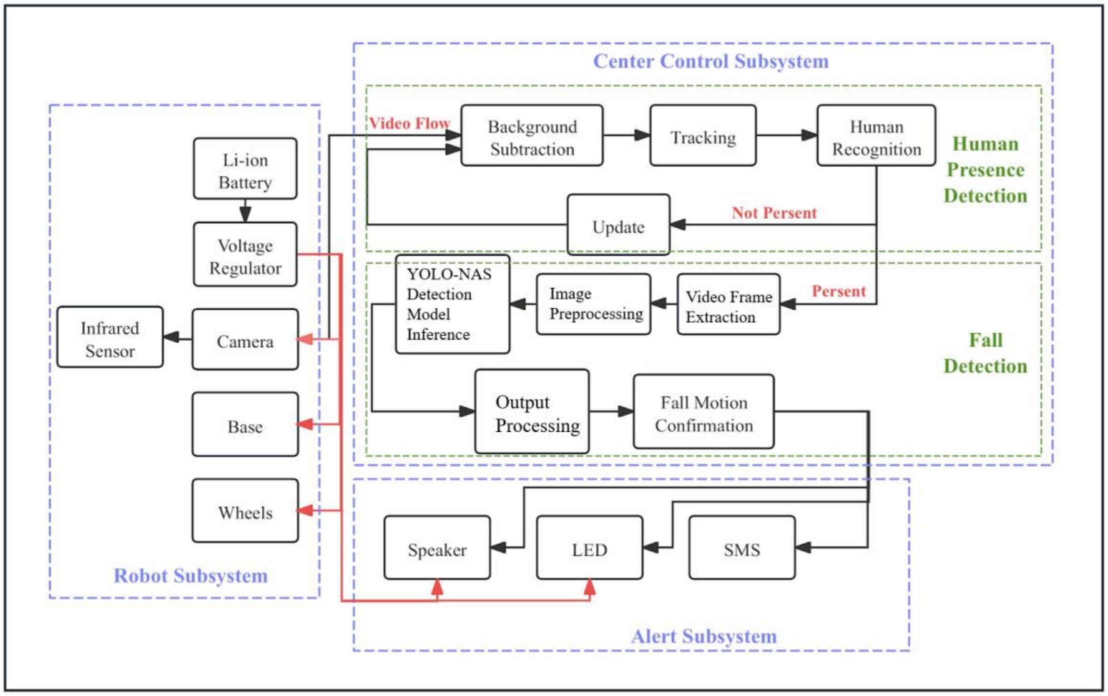

Figure 1: Block Diagram

2.2 Block Design

2.2.1 Robot Subsystem

The robot subsystem is the main hardware unit used to track and capture moving peo-ple. It includes a camera, base, wheels and infrared sensors that work together to ensure smooth and efficient system operation. The camera can rotate at least 270 degrees and can be stabilized at three preset upward angles to ensure optimal target tracking while transmitting real-time video to the center control subsystem. Below the camera is the base, which is used to keep the camera stable and is attached to wheels for smooth and flexible robot movement. Infrared sensors are mounted on the camera to detect human movement and provide real-time data to support the robot's autonomous tracking func-tion. When the sensor detects movement, the wheels reorient and the camera rotates to maintain focus and capture visual data.

- Requirement 1: Low-latency video transmission: The camera must deliver video with minimal delay to ensure real-time tracking of moving subjects.
- Requirement 2: The infrared sensor must accurately detect human movement to ensure that the robot can effectively follow the target within a set range.
- Verification 1: Record a person's movement and measure delay from real motion to control display using timestamp logging. Ensure delay is <200ms.
- Verification 2: Place a person at 1m, 3m, 5m and 45°, 90° angles. Confirm the sensor accurately detects motion with >90% reliability.

2.2.2 Center Control Subsystem

Human Presence Detection [1] The human presence detection system processes video input from the robot's camera to identify and track human presence. It uses background subtraction, tracking, and human recognition to determine if a person is present in the scene. If a person is detected, the system sends a signal to the fall detection algorithm for further analysis.

- Requirement 1: The system must process video input in real-time with a latency of less than 200ms.
- Requirement 2: The tracking and recognition accuracy must exceed 90% under normal lighting conditions.
- Verification 1: Input live video and log timestamps at entry and detection. Confirm system latency is consistently <200ms.
- Verification 2: Test with 50+ human samples under indoor lighting. Compare results to ground truth and verify recognition accuracy >90%.

Fall Detection The fall detection module is capable of accurately recognizing fall events when the presence of a person is detected. The module is based on a deep learning human target detection framework, and adopts a pre-trained YOLO-NAS model fine-tuned for fall scenarios to realize real-time analysis of the state of a person in a video stream. The system contains a series of algorithmic processes such as video frame preprocessing, multi-scale feature extraction, path aggregation feature fusion and bounding box classification for pinpointing and determining fall events[2]. Once the model detects a fall with high confidence, the alarm subsystem is triggered immediately to ensure a fast response.

- Requirement 1: Human motion update rate≤200ms/frame to ensure real-time.
- Requirement 2: Pose Correction≥ 90%accuracy of human key point detection under normal lighting conditions.

- Requirement 3: Processing time from detection to fall confirmation ≤ 5s to ensure system response speed.
- Verification 1: Simulate falls with real actors. Log frame update intervals and verify ≤200ms.
- Verification 2: Compare pose output with labeled joint data. Ensure ≥90% keypoint accuracy.
- Verification 3: Measure time from fall onset to system alert. Confirm ≤5s for 95% of cases.

2.2.3 Alert Subsystem

The Alert subsystem is responsible for triggering alarms in a timely manner after a fall of people has been detected. This subsystem consists of a LED light, a speaker and an SMS notification.

LED The LED component is used to provide visual cues for fall detection. When the control unit recognizes that a person has fallen, the LED illuminates and provides a visible alert to those in the surrounding area.

- Requirement 1: The LED must be bright enough to be clearly visible within at least 5 m under normal indoor conditions.
- Requirement 2: Once the system receives a signal that someone has fallen, the LED must be activated and lit within 1s.
- Verification 1: Trigger fall and observe LED from 5m indoors. Confirm visibility by three testers.
- Verification 2: Use stopwatch to time delay between signal and light; confirm <1s.

Speaker The speaker is used to provide audible alerts. When the system receives a signal that someone has fallen from the Control Unit, the speaker will sound an alarm to alert the surrounding people to pay attention.

- Requirement 1: The Speaker must be able to emit 80 dB or more so that people in different rooms can hear it.
- Requirement 2: The speaker must sound an alarm within 1 second of receiving a triggering signal and continue to ring for more than 10 seconds.
- Verification 1: Trigger speaker and measure output using decibel meter from 3m away. Confirm ≥80dB.
- Verification 2: Use stopwatch to ensure sound starts <1s after signal and continues >10s.

SMS The SMS component needs to send a cell phone text message to preset contacts after receiving the triggering signal.

• Requirement 1: The SMS must be sent to the preset emergency contacts within 5 seconds of receiving the trigger signal.

• Requirement 2: The SMS should contain essential details about the incident of falling, such as the time and location.

• Verification 1: Trigger fall event and time SMS delivery to a preset phone. Confirm receipt in <5s.

• Verification 2: Check message content includes timestamp and preset location; verify against system log.

2.2.4 Flowchart

The system is based on the camera real-time video stream for continuous monitoring. The core logic of the flow chart includes: data acquisition, human presence detection, robot tracking and fall detection. Once a fall event is detected, the system immediately triggers the alarm subsystem to quickly issue an alarm. The following is a flowchart of the whole system：

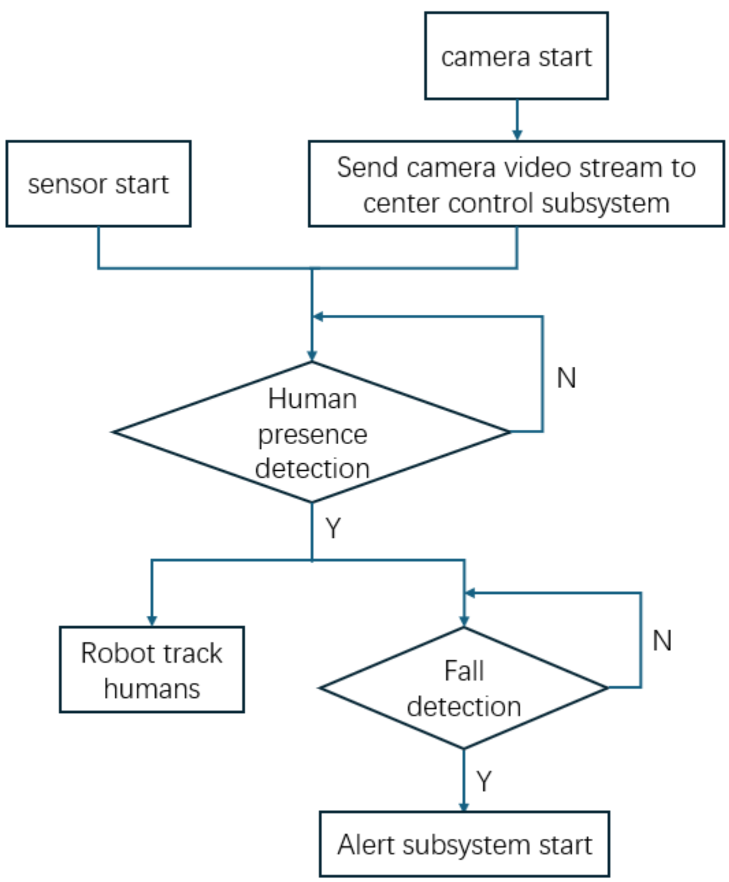

Figure 2: Flowchart

2.2.5 Calculations and Simulation

The following key calculations and simulations were performed to ensure that the system performs in real-time and accuracy:

Power system power consumption calculation

• Battery output power:

The theoretical maximum power of the 24V 5000mAh lithium battery is:

P = V x I = 24V x 5A = 120W.

It is expected to provide about 4-5 hours of continuous operation for the system.

• Estimated power consumption distribution of each module:

Drive motor: about 30W × 2

Camera: about 3W

Controller and sensor: about 5W

Total power consumption: about 70W (average)

Estimation of fall detection processing delay

• Single frame image (1920x1080, 30 FPS) processing flow:

Video frame extraction: approx. 30 ms

Image preprocessing: approx. 30 ms

YOLO-NAS-L model inference: about 80 ms

Output processing: approx. 20 ms

Total: ~160 ms, meeting real-time requirements (<200 ms)

ADC Resolution Estimation

If an external accelerometer and other sensors are used to assist in fall judgment, the sampling accuracy is:

10-bit ADC, 3.3V input: 3.3V/2^10 = 3.22mV.

Sufficient resolution for subtle motion changes.

2.3 Tolerance Analysis

In order to ensure high accuracy of fall detection, the system should ensure that the following key parameters are within a reasonable range:

- **Image clarity**: Camera resolution is not less than 1080p (1920×1080), ensuring that the human body contours can be clearly captured.
- **Minimum Light Requirement**: Support low light mode (≥ 0.1 lux), basic identification can still be performed in a low light environment.
- **Frame Rate Requirement**: The minimum frame rate requirement is ≥ 30 FPS to avoid the influence of motion blur on the detection results.
- **False Positive Rate**: Less than 5%, i.e., no more than 5 times per 100 detections, to avoid frequent false alarms.
- **False Negative Rate**: Less than 2% to ensure that most real fall events can be successfully detected.

3 Cost Analysis

Parts	Description	Price(RMB)	Quantity	Total
Camera Gimbal Kit	USB 2-DOF servo gimbal	150	1	150
Voice Playback Module	Speaker with audio output	10	1	10
PIR Motion Sensor Module	IR sensor, PH2.0, UNO compatible	20	2	40
Servo Driver Board	Multi-channel, STM32/Arduino compatible	100	1	100
4WD Car Chassis Kit	Aluminum base with 4 motors & wheels	20	1	20
RGB LED Ring Module	Full-color LED, UNO/STM32 compatible	10	1	10

4 Schedule

Week	Tasks	Member
4/14	Complete the material procurement	Jiaxuan Zhang
	Assemble the robot	Yuxin Xie
	Design and test circuit (LED, alarm)	Danyu Sun
	Process videos sent from robot to control system	Ge Shao
4/21	Test the system's ability to send alerts in case of a fall	Danyu Sun
	Optimize structural design and layout	Yuxin and Jiaxuan
	Basic integration testing	All
4/28	Run detailed fall detection experiments	All
	Improve the algorithms	Danyu and Ge
	Finalize the debugging on robot structures	Jiaxuan and Yuxin
	Prepare final documentation draft	All
5/5	Finalize report and presentation materials	All
	Deliver presentation	All

5 Ethics and Safety

5.1 Ethics [3]

5.1.1 Concern about Privacy

Our project involves the development of fall detection algorithms, which require video data for training and testing. However, the collection and use of human activity data have concerns about privacy, as improperly handling sensitive footage could expose in-dividuals to potential misuse of their personal information. To ensure the privacy of individuals, we will use publicly available datasets of fall detection videos for training and testing our recognition algorithms. No personally identifiable or sensitive data will be collected, stored, or utilized in our research.

5.1.2 Concern about Public Understanding

Intelligent systems, especially those related to health and safety, can significantly impact individuals and society. However, a lack of clear understanding of such technologies may lead to misinformation, misuse, or even distrust in automation. To avoid these risks, we will ensure that our system's design principles and usage instructions are presented in an accessible way. We will also provide comprehensive explanations of its capabilities, limitations, and potential risks to help users have a full understanding of our intelligent system.

5.1.3 Concern about Integrity and Accountability

Developing a reliable and accurate fall detection system requires rigorous validation and continuous improvement. Inaccurate claims, unverified results, or failure to acknowledge errors can lead to unsafe applications or reduce trust in our work. Therefore, throughout the project, we will adhere to principles of honesty, transparency, and continuous im-provement. We will actively seek, accept, and provide constructive feedback on technical work, acknowledge and rectify errors, and ensure that our claims and estimates are based on accurate and reliable data. Furthermore, we will give due credit to all contributors to maintain fairness and academic integrity.

5.1.4 Concern about Testing Safety

Prototype testing, especially in a project involving fall detection, carries risks of injury if not conducted properly. Involving participants without adequate precautions could lead to accidents or ethical concerns regarding informed consent. Therefore, to minimize risks, we will serve as the primary test subjects ourselves, as we have the expertise to manage potential hazards. We will not involve individuals outside our team unless proper safety measures and risk assessments are in place.

5.2 Safety

This section discusses the safety issues related to the Intelligent Home Security System, including electrical safety, mechanical safety, battery safety and laboratory safety, and proposes corresponding risk prevention measures.

5.2.1 Electrical Safety

The robotic subsystems, alarm system and central control system of our Intelligent Home Security System project involve electronic components and power management, so elec-trical safety is crucial. In order to avoid short circuit, overload, leakage and other prob-lems that may affect the normal operation of the system, we will take the following safety measures:

Circuit protection

- Overcurrent protection (e.g. PTC fuse) is used to prevent the circuit from being damaged due to short circuit or overload.
- Add thermal protection and current limiting circuits to all high-power components (e.g. motor drivers, power conversion modules).
- Adopt insulating coating and shielding for critical circuit parts to avoid the risk of electric shock caused by accidental contact.

Power Management

- Using a DC-DC converter, the MCU, camera, and sensors are powered by a DC-DC step-down module, which improves power utilization and reduces the risk of overloading the power supply. The robot uses a separate power supply from the central power supply.
- The robot is isolated from the central control unit (CCU) using a separate power supply to prevent power fluctuations from affecting the stability of the control sys-tem.

Safety design

- All terminals and power connections must be clearly labeled with voltage and polarity to prevent misconnections.
- Critical components (e.g. motor driver) housing using fireproof insulation materials to avoid the risk of fire caused by short-circuit.

- The power disconnect switch is designed in an easy-to-operate location for quick disconnection in case of emergency.

These measures ensure that the system can respond quickly in the event of short circuit, overloads, and other abnormal conditions, preventing damage to equipment and electrocution of personnel.

5.2.2 Mechanical Safety

Our robotic system involves mechanical moving parts (e.g., wheels, camera rotation mechanism, etc.), which may pose safety risks such as pinching and impact. Therefore, we take the following measures:

Physical protection

- The robot housing is designed with rounded corners and chamfered edges of at least 3 mm to avoid sharp parts from harming the user.
- The mobile components (e.g. drive wheels) are protected to prevent the user's fingers or foreign objects from entering the danger zone.

Motion safety restrictions

- The robot adopts the maximum speed limit (≤0.5m/s) to avoid accidental collision caused by high-speed movement.
- Install infrared obstacle avoidance sensors to automatically avoid obstacles when they are detected to prevent collisions.
- Add mechanical limit to the camera rotation mechanism to prevent excessive rota- tion from damaging the motor or causing cable entanglement.

Emergency stop and remote control

- The robot is equipped with a physical emergency stop button to stop all moving parts immediately in case of emergency.
- The remote console can send emergency stop commands to avoid loss of control due to software failure.

These measures effectively minimize the safety risks associated with mechanical motion and ensure safe operation of the robot in indoor environments.

5.2.3 Battery Safety [4]

This project adopts a Li-ion Battery to provide power for the robot. Although Li-ion Battery has high energy density, there may be risks of over-charging, over-discharging, short-circuiting, overheating, etc., which may lead to fire or explosion. Therefore, we take the following safety measures.

Battery Management System

- Intelligent Battery Management System (BMS) is adopted to ensure that the battery voltage, current and temperature are in the safe range.
- Over-charging protection: When the voltage exceeds 4.2V/cell, charging will be stopped automatically.
- Over-discharge protection: when the voltage is lower than 3.0V/cell, it will automatically cut off the power to avoid battery damage.
- Temperature monitoring: automatically cut off power supply if the battery temperature exceeds 60 ℃ to prevent overheating and fire.

Safe Charging Management

- Use only officially certified chargers to ensure that the charging process meets safety standards.
- When charging, the battery must be placed in a Battery Safety Bag to avoid accidental fire. Prohibit charging in extreme environments (e.g. high temperatures).
- Prohibit charging in extreme environments (e.g., temperatures above 50 ℃) to avoid battery damage or explosion.

Short Circuit and Physical Protection

- Battery polarity is clearly labeled to prevent misconnection.
- The battery case is made of high temperature resistant materials (e.g. ABS+PC flame retardant case) to reduce the risk of short circuits caused by physical damage.

These measures can effectively reduce the risk of battery explosions and fire and ensure the safety and reliability of the power system.

5.2.4 Laboratory Safety

During development and testing, we strictly observe laboratory safety regulations to prevent accidents。

Safety practices

- Perform soldering in a well-ventilated environment to avoid inhaling harmful fumes.
- Place high-temperature tools on a special stand to avoid accidental touching of burns or causing fire. Promptly disconnect the power when not in use for a long time.
- Before any high-power experiment (e.g. motor drive test), the wiring must be checked for correctness to avoid short-circuiting and damaging components.

Emergency Handling

- If a battery fire occurs, immediately use a dry powder fire extinguisher to extinguish the fire and strictly prohibit using water to extinguish the fire.
- If the robot moves unexpectedly or loses control, press the emergency stop button or disconnect the power supply immediately.

These measures will ensure the safety of the experimental environment and prevent equipment damage or personal injury.

5.2.5 Security Testing and Compliance

Our systems follow stringent safety standards to ensure reliability, compliance and user protection throughout their lifecycle. Given that our projects involve mobile robotics, AI fall detection, wireless communications and battery-powered operations, we inte-grate multiple layers of safety verification and compliance testing. The system follows IEC 61010 [5] electrical safety to ensure protection against overcurrents, short circuits and overheating, and IEC 60950 [6] to ensure that our computing hardware complies with information technology safety standards, reducing the risks associated with power fluc-tuations and overheating. For robot mobility and mechanical safety, we comply with ISO 13482 [7], and our robots are equipped with collision detection sensors and speed-limiting mechanisms to prevent accidental injury. In addition, the battery system is compliant with IEC 62133 [8], ensuring that our lithium-ion battery packs are tested for overcharge, short-circuit and thermal runaway protection.
Given that our system handles wireless data and air-driven fall detection, we ensure compliance with FCC Part 15 [9] to mitigate electromagnetic interference and ensure safe wireless operation. Additionally, our AI model follows ISO/IEC 23894 [10] to ensure reliable decision making with fall detection accuracy exceeding 80% while reducing false alarms to less than 5%. Data privacy and encryption standards are compliant with GDPR [11] and ISO/IEC 27001 [12], ensuring secure storage and transmission of sensitive user data. By integrating these industry-leading security measures and compliance standards, we ensure that our systems remain robust, safe, and ethically responsible, aligning with the IEEE Code of Ethics [3] and prioritizing the safety, health, and welfare of our users.

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