

ECE 445
SENIOR DESIGN LABORATORY
PROJECT PROPOSAL

**Project Proposal for ECE445:
Intelligent Home Security System**

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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 obstacles, 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 implement 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.

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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 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.

1.1.3 Benefits

- The system monitors elderly activities in real time and immediately triggers an alarm and SMS alerts to emergency contacts upon detecting a fall, ensuring timely assistance and reducing medical costs and risks due to delayed treatment.
- The monitoring and companionship of the robot can reduce the dependence of older people on family members and caregivers.
- The robot can adapt to different home environments, autonomously adjust its path based on different home layouts, move flexibly in various complex environments, and avoid obstacles to ensure efficient operation.

- The control unit will utilize a large amount of historical data to empirically analyze real-time videos through a multi-angle vision system.

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 according to different home layouts to ensure efficient operation.
- **Multi-angle Visualization and Data Analysis:** The robot is equipped with a rotatable 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 activate 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

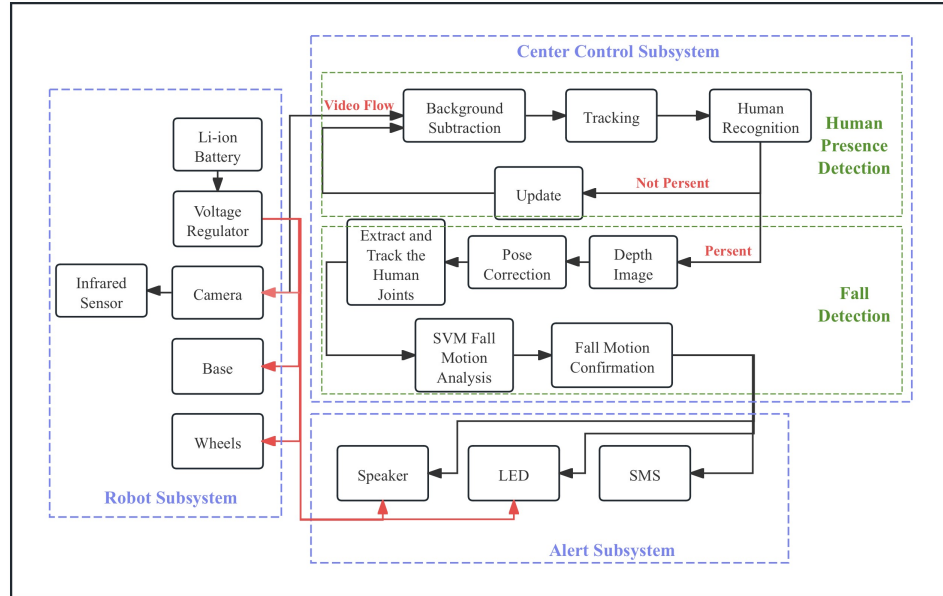


Figure 1: Block Diagram

2.2 Block Description

2.2.1 Robot Subsystem

The robot subsystem is the main hardware unit used to track and capture moving people. 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 function. 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.

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.

Fall Detection The fall detection component accurately identify fall events when a person is detected. It consists of a series of algorithmic components for video stream processing, human pose correction, human joints extracting and tracking, and Support Vector Machine (SVM) motion analysis[2], which are capable of detecting a fall and triggering an Alert Subsystem response quickly upon confirmation.

- Requirement 1: Human motion update rate $\leq 200ms/frame$ to ensure real-time.
- Requirement 2: Pose Correction $\geq 90\%$ accuracy of human key point detection under normal lighting conditions.
- Requirement 3: Processing time from detection to fall confirmation $\leq 5s$ to ensure system response speed.

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 illuminate and provide a visible alert to those in the surrounding area.
- Requirement 1: The LED must be bright enough to be clearly visible within at least $5m$ under normal indoor conditions.
- Requirement 2: Once the system receives a signal that someone has fallen, the LED must be activated and lit within $1s$.

Speaker

- The Speaker component 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.

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.

2.3 Risk Analysis

2.3.1 Risk Identification

In this system, the accuracy of fall detection is crucial. However, as the video quality captured by the camera may be affected by lighting conditions, camera resolution, motion blur, network latency, it may cause the system to misdiagnose a fall event or omit to diagnose a real fall incident.

2.3.2 Risk Justification

- **Dependence of deep learning algorithms on clear data:** This system relies on deep learning algorithms for human presence detection and fall detection, and video blurring may reduce the model's recognition ability, leading to false or missed alarms.
- **Environmental lighting changes:** Insufficient light or strong backlighting may cause the camera to fail to clearly capture human body contours, thus affecting detection accuracy.
- **Motion blur:** Elderly people may be accompanied by faster movements when falling, which may result in missing critical image information if the camera frame rate is insufficient or the anti-shake function is poor.
- **Network latency:** Since video data needs to be transmitted to the central control unit for processing, network instability may cause data loss or blurring.

2.3.3 Acceptable Tolerances

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 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.

2.3.4 Relation to High-Level Requirements

Video blurring can directly affect the accuracy of fall detection, thus reducing the overall reliability of the system. If the camera fails to clearly capture the moment of an elderly person's fall, the system may misjudge normal activity as a fall, triggering the automatic alarm system, leading to unnecessary emergency notifications; or miss the real fall, delaying rescue time and violating the high-level requirement that remote notifications must send alerts within 5 seconds. In addition, video blurring may affect data analysis of multi-angle vision and reduce the system's ability to adapt in complex environments. Therefore, ensuring camera clarity and optimizing image processing algorithms are critical to achieving the system's core functionality.

2.3.5 Mitigation Strategies

- **Optimize camera hardware:** Use wide-angle camera, add auto focus and anti-shake function to ensure picture clarity.
- **Add intelligent image augmentation algorithms:** Combine denoising and data augmentation techniques to improve the usability of low-quality videos.
- **Multi-angle data fusion:** Combine data from multiple views to reduce misjudgments caused by blurring from a single angle.

3 Ethics and Safety

3.1 Ethics[3]

3.1.1 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 individuals 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.

3.1.2 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.

3.1.3 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 improvement. 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.

3.1.4 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.

3.2 Safety

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

3.2.1 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 electrical safety is crucial. In order to avoid short circuit, overload, leakage and other problems 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 system.

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.

3.2.2 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 3mm 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 (≤ 0.5 m/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 rotation 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.

3.2.3 Battery Safety[4]

This project adopts 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 $60^{\circ}C$ 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 $50^{\circ}C$) 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.

3.2.4 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 personnel injury.

3.2.5 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 integrate 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 fluctuations 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 ai-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.

References

- [1] Y. Benezeth, H. Laurent, B. Emile, and C. Rosenberger, "Towards a sensor for detecting human presence and characterizing activity," *Energy and Buildings*, vol. 43, no. 2, pp. 305–314, 2011. DOI: 10.1016/j.enbuild.2010.09.014.
- [2] Z.-P. Bian, J. Hou, L.-P. Chau, and N. Magnenat-Thalmann, "Fall detection based on body part tracking using a depth camera," *IEEE journal of biomedical and health informatics*, vol. 19, no. 2, pp. 430–439, 2014.
- [3] IEEE. "'IEEE Code of Ethics'." (2016), [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html> (visited on 03/11/2025).
- [4] S. 2. C. Staff, *Safe practice for lead acid and lithium batteries*, Last Revised: April 13, 2016, ECE 445: Senior Design Project Laboratory, 2016. [Online]. Available: <https://courses.grainger.illinois.edu/ece445zjui/documents/GeneralBatterySafety.pdf> (visited on 03/11/2025).
- [5] *Safety requirements for electrical equipment for measurement, control, and laboratory use*, International Electrotechnical Commission, 2010.
- [6] *Information technology equipment - safety - part 1: General requirements*, International Electrotechnical Commission, 2005.
- [7] *Robots and robotic devices - safety requirements for personal care robots*, International Organization for Standardization, 2014.
- [8] *Secondary cells and batteries containing alkaline or other non-acid electrolytes - safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*, International Electrotechnical Commission, 2012.
- [9] *Code of federal regulations, title 47, part 15 - radio frequency devices*, Federal Communications Commission, 2023. [Online]. Available: <https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15>.
- [10] *Information technology - artificial intelligence - guidance on risk management*, International Organization for Standardization and International Electrotechnical Commission, 2023.
- [11] *General data protection regulation (gdpr)*, European Union, 2016. [Online]. Available: <https://eur-lex.europa.eu/eli/reg/2016/679/oj>.
- [12] *Information technology - security techniques - information security management systems - requirements*, International Organization for Standardization and International Electrotechnical Commission, 2013.