

Automatic Safety Net for Building

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Abstract—High-rise apartments provide comfort and scenic views, but they also pose potential safety hazards for children. Even a moment of carelessness can lead to serious accidents when children access balconies or lean near railings. To prevent such incidents, an Automatic Balcony Safety Net System has been developed as a precautionary safety solution. The system uses ultrasonic sensors for continuous monitoring and a camera module for accurate identification of a child has entered the balcony area. Once a child is detected, the system activates a buzzer to alert nearby adults and automatically deploys a safety net, ensuring protection before any risky action occurs. The process is controlled by an STM32 microcontroller, with remote monitoring and manual control provided through an ESP32 and MIT App-based interface. This approach emphasizes preventive safety, offering a fast, automated, and reliable safeguard for children in high-rise homes.

Index Terms—child detection, Automatic Safety Net, Fall Prevention System.

I. INTRODUCTION

In today's urban environment, families living in high-rise buildings enjoy convenience and modern living spaces, but balconies often remain a critical point of concern—especially for households with young children. Children are naturally curious and may wander onto balconies unsupervised, leading to potential dangers. Conventional safety methods like door locks, grills, or CCTV cameras offer only limited protection and may not act immediately to prevent accidents. To address this issue, our project introduces an Automatic Safety Net System designed as a preventive safety measure rather than a reactive one. The system uses ultrasonic sensors to monitor balcony

entry and a camera module to confirm whether the detected object is a child. As soon as the child is identified, a buzzer rings to alert parents or guardians, and the motor-driven safety net automatically deploys to ensure protection, even before any dangerous movement occurs. The system operates through an STM32 microcontroller, with additional remote control and monitoring enabled using ESP32 and a mobile application built in MIT App Inventor. This proactive design enhances safety in high-rise buildings by providing instant protection and peace of mind to families.

1.1 Traditional Safety Measures:

Many buildings use several basic safety methods to protect children from balcony accidents.

1. Balcony railings are the most common feature; they help prevent falls, but curious children may still try to climb over them.
2. Door and window locks are used to stop children from going out onto balconies, but these depend on parents remembering to lock them every time.
3. CCTV cameras are installed to monitor the area, but they only record what happens and cannot stop an accident in real time.
4. Safety nets or glass barriers are sometimes added for extra protection, but they can be expensive and may block airflow or sunlight.

Although these safety features help reduce the chances of accidents, they do not take immediate action when a child is in danger. They mainly depend on human attention and cannot automatically prevent a fall.

1.2 Problems with Existing Solutions:

Even with new technologies, current safety systems still face several challenges:

1. Lack of real-time prevention: Most systems, like CCTV cameras, only record incidents instead of stopping them.
2. No automatic response: There are no mechanisms to take instant action—such as opening a safety net—as soon as a child enters the balcony.
3. Dependence on human control: Safety measures like locks and barriers require constant supervision and may fail if adults forget to use them.
4. High cost and inconvenience: Some solutions, like glass barriers, can be expensive and may reduce ventilation or light.

Because of these limitations, there is a growing need for an automatic, intelligent system that can detect a child's presence and act immediately—for example, by deploying a safety net and sounding an alarm to prevent accidents before they happen.

II. METHODOLOGY

It focuses on detecting a child's presence in the balcony area and automatically deploying a safety net as a precautionary measure. The system uses both hardware and software coordination, combining STM32, ESP32, sensors, a camera module, and a motorized mechanism controlled through a microcontroller and PC-based Python detection.

2.1 COMPONENTS AND SPECIFICATIONS:

1. STM32 Microcontroller Board
 - 32-bit ARM Cortex-M3 @ 72 MHz, 64 KB Flash, 20 KB SRAM
 - Controls sensors, motor driver, and buzzer
 - Handles serial communication with PC for child detection
2. ESP32 Wi-Fi Microcontroller
 - Dual-core @ 240 MHz with built-in Wi-Fi and Bluetooth
 - Creates hotspot and connects with MIT App for remote operation
3. Ultrasonic Sensors (HC-SR04 ×2)
 - Detect movement or presence near balcony edge
 - Upper sensor monitors height level; lower sensor detects child position
4. USB to TTL Converter (HW-597)
 - Provides serial communication between PC and STM32

5. Camera (Zebronics ZEB-CRYSTAL PRO)
 - Captures live video for face detection
 - Works under normal and low-light conditions with built-in LEDs
6. Motor Driver (L298N)
 - Drives DC motor for deploying and retracting safety net
 - Controlled using PWM signals from STM32
7. DC Motor
 - 12V motor for quick net deployment (<0.5 s)
8. Buzzer
 - Alerts nearby people when a child is detected or during testing

2.2 SYSTEM OPERATION:

The system works in several stages, ensuring continuous monitoring, real-time detection, and automatic protection.

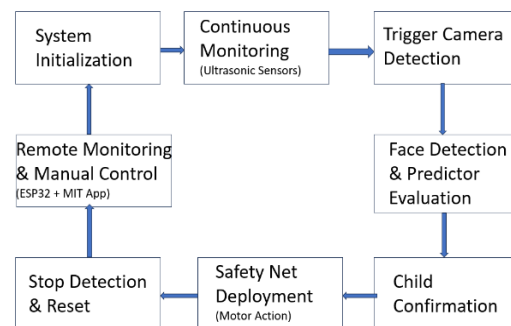


Fig.1-Methodology Block Diagram

1. System Initialization

- When powered on, the STM32 microcontroller, ESP32, ultrasonic sensors, motor driver, camera, and buzzer are all initialized.
- The ESP32 creates a Wi-Fi hotspot (Access Point) to connect with the MIT App for remote monitoring and manual control.
- The PC runs a Python program using OpenCV to initialize the face detection model and establish a serial connection with STM32.

2. Continuous Monitoring (Ultrasonic Sensors)

- The STM32 continuously reads data from two ultrasonic sensors — one placed at the upper position and another at a lower position.
- The lower sensor detects motion or objects near the balcony edge (possible child presence).

- Once the lower sensor detects an object within a set range, the STM32 prepares to trigger the camera for verification.

3. Triggering Camera Detection

- When movement is detected, the STM32 sends a command ('s') to the PC through the serial port.
- The PC activates OpenCV-based detection mode, which begins processing live video from the camera.

4. Face Detection and Prediction

- The PC captures real-time video frames using the Zebronics ZEB-CRYSTAL PRO webcam.
- The OpenCV DNN face model detects faces in each frame and calculates the bounding box size.
- If the detected face size is below a predefined threshold (indicating a small child), the system increments a counter for confirmation.

5. Child Confirmation

- When a child's face is detected consistently for a few frames (counter $\geq$ threshold value), the PC sends a command ('1') to the STM32 via serial communication.
- If no face is detected or the condition is not met, the system resets the counter and continues scanning.

6. Safety Net Deployment

- On receiving the signal ('1'), the STM32 activates the L298N motor driver module.
- The motor driver powers the DC motor, which deploys the safety net automatically in less than a second.
- At the same time, a buzzer sounds to alert parents or nearby adults about the potential risk.

7. Stop Detection and Reset

- After the net is deployed, the STM32 sends a stop signal ('t') back to the PC to disable the detection mode.
- The motor stops after completing one deployment cycle, and the system resets itself to monitoring mode, ready for the next detection.

8. Remote Monitoring and Manual Control

- The ESP32 module provides Wi-Fi connectivity for remote operation through the MIT App Inventor-based mobile application.
- Users can connect their phone to the ESP32 hotspot and send simple HTTP commands (/1 = ON, /2 = OFF) to control the relay or motor manually.
- This allows remote testing or emergency override, such as retracting the net during maintenance or deploying it manually in case of danger.

III. IMPLEMENTATION

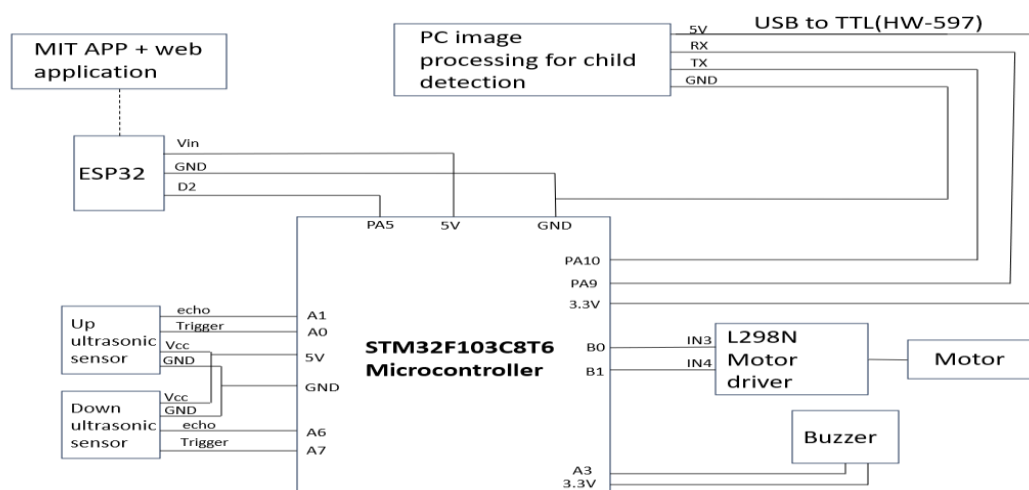


Fig. Circuit diagram

The project is built around the STM32 microcontroller, which works as the main control unit. It continuously receives input from sensors, communicates with the PC for image processing, and finally controls the motor and alarm system. Below is the detailed explanation of how each component is connected and used.

1. STM32 Microcontroller

The STM32 acts as the brain of the system. All sensors and actuators are linked to it. Two GPIO pins are assigned for ultrasonic sensors, another set of pins for the motor driver, and separate pins for the buzzer and LED indicators. A UART serial link connects the STM32 with the computer so that it can send and receive signals related to face detection.

2. Ultrasonic Sensors (Two Units)

Two ultrasonic sensors are placed vertically, one at a higher level and the other closer to the balcony base. The lower sensor detects objects near the ground, while the upper one checks for obstacles at head height. Both sensors are powered with 5V. Their trigger pins are connected to STM32 output pins, and the echo pins go to STM32 input pins (through a voltage divider to match 3.3V logic).

If the bottom sensor detects an object while the top one does not, the microcontroller assumes a child might be present and signals the computer to start camera-based verification.

3. Webcam (Zebronic ZEB-CRYSTAL PRO)

After the ultrasonic sensors indicate the possible presence of a child based on height detection, the system activates the camera module for visual verification. The Zebronic ZEB-CRYSTAL PRO webcam captures live video frames, which are then processed in Python using OpenCV's Deep Neural Network (DNN)-based face detection algorithm.

The algorithm identifies faces in each video frame and extracts their bounding box coordinates — defined by the top-left corner (x_1, y_1) and bottom-right corner (x_2, y_2). Using these coordinates, the system computes the face's width and height in pixels.

Step 1: Frame Capture

Suppose the webcam captures a frame of resolution 640×480pixels.

The DNN face detector identifies a face with bounding box coordinates:

$$(x_1, y_1) = (100, 120), (x_2, y_2) = (220, 260)$$

Hence:

$$\text{Face Width} = x_2 - x_1 = 220 - 100 = 120 \text{ pixels}$$

$$\text{Face Height} = y_2 - y_1 = 260 - 120 = 140 \text{ pixels}$$

Step 2: Age Predictor Calculation

To determine whether the detected face belongs to a child or adult, the system computes a predictor value using the following equation implemented in Python:

$$\begin{aligned} \text{age_predictor} \\ &= \text{int}(\sqrt{(\text{face_width})^2 + (\text{face_height})^2}) \end{aligned}$$

Substituting the values:

$$\begin{aligned} &= \sqrt{(120)^2 + (140)^2} = \sqrt{14400 + 19600} \\ &= \sqrt{34000} \approx 184 \text{ pixels} \end{aligned}$$

Thus, the predictor value = 184.

Step 3: Threshold Check (Child vs. Adult Classification)

The system then compares the computed predictor value with a predefined threshold determined by the parameter $\text{max_age} \times 10$.

$$\text{Threshold} = 15 \times 10 = 150$$

Based on the comparison:

- If $\text{age_predictor} < 150$, the detected face is classified as a child.
- If $\text{age_predictor} \geq 150$, the detected face is classified as an adult.

Step 4: Decision and Response

If the detected face is classified as a child, the system sends a command ('1') from the PC to the STM32 microcontroller via serial communication, initiating the safety net deployment and buzzer alert. If an adult is detected or no face meets the threshold condition, the system resets and continues monitoring. The webcam is directly connected to the computer via USB. It captures live video, which is processed in Python using OpenCV. When a face is detected, the program calculates its size to distinguish between adults and children. If a child's face is confirmed, the program sends a signal ('1') through the serial port to the STM32.

4. Motor Driver (L298N) and DC Motor

The deployment of the safety net is handled by a geared DC motor. Since the STM32 cannot supply enough current to drive the motor directly, an L298N motor driver is used. The IN1 and IN2 pins of the driver are connected to STM32 GPIO pins, while the motor terminals are connected to the OUT1 and OUT2 pins of the driver. The driver's VCC is supplied by a 12V battery, and the ground is shared with STM32. This arrangement allows the STM32 to control the

direction and activation of the motor, ensuring the net can be quickly deployed.

5. ESP32:

The ESP32 provides remote control through a simple MIT App Inventor interface. It creates a local Wi-Fi hotspot and acts as a web server. The relay module is driven by one of the ESP32 GPIO pins. The common and normally open contacts of the relay are connected in series with the motor driver's power line. This allows the motor supply to be manually switched ON or OFF from the mobile application, giving users the option to test or override the system.

6. Buzzer

For emergency indication, a buzzer is added. connected to GPIO pins of the STM32 through current-limiting resistors. Whenever the net is deployed, the microcontroller turns these indicators ON to provide audio alerts.

IV. RESULTS AND DISCUSSION



Fig. hardware of project

The proposed Automatic Safety Net System was designed and developed to protect children from falling accidents in high-rise balconies or open manholes. After implementation and testing, the system demonstrated that it could successfully detect the presence of a child, alert nearby adults, and deploy a safety net in time to prevent accidents. The integration of sensors, camera detection, and motorized action worked in a coordinated and reliable manner, making the system an effective preventive safety solution.

4.1 Height Detection Using Ultrasonic Sensors

The system uses two ultrasonic sensors positioned at different levels to monitor the height of any approaching object or person. These sensors act as the first stage of detection. The lower sensor is placed at a height that roughly matches the height of a small child, while the upper sensor is positioned higher to detect taller individuals, such as adults.

When the lower sensor detects movement within a certain range and the upper sensor does not, the system assumes that the detected object is short in height — possibly a child — and triggers the next stage of verification through the camera. However, if both sensors detect an object, it is assumed that the object is tall (likely an adult), and therefore the system does not proceed further.

It is important to note that ultrasonic sensors can only measure distance or height — they cannot distinguish whether the object is a human, animal, or non-living item. Because of this limitation, an additional layer of verification was added through camera-based detection to ensure accurate identification before any safety action is taken.

4.2 Camera-Based Child Confirmation

After the ultrasonic sensor indicates the possible presence of a child based on height, the system activates the camera for visual confirmation. The webcam, connected to the computer, begins capturing live video, which is analysed using a face detection algorithm built with OpenCV.

This camera-based stage is crucial because it ensures that the object detected by the sensor is indeed a child, not a pet, toy, or other moving object. The computer processes the live video feed, detects faces, and checks their relative size. Smaller faces that match the proportions of a child trigger the next safety response. Once the system consistently identifies a child's face across several video frames, the computer sends a signal to the STM32 microcontroller, confirming the detection. This step greatly increases accuracy and prevents unnecessary net deployment due to false triggers.

4.3 Automatic Safety Response

Upon receiving confirmation from the computer, the STM32 microcontroller initiates the safety process. The buzzer is activated first to immediately alert

nearby adults about the possible danger. At the same time, the motor driver (L298N) receives control signals to power the DC motor, which rapidly deploys the safety net.

The safety net moves from its resting vertical position to a horizontal position, creating a protective barrier that prevents the child from falling. Once the deployment is complete, the microcontroller stops the motor and resets the system for further monitoring.

The buzzer and motor worked in coordination throughout testing, responding quickly and reliably each time a confirmed child detection occurred. This ensured both safety and awareness in real time.

4.4 Remote Monitoring and Control via ESP32

The system also includes an ESP32 Wi-Fi module, which enables remote access and manual control. The ESP32 acts as a small web server, allowing users to connect their smartphones using a mobile app or a web browser.

Through this app, parents or supervisors can manually deploy or retract the safety net, check connection status, or override the system in case of maintenance. This remote feature makes the system not only automatic but also user-friendly and practical for modern homes.

The Wi-Fi communication between the ESP32 and mobile device worked smoothly, allowing users to control the system even from a distance.

4.5 System Integration and Performance

All components of the system — ultrasonic sensors, camera, microcontrollers, motor driver, and Wi-Fi module — worked together seamlessly to form a complete, intelligent safety mechanism. The workflow was structured and efficient:

1. Ultrasonic sensors first detected the height of any nearby object.
2. If the height matched that of a child, the camera was activated for confirmation.
3. The camera then verified whether the object was truly a child using face detection.
4. Once confirmed, the microcontroller activated the buzzer and motor to deploy the safety net.
5. The system automatically reset after completing the process.

This step-by-step coordination helped eliminate false detections and ensured accurate, real-time protection. The system's design balanced automation, speed, and

safety, making it a reliable solution for accident prevention.

4.6 Discussion

The results showed that combining height-based sensing with camera-based confirmation creates a much more accurate and intelligent system. The ultrasonic sensors provide a quick, simple way to detect presence based on height, while the camera ensures that the detected object is actually a child before taking any action.

This layered approach minimizes false alarms and prevents unnecessary net deployment when an adult, pet, or object passes by. The camera acts as the decision-maker, confirming the real threat before the motor and buzzer are activated.

The integration of the STM32 for control, the ESP32 for connectivity, and the OpenCV-based detection for visual confirmation made the system smart and responsive. During testing, it consistently demonstrated the ability to detect children accurately and deploy the net quickly to ensure safety.

Overall, the system proved to be a reliable, preventive safety measure — combining automation, intelligence, and practicality. It not only detects danger but also takes immediate action, providing peace of mind for families living in high-rise buildings.

V. CONCLUSION

In conclusion, the project successfully demonstrates and validates the concept of an automated balcony safety net system designed to prevent accidents involving children in high-rise buildings. The system effectively combines sensors, image detection, and motorized control to create a preventive safety mechanism rather than a reactive one. By automatically deploying a safety net the moment a child is detected through the camera, it ensures immediate protection and minimizes the risk of tragic falls.

This innovation represents a promising step toward improving child safety in modern urban environments, where balconies and open spaces pose hidden dangers. The design emphasizes quick response, reliability, and user-friendly operation through both automated control and mobile-based remote access.

With further optimization, stronger hardware integration, and advanced AI-based image

recognition, this prototype can evolve into a commercially viable product capable of saving lives and offering peace of mind to parents and guardians. Ultimately, this project highlights how technology, when applied thoughtfully, can make our living spaces safer and more secure for families everywhere.

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