Power System Technology
ISSN:1000-3673
Received: 16-11-2025 Revised: 05-12-2025 Accepted: 01-01-2026

Image Processing Based 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 Safety Net System has been developed as a precautionary safety solution. The system uses ultrasonic sensors for continuous monitoring and a camera module by using Image processing 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 micro-controller, 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.

Keywords: child detection, Automatic Safety Net, Fall Prevention System.

1. 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 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 micro-controller**, 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.

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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.

2. Objectives

The primary objective of this project is to design and develop a **fully automatic child safety system** that can effectively prevent accidental falls from balconies in high-rise buildings. With the rapid growth of urban living and increased use of high-rise residential structures, ensuring child safety has become a critical concern. Traditional safety methods often depend on constant human supervision, which may not always be possible. This project aims to overcome that limitation by introducing an intelligent and automated safety solution that functions independently and reliably.

Another important objective of the system is to **continuously monitor movement near the balcony edge using ultrasonic sensors**. These sensors play a crucial role in detecting the presence of any object or person approaching a potentially dangerous area. By providing real-time distance measurement and motion detection, ultrasonic sensors ensure that the system remains alert at all times, even when adults are not actively supervising the child. This continuous monitoring helps in identifying risky situations before an accident occurs.

To improve the accuracy and reliability of detection, the project also aims to **implement camera-based verification for child identification**. Merely detecting motion is not sufficient,

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as it may lead to false alarms caused by adults or pets. Therefore, a camera module is used to analyze the detected object and confirm whether it is a child. This verification step significantly enhances system precision by ensuring that the safety mechanism is activated only when a child is genuinely at risk.

A key objective of this project is to **automatically deploy a motorized safety net** when a child is detected near the balcony edge. Unlike conventional systems that only provide warnings, this system takes immediate preventive action. The motor-driven safety net is deployed instantly, forming a protective barrier that can prevent a fall even if the child slips or leans forward. This proactive approach transforms the system from a passive monitoring solution into an active life-saving mechanism.

Finally, the project aims to **integrate buzzer alerts and wireless mobile control using Wi-Fi technology** to enhance user convenience and system effectiveness. The buzzer provides immediate audible alerts to nearby adults, ensuring quick human response. At the same time, Wi-Fi connectivity allows parents to monitor the system remotely through a mobile application and manually control it if required. This combination of automation and remote accessibility ensures both safety and peace of mind for parents, making the system practical for real-world residential use.

3. Methods

System focuses on detecting a child's presence in the balcony area and automatically deploying a safety net as a precautionary measure. As shown in fig.3.1 The system uses both hardware and software coordination, combining STM32, ESP32, sensors, a camera module, and a motorized mechanism controlled through a micro-controller and PC-based Python detection.

3.1 COMPONENTS AND SPECIFICATIONS:

1. STM32 Microcontroller Board
   a) 32-bit ARM Cortex-M3 @ 72 MHz, 64 KB Flash, 20 KB SRAM
   b) Controls sensors, motor driver, and buzzer
   c) Handles serial communication with PC for child detection
2. ESP32 Wi-Fi Microcontroller
   a) Dual-core @ 240 MHz with built-in Wi-Fi and Bluetooth
   b) Creates hotspot and connects with MIT App for remote operation
3. Ultrasonic Sensors (HC-SR04 ×2)
   a) Detect movement or presence near balcony edge
   b) Upper sensor monitors height level; lower sensor detects child position
4. USB to TTL Converter (HW-597)
   a) Provides serial communication between PC and STM32
5. Camera (Zebronics ZEB-CRYSTAL PRO)
   a) Captures live video for face detection
   b) Works under normal and low-light conditions with built-in LEDs
6. Motor Driver (L298N)
   a) Drives DC motor for deploying and retracting safety net

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b) Controlled using PWM signals from STM32
7. DC Motor
a) 12V motor for quick net deployment.
8. Buzzer
a) Alerts nearby people when a child is detected or during testing

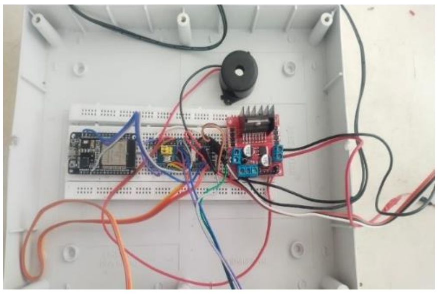

Fig.3.1 Connections of Components

3.2 SYSTEM OPERATION:

As shown in fig3.2 the system works in several stages, ensuring continuous monitoring, real-time detection, and automatic protection.

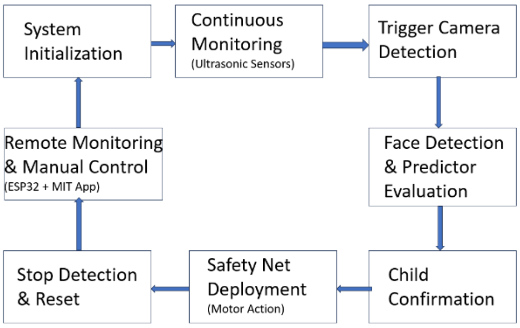

Fig.3.2-Methodology Block Diagram

1. System Initialization

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

2. Continuous Monitoring (Ultrasonic Sensors)

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

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

3. Triggering Camera Detection

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

4. Face Detection and Prediction

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

5. Child Confirmation

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

6. Safety Net Deployment

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

7. Stop Detection and Reset

1. After the net is deployed, the STM32 sends a stop signal (‘t’) back to the PC to disable the detection mode.
2. 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

1. The ESP32 module provides Wi-Fi connectivity for remote operation through the MIT App Inventor-based mobile application.
2. 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.

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This allows remote testing or emergency override, such as retracting the net during maintenance or deploying it manually in case of danger.

3.4 IMPLEMENTATION

As shown in fig.3.3 the project is built around the STM32 micro-controller, 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.

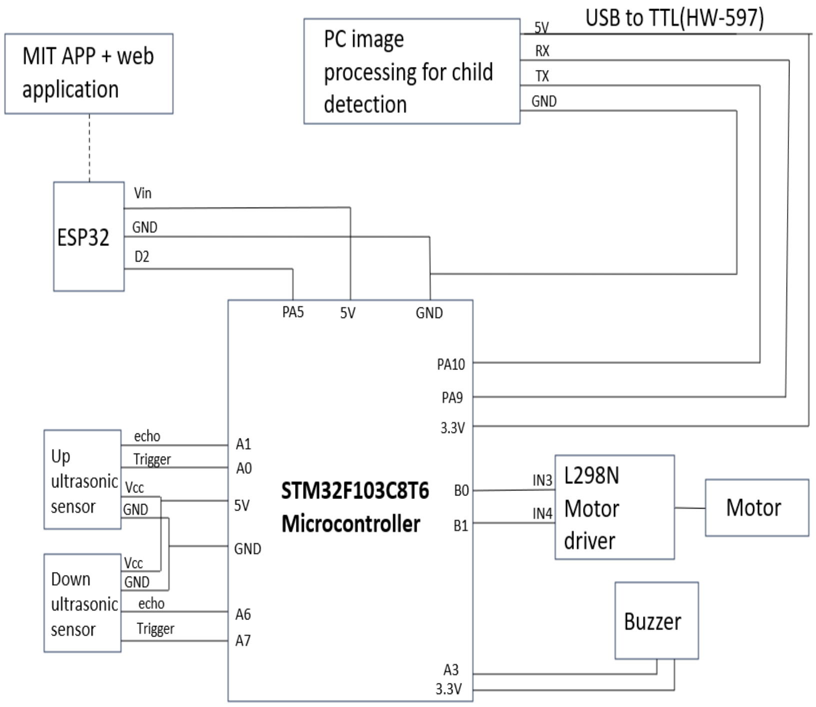

Fig.3.3 Circuit diagram

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).

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

3. 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.

4. 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.

5. 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 micro-controller turns these indicators ON to provide audio alerts.

6. Webcam (Zebronics 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 Zebronics 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.

Child detection algorithm:

The algorithm looks for faces in every video frame and marks them with a bounding box that is defined by the bottom-right corner (x_2, y_2) and top-left corner (x_1, y_1). The system uses these coordinates to calculate the face's height and width in pixels, which aids in determining whether the detected individual is most likely an adult or a child.

Step 1: Frame Capture

Suppose the webcam captures a frame of resolution

As shown in fog.3.4 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.

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Fig. 3.4 Analysis of Pixel value

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:

$\text{age\_predictor} = \text{int}(\sqrt{(\text{face\_width})^2 + (\text{face\_height})^2})$ Substituting the values:

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

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 max_age × 10.

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

Based on the comparison:

- If age_predictor < 150, the detected face is classified as a child.

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- If age_predictor ≥ 150, the detected face is classified as an adult.

Step 4: Decision and Response

As shown in fig.3.5, if the detected face is classified as a child, the system sends a command ('1') from the PC to the STM32 micro-controller 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.

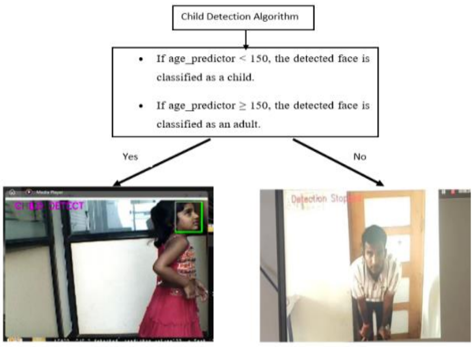

Fig. 3.5 child detection algorithm

4. Results

As shown in fig. 4.1, 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.

Fig.4.1 implementation of hardware of project

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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 analyzed 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 micro-controller, 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 micro-controller 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.

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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

As shown in table 4.1, All components of the system — ultrasonic sensors, camera, micro-controllers, 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 micro-controller 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 detection's and ensured accurate, real-time protection. The system's design balanced automation, speed, and safety, making it a reliable solution for accident prevention.

Sr. No.	Test Activity	Expected Output	Actual Output	Result
1	Child detection using OpenCV	System should detect a child within 3 meters and classify correctly	Child detected successfully with bounding box < 200 pixels	**Successful**
2	Adult detection	Adults should not trigger safety net	Adults detected and classified correctly (bounding box ≥ 200 pixels)	**Successful**
3	Distance measurement	Correctly estimate distance using height formula	Distance estimation accurate for 2–3 meters	**Successful**
4	UART communication (Camera → STM32)	STM32 should receive '1' for child, '0' for no child	UART signals received correctly without delay	**Successful**
5	Motor activation for net deployment	Motor should rotate forward when child detected	Motor rotated forward instantly when signal = '1'	**Successful**
6	Motor reverse operation	Motor should reverse when reset manually	Reverse function operated smoothly	**Successful**
7	Alarm (Buzzer) activation	Buzzer should sound when child is detected	High-pitch alarm activated immediately	**Successful**
8	Safety net opening speed	Net must open quickly (under 0.5 seconds)	Net deployed fast and smoothly within < 0.5 sec	**Successful**
9	Wi-Fi communication (ESP8266)	System should send mobile alert	Message sending in progress (initial tests successful)	**Partially Successful**
10	Mobile App manual control	App should turn net ON/OFF	App under development, basic switching tested	**Partially Successful**
11	Overall system integration	All modules should work together without delay	Modules worked reliably together during testing	**Successful**

Table:4.1 result table

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5. 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 Open CV-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. Future scope is - By incorporating cutting-edge technologies, the Automatic Safety Net System can be further enhanced in the future. AI and deep learning, for instance, can be used to improve child detection. With the aid of these tools, the system would be able to distinguish between safe play and risky circumstances, such as leaning over the balcony, by understanding a child's posture, movements, and behavior. It is also possible to upgrade the hardware. The system would be more resilient for extended outdoor use if it had stronger, lighter net materials and smaller, weatherproof sensors. Adding solar panels would allow the system to run on renewable energy, reducing the need for external power. A cloud-based system could be developed to store activity logs and notify parents in real time, even when they are not at home, for greater convenience. For added convenience, the system could be linked to smart home appliances like Google Home or Alexa, enabling voice control. In order to prevent unintentional falls, this technology may be applied in other locations in the future, such as open terraces, stairwells, and construction sites. These enhancements would help increase safety and safeguard children in contemporary urban settings by making the Automatic Safety Net System more intelligent, user-friendly, and appropriate for large smart buildings.

References

[1] R. Singh, A. Kumar, and S. Mehta, “Smart Home Automation System Using IoT,” International Journal of Advanced Research in Computer Science and Communication Engineering, vol. 9, no. 5, pp. 102–108, 2020.

[2] P. Sharma and M. Gupta, “IoT-Based Home Safety and Security System,” IEEE International Conference on Emerging Trends in Smart Computing and Informatics (ETSCI), pp. 235–240, 2021.

Power System Technology
ISSN:1000-3673
Received: 16-11-2025 Revised: 05-12-2025 Accepted: 01-01-2026

[3] K. Patel, R. Bansal, and V. Nair, "Intelligent Surveillance System for Residential Safety Using Raspberry Pi and OpenCV," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 11, no. 2, pp. 45–50, 2022.

[4] S. Kulkarni, D. Jadhav, and R. Deshmukh, "Smart Balcony Monitoring System Using Ultrasonic Sensors and GSM Module," International Journal of Engineering Trends and Technology (IJETT), vol. 71, no. 3, pp. 118–123, 2023.

[5] A. Mishra, P. Sinha, and R. Tiwari, "IoT-Based Building Safety System Using STM32 and ESP32 Microcontrollers," IEEE International Conference on Automation and Smart Infrastructure (ICASI), pp. 90–96, 2024.

[6] Z. Yang et al., "Falling Detection of Toddlers Based on Improved YOLOv8," MDPI Sensors Journal, vol. 24, 2024. [Online]. Available: https://www.mdpi.com/2319882

[7] S. Gujarathi, "Child Detection and Safety System Using YOLO," GitHub Repository, 2023. [Online]. Available: https://github.com/Sejalgujarathi/Child_Detection_With_YOLO

[8] "Applications of Ultrasonic Sensors: A Review," ResearchGate, 2024. [Online]. Available: https://www.researchgate.net/publication/386118233_Applications_of_Ultrasonic_Sensors_A_Review

[9] "Computer Vision and Artificial Intelligence for Child Safety Monitoring," IGI Global Book Chapter, 2023. [Online]. Available: https://www.igi-global.com/gateway/chapter/380944

[10] "Real-Time Object and Person Detection Using Deep Learning and STM32 Microcontrollers," IEEE Xplore Digital Library, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/10590288

[11] "STM32F103C8T6 Reference Manual," STMicroelectronics Official Documentation. [Online]. Available: https://www.st.com/resource/en/reference_manual/rm0008-stm32f103xx