Smart Home Locking System: A Study in Edge AI and Computer Vision

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Abstract

This paper presents the design and implementation of a smart home locking system that integrates Raspberry Pi 5 and Pi AI camera technology, utilizing advanced computer vision and machine learning techniques. The system uses object detection and classification algorithms to identify individuals and objects, enabling automated actions such as unlocking doors based on recognized faces or delivery personnel. Additionally, the system facilitates real-time monitoring by updating a central server and web application. We discuss the challenges, including image variability, data privacy, and computational constraints, and provide insights into future research opportunities aimed at enhancing system accuracy and efficiency.

Introduction

The increasing prevalence of smart home technologies has led to advancements in automated security systems. The advent of low-cost embedded computing platforms, such as the Raspberry Pi 5, coupled with the Pi AI camera, provides new opportunities for developing intelligent home security solutions. This project aims to create a smart home locking system that utilizes facial recognition and object classification to control access based on the identity of the person at the door.

By leveraging edge AI capabilities, this system performs real-time image processing locally on the Raspberry Pi, reducing latency and ensuring data privacy. The system is designed to differentiate between residents, visitors, and delivery personnel, taking specific actions based on these classifications. This paper provides an overview of the system's architecture, its implementation, and the challenges encountered during development, as well as future directions for research.

Related Work

The use of facial recognition for security purposes is a well-established area of research. Several systems have been developed that use AI for automated door access control. For example, existing smart locks often rely on biometric authentication (e.g., fingerprint, iris scan) or facial recognition to grant access. Some systems also incorporate motion detection and object classification algorithms to determine the nature of the individual or object at the door.

However, most of these systems require high computational power and cloud-based processing, which may introduce latency and raise concerns about data privacy. Some recent advancements, such as the integration of edge AI and embedded platforms like Raspberry Pi, have allowed for local processing, significantly reducing response time and increasing privacy. Our system aims to build on these

advancements by utilizing the Pi AI camera, which provides on-device image processing with minimal computational load.

My Work

The work presented here builds on previous research by integrating a low-cost, efficient edge AI system for home security. Our approach involves using the Raspberry Pi 5 as the main processing unit, along with the Pi AI camera, which employs a Sony IMX500 sensor for image capture. The core of the system is based on object detection (OD) and object classification (OC) techniques, where the system can identify faces and distinguish between different types of objects (e.g., delivery packages).

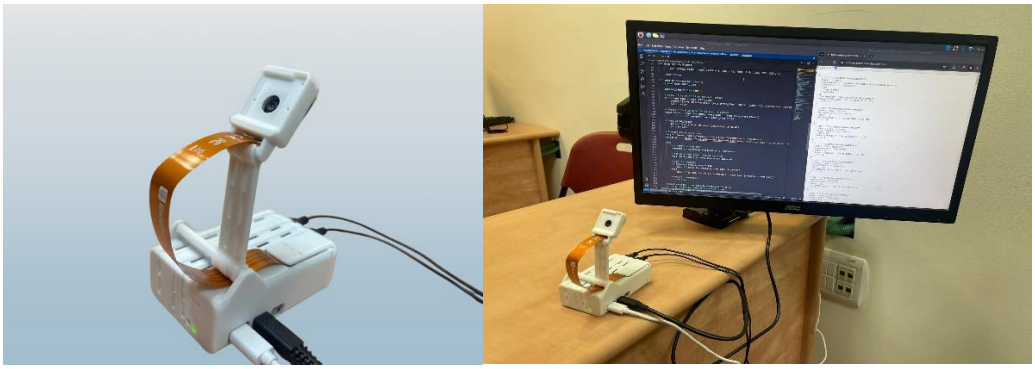
The face recognition algorithm classifies individuals as either residents, visitors, or delivery personnel, which then triggers appropriate actions, such as unlocking the door or sending notifications to the homeowner's device. The system also logs all entries and sends real-time updates to a centralized server, ensuring continuous monitoring of access to the premises.

Implementation

The implementation of the smart home locking system is carried out in several stages, involving hardware setup, software development, and algorithm training.

Hardware Setup

The system is powered by a Raspberry Pi 5, which acts as the central processing unit. The Pi AI camera, equipped with the Sony IMX500 sensor, is used to capture images of individuals at the door. The camera is connected to the Raspberry Pi, which processes the captured images for object detection and classification.



The hardware used for this research

Software Development

The system is built using Python and utilizes several libraries for image processing and machine learning, including OpenCV and TensorFlow. The facial recognition model is trained on a dataset of resident faces, while the object detection model is trained to identify common objects related to delivery personnel, such as packages or uniforms. The software also integrates with a web server, allowing real-time monitoring of entries and logging.

Algorithm Training

To improve the accuracy of the system, deep learning models were employed for both object detection and facial recognition tasks. A convolutional neural network (CNN) architecture was used for face classification, and a pre-trained object detection model was fine-tuned to detect delivery-related objects. Data augmentation techniques were used to improve the robustness of the models, allowing them to perform well under varying environmental conditions, such as different lighting and weather scenarios. The system was trained using labeled datasets, including face images and object images, to ensure high classification accuracy.

Challenges

The main challenges encountered during the implementation of the system were related to:

1. *Environmental Variability: Changes in lighting, weather, and the positioning of individuals at the door impacted the performance of the object detection and facial recognition models. To address this, various preprocessing techniques, such as histogram equalization and contrast adjustment, were employed.*
2. *Data Privacy and Security: Since the system processes biometric data (i.e., faces), data privacy concerns had to be addressed. All images captured by the camera are processed locally on the Raspberry Pi, with no data transmitted to external servers unless required for logging purposes. Furthermore, encryption protocols were implemented for the communication between the Raspberry Pi and the central server.*
3. *Computational Constraints: The Raspberry Pi, while powerful, has limited resources compared to traditional desktop computers. Optimizing the models for real-time processing was a crucial aspect of the project. Hardware acceleration and model pruning techniques were used to ensure that the system could run efficiently on the Raspberry Pi.*

System Operation

Once the system is set up and the models are trained, the Pi AI camera continuously monitors the entrance. When a person or object is detected, the system classifies the entity and determines the appropriate response. For example, if a resident is recognized, the door is unlocked automatically. If a visitor is detected, the system sends a notification to the homeowner's mobile application. In case of delivery personnel, the system logs the event and sends a package confirmation notification.

Future Research Directions

Future research could explore the following areas to further enhance the system's capabilities:

1. *Multimodal Sensor Integration: Incorporating other sensors, such as motion detectors, infrared sensors, or microphones, could improve system performance, especially in low-light or noisy environments.*
2. *Advanced Learning Models: Leveraging advanced machine learning techniques, such as transfer learning or few-shot learning, could allow the system to better handle unseen faces or new delivery objects.*
3. *Energy Efficiency: Further optimization of the system to reduce its power consumption, especially in continuous monitoring scenarios, could make the system more suitable for long-term deployment in smart homes.*
4. *User Interaction and Customization: Allowing users to configure and customize the system's behavior, such as setting thresholds for object recognition or configuring security levels based on time of day, would increase the system's adaptability to different user needs.*

Conclusion

The proposed smart home locking system offers an innovative solution to home security, integrating the latest advancements in computer vision and embedded systems. The combination of the Raspberry Pi 5 and Pi AI camera creates a cost-effective, privacy-conscious, and efficient system capable of real-time image processing. The implementation of object detection and facial recognition algorithms ensures that the system can accurately identify and differentiate between residents, visitors, and delivery personnel, making it a versatile tool for enhancing home security.

Through addressing current challenges and exploring future research directions, this system can be further refined to become an indispensable component of smart homes, contributing to the growing field of intelligent automation.