

Title of the Project

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I. INTRODUCTION

In today's rapidly evolving technological landscape, security concerns have driven the development of innovative products and systems aimed at safeguarding homes and personal spaces. While established market players like Google Nest, Arlo, Ring, and Eufy have made significant strides in home security, there exists a compelling opportunity to take these advancements even further.

The "Biometric Homeland Security System" project is motivated by the desire to offer homeowners an unparalleled level of security, convenience, and peace of mind. We recognize that the market currently boasts a range of security products, including smart doorbells and surveillance systems. However, we aim to set our project apart by introducing a cutting-edge home smart doorbell system that integrates multiple biometric and security features, including facial recognition, fingerprint recognition, voice recognition, live feed monitoring, and automatic door lock control for homeowners.

By combining these advanced features, the "Biometric Homeland Security System" is poised to redefine the standards of home security. Our project represents a significant leap forward in technology, offering homeowners a comprehensive, intelligent, and user-friendly solution that ensures their homes remain safe and secure.

II. TECHNICAL BREAKDOWN

The block diagram shows the overall logic of our system. In order to archive there logic, we are using there following technical modules:

- Face recognition based verification system (25%)
- Fingerprint reader based verification system (25%)
- AI voice assistant and voice wave based verification system (25%)

- Logic board which controls all the hardware (15%)
- Distance measuring using camera (5%)
- Graphic user interface (5%)

Our project primarily revolves around identity verification through biometric information. Face recognition and fingerprint reading stand out as pivotal modules, each carrying 25% weightage in the overall project.

AI voice assistants and voice wave verification contribute significantly, constituting 25% of the project. These components guide users through the biometric verification process, leveraging natural language interactions. The AI voice assistant plays a crucial role, facilitating seamless user experiences. Additionally, employing AI-powered audio signal comparison algorithms, we verify the user's voice as the third biometric information.

The Arduino and logic board serve as central components, controlling and interfacing all hardware elements, including the fingerprint reader, stepper motor for door locking, and three LED lights for status indication. These components are indispensable; without them, system interaction would be impossible.

We utilize distance measuring techniques through graphical processing. This involves reading frames from the webcam, detecting facial landmarks, and computing the distance between the user's head and the camera. This information aids in determining the operational mode of the system.

Graphic user interfaces (GUIs) enhance the system's usability by providing an intuitive platform for users. With GUIs, users can easily manage the biometric database without delving into the code. This functionality is pivotal for expanding the system's user base.



Module #1 Fingerprint reader based verification system(25%, Tianze Zhang):

For this module, we have following items needed in order to develop this module and their weight:

- Integration of fingerprint reader hardware: 20%
- Development of fingerprint scanning algorithm: 25%
- Implementation of user database management: 20%
- Integration with the GUI for user interaction: 20%
- Testing and debugging of the fingerprint verification system: 15%

Tianze Zhang worked on this module and spend 45 hours

Module #2 Graphic User Interface (5%, Tianze Zhang):

For this module, we have following items needed in order to develop this module and their weight:

- Designing the layout and aesthetics of the GUI: 25%
- Implementing interactive elements: 30%
- Integrating functionality with the fingerprint verification system: 20%

- Testing the GUI: 15%
- Debugging: 10%

Tianze Zhang worked on this module and spend 25 hours

Module #3 Face recognition based verification system (25% Mike Zhang)

For this module, we trained our own deep learning neural network to detect and match faces. We implemented a face recognition deep learning algorithm inspired by facenet. FaceNet employs a Convolutional Neural Network (CNN) structure to create embeddings, or numerical representations, of faces within a high-dimensional space. These embeddings are designed so that similar faces are positioned near each other in this space, facilitating tasks such as face recognition and clustering. Notably, FaceNet introduces a groundbreaking capability: the network can learn embeddings directly from raw images, eliminating the requirement for manual feature extraction. This feat is accomplished through the utilization of a triplet loss function during network training.

The following is the breakdown for this face recognition-based verification system:

- Face Detection Algorithm: 20%
- Feature Extraction Model: 25%
- Database Management: 15%
- Verification Algorithm: 20%
- Testing and Batch Regulation: 25%
- Documentation: 10%

Mike Zhang worked on this part and spend 60 hours

Module #4 Distance measurement system for pedestrian detection (5% Mike Zhang)

Cameras have to first detect if a person intends to open the door, a distance measurement system is implemented by calculating the distance between a person's eyes to determine if they are close enough to the door. In this section we implemented a distance measuring algorithm using OpenCV and various other supporting computer vision packages such as mediaPipe, and spaCy to accurately determine how far away the person is relative to the camera. Only if this test is passed, facial recognition process start. A breakdown is as follows:

- Camera Calibration: 15%
- Depth Estimation Algorithm: 30%
- Integration with Face Recognition System: 20%

- Accuracy Testing: 20%
- Optimization and Performance Tuning: 10%

Mike Zhang worked on this part and spend 48 hours

Module # 5 AI voice assistant and voice wave based verification system (Ce Zhan 25%)

We've integrated a voice recognition system to enhance security and interactivity. This system utilizes Python's SpeechRecognition library, TensorFlow, and NLTK to recognize specific voice commands or authentication phrases. When the system detects sound, it analyzes the voice wave patterns, comparing them with a pre-trained model of authorized voices using TensorFlow, and then interprets the commands or phrases with NLTK. This process, as part of a multi-factor authentication system, ensures that the door only opens for individuals who pass both visual and voice verification, thus improving security and user experience.

- Microphone calibration: 20%
- Depth estimation algorithm: 20%
- Integration with voice recognition systems: 20%
- Accuracy test: 20%
- Optimization and performance tuning: 20%

Ce Zhan worked on this part and spend 55 hours

Module #6 Logic board which controls all the hardware (Ce Zhan 15%)

Module #6, acting as the logic board within the automated door lock system, coordinates and controls the integration of a fingerprint scanner, camera, microphone, and motor. This module processes data and commands from various sensors to provide an efficient and secure door lock solution. Integrating various sensors and actuation mechanisms while ensuring system coordination and efficiency poses a significant challenge. By adopting a modular design and intelligent algorithms, the data processing flow and response mechanisms have been optimized, improving the overall performance and reliability of the system.

- Fingerprint Recognition Integration: 20%
- Visual Recognition and Monitoring: 30%
- Voice Activation Control: 20%
- Motor Drive Management: 20%
- System Optimization and Energy Efficiency: 10%

Ce Zhan worked on this part and spend 45 hours

III. PROGRESS AND RESULTS

This section starts with the module progress of each student, as follows.

Progress of Module #1 Fingerprint reader based verification system(99%, Tianze Zhang):

Summary:

We have successfully integrated the fingerprint reader hardware with our system and developed a robust fingerprint scanning algorithm. Our testing results show a high accuracy rate in fingerprint recognition.

Table:

Item	Work Hours	Percentage of Completion
Integration of fingerprint reader	9	100%
Development of fingerprint scanning algo	9	100%
Implementation of user database mgmt	9	100%
Integration with GUI	9	90%
Testing and debugging	9	95%

Learnings:

- We gained a deeper understanding of biometric authentication systems and the complexities involved in fingerprint recognition algorithms.
- Enhanced our skills in hardware integration, software development, and system testing.

Encountered Problems and Solutions:

- **Problem:** Initially, we faced compatibility issues between the fingerprint reader hardware and our system.
- **Solution:** We resolved this by updating device drivers and ensuring proper communication protocols.
- **Problem:** Some fingerprints were not recognized accurately during initial testing.

- **Solution:** We refined our algorithm by implementing advanced data processing techniques to improve recognition accuracy.

Reasons for and Weight of Uncompleted Items:

Integration with GUI (15%):

This item remains incomplete due to the complexity of integrating the GUI with the backend system. Additional time is required for thorough testing and ensuring seamless interaction between the GUI and fingerprint verification system.

Progress of Module #2 Graphic User Interface(99%, Tianze Zhang):

Summary:

We have made substantial progress in designing and implementing the GUI for our fingerprint verification system. The GUI layout and interactive elements have been developed, and initial testing has been conducted to ensure functionality.

Table:

Item	Work Hours	Percentage of Completion
Designing GUI layout and aesthetics	5	100%
Implementing interactive elements	5	100%
Integrating functionality with the system	5	95%
Testing the GUI	5	100%
Debugging	5	95%

Learnings:

- We gained valuable experience in UI/UX design principles and practices.
- Enhanced our skills in front-end development and user interaction design.
- Learned to effectively collaborate and communicate to ensure seamless integration with the fingerprint verification system.

Encountered Problems and Solutions:

- **Problem:** Difficulty in achieving the desired aesthetic appeal and user-friendly layout.
- **Solution:** We conducted extensive research on UI design trends and received feedback from stakeholders to refine the GUI design.

- **Problem:** Challenges in integrating GUI functionality with the backend fingerprint verification system.
- **Solution:** We collaborated closely with the Module #1 team to ensure compatibility and smooth interaction between the GUI and the verification system.

Reasons for and Weight of Uncompleted Items:

Integrating functionality with the system (15%):

This item remains partially complete due to the complexity of integrating GUI functionality with the backend system. For example, to register a new fingerprint ,we still need to run the hardware script instead of adding it directly via GUI. Additional time is needed to finalize the integration and conduct thorough testing to ensure seamless operation. The weight reflects the remaining effort required to achieve full integration and functionality.

Progress of Module #3 Face recognition based verification system (100% completion, Mike Zhang)

Summary:

Pose and illumination have been a long standing problem in face recognition. The result is a successful recognition of faces under various lighting and angles with a high probability of accuracy.

Table:

Item	Work Hours	Percentage of Completion
Face Detection Algorithm	12	100%
Feature Extraction Model	12	100%
Database Management	12	100%
Testing and Batch Regulation	12	100%
Documentation	12	100%

Learnings:

- Understanding and implementing deep learning algorithms for face detection and recognition
- Familiarity with computer vision techniques for feature extraction and matching.
- Database management skills for storing and retrieving facial data efficiently.
- Integration of multiple components into a cohesive system.
- Testing and evaluation methodologies for assessing system performance and accuracy.
- Proficiency in programming languages and frameworks relevant to machine learning and computer vision (e.g., Python, TensorFlow, OpenCV).

Encountered Problems and Solutions:

- **Problem:** Images captured may have low resolution, poor lighting, or occlusions, leading to inaccurate face detection and recognition.
- **Solution:** Implement image preprocessing techniques such as noise reduction, contrast enhancement, and illumination normalization to improve image quality before processing.
- **Problem:** Faces in images may exhibit different expressions and poses, making it challenging to accurately match them with reference images.
- **Solution:** Train the recognition model with a diverse dataset that includes various facial expressions, poses, and angles to enhance robustness. Augment the training data by applying transformations such as rotation, scaling, and flipping.
- **Problem:** Storing and processing facial data raises privacy and security risks, including unauthorized access or misuse.
- **Solution:** Implement robust encryption and access control mechanisms to secure stored facial data. Adhere to privacy regulations such as GDPR or HIPAA and adopt anonymization techniques to protect user identities.

Reasons for and Weight of Uncompleted Items:

All components of this section are completed on time and fully functional.

Progress of Module #4 Distance Measuring Using Camera (100% completion, Mike Zhang)

Summary:

In the end we are able to successfully and accurately determine the distance between the person and the camera. Although the processing time is the limiting factor due to hardware and language limitation, the end product passes acceptability testing and is fully functional.

Table:

Item	Work Hours	Percentage of Completion
Camera Calibration	11	100%
Depth Estimation Algorithm	11	100%
Integration with Face Recognition System	10	100%
Accuracy Testing	10	100%
Optimization and Performance Tuning	10	100%

Learnings:

- Gain proficiency in computer vision techniques, including facial landmark detection algorithms, image processing, and feature extraction methods.
- Understand geometric principles and mathematical computations involved in estimating distances from image data.
- Learn to apply machine learning algorithms for facial feature detection and distance estimation, including supervised learning techniques for training models on labeled data.
- Acquire knowledge of image preprocessing techniques such as noise reduction, edge detection, and normalization to enhance the quality of input images for distance measurement.
- Gain insights into the interdisciplinary nature of computer vision, incorporating principles from mathematics, physics, and engineering to solve real-world problems.

Encountered Problems and Solutions:

- **Problem:** The accuracy of distance measurement may be compromised due to factors such as occlusions, variations in facial expressions, and inaccuracies in facial landmark detection.
- **Solution:** Implement robust error handling mechanisms and validation checks to identify and mitigate inaccuracies. Incorporate data augmentation techniques and train models on diverse datasets to improve robustness.
- **Problem:** Depth perception based solely on 2D facial landmarks may be limited, leading to inaccuracies in distance estimation, especially for objects at varying depths.

- **Solution:** Explore additional depth sensing techniques such as stereo vision, time-of-flight (ToF) sensors, or structured light to complement facial landmark-based distance measurement and improve depth perception.
- **Problem:** Real-time processing of facial landmarks and distance estimation may require significant computational resources, limiting the system's scalability and performance.
- **Solution:** Optimize algorithms for efficiency and parallelization to reduce computational overhead. Utilize hardware acceleration techniques such as GPU computing or specialized processors to speed up processing.

Reasons for and Weight of Uncompleted Items:

All components of this section are completed on time and fully functional

Module # 5 AI voice assistant and voice wave based verification system (Ce Zhan 100%)

Summary:

We've successfully integrated an AI voice recognition system that enhances security and interactivity. This system leverages advanced technologies including the SpeechRecognition library, TensorFlow, and NLTK for accurate recognition and authentication. It operates as part of a multi-factor authentication system, enhancing security by ensuring that access is granted only to individuals verified through both visual and voice analysis.

Table:

Item	Work Hours	Percentage of Completion
Microphone Calibration	11	100%
Depth Estimation Algorithm	11	100%
Integration with Voice Recognition Systems	11	100%
Accuracy Testing	11	100%

Optimization and Performance Tuning	11	100%
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Learnings:

- Mastery in utilizing Python's SpeechRecognition library for effective voice command detection.
- Proficiency in TensorFlow for creating and training models to recognize specific voice patterns.
- Understanding of natural language processing with NLTK to interpret voice commands accurately.
- Experience in integrating voice recognition systems with other security measures for a comprehensive security solution.
- Skills in conducting thorough accuracy tests and performance optimization to enhance system reliability and efficiency.

Encountered Problems and Solutions:

Problem: Variability in voice pitch and accents resulted in recognition errors.

Solution:Enhanced the model's training with a diverse dataset including different accents and voice modulations to improve system's adaptability and accuracy.

Problem: Background noise significantly interfered with voice recognition accuracy.

Solution:Implemented advanced noise reduction algorithms and adjusted microphone sensitivity settings to minimize background noise impact.

Problem: High computation requirements for real-time voice analysis led to delays.

Solution: Optimized the algorithm for performance and conducted hardware upgrades to ensure swift processing and analysis.

Reasons for and Weight of Uncompleted Items:

All components of this section are completed on time and are fully functional, reflecting a comprehensive and effective integration of the AI voice assistant and voice wave based verification system into the security framework.

Module #6 Logic board which controls all the hardware (Ce Zhan 100%)

Summary:

Module #6 serves as the central logic board for the automated door lock system, expertly managing the integration and coordination of various components such as the fingerprint scanner, camera, microphone, and motor. This critical part of the system processes inputs from different sensors to ensure an efficient, secure door locking mechanism. The adoption of a modular design alongside intelligent algorithms has significantly optimized the data processing flow and the system's response mechanisms, leading to an enhancement in performance and reliability.

Table:

Item	Work Hours	Percentage of Completion
Fingerprint Recognition Integration	9	100%
Visual Recognition and Monitoring	13.5	100%
Voice Activation Control	9	100%
Motor Drive Management	9	100%
System Optimization and Energy Efficiency	4.5	100%

Learnings:

- Integration skills for combining hardware components like fingerprint scanners, cameras, and microphones with software logic to create a cohesive security system.
- Knowledge in developing and implementing modular designs for easy maintenance and upgradeability of the system.
- Advanced understanding of motor control mechanisms for precise actuation of the locking mechanism.
- Techniques for optimizing system performance to ensure rapid response times and high reliability.

- Strategies for enhancing energy efficiency, reducing the system's overall power consumption.

Encountered Problems and Solutions:

Problem: Difficulty in synchronizing data processing and actuation commands among various components, causing delays.

Solution: Implemented an event-driven architecture to improve the coordination and response speed of different modules within the system.

Problem: Challenges in minimizing the system's energy consumption while maintaining high performance.

Solution: Adopted low-power consumption components and optimized the software algorithms for energy efficiency without compromising system effectiveness.

Reasons for and Weight of Uncompleted Items:

All components of this section are completed on time and are fully functional. The system's design and implementation effectively address the integration challenges of the various sensors and actuators, ensuring a high-performance and efficient automated door lock solution.

Progress of the Final Project:

The project is 95% complete; the remaining tasks involve fine-tuning aspects that can enhance our project, such as integrating the GUI and fingerprint readers. However, the key features of the system, including facial recognition, voice recognition, and fingerprint scanning, have all been successfully implemented.

Video link:

<https://youtu.be/gc4aTQci1kE>

IV. CONCLUSION/SUMMARY

In this project, we have explored the intricacies of implementing various biometric information verification as a security system., focusing on both technical methods and machine learning approaches to enhance its functionality. Our efforts have been aimed at developing a robust and reliable system capable of accurately identifying users' biometric information

Throughout this project, our efforts have been focused on achieving a comprehensive understanding of the technical methods and machine learning approaches involved in implementing a biometric information verification system. By combining these methodologies, we aim to develop a sophisticated and dependable system that meets the requirements of modern security applications.

In conclusion, this project represents a significant endeavor to integrate cutting-edge technologies into the field of access control, showcasing our dedication to innovation and problem-solving. We believe that our efforts in this course demonstrate our commitment to mastering complex concepts and delivering practical solutions in the realm of technology and security.

REFERENCE/APPENDIX

Reference:

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Part and price list:

New purchase only:

Arduino Uno (\$20),
fingerprint reader (\$30),
Step motor (\$5)
LED lights(\$3)