Visual Surveillance System

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Abbreviations

HAR	- Human Activity Recognition
BT	- Bluetooth
LED	- Light Emitting Diode
DC	- Direct Current
AI	- Artificial Intelligence
STEM	- Science Technology Engineering Medicine
IoT	- Internet of Things
CNN	- Convolution neural network
LCD	- Liquid Crystal Display
AR	- Augmented Reality
OLED	- Organic Light Emitting Diode
IP	- Internet Protocol
RNN	- Recurrent Neural Network
RTC	- Real-time clock
Wi-Fi	- Wireless fidelity
SPI	- Serial peripheral interfaces
RISC	- Reduced instruction set computer
STEM	- Science Technology Engineering Medicine
RGB	- Red Green Blue
SVM	- Support Vector Machine
HoG	- Histogram of Gradient
CCTV	- Closed Circuit Television
SPU	- Sensor Processing Units
OCU	- Operator control unit
GUI	- Graphical User Interface
DL	- Deep learning
ML	- Machine learning
AI	- Artificial Intelligence
IT	- Information Technology
DARPA	- Défense Advanced Research Projects Agency

AUC	- Area under the ROC curve
VIS	- Visual Instruction Set
AT	- ATtention
GSM	- Global System for Mobile Communication
SMS	- Short Message Service
IDE	- Integrated Development Environment

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Abstract

Nowadays robberies and intruders are rare therefore it is vital to take necessary measures to protect houses and other assets hence with the aid of modern advancement in STEM, there are many equipment and tools have been introduced to serve society such as CCTVs, SMART door locks, Alarms etc. The rise of IoT-powered devices enabled remote monitoring and surveillance of valuable assets. Video surveillance systems provide the most reliable, trusted security service device and this also enables remote video monitoring to identify intruders and suspicious scenarios. These devices can be advanced with the integration of HAR systems and provide on-time action for suspicious scenarios therefore the user can protect their valuables without the aid of any other unreliable solutions such as human-invaded monitoring because humans are not always energetic since these devices will help the humans by alerting the intruders and suspicious activities.

A solution to detect intruders vital need for address this problem and DL based algorithm will provide solution to this problem with simple IoT paradigm. Wi-Fi network will communicate in between local network nodes and take necessary protective measurements while recording the video footages as evidences.

Keywords: IoT, Smart devices, Wi-Fi, Bluetooth, Camera module, real-time monitoring, embedded engineering, sensors, ESP32, Robotics

1. INTRODUCTION

A visual surveillance system is a measurement that we can take to protect vital assets these devices can be integrated with the HAR system to detect suspicious activities. Some organizations and other industrial firms use these devices to provide a high level of security service to protect their vital assets also these systems are highly reliable and cost-effective. Also, we need to focus on the device protection. Market available visual surveillance system not provide automated solutions. Also, as we know IoT and AI are modern technologies which involve in many fields to address many solutions. This study will be explored a brief intro to application of modern technologies and innovations using AI and implementation of SMART device.

There are many embedded solutions are available in the industry for many problems. Embedded system engineering is widely expanded field which focused to develop advanced solution for modern day problems. IoT is one of the branches in this area hence it is really important to learn and study about this. A specialize computer system working on dedicated function or task can identified as embedded system, this specializes computer system has own internal peripheral modules rather than external peripheral modules.

In normal surveillance system only provide the monitoring and storing the data but that might not be enough to address modern problems therefore from this study, focused to implement a visual surveillance system with intruder detection to minimize the crimes due to intruders. Intruders have various of behaviour patterns therefore we need to focus on these criteria and apply solution for this problem. As mentioned, earlier it is really important to use AI for automate this process else this might not be well fitted solution to this problem. Therefore, throughout this study focused to implement a solution for following problem.

Problem Statement.

A solution required to protect the property from intruders. Now a day's number of criminal activities are increased therefore many security challenges are needed to be overcome including terrorism, crime, social unrest. Due to the manual review and monitoring the visual data is difficult and it is time consuming, labour insensitive and prone to human error hence automated process of identifying and tracking individuals and providing real time alerts are important.

Problem Definition.

Intruders break in to the property is the problem needed to be address to protect the property and valuables including humans. Labour power is not cost effective also, not efficient and sometimes not reliable. There are many intruders could be happened due to the lack of attention and carelessness of the human. Intruders can damage your property also, threaten to your life. Therefore, it is really important to find an optimal solution to address this issue.

1. LITERATURE REVIEW

Today, robberies, burglars and crimes are among some of the most common negative things that we can hear from society. Burglary can be categorised as a property crime which is hard to solve. According to the Pew Research Center in 2022 only 12.1% of cases were solved [8] in the US. Even though from 2012 to 2021, the burglary rate decreased from 65% it was raised in 2022 with 847,577 incidents but from these incidents only 57% are residential burglaries but still these rates are still considerably high, on average 3062 burglaries happen in the US every day therefore over 1 million burglary events are recorded in most of every year in the US [8][9]. According to the [9], there is at least one incident recorded every 26 seconds and as reported by the FBI these incidents are considerably high during the daytime between 10 AM to 3 PM also, summer months have more property crime than cold seasons. These crimes are life-threatening and also damage financial properties in 2021 there were $737,294,919,165 damaged and only was $89,484,651,977 able to be recovered and which means $2692 cost per burglary. Hence these criminal activities can become more unfortunate incidents including life-threatening scenarios [8][9][10]. These criminals most of the time walk into the house from the front door and also reported that most of these are not violent 34% of them target the front door, 23% try to enter the home through the first-floor window and they can complete these burglars only within 90 seconds to 12 minutes on average [8]. Therefore, it is really important to address this problem technically too.

Locally during the period 2012 to 2020 in Sri Lanka, the crime rate decreased by 36.8% but it can be observed that the increase in the crime rate in some cities in Sri Lanka such as Kilinochichi and Mulativu. Even the percentile of house break-ins also decreased there were 4,428 residential break-ins recorded in 2023 from January to May [10] [11]. According to [10], but not just like the US Sri Lanka was able to solve 41% of crimes in 2023. According to 2020 data and statistics Nugegoda, Kelaniya, Mt.Lavinia, Ratnapura and Gampaha have the highest crime rates above 95% and these same cities are also common for house break-ins above 90% break-ins [11]. In Sri Lanka, most burglars tend to do this kind of activity due to loss of income, unbearable food and medicine costs or lack of trust in the law and it was reported that most people are drug addicts [10].

According to [12], it was mentioned home burglars straight targeted the master bedroom and it is recommended not to let intruders leave you alone or create a tempting situation otherwise it could

cause serious life-threatening injuries hence according to the literature [12][10], seeking a safe place to hide and staying quiet as possible is a good option to protect yourself from the intruders. Also, the literature [12], mentioned that it only takes ten minutes for this criminal activity to complete therefore it is really important to take security measures while protecting yourself during this time.

2.1 Why do we need a surveillance system?

According to the newest 2024 statistics and data home burglary occurs every 15 seconds in the US and locally also a considerable amount of events have occurred during the past few years [10][12]. Also, in 2020 it was able to observe a burglary rate of 1353.6 occurrences per 100,000 the highest rate around the world Chillie, Denmark and Sweden face the same issue [14] Hence this problem should not only be addressed locally it is important to address this globally is also important. This not only damages physical property but also, could lead to damage to life therefore it is really important to take the necessary steps to protect your valuables and life. As a regular protection mechanism, many people try to make valuables inaccessible to others, by inserting exterior lights, installing fences or walls, installing high-quality doors and windows with high-end locks and following the chorus to check the home security daily to protect their valuables [13]. Also, the same literature [13], suggests that joining with your neighbours for close watch is also a good habit to protect valuables but this might not be enough for this therefore it is really important to take necessary steps to mitigate these vulnerabilities with the aid of science and technology too. Home surveillance systems are another important step that we can take a step to reduce the chance of burglary there is statistically shown that in literature [8] 83% of intruders are looking for a surveillance system before break-ins hence having this kind of technology will discourage the attack and will provide valuable evidence for further investigation if the intruder happens. Another important fact is that visual surveillance systems and some other surveillance systems provide external protection to the area that is under the protection [15]. These systems protect from fire, carbon monoxide and flood [15]. Hence, it is important to install a surveillance system for our house or business place or where we need to protect.

Surveillance systems are capable of monitoring the area under protection and protecting the area or place from fire, flood, and smoke. These surveillance systems consist of cameras, smoke detectors, alarms, locks and fire extinguishers. Because of that enhancing the ability of a surveillance system is really important for human civilisation's future to protect your assets not only from the thieves also from natural disasters [15].

2.2 Smart surveillance system vs. Regular surveillance system

Many people install surveillance cameras to protect their valuables and enhance the security of their assets also, in case of crime the data from the surveillance system will provide valuable evidence for the investigation these surveillance systems will also help to ensure whether the security protocol is followed or not hence many peoples are seeking to install this kind of systems [16]. There are barriers to discouraging installing this kind of system: installation, maintenance and upgrade expenses need to be tolerated, and complexity is another problem for people who lack technological knowledge, dependence on technology is another issue that needs to be addressed, as privacy, legal and ethical issues need to be covered too [17] [16]. Another fact is that surveillance systems are not automated to detect vulnerabilities and act, most surveillance systems consist of sensors which are only can detect pre-defined threats only and respond to them because those devices do not consist of intelligence and memory [19] [18].

According to the [17], most home security systems consist of motion, sound and smoke sensors to trigger an alarm and another security system called Ring Alarm Kit capable of connecting with Amazon Echo or Alexa intelligent devices and controlling it also this device has another product for video monitoring with smart devices but need to pay extra wedge for subscriptions. There are other companies that provide DIY home security options for society in the article [18], there are devices that come to market with sensors that only need to be installed by people who have high technological literacy to make the sensors (motion and smoke) more customisable also, they can connect with other third-party devices and extend their protection. Another important fact that in the literature [18], mentioned is these devices have features to enhance connectivity ZWave, Zigbee, Wi-Fi and Bluetooth which allow them to connect with multiple devices at once and operate more reliably.

Braicov et al. [20] suggest integrating IT technologies with surveillance systems and providing intelligence and memory to make this surveillance system smarter by enabling devices to monitor with different kinds of visual modes. Not only that further this can enhance to identification the of visual motions that predict the behaviour of an intruder and also identify other vulnerabilities with the aid of other sensors [5][6]. Simply smart devices can be defined as devices which are connected to the internet and interact with users to share data and other services. These devices use IoT to

interconnect with other devices and complete the other operations [21]. Therefore, rather than regular surveillance systems these devices can provide IoT services such as real-time monitoring, integration of ML and AI models and enhanced security with different technologies [16] [21].

2.3 Previous Related Works

N. Surantha et al [1] suggest a home security system that can detect humans with the aid of Raspberry Pi 3 and Arduino. In this study, suspicious objects were detected using SVM and HoG. This methodology aims to improve CCTV monitoring by adding the advantage of capturing suspicious objects and warning of suspicious activities. Also, this study is concerned with the huge storage consumption of media storage and bandwidth and tries to minimise the disadvantages. As well as the motion detection they suggest the presence of intruders by the combination of motion detection and object recognition with the IoT system. PIR sensor is used to capture the motions and warning is done by using the alarm when the object detection detects the intruder. As the first step of object detection HoG methodology extracts the information of the image by converting the RGB image to a grayscale image then gamma normalisation will be done to calculate the result of the square root of each channel, then the gradient value of each pixel will be calculated, as the final step of normalisation process calculates the HoG feature vector. The SVM method will determine whether this image has human features or not. According to this study, this methodology takes 2 seconds to detect the intruder with an accuracy of 89%.

A review of Home Automation and surveillance by K.S. Pachpor et al [2] explained and described the usage of IoT in Home Automation and surveillance systems. This literature explained how the initial systems were used and how modern home surveillance is used with the aid of advancements in automation technologies. According to this study microcontroller-based embedded systems can be used to control most electrical tools. Wireless technologies such as Wi-Fi Zigbee were reviewed and described in this study. A set of sensory networks is used by them to investigate the behaviour and performance of the system. Also, this study mentioned the design considerations such as modularity, plug and play, robustness, Reconfigurable, security, power consumption, portability, integration etc.

The study on three-year video surveillance and monitoring (VSAM) under the DARPA explains multi-sensor battlefield surveillance [4]. This study researches tracking people, vehicles, and their interactions and "parses" them with their geo-locations by using their shape and colour. This project classified into such as humans, human groups, cars, trucks, etc. also further this classification system was able to classify the activity of the object. Another important fact

mentioned by this literature is taking the geo-locations of the labelled entities which was done by taking the image coordinates from two or more overlapping cameras [4]. This project was able to develop a system with SPUs, OCU, GUI, and VIS. Another important fact that this system is even this system was developed between 1997 and 1999 it was able to achieve milestones of better understanding of human motion, improved data logging, bootstrapping functional site models, better detection and classification of multi-agent events and activities, and better camera control [4].

The development of the IT industry advanced urban surveillance and security [3], according to the A. Braicov et al. [3] discussed the common problems that arise when developing smart surveillance systems. This study mentioned that speed, data analysis, and reliability are the most common problems. Also, implementing computer vision algorithms to detect hostile or abnormal behaviour is another issue that addressing when we are developing these systems [3].

G. Karuna et al [5] proposed a CCTV camera with intrusion detection with the aid of DL methods. The main issue addressed in this paper was high human intervention in CCTV camera monitoring to identify suspicious behaviour or potential risk and this paper proposed a solution with the OpenCV framework to automate the analysis of video footage including object detection, face recognition, and license plate recognition, therefore, their solution will increase the reliability and reduce errors in human decision making while supporting to detect anomalies. As the solution G. Karuna et al [5] proposed a smart surveillance system using OpenCV needed to detect and track objects of interest in real-time, should have a user-friendly GUI application, and recognize the faces of individuals. GUI was developed with the Python Tkinter library and the cv2 module was used for image processing, computer vision, and video analysis tasks. There are a few modules introduced as monitor, identify, Visitor detection, Recording, Noise detection, and Interface of smart surveillance. According to this study, OpenCV is a powerful library for performing computer vision applications.

Yu Tian et al. [6] proposed another method for video surveillance anomaly detection from multiple instance learning (MIL) this proposed method addresses the issues in MIL such as top anomaly not from abnormal snippets, challenges in training converges, chance of losing effective training

process, not been able to separate between normal and abnormal snippets. The RTFM (Robust Temporal Feature Magnitude) learning methodology which addresses the issues mentioned above can be solved by increasing the probability of selecting abnormal snippets, improving training convergence, allowing the inclusion of more than one abnormal snippet per video, and recognizing positive instances in video footage. MILs are capable of mitigating the issues in video footage where it addresses to problem of detecting anomalous snippets from a video labelled as abnormal by balancing the training set with the same number of abnormal and normal snippets. According to this paper, the RTFM approach can differentiate between abnormal and normal snippets using weakly labelled videos. In this study, different data sets were used to experiment with the proposed learning methodology. This model was able to obtain an AUC of 91.51% by outperforming other methodologies for the Shanghai Tech dataset, for the UCF-Crime dataset this model was also able to outperform other models with an AUC of 84.3%, the XD-violence dataset had 75.89% AUC [6].

According to the literature [7], humanoid surveillance monitoring is time-consuming and could lead to inaccurate observations also, this needs a higher level of focus and attention. Hence the study [7] by SELVAM et al. proposed surveillance monitoring using an ESP32-CAM module which can send a notification alert whenever the intrusion is detected. In this study, ESP32-CAM is used to detect the presence of human beings and detect suspicious persons. Also, addition to that this system has Arduino uno, an IR sensor, SIM900A GSM module. ESP32-CAM module and Arduino uno were programmed and connected to the network. ESP32-CAM module was programmed to send captured data to the cloud and an Arduino Uno board was used to communicate with the GSM module using AT commands. There were two main types of SMS alerts that were sent: informing intruders and fire [7].

2.4 Scientific Review

Working principle of the camera

There are two main types of cameras available: film cameras and digital cameras. The film camera has film instead of a camera sensor this film got hit by the light rays from the field of view and captured in the film as shown in the figure 2.1. In a digital camera, a camera sensor is used to capture image data and transform it into a digital format. Both cameras have lenses to amplify the light strike through the aperture.

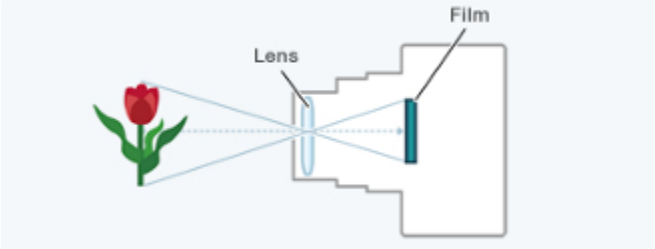

Figure 1 Film Camera

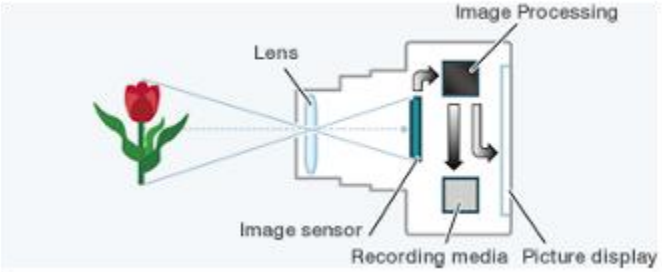

Figure 2 Digital Camera

In a digital camera image processor, recording media and a picture display are available [22]. CCD, CMOS, DGO, and SPAD are camera sensor types which have different features and qualities [23][24][25]. The main process of the digital camera sensor is called digital imaging in this step the sensor captures light from the camera lens and from this silicon-based sensor chip that data is transformed into an electrical charge using light receptors, light-sensitive material or photosites when the higher intensity light strikes the sensor the magnitude of the charge will be increased [23][24] and colour of each pixel is determined by the frequency of light wave passing through the filter [24].

CCD - An integrated grid of semiconductor capacitors used to construct these kinds of sensors and capacitors act as individual photosites for this sensor [23]. These kinds of sensors have a special manufacturing process which enables less noise in images therefore these sensors are capable of processing high-quality images even though they consume lots of power. [25] Also, CCD is capable of better low-light performance and high-speed capture [24].

CMOS - Same as the basic structure of a small microprocessor which allows an easy manufacturing process [25]. Only one single output node is used to transfer the charges in each photo site containing multiple transistors to process the charge directly at the site therefore this technology enables less power requirement and reads electrical charges at a much faster rate [23]. The disadvantage of these sensors is more susceptible to noise [25]. The full frame, APS-C and micro four-thirds are the available sensor sizes. [24]

DGO - Each photosite in the sensor is read by two amplification levels (high gain and low gain). This kind of sensor can be found in high-quality cameras. The noise of the image was reduced and maintained and accurately reproduced the information in the highlights [23].

The following figure shows the typical application of Image sensor

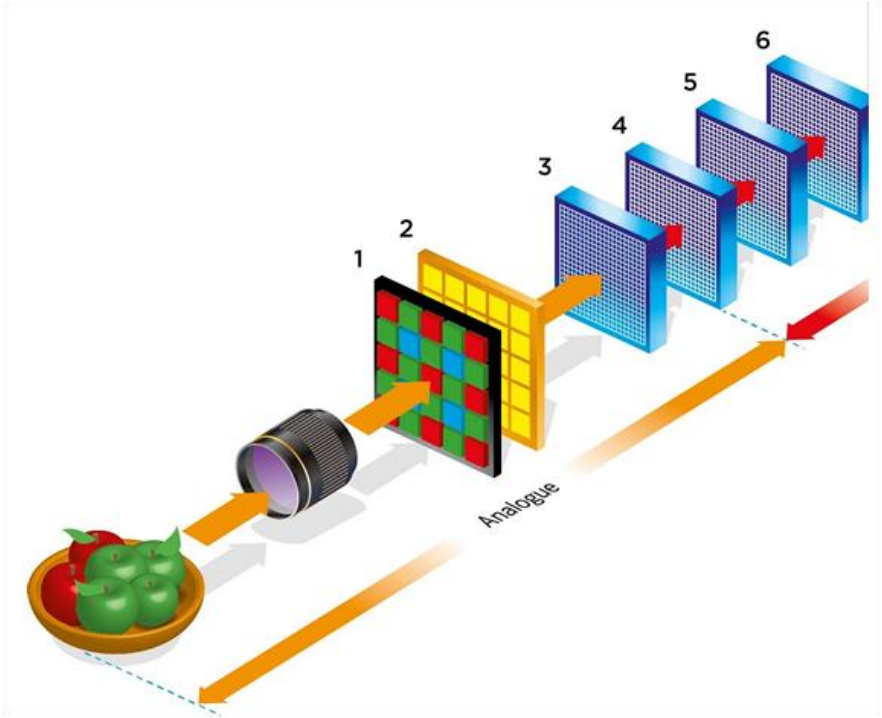

Figure 3 Image Sensor and Image Processor

Image sensor size affects the light capability, image quality depth of field and angle of view. When the image sensor is larger than increases the image resolution, and better low-light performance, and many scenes can be captured by the sensors but images can be blurred by shallowing the depth

of field hence mostly suitable for capturing portraits [24]. Full-frame sensors are mostly used in landscape, portrait, and street photography [24]. APS-C-sized sensors are used in a wide range of cameras from entry-level DSLRs to mirrorless cameras [24] [25]. A camera that specialises in travel photography uses micro four third sensors. Medium-format sensors are used in studios and commercial works [24].

Digital images are created by passing the lights through the camera lens onto the image sensor with a mosaic filter or a Bayer array this filter enables detecting the colour and light intensity. After that electrical signal generated by the sensor is amplified by analogue circuitry and then pass these data to ADC to the image processor. As the final step, a temporary buffer holds images until they are written into storage [23].

Resolution - Images have higher quality if it has higher detail levels, resolution is another factor that affects the image quality and details it. There are 1080p, 2k and 4k higher resolution cameras available which are mainly used in surveillance activities. Phone cameras have ideally 12MP to 48MP resolutions. Resolution affects image details and sharpness, print size, cropping and display size therefore it is really important to selecting a higher resolution camera is really vital.

Focal length - The distance from the lens to the image sensor. When the focal length is shorter smaller objects will appear and widen the angle of view and focal length is higher larger objects will appear to narrow the angle of view.

F-number - This number indicates the amount of light that enters from the lens. The more the aperture less the F-number and the bigger the bokeh effect. Less the aperture smaller bokeh effect.

The lenses of a camera are another important factor which allows you to shoot different scenarios. Wide-angle lens allows to shoot wider area. Telephoto lens for shooting sports and events.

Theories behind AI

AI is a technique that we used to make smart devices more intelligent by allowing them to take intelligent self-decisions. Hence, we can use these techniques to make able to computers and smart devices to mimic human behaviour. There are mainly three branches are discussing in this area. Deep learning and Machine learning are the two main clusters that taken in to account in AI [52].

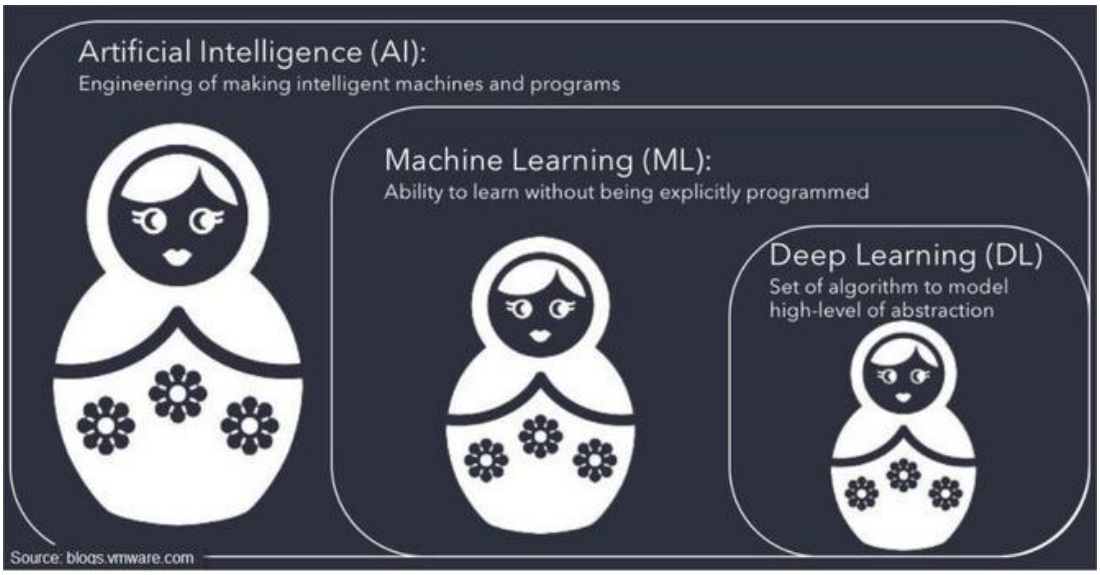

Figure 4 Matryoshka Dolls of AI

As per above figure deep learning is all about feature extraction including low-level, mid-level and high –level features. Machine learning is ability to learn by itself without aid of the any other interference [53].

Artificial intelligence (AI), particularly deep learning, has revolutionised this field, leading to significant advancements in accuracy and efficiency. Object detection is one of the AI applications we use to solve many problems. CNNs, R-CNNs, SSDs are the most popular object detection algorithms that we use in autonomous vehicles, surveillance systems, medical imaging and agriculture. Computational cost, data requirement and real-time performance are future challenges that we need to address. Therefore most of the researchers are focusing develop more efficient and accurate models while improving robustness to challenging conditions and integrating object detection with other tasks [26][27][28].

Neuron is the building block of the AI; neural network consists of artificial neuron or perceptron following figure shows the simple perceptron.

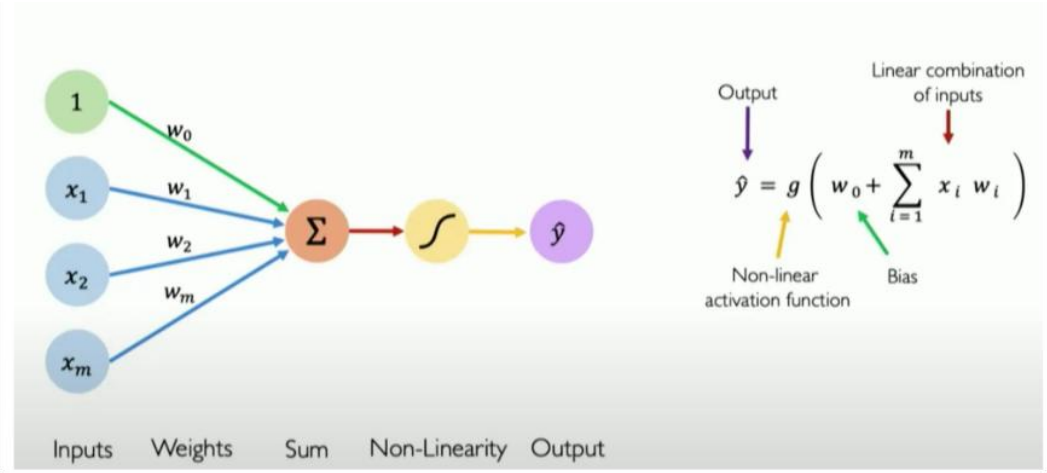

Figure 5 Perceptron

In a perceptron we multiply each input from the weight term and sum all of them then add biasing term after that multiply from the non-linear activation function. This process is to take an output for a given input data and for the different feature data (numerical) perceptron has different values called weights and then summation of these values are taken into account and then add biasing then add non-linearity by multiplying from the non-linear function else it may not be able to represent the output data to fit in to the model and also this will reduce the complexity of the data representation in the model then it allows the faster learning ability. [29]

Neural network is collection of sequential layers developed with parallel perceptron which working together to process data and information to make intelligent data and decisions. A technique called backpropagation is used to minimize the difference between expected output and network output then train the neural network. These trained networks have ability to process information and make decision accordingly.

There are mainly five types of decisions are can be made by the neural network classification, regression, clustering, anomaly, generative modelling are the decisions that can be taken by the neural network.

- Classification - Categories the possible outcomes then decide the most accurate outcome that can be obtained from the given input.
- Regression - Prediction based decisions are made from this kind of decision making a continuous value output make by the algorithm.
- Clustering - Identify the grouping within the given datasets.
- Anomaly detection - Detecting the abnormal data points.
- Generative modelling - By referencing samples generate new data sets.

Reinforcement learning, supervised learning, unsupervised learning are three main types of models that we developed in AI applications. Supervised models only directly reference into a label while un-supervised learning is learning underlying structure of a dataset and reinforcement learning are state-action pairs where focused to maximize the future rewards.

IoT

IoT is modern technique that used to monitor and control smart devices over the air using wireless techniques therefore this allows remote monitoring and controlling to users. A network of interconnected smart devices embedded with sensors, software and network connectivity with ability to exchange data called IoT. In IoT there few key components are available to consider including sensors actuators, connectivity, data processing and analysis and application. Following figures will explain the simple application of IoT [54].

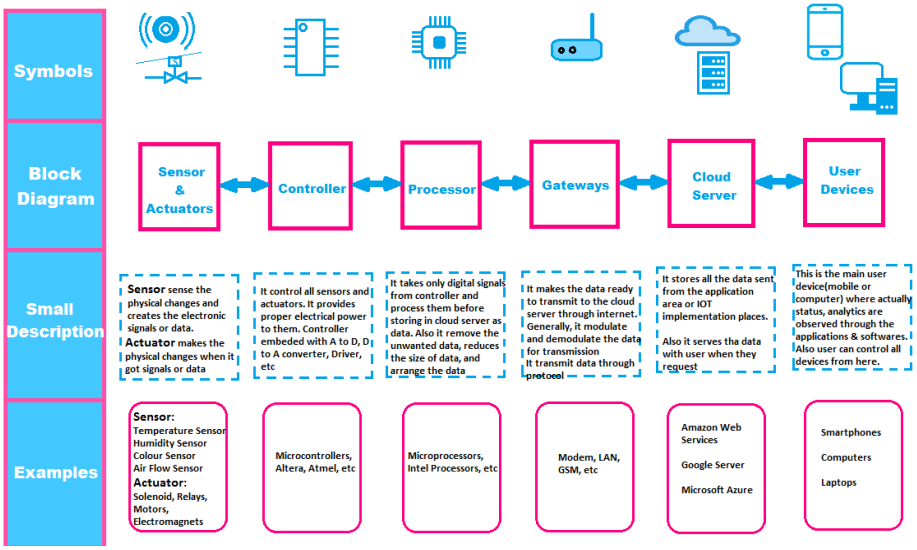

Figure 6 Typical IoT block Diagram and Architecture source www.ztechnog.com

IoT needs when we need to communicate data remotely to the distant and control devices and automated systems remotely.

Electromagnetic Locks

These locks are consisting of a long piece of wire with the shape of a coil which call as solenoid. This component creates magnetic field hence using a metal core inside of this coil to move back and forth. Working principle of the solenoid follow the principle of "electromagnetism" [55].

- Electromagnetic Induction – Due to the changing magnetic field inside a coil electromotive force will be produced and produce current will flow through the coil. According to this principle, [56]

$$e = N\left(\frac{d\Phi}{dt}\right)$$

Which means e = induced voltage (volts) , N = # of turn in the coil, Φ = magnetic flux (Weber), t = time (seconds)

Same as above theory inversion of the above theory is used in solenoid lock, when the voltage is applied in between to the coil then electromagnetic force will be inside the coil metal rod will be moved inside [55]. Simple block diagram of a solenoid lock shown in the following figure.

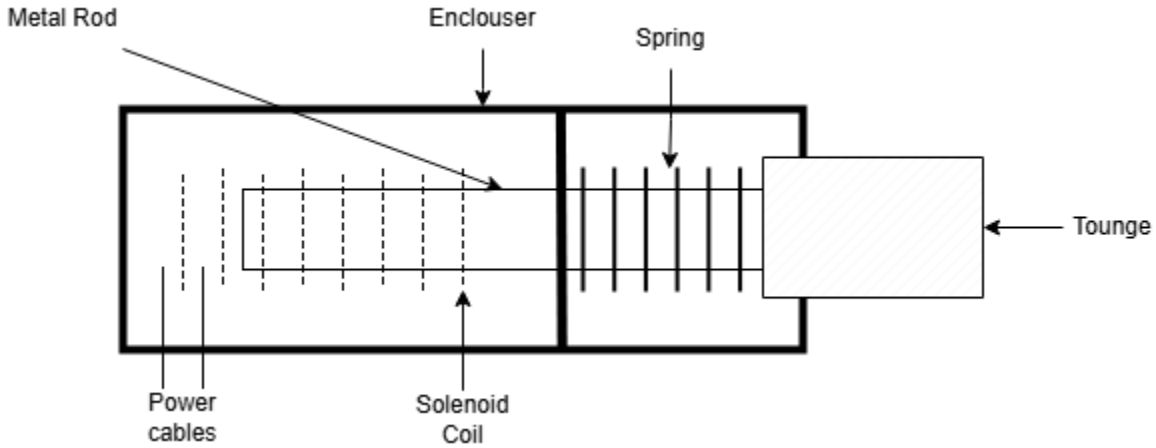

Figure 7 Block diagram of Solenoid Lock

Relays

Relays are switches which can be open and close electromagnetic-electromechanically. There are mainly two types of relays are available as mechanical relays, MOS FET relays and solid-state relays. In mechanical relay contacts that are mechanically actuated to open/close by a magnetic force. As shown in the following figure relay has a coil which generate electromagnetic field when the coil is energized then contact will be moved and closed the circuitry when the coil is de-energized contact will loosen and open the circuitry [56].

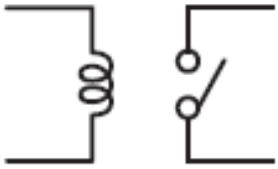

Figure 8 Relay coil schematic diagram

In MOSFET and solid-state relays there is no moving relays but the electrical switching elements such as MOSFET or triac used to operate the circuit [56].

Optocoupler.

A semiconductor device which allows to transmits electrical signal between two isolated circuits. This device uses photodetector and LED emitter to isolate circuitry for safety purposes [56]. A simple block diagram of the optocoupler described in the following figure.

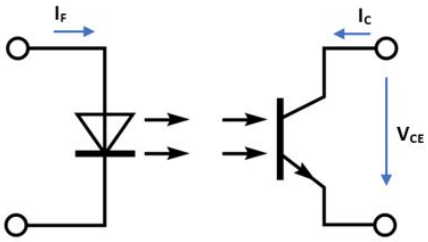

Figure 9 Optocoupler schematic diagram

As described in above figure forward current (IF) of the emitting diode and reverse voltage (VR) should not be exceeded. When the LED emit the light, photo detector switch will be closed and allowed to flow the current (IC) in the other circuitry [56].

Technical Review

Microcontroller

There are mainly two microcontrollers are used in the IoT based applications hence this study can be span over the IoT based project ESP32 and ESP8226 microcontrollers were referred based on the performance. Following Table 2-1 provide abstracted data from the datasheets of the ESP32 and ESP8226 MCUs [31][32].

Table 1 Microcontroller review

Specification	ESP32	ESP8226
Processor	240MHz 32bit LX6 dual core	L106 32-bit single core
RAM	520 KB SRAM	50 KB <
ROM	448KB ROM	-
Connectivity	Wifi / Bluetooth	Wifi
Peripheral Communication	SPI/UART/I2C/I2S/SDIO/TWAI/DAC/ADC	UART/SDIO/SPI/I2C/I2S/IR Remote Control
Cost	700 LKR approx	400 LKR approx.

ESP32 is high performance microcontroller which has dual core CPU. This two 32-bit LX6 CPUs can be operate up to 240 MHz while ESP8226 only has 32-bit single core CPU. Also, ESP32 has 10x capacity for the SRAM while ESP8226 has only 50KB< RAM for heap memory. Also, ESP32 and ESP8226 both have useful communication technologies such as UART and SDIO which mainly used to communicate with cameras. Hence ESP32 is more suitable high resource insensitive tasks [33].

Mini Computer.

Mini Computers has more powerful computing power over micro-controllers these devices are mostly suitable for heavy loaded data abstractions such as collecting data from various of sensors and process data and take decisions using AI algorithms. This process also defined as edge computing in distributed network of computers working collaboratively to exchange, process data and information to make useful decision making in a distributed system by pushing data into cloud servers. Hence closure the edges reduced latency and faster the response for sensor data. Also increased reliability makes the system more resistance for network problems [34].

Raspberry pi, orange pi and intel NUC are most famous mini pcs available in market. All of this mini-PCs has many different versions released by each year hence analysing each accordingly is really important for the task to reduce the cost [35][36].

Table 2 Raspberry pi comparison

Specification	Raspberry pi 3	Raspberry pi 4	Raspberry pi 5	Orange pi 3	Orange pi 4	Orange pi 5
Processor	Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz	Quad core 64-bit ARM-Cortex A72 @ 1.5GHz	2.4GHz quad-core 64-bit Arm Cortex-A76	1.8 GHz 64-bit Quad core RK3566	2.0GHz 6-core ARM® 64-bit RK3399	2.4 GHz 8-core 64-bit RK3588S
RAM	1GB	1-8GB	2-8GB	2-8GB	4GB	4-16GB
ROM						
Connectivity	Wifi/Bluetooth.	Wifi/Bluetooth.	Wifi/Bluetooth.	Wifi/Bluetooth.	Wifi/Bluetooth.	Wifi/Bluetooth.
Available ports	CSI /DSI / USB / UART	CSI /DSI / USB / UART / SDIO	CSI /DSI / USB / UART / SDIO	CSI /DSI / USB / UART	CSI /DSI / USB / UART	CSI /DSI / USB / UART
Cost	22000LKR	23000LKR - 33000LKR	25000LKR - 60000LKR	25000LKR	35000LKR	50000LKR

Orange pi has more cost-efficient and higher performance mini single board PCs while raspberry pi is not but has more community and software support [37].

Camera

There are many camera modules are available in market depending on the sensor technologies and features cameras can be taken into different applications accordingly the specifications. Following table will explain the different cameras and features available in the market [38][39][40].

Table 3 Camera Review

Camera	Pi-camera module 3	OV2640	OV7670	Pi-camera module 2
Resolution	12 MP	2 MP	VGA	8 MP
Sensor	CMOS	CMOS	CMOS	CMOS
Interface	CSI-2	SCCB	SCCB	CSI
Image transfer rate	30/60/90 fps	15/30/60 fps	60 fps	30 fps
Cost	12400LKR	600LKR	500LKR	9000LKR

Wireless technologies

Communicate over the air we use wireless technologies such as Wi-fi, Bluetooth, BLE etc. These technologies have its own kind of characteristics to serve the different applications. Following table shows the characteristics of these two technologies [41].

Table 4 WiFi and BT review

Specification	Wi-fi		Bluetooth		
Versions	802.11ac	802.11ax	Classic	BLE	5.0
Bandwidth	3466Mbps	240.2Mbps	3 Mbps	2Mbps	2Mbps
Channel width	80+80 MHz	160 MHz	1 MHz	2MHz	-
Area	100M	100M	10M	>10M	>>10M
Power consumption	5-20 watts	5-20 watts	1-100mW	1-15 mW	1-150 mW

IDE

IDEs are powerful tool used by programmers to program embedded device and develop software. These software piece has many powerful tools to provide programmers to develop software and program embedded devices [43]. Arduino IDE and Platform IO are popular tools that used by the embedded engineers. Arduino has many libraries and supported many development boards and devices including raspberry pi thanking to the wide supporting community. Platform IO also provide same support even with Arduino framework support also this IDE tools function as a third-party software tool for VScode the universal IDE [44] [42]. Hence this Platform IO tool very user-friendly to many embedded programmers.

Cloud Computing

In modern day computing tasks need lot of computational power hence as a solution cloud computing make revolutionized step to minimize this issue by providing virtual computer resources over the internet. Hence most of the AI applications are resource insensitive because of the larger datasets therefore high-capacity RAMs and high-performance processors and GPUs are working collaboratively in cloud computers. Therefore, users only need high performance internet activity for the heavy load of tasks [45].

Relays module.

There are few types of relay modules are available in the market. 1 channel relay has 3 pins, one pin for power (VCC), another pin for GND and Input pin this pin control, the logic of the relay. Another 3 connections are available to insert the separate circuitry for this there is one input used to connect common input and NC and NO for normally open and closed path circuits for select suitable configuration for circuitry. When NC is selected when the input pin is high closed the circuitry and NO is selected when the input pin is high open the circuitry [46].

Figure 10 1ch Relay module

ESP32 cam module

This camera module is low-cost high-performance camera module which can be programe with ESP-IDF and Arduino platforms. Platform IO is another alternative tool that we can used as VScode plugin. This cam module allows to install camera modules such as ov2640, ov3640, ov5640, GC032A. Also, typically these modules consist with ESP32-S MCU, IPEX block output, tantaium capacitor, PSRAM, voltage regulator chip, TF Card holder, FPC connector and Flash lamp. The following figure 11 shows the ESP32-CAM module [47].

Figure 11 ESP32 Cam module

Brief details and specifications of ESP32 CAM module was described in the following table.

Table 5 Components of ESP32

Component	Description
PSRAM	Expanded ram for resource intensive audio or graphics processing
ESP32-S	Main controller unit with Wi-Fi and Bluetooth connectivity
IPEX block	External antenna
Voltage regulator chip	to provide 3.3v regulated voltage to the mcu
TF card holder	microSD card slot.
FPC connector	To connect camera output.

This cam-module need special breaker board or FTDI adapter to program this ESP-cam module. Breaker board has female headers to connect the cam module. This board will consist of either CP2102x or CH340x chip to convert USB to TTL and also this board has in built voltage regulators to regulate the power input to the cam board [47].

FTDI adapter

This adapter is another adapter used in USB to serial conversion. The adapter typically use FTDI chipset which is mostly supported by windows and other software this chip does not have many issues like other chips. Typical application of this adapter shown in the following figure [47][48].

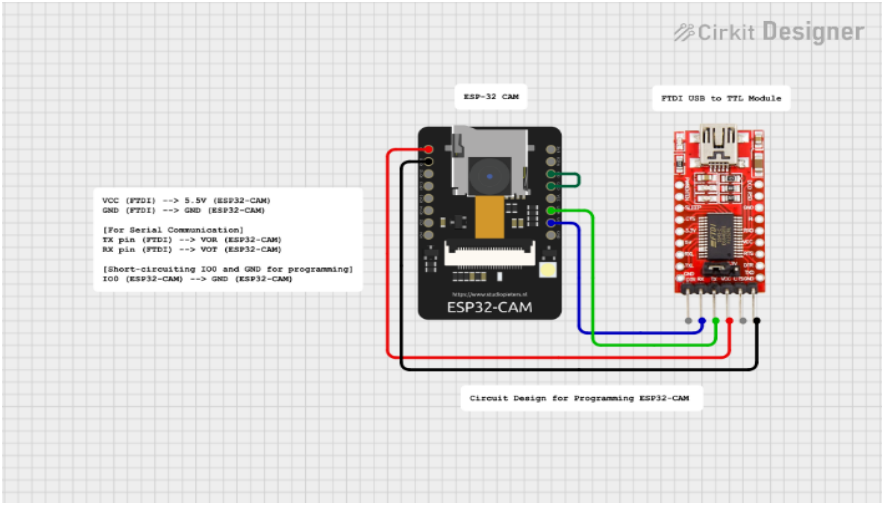

Figure 12 How to connect FTDI adapter to the ESP32 CAM

ESP32 module.

ESP32 is powerful Wi-Fi and BT module which powered with ESP32 chip [31]. This module has voltage regulator to maintain the power input to the ESP32 chip also this has either CP2102x or CH340x USB to serial chip to program the ESP hence no need of additional components to program the microcontroller. A micro-USB port was attached to the board to allow the programming the ESP. This module has 30, 36, 38 pins connected to the ESP. As shown in the figure there are two buttons are included to reset and boot the mcu when needed [49].

Figure 13 ESP32 Module

Solenoid lock

Solenoid lock is electromechanically device as mentioned earlier there is many solenoids locks available in the market. Following table was implemented for categorise the key characteristics of the available locks [50] [51].

Table 6: Key Characteristics of Solenoid Lock

Voltage	9V-12V	5V
Current	500mA-650mA	1A
Power	6W-7.8W	5W
Size	23.57 x 67.47 x 27.59mm	14 x 10 x 8mm

12V Solenoid lock is shown in the following figure.

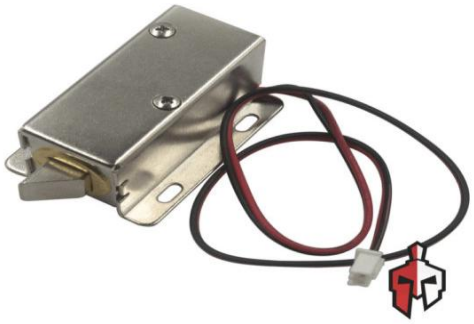

Figure 14 Solenoid lock

3. METHODOLOGY

3.1 Needs analysis

In this section, we are looking forward to the design needs which allow us to understand the needs of the designs therefore this explains the requirements needed for this design.

Stakeholders Needs.

- User-friendly and simple easily operatable device/system.
- Cost-effective device/system.
- A portable device/system with easy installation and must not be heavy.
- A device/system with high reliability and durability.
- Easy repairable system/device.
- Secure device/system.

Safety Needs.

- No electrical hazards.
- Capable of operating in harsh environments.

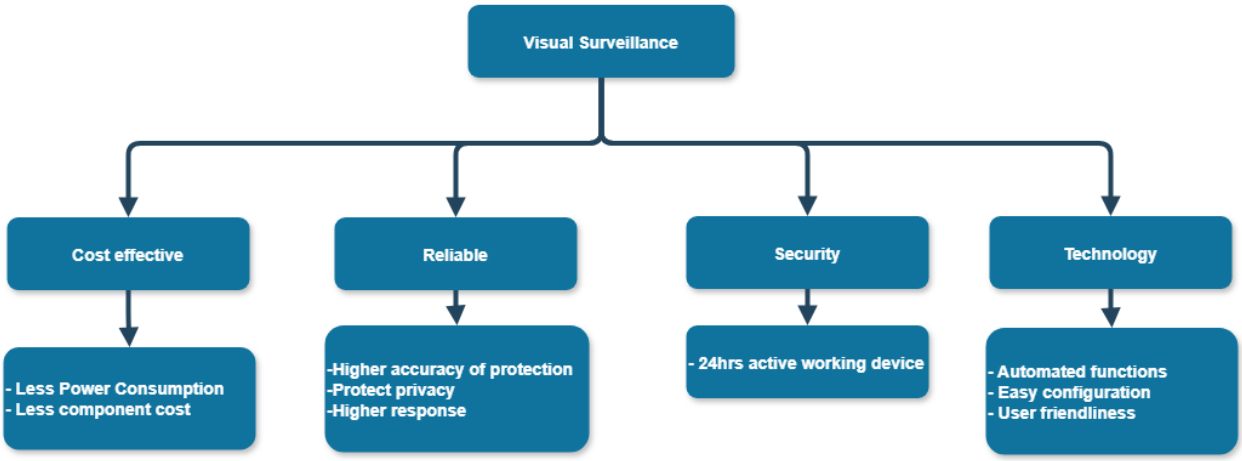

Figure 15 Needs Tree

3.2 Methods of identification problems and needs.

1. Conducting a literature review.
    - Literature review provide in-depth knowledge about the problems going to be address. There are many resources were needed be referred including previous experiments and expert experiences. Also, this will help to gain new expertise in new technologies therefore this will enhance and open new doors to the new solutions. This data will also help to analysing new methodologies and implement new methodologies. This literature review was conducted in following areas including addressing global problem, needs of the solution, scientific review and technological review. From this in-depth knowledge of AI, Embedded systems were covered therefore during next few steps those knowledges will be analysed to implement the solution
2. Informal discussions.
    - From this gain some knowledge and related experience from colleagues and mentors.
        - PCB designing
        - Software tools
        - AI
        - Prototype implementation
3. Online resources and references.
    - There are many online resources were available videos, articles, eBooks etc.
        - Youtube – MIT OCW
        - EBooks

3.3 Objectives

3.3.1 Defined Objectives

This device/system must have objectives to construct a high-quality design product therefore for this project, we needed to define the objectives for the designing objectives.

- Notify the householders when intruders happen.
- A methodology to protect the system from harsh environments.
- Protect the device/system from electrical hazards.
- Good carbon foot-print and environmentally friendly.
- Cost-effective, less design cost and manufacturing cost.
- Simple, user-friendly design.
- Durable device/system.
- High responsive.

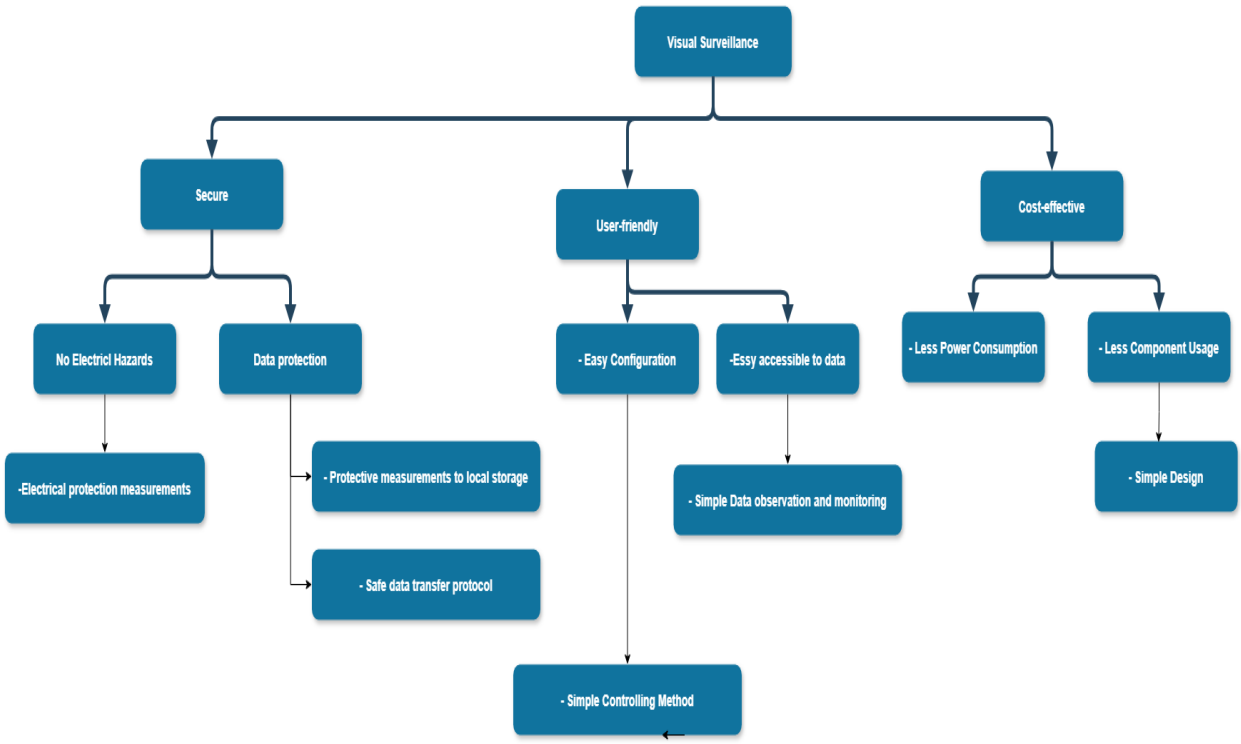

Figure 16 Objective Tree

3.3.2 Objective, Constraints and Limitations Analysis

This device must be a user-friendly product because it is a product which will be mostly used by adults and patients therefore it is really important to consider product objectives, constraints and limitations analysis. From the objectives, the most important thing is reliability which covers most of the important factors that affect the quality of the medicines.

As a designer of this system, our main objective is to implement a device/system which protects the assets of the user. This device should inform the user when the intruder happens or suspicious activity is detected.

Table 7 Objective and Limitation Analysis

Objectives	Constraints	Limitations
This should be cost-effective	There must be less manufacturing cost	High-end material costs
	Must be less design Cost	-
	There must be less operation cost	Power consumption of components.
This should be user-friendly	Must be easily configurable	Complex configuration options
	Must be easily operatable	user-friendliness
	Must be able to operate remotely	Connectivity strength and reliability
This should protect assets	Must be able to detect human activities.	Accuracy of identifying human activity.
	Must be able to detect the objects.	Object detection accuracy.
	Must be able to notify the user when an intruder happens.	Proper method.
	Must be on time	Hardware and software bugs

This should be reliable	There must be fewer repairs	Durability of components
This should be safe to use	Must be no electrical hazards	Water-resistant and dust protection level of components
	Must not violate the storage environments	Temperature and humidity levels
This should be durable	Must use good materials	Materials properties
	Must be used good durable hardware components	Number of times that hardware components can be used.

3.2.3 Intended Objectives

Intended objectives are derived from defined objectives from the above-mentioned objectives for notifying the user when intruders happen and threatening the assets of the user. Therefore, this system must be capable of providing 24hrs of surveillance protection to the user. Also, this emphasizes system must be able to work under harsh environments too. Also, the components used in this system have to work continuously therefore components must have less heat dissipation and power consumption. Another important fact is the ability of the system to detect the intruder which depends on the algorithm implemented using the AI. Therefore, this device/system should have a high accuracy rate of object detection and activity recognition. Precision is another important fact that needs to be considered in this system/device because otherwise it may not be able to detect the intruder and run into semantic errors. Hence this is a visual surveillance system it is important to focus on selection of good components considering the durability and reliability. Therefore, this device must have a simple design.

- Internal circuitry and cabling should be waterproof and dustproof.
- A circuitry protection mechanism should be implemented.
- Need to select the components considering the cost and durability.
- The design should be minimalistic.
- Easy component decomposition in case of repair.
- The device must operate in low-voltage conditions.
- Must select the suitable interactive mechanism (selecting the switches, interfacings, sensor etc.)

- Either Deep learning or machine learning algorithm must need with high accuracy.
- Less components and simple design.

Table 8 Objective Analysis

Objective	Metric	Target
Cost-effective	Manufacturing cost, design and implementation cost.	Rs.5000
Durability	Duration of materials and components.	5 years approximately
Notify the intruder to user	Accuracy of notifying methodology and response time.	less than 5s response time and 95% of accuracy of catching the notification by the user.
Emergency alerting for critical situations	Responding time and mechanism viability.	Maximum 1 min (response time) 50-100 % (viability)
Protect the assets from intruder	Accuracy of object detection and human activity recognition	More than 95% of accuracy.
Protect the device from electrical hazards	Voltage, current, resistivity, electrical power	below 50 VDC operating voltage
Should be environmentally friendly	carbon-footprint	low

Redefined Problem Statement.

A surveillance system is required to be implement to protect properties while detecting suspicious activities of a human while taking protective measurements to protect the properties. This solution should be secure, cost-effective, reliable and robust the harsh environment.

3.4 Requirement Analysis

From this step, we will be able to derive the specifications of the device and this step is an extended step of the previous step. This analysis mainly consists of two steps: identified requirements and categorised requirements. During these steps we might explore the device components requirements, sizing requirements, weight, strength, material requirements etc.

3.4.1 Identified Requirements

- The initial cost should be 5000 LKR.
- Microcontroller with Camera interfacing and Wi-Fi/Bluetooth Connectivity.
- Power Supply unit.
- Rechargeable Batteries (Not Mandatory).
- Buzzer or Speaker.
- Screening and monitoring.
- Camera.
- Enclosure and Hardware Design
- Circuitry Protectors.
- Web Server.
- AI model.

3.5 Specifications Analysis

In this step we have to focus on analysing the specifications of the device with the aid of the above analysis. There are mainly three types of specifications that can be found as functional specifications, technical specifications and design specifications therefore during this step we will look forward to analysing those specifications.

First, we compared the microcontrollers available in the market. Therefore, we need to get a rough idea of what kind of specifications are needed for the microcontroller such as the number of GPIO pins, Clock frequency, power consumption, connectivity data, cost, and modules available such as timers, ADC, Wifi, Bluetooth etc. also it is vital to check the supported communication protocols

in microcontroller which we used to communicate with other peripherals such as SPI, I2C, UART, CAN irDA etc.

3.6 Cost analysis

Most of the people who installed CCTV or surveillance systems have high literacy in computers and technologies. Therefore, these people who are looking for installation are willing to spend some amount of money to protect their values, hence cost may not be a problem at all but in this research project we are developing an experiment to test our surveillance model which functions as intelligence of this system hence we have to implement the model and test this in minimal condition.

Table 9 Cost Analysis

Component	Requirement	Max cost
Camera	Should be clear enough to analyse.	1500 LKR
Micro-controller	Should be powerful enough to establish visual data communication between the PC and read the reading from the camera.	2000 LKR
PC	Should be able to run the AI model	-
Power supply unit	Should be able to power the Camera setup.	1000 LKR
Additional	Should be able to cover the additional component requirement.	500 LKR

3.7 Mind Map

Following Mind Map as shown in the below figure was graphed for get rough idea about the design

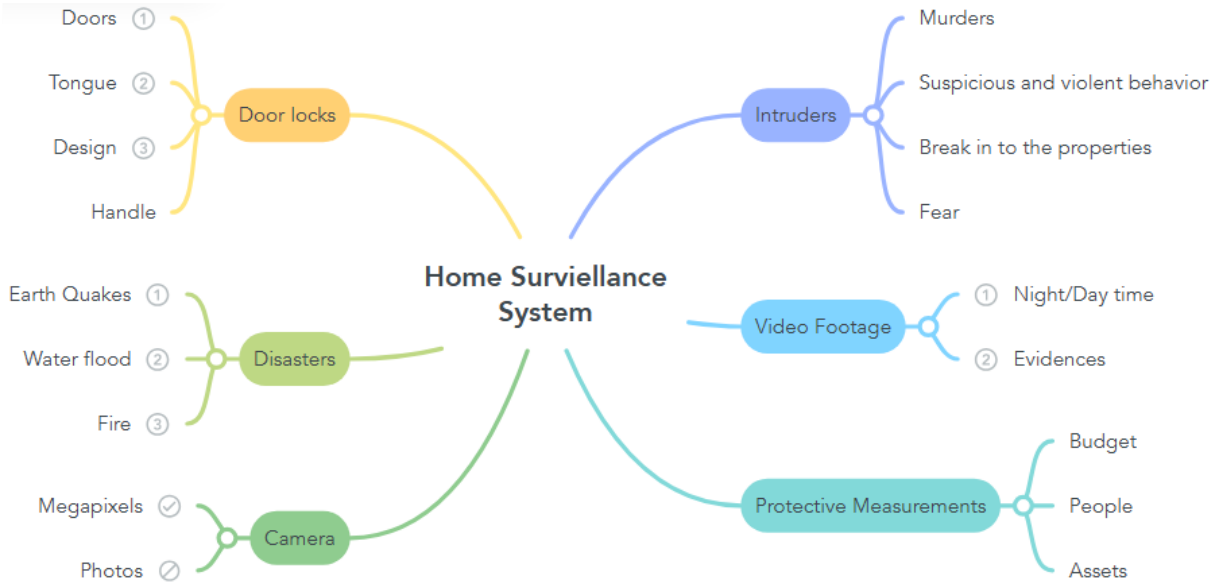

Figure 17 Mind map

3.8 Ishikawa Diagrams.

The following figure shows fish bone diagram was implement to analyse and root causes for the problem

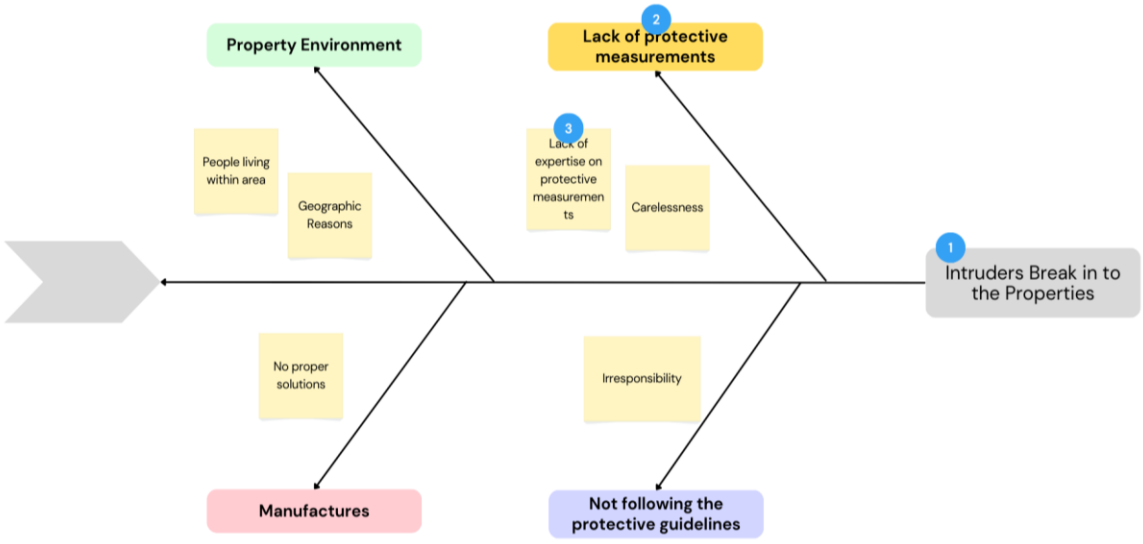

Figure 18 Fishbone Diagram

3.9 Objective Alternatives

1. Intruder Detection

Table 10 Intruder detection objective alternative analysis

Alternative	Physical Principle	Abstract Embodiment
1	Ultrasonic wave reflection	Ultrasonic sensors
2	IR wave reflection	IR sensors
3	Image processing	Camera

2. No electrical Hazards

Table 11 No electrical hazards objective alternative analysis

Alternative	Physical Principle	Abstract Embodiment
1	Electrical Conductivity	Plastic cover
2	Electrical Conductivity	Rubber clips
3	Water resistance	Water proof sensors

3. Protect the Assets from the intruder

Table 12 Protective measurement objective alternative analysis

Alternative	Physical Principle	Abstract Embodiment
1	Electromagnetism	Speaker
2	Electroluminescence	LEDs and indicators
3	Electromagnetism	Solenoid locks

3.10 Working principles

Following table will describe the working principles that should be work in each objective.

Table 13 Working principle of each objective

Objective	Selected Alternative	Working principle
1	Camera	Capturing the light
2	Solenoid Lock	Electromagnetism
3	Plastic Cover	Water resistance

3.11 User interaction list

Following table describe the how the device should be needed to be interacted with user this will give brief idea to how to implement our targets to develop this product

Table 14 User interaction list analysis

Use	Setup	Open the package
		Examine the wires
		Read the manuals
		Assemble the product
	Daily Use	Automatically detect the intruders
		Taking protective measurements
		Replace the damage parts and repair the system
		Repeat until the solution is unrepairable
Retirement	Recycle the system	Return the solution to the manufacture

3.12 Sub function Analysis of Concept alternative

Sub function and concept alternative analysis was done to find most optimal solution for achieve most suitable solution following tables will describe each alternatives and most optimal solution.

1. Detect intruders

Table 15 Weighted rating criteria for detect intruder objective

Detect intruders		Concept Alternative					
		Ultrasonic waves		IR waves		Image processing	
Criteria	Importance weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Reliable	30	3	0.9	3	0.9	4	1.2
High Accuracy	50	2	1.0	2	1.0	6	3.0
Low cost	10	4	0.4	4	0.4	2	0.2
Maintenance	10	3	0.3	3	0.3	4	0.4
	100	N/A		N/A		N/A	

2. Protect the Assets from the intruder

Table 16 Weighted rated criteria for protect the assets from the intruder

Protect the assets from the intruder		Concept Alternative					
		LED		Solenoid lock		Speaker	
Criteria	Importance weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating

Reliable	50	2	1.0	6	3.0	2	1.2
High Accuracy	30	5	1.5	3	0.9	2	0.6
Low cost	10	5	0.5	2	0.2	3	0.3
Maintenance	10	4	0.4	2	0.2	4	0.4
	100	N/A		N/A		N/A	

3. No electrical hazards

Table 17 Weighted rated criteria for the No electrical hazards objective

No Electrical Hazards		Concept Alternative					
		Plastic cover		Rubber Clips		Waterproof sensors	
Criteria	Importance weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Reliable	50	2	1.0	1	0.5	7	3.5
High Accuracy	30	5	1.5	3	0.9	2	0.6
Low cost	10	5	0.5	2	0.2	3	0.3
Maintenance	10	4	0.4	2	0.2	4	0.4
	100	N/A		N/A		N/A	

From the above tables Camera, Solenoid lock and plastic cover was selected to achieve the objectives. Then we need to a methodology to control the camera and solenoid lock therefore let's focus into those criteria.

Camera

This project needs a DIY setup for experimentation with the developed model therefore it is important to consider the camera resolution, sensor type, Field of view, lens type, connectivity, power consumption and cost. There are different kinds of camera modules with different purposes: Raspberry pi camera modules, Arduino compatible models, USB webcams and security camera modules.

Hence our objective is to establish the connection with the PC and capture clear images and train a model. Also, in this project our primary goal is to train a model and experiment. We don't need to consider high end cameras. Hence Arduino-compatible cameras, security cams and USB webcams are mostly suitable for these kinds of applications. Security camera modules are specially designed for surveillance-based activities and we can find this camera in 720p,1080p and 4k resolutions. Also, it can be found in field of view with wide-angle, standard and telephoto hence these cameras are most suitable for this project in terms of resolution, field of view also these cameras have additional features such as night vision, motion detection, weatherproofing etc.

An additional processing power is need to convert sensor data to byte data and communicate process data to change the state of the solenoid. Therefore, using mini-computer in each node and running python script with in it controlling the solenoid by it-self might not be cost efficient but there might be able to take advantages distributed computing system. But using MCU such as ESP32 or Atmega 328p will be gave advantages cost efficient solution to communicate image data over the air to a local network and from the local network computer can extract the video data through the server and process video frame by frame then, apply it to a CNN network for detect faces and extract face features for detect suspicious activity then through this local network we can sent data to control solenoid data. Therefore, ESP32 MCU was selected to communicate with network wirelessly through the Wi-Fi. This centralized mechanism will provide ability to deploy the system in cloud computing platform and make the system more cost efficient and more secure. Therefore, an experimental hardware model was developed to experiment this on local computing resource.

Solenoid Lock

Solenoid locks can’t be controlled by it-self but need another input signal from another MCU or any other possible way hence as above-mentioned scenario using ESP32 will be added advantage, also another important fact that solenoid locks are work in 12V DC power hence a relay switch was used to control the solenoid.

Then following block diagram for the system was obtained as shown in the below figure.

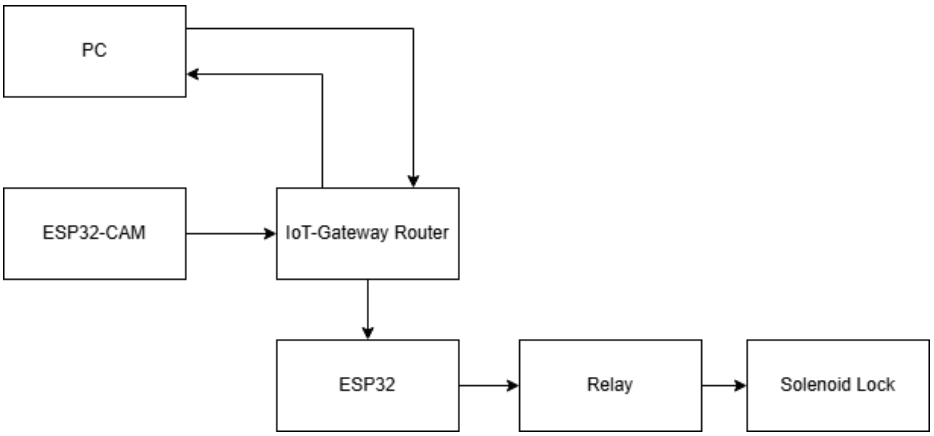

Figure 19 Block diagram of the entire setup

Hence, we can develop following flow diagram as in the figure by discussing the above scenario.

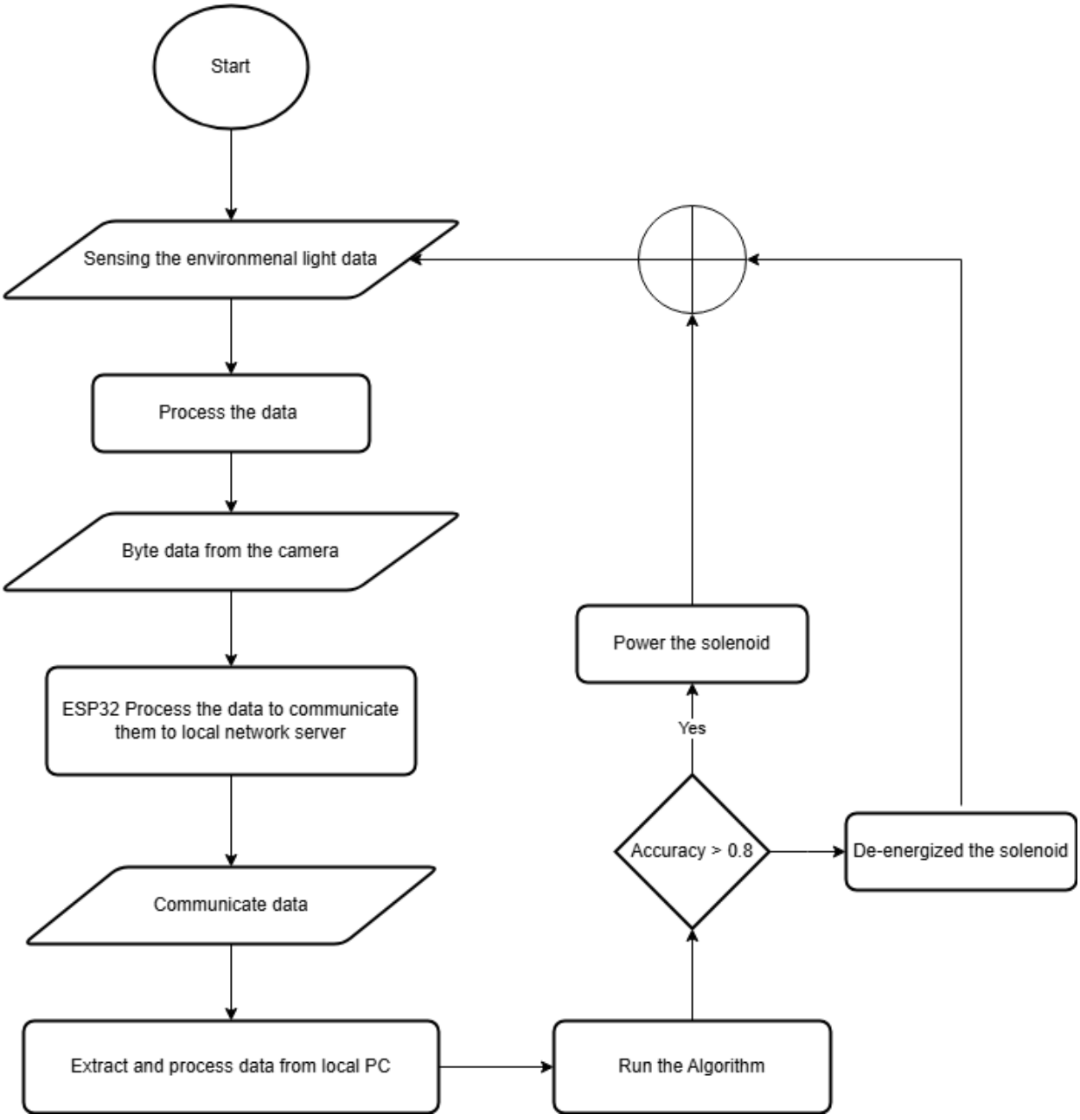

Figure 20 Flow chart of the entire solution

3.12 Experimental Model Evaluation

Apparatus

-12V solenoid lock

-ESP32 cam module

-ESP32 WiFi module

-1ch 10V Relay

-Buck Converter

-USB Cable

-micro USB cable

-Male headers

-Dot board

-Connector

-Soldering gun

-Soldering wire

Following Schematic was designed using Easy EDA.

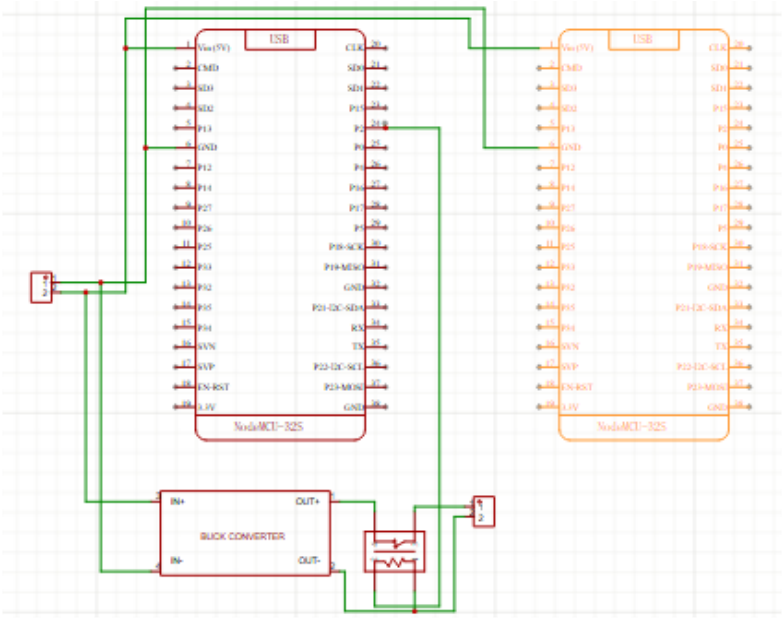

Figure 21 Schematic Diagram

Assemble the components and soldered wire and pin headers as shown in the schematic. Then as shown in the following figure 11 device was assembled.

Step 1 – Mounting the pin headers to the dot board.

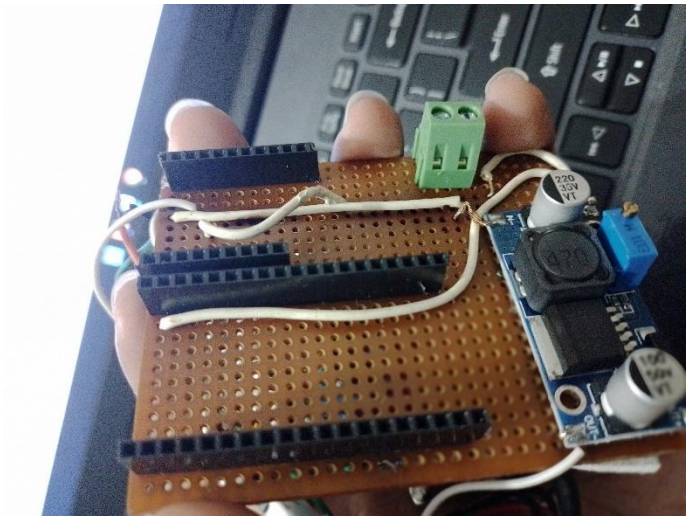

Figure 22 Soldered and mounted pin headers and other components

Step 2 – Mount the Connector and soldered it as figure 22

Step 3 – Attached the buck converter as shown above figure 22

Step 4 – Soldered all of the items accordingly.

Step 7 – Connect the Wires to the Relay as shown in the Figure 23 and Figure 21

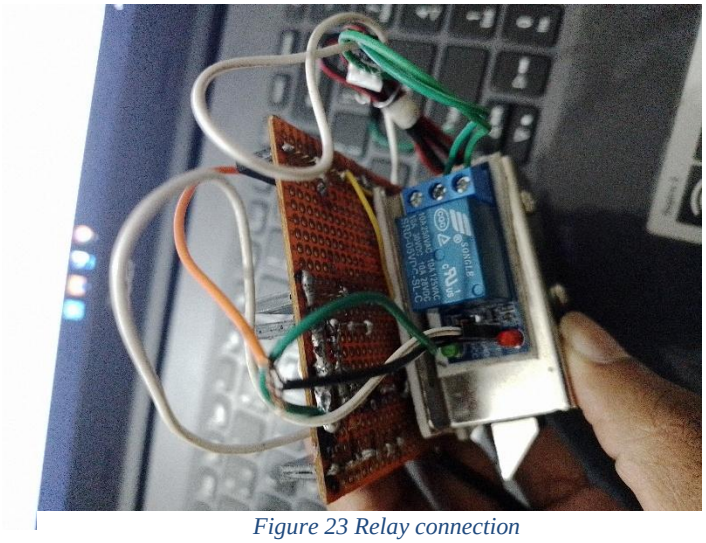

Figure 23 Relay connection

Step 6 – Program the ESP32 using Platform IO.

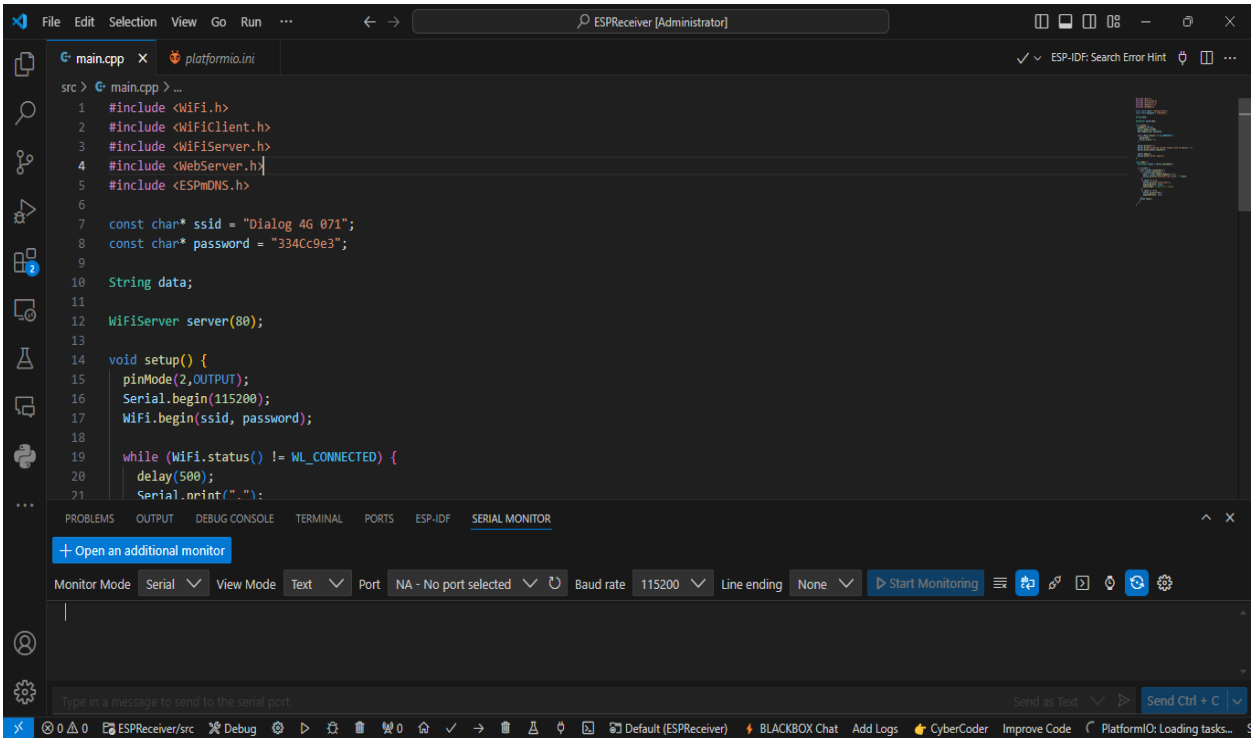

Figure 24 Platform IO

Step 7 – Program the ESP cam module to establish video streaming server using platform IO using ESP-CAM breaker board (Code is Available in Appendix 2)

Figure 25 ESP CAM breaker Board

Step 8 – Mount the ESP32 and ESP CAM to the board.

Step 9 – Connected to the USB power.

Step 10 – Wait until the device is connected to the network and start streaming.

Step 11 – Configure the video streaming through the video stream server.

Step 12 – Run the necessary scripts for the tasks.

Algorithm Implementation.

Enrolling Faces.

In this step we implement following algorithm to introduce new faces to the model. A model named face.h5 will be saved and trained after capturing faces from the stream.

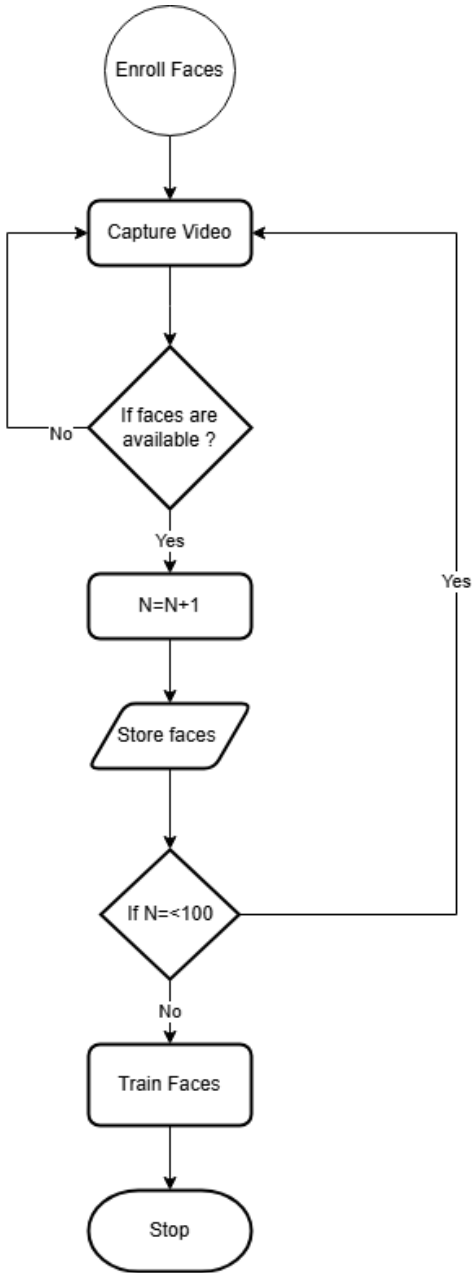

Figure 26 Flow chart of the Enrolling new faces

Flow chart of the entire system was shown in the following.

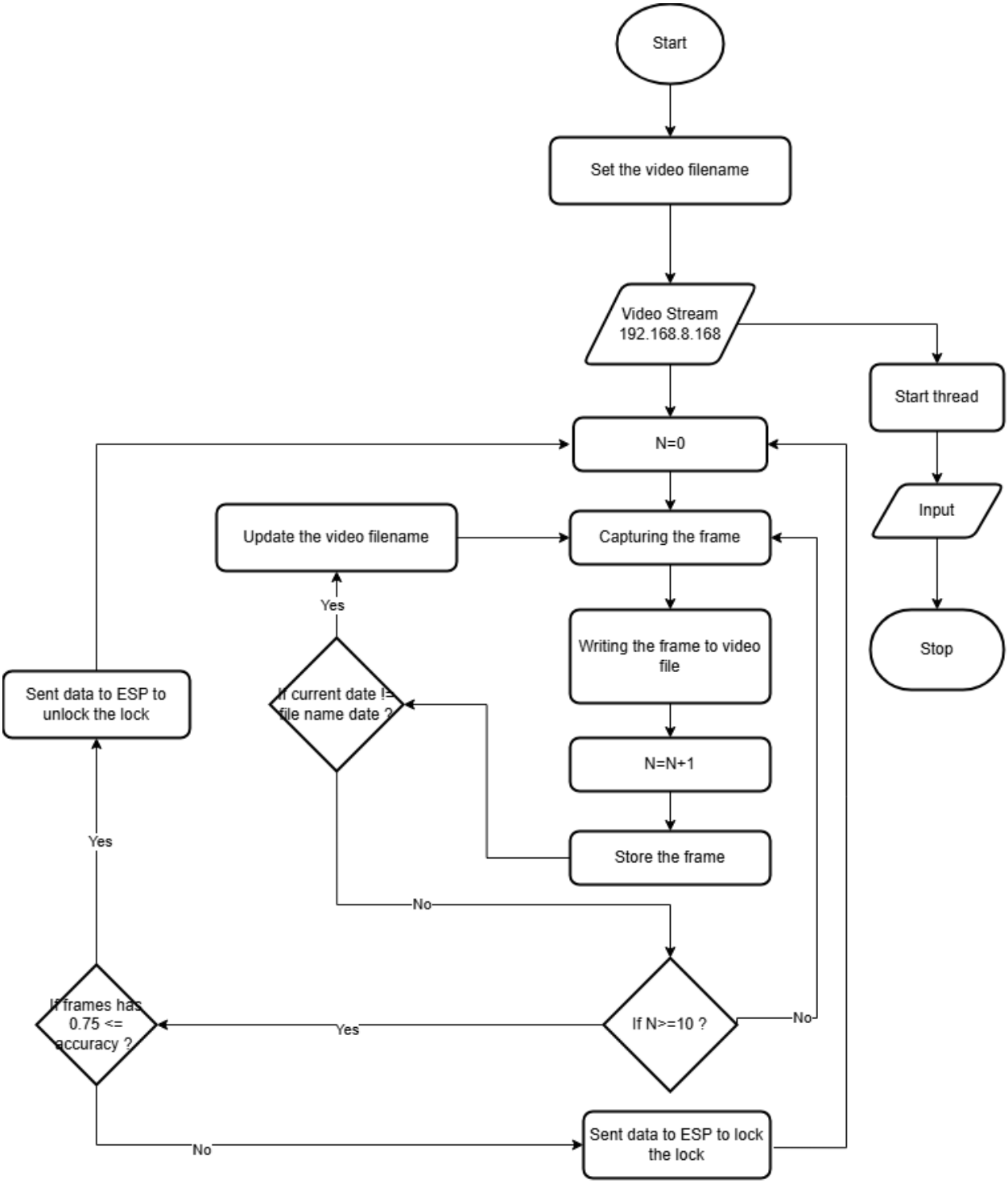

Figure 27 Flow chart of the Algorithm

For the above algorithms all of the codes implemented using Vscode IDE with Jupiter notebook. All the codes are available in Appendix 2.

4. RESULTS

In this chapter we will discuss about the experimental model developed using ESP32 and cam module also, this experimental model was intended to experiment with suspicious face detection and recording video footages.

Experimental setup.

Experimental setup was connected to USB power as shown in the following figure.

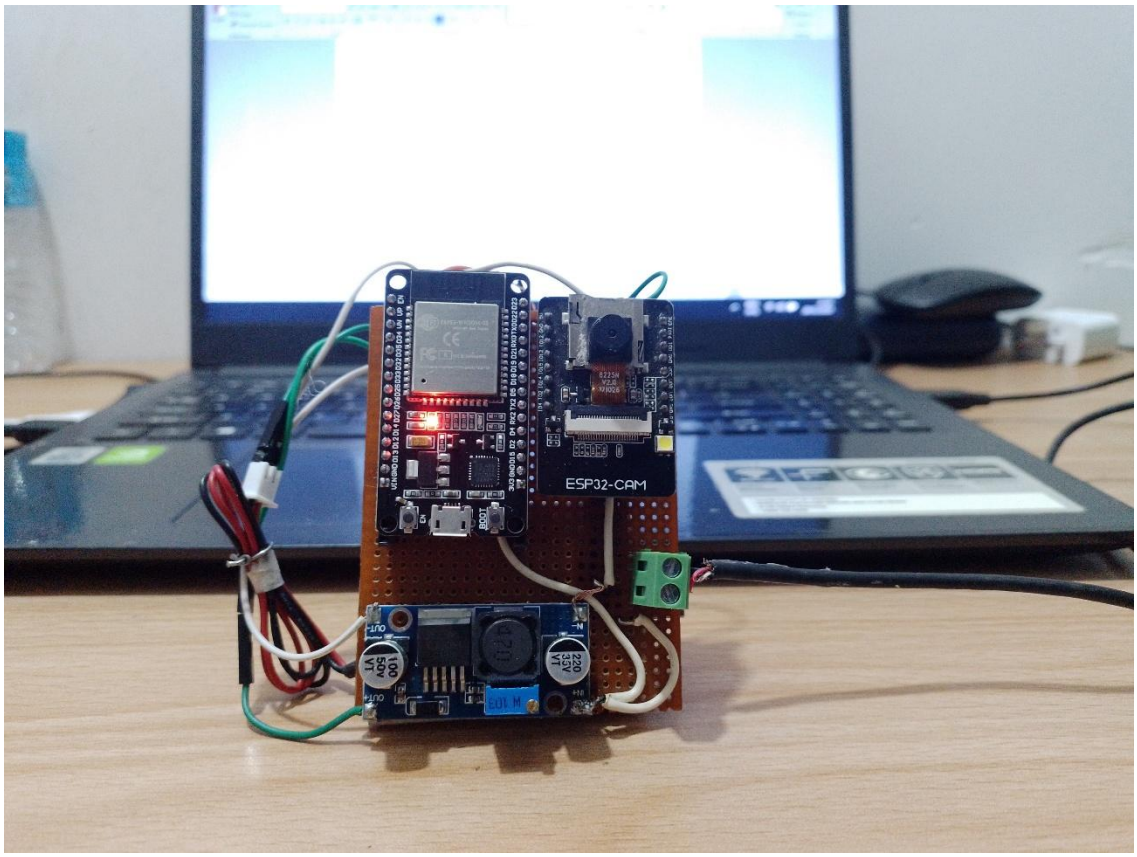

Figure 28 Experimental Prototype

Then after that following experimentations were done to verify the system.

1. Check the cam module server and configure it.

   Following figure shows that cam module was successfully connected to the server and sending video footage to the local network. The following two figure 21 and 22 shows the server implemented on 192.168.8.168 IP address. Also, this step was successfully completed and configuring the camera also, successful.

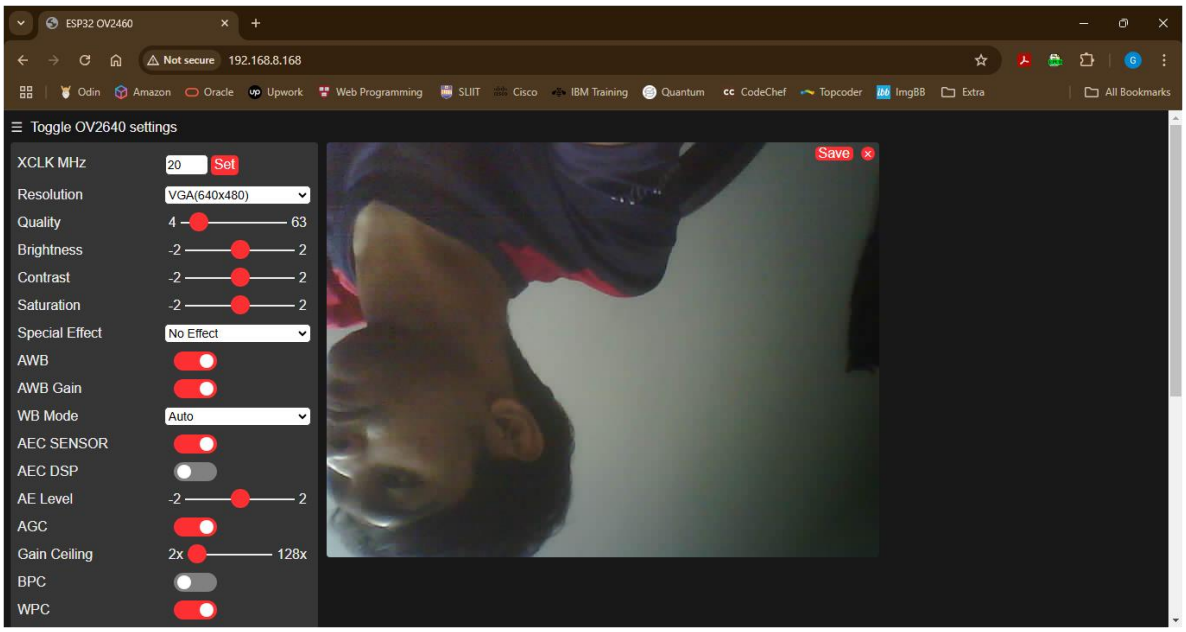

Figure 30 Checking Configuration from the server

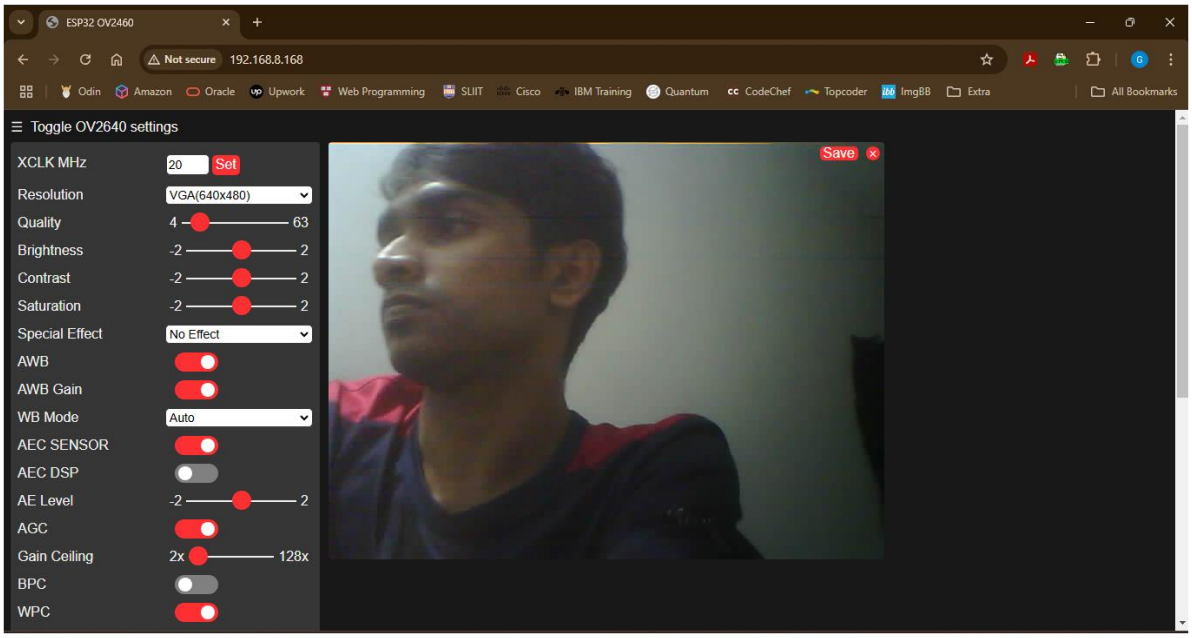

Figure 29 Checking Configuration from the server

2. Run the face enrolling script to enrol new face to the model

   After that opened the VScode to run the implemented scripts then run the block of code to enrol the new faces for the model. Then that was also successful as shown in the following figure 23 and 24.

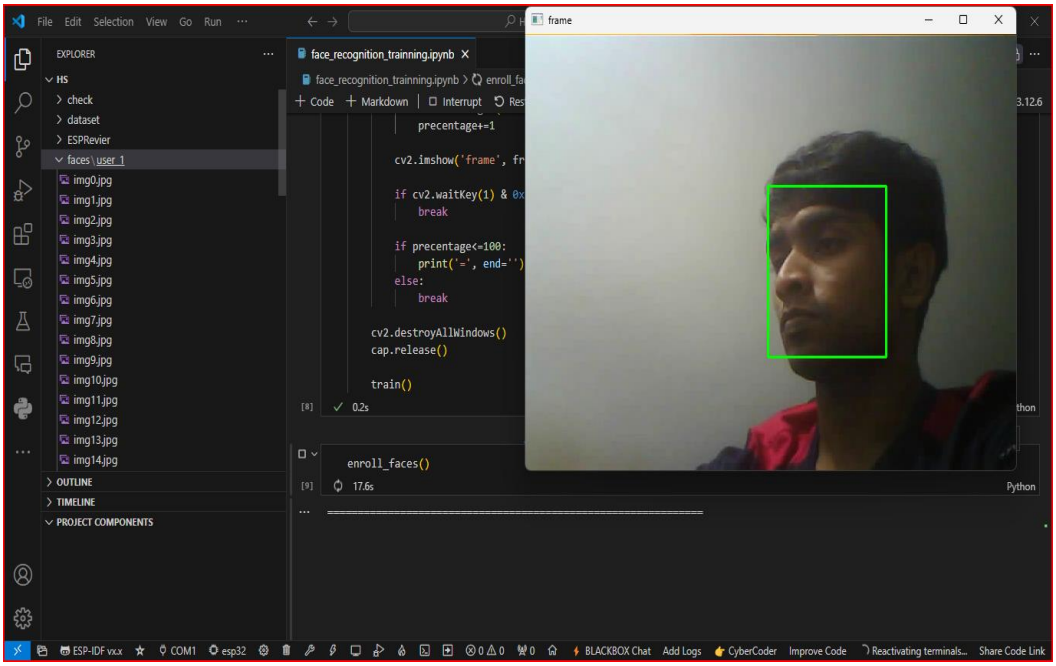

Figure 32 Running the script to enrol new faces

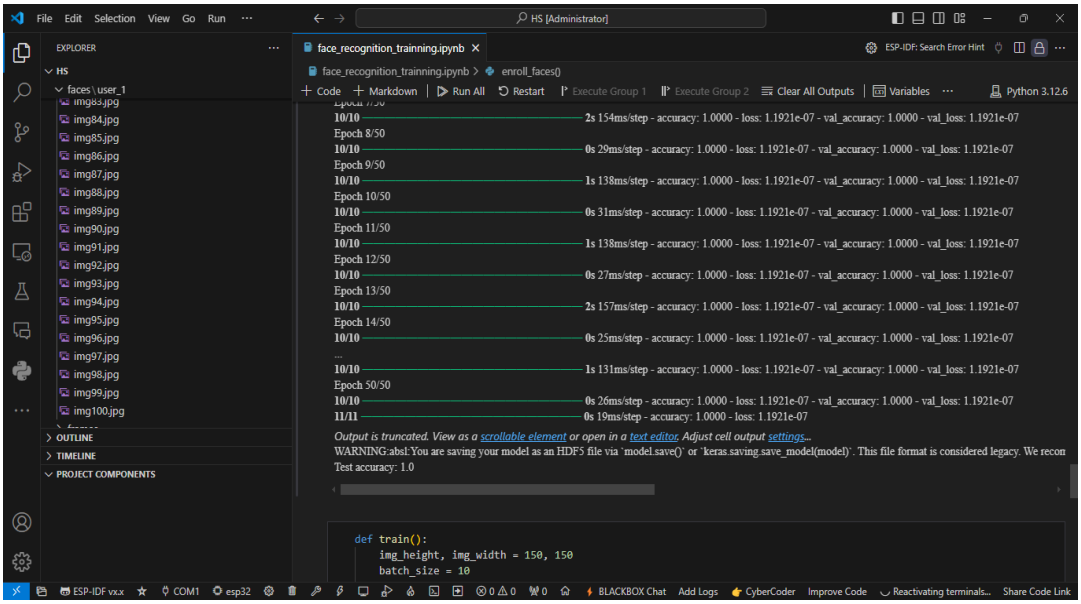

Figure 31 Running the new face enrolling script

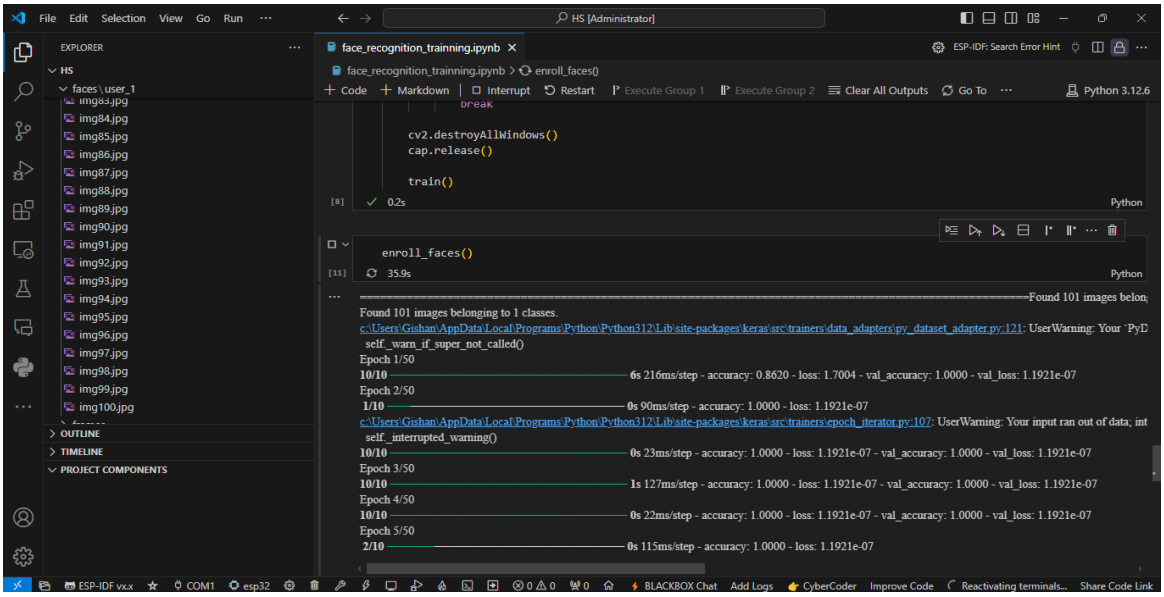

Figure 33 Results from the enrolled face

Loss for the newly enrolled faced is less than 1.99x10-7 hence system is highly accurate

3. Run the main script to record the video footage and verify the facial detection system. The following figures 26, 27,28 shows how the facial detection is works and accuracy and result obtained for the enrolled faced.

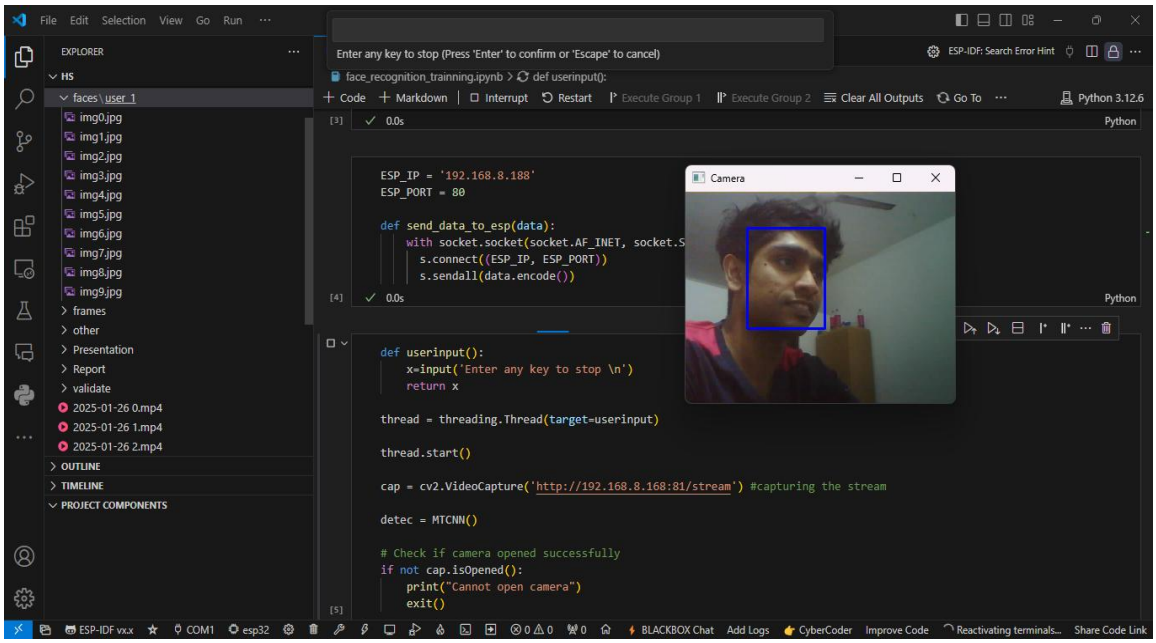

Figure 34 Running the facial detection and recognition system

Also I was able to observe recording the video footages and storing them in local storage was successful the following figure shows sample of recorded video footage.

Figure 35 Recorded Video Footages

4. Then observe whether system is act to the non-recognize faces or not

According to the following captured screenshot facial detection and recognition was successfully implemented and had accuracy of almost 100% for every 10 frames per count.

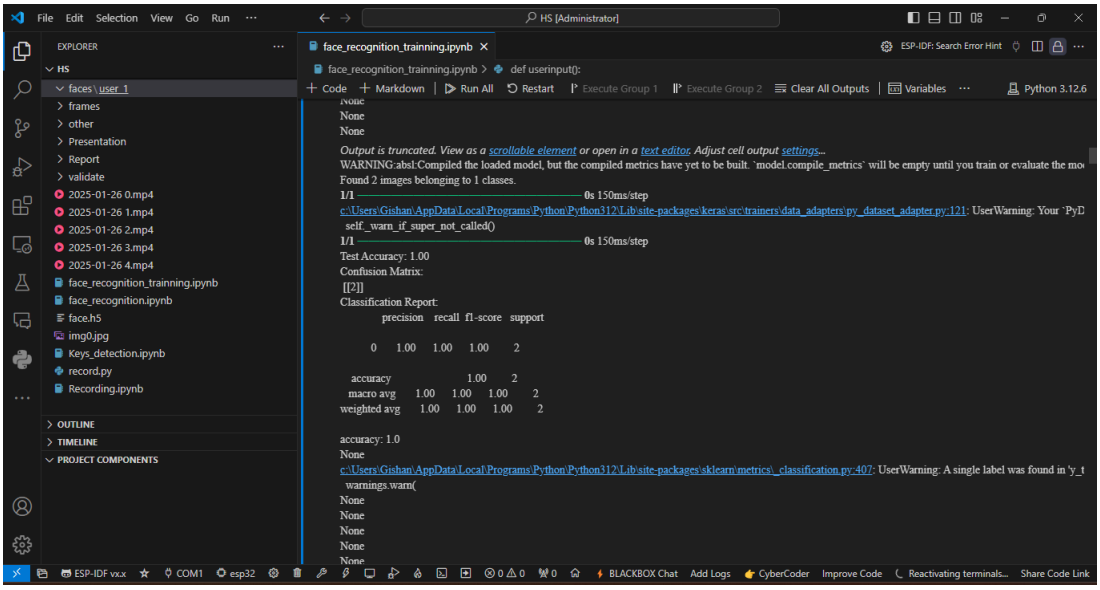

Figure 36 Results of the facial recognition system

The following figure shows how the experimental prototype is act for the non-recognize face is detected it sent no signal to the solenoid via pin 2

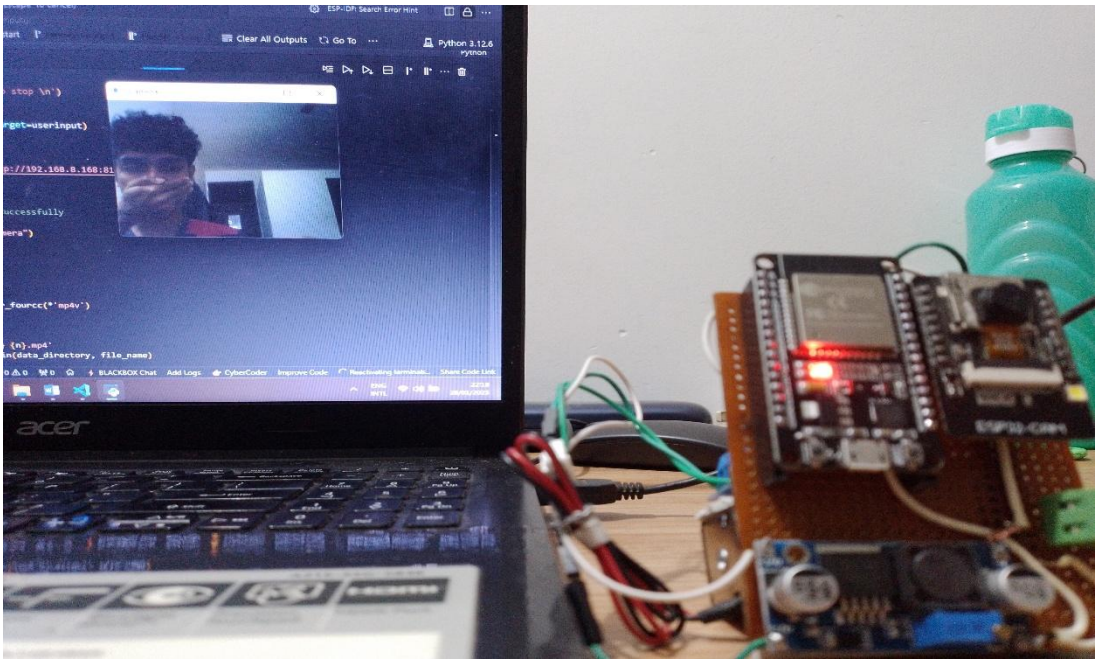

Figure 37 When no face is recognized from the setup

When the trained face was recognized by the experimental setup Pin 2 was high and LED was blinked to sent the signal to solenoid lock.

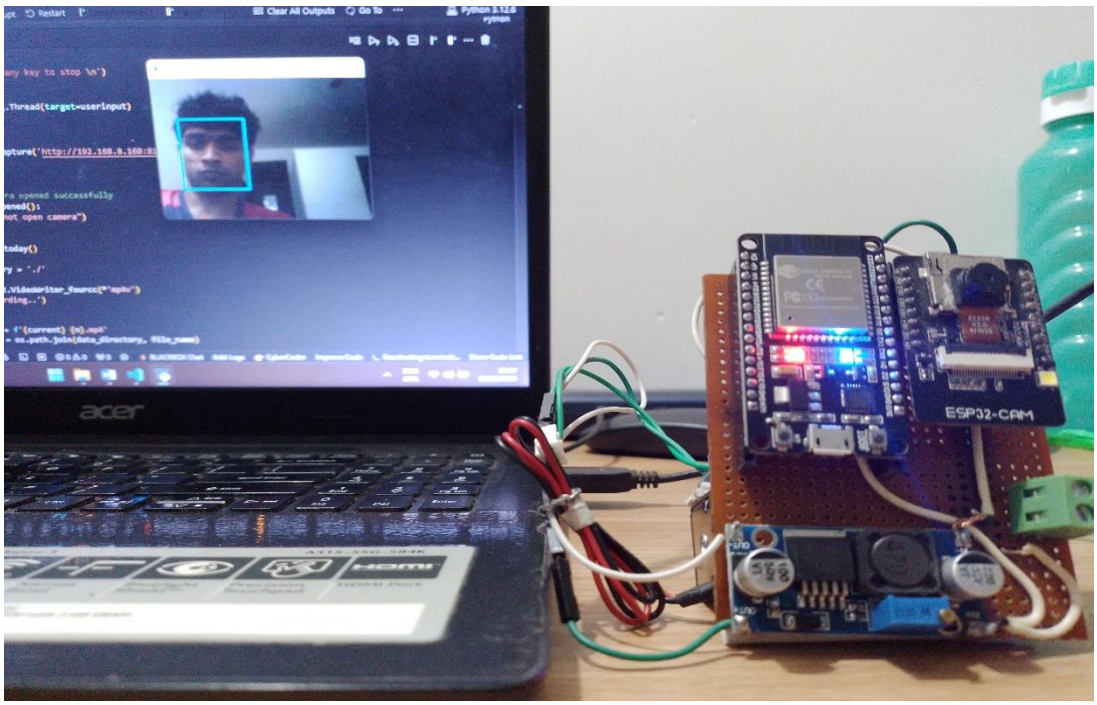

Figure 38 When enrolled face is detected

5. DISCUSSION

During this study I was able to implement experimental sequential model using tensor flow API and trained to recognize the faces of non-intruder and 24 hrs active surveillance working to protect the property from the intruders, all of these surveillance data stored in local storage. In nominal surveillance system only record the data and store them in a local storage. According to this study intruder detection system is working on to detect the intruders and act accordingly therefore for this project an AI based system required to achieve the tasks. According to this study there are many cameras working simultaneously and observing the behaviour of the human then decide the intruder or not. This including face of the human, violent behaviour of the human and whether tools or equipment are carried by the human therefore for this task there are many models needed to be implemented for detect the intruder.

In this experiment as I mentioned before I implement one of the models from above required models. This CNN based sequential model had # layers to recognize the faces. Input features from the image taken from the 4 convolution layers and then flatten input to the flatten layer finally dense layer used to output the result. After implement this model I was able to understand that this model work accurately and done the feature extraction from the faces and learn the features and predict the face features.

Above mentioned tasks were completed using this VScode and Platform IO. VScode was used to run jupyter notebook. Platform IO used to programme the ESP32 camera module. Hence from this experiment I was able to gain the experience on IDE tools and embedded platforms. Therefore, this project enhances my programming skills. When implementing the jupyter notebook I was able to hone my skills on python programming, I was able to learn new tools and functions in python. Python is the most widely used language for AI based tasks because most useful APIs such as tensor flow and matplotlib are supported this language.

During this project I had to enhance my expertise on python, deep learning and embedded systems because I was lack of expertise on that area. During prototype evolution ESP32 module was started to malfunctioning due to power issue then that was successfully repaired by replacing the board with new after fixing the power issue. There was some another issue in camera module the module was not able to program by the Platform IO and does not response to the serial input after some investigation I was able to understand that there is issue in power rails of the ESP32 cam module

programmer hence this was fixed by taking power from another source then only serial data communicate to the module using the programmer. There is another important fact that needed to be consider regarding the experimental prototype in the design implement both ESP32 MCUs and Solenoid locks (Electromagnetic lock) are closer without any enclosures hence it can interfere the Wifi but when doing the experiment there were no disturbance or error could not be found but this fact needed to be considered when improving this design in future.

This solution can be expanded by deploying scripts in to cloud server and running 24hrs without any disruptions. Hence adding this solution will enhance the performance of the algorithm considerably while saving the initial cost to computational power and simplify the hardware then this will be minimizing the overall system

Therefore, this discussion can be concluded this project was helped me to gain lot of expertise on Deep learning and AI concepts, embedded engineering, electrical design concepts and enhanced the expertise on software tools. Hence the hardware implementation is done for experiment that also enhance the skills on PCB design and creative thinking.

6. CONCLUSION

I can conclude that this study motivates me to do more projects on related to AI, Embedded Engineering and IoT because throughout this project I was able to get motivated by the new areas on deep learning, IoT, embedded engineering, programming, electrical and electronic engineering. Also, this distributed learning study helped to gain lot of expertise on critical thinking and problem-solving. Therefore, this project develops the soft skills as well as the technical skills. Not only that from this study we were able to observe that how embedded systems and IoT collaboratively can be worked to solve modern day problems.

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Appendix I

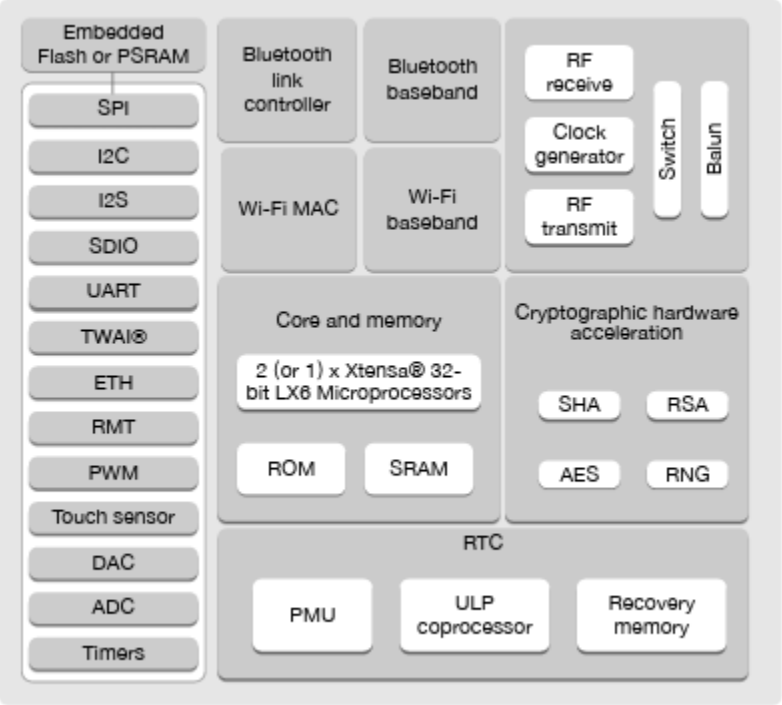

Figure 6.1. Functional Block diagram of ESP32

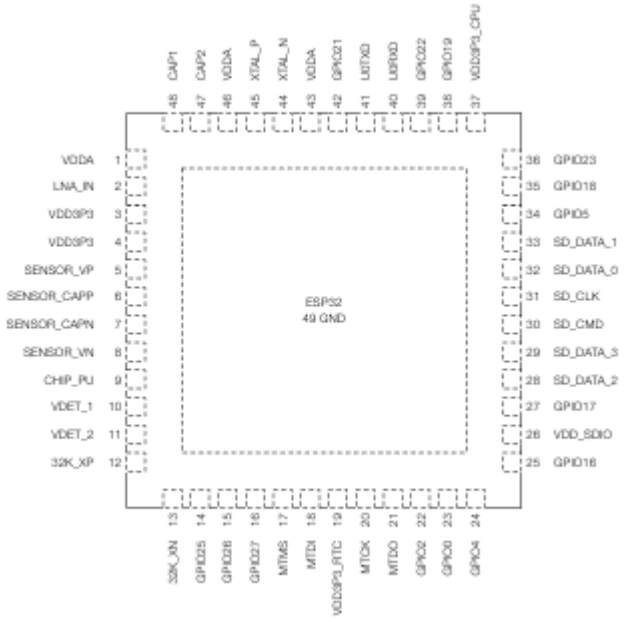

Figure 6.2 Pinout of the ESP32

Figure 39.3. Raspberry pi Board

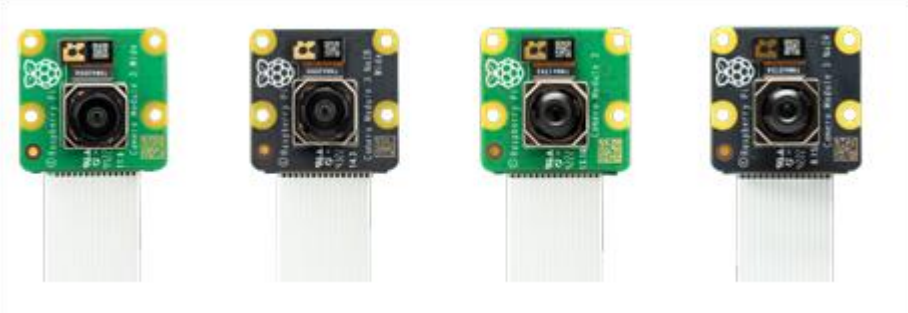

Figure 6.4 Raspberry pi camera module

Appendix II

Jupyter notebook Code for implementing CNN and Communicate with nodes

Block 1

```
import tensorflow as tf
import matplotlib.pyplot as plt
import os
import functools
import numpy as np
import random as rndm
from tqdm import tqdm
import pandas as pd
from PIL import Image
import cv2
import h5py
import sys
import threading
import glob
from IPython import display as ipythondisplay
from string import Formatter
import time
from datetime import date
from mtcnn import MTCNN
import socket
from tensorflow.keras.preprocessing.image import ImageDataGenerator
from sklearn.metrics import accuracy_score, confusion_matrix,
classification_report
```

Block 2

```
def test_images():
  model = tf.keras.models.load_model('face.h5')

  # Create a test data generator
  test_datagen = ImageDataGenerator(rescale=1./255)

  # Path to the test directory
  test_dir = 'C:/Users/Gishan/Documents/HS/faces'

  # Image dimensions
  img_height, img_width = 150, 150
  batch_size = 32
```

```
# Create test data generator
  test_generator = test_datagen.flow_from_directory(
    test_dir,
    target_size=(img_height, img_width),
    batch_size=batch_size,
    class_mode='binary',
    shuffle=False
  )

# Get predictions
  predictions = model.predict(test_generator)

# Convert probabilities to class labels (0 or 1)
  predicted_classes = (predictions > 0.5).astype(int)

# Get true class labels
  true_labels = test_generator.classes

# Evaluate model performance
  accuracy = accuracy_score(true_labels, predicted_classes)
  conf_matrix = confusion_matrix(true_labels, predicted_classes)
  classification_rep = classification_report(true_labels, predicted_classes)

# Print results
  print(f"Test Accuracy: {accuracy:.2f}")
  print("Confusion Matrix:\n", conf_matrix)
  print("Classification Report:\n", classification_rep)

  delete_files_in_directory('C:/Users/Gishan/Documents/HS/faces/user_1')

  return accuracy
```

Block 3

```
def delete_files_in_directory(directory_path):
    if not os.path.exists(directory_path):
        raise FileNotFoundError(f"Directory '{directory_path}' not found.")

    for filename in os.listdir(directory_path):
        file_path = os.path.join(directory_path, filename)
        os.remove(file_path)

def mse(imageA, imageB):
```

```
    err = np.sum((imageA.astype("float") - imageB.astype("float")) ** 2)
    err /= float(imageA.shape[0] * imageA.shape[1])
    return err
```

Block 4

```
ESP_IP = '192.168.8.188'
ESP_PORT = 80

def send_data_to_esp(data):
    with socket.socket(socket.AF_INET, socket.SOCK_STREAM) as s:
      s.connect((ESP_IP, ESP_PORT))
      s.sendall(data.encode())
```

Block 5

```
def userinput():
    x=input('Enter any key to stop \n')
    return x

thread = threading.Thread(target=userinput)

thread.start()

cap = cv2.VideoCapture('http://192.168.8.168:81/stream') #capturing the stream

detec = MTCNN()

# Check if camera opened successfully
if not cap.isOpened():
    print("Cannot open camera")
    exit()

current=date.today()

data_directory = './'

fourcc = cv2.VideoWriter_fourcc(*'mp4v')
print('recording..')

n=0
file_name = f'{current} {n}.mp4'
```

```
file_path = os.path.join(data_directory, file_name)

while os.path.exists(file_path)==True:
    n+=1
    file_name = f'{current} {n}.mp4'
    file_path = os.path.join(data_directory, file_name)

ind=0
filename = f'img{ind}.jpg'
data_directory = './frames'
file_path = os.path.join(data_directory, filename)

while os.path.exists(file_path)==True:
    ind+=1
    filename = f'img{ind}.jpg'
    file_path = os.path.join(data_directory, filename)

ind-=1

out = cv2.VideoWriter(file_name, fourcc, 10.0, (640, 480))
data = '0'

num=0
while thread.is_alive():
    ret, frame = cap.read()
    i=1
    out.write(frame)
    print(out.write(frame))
    while not ret:
        ret, frame = cap.read()
        if i==1:
            print('wait')
            i+=1

    if current != date.today():
        current = date.today()
        out = cv2.VideoWriter(file_name, fourcc, 10.0, (640, 480))

    if cv2.waitKey(1) == ord('q'):
        break

    frame=cv2.resize(frame,(320,240))

    faces = detec.detect_faces(frame)
```

```
    for face in faces:
        x, y, w, h=face['box']
        face_roi = frame[y:y+h, x:x+w]
        cv2.imwrite(f'C:/Users/Gishan/Documents/HS/faces/user_1/img{num}.jpg',fac
e_roi)
        cv2.rectangle(frame, (x, y), (x+w, y+h), (255, 0, 0), 2)

    cv2.imshow('Camera', frame)

    num+=1
    if num==10:
        num=0
        data = '0'
        if len(os.listdir('./faces/user_1'))>0:
            accuracy=test_images()
            print(f'accuracy: {accuracy}')
            if accuracy>=0.75:
                data = '1'
            else:
                cv2.imwrite(f'C:/Users/Gishan/Documents/HS/frames/img{ind}.jpg',f
rame)
        send_data_to_esp(data)

out.release()
cap.release()
cv2.destroyAllWindows()
thread.join()
```

Block 6

```
send_data_to_esp('0')
delete_files_in_directory('C:/Users/Gishan/Documents/HS/faces/user_1')
```

Block 7

```
detec = MTCNN()
for i in range(100000, 100300):
    prev=cv2.imread(f'./dataset/img_align_celeba/img_align_celeba/{i}.jpg')
    faces = detec.detect_faces(prev)


    for face in faces:
        x, y, w, h=face['box']
```

```
        face_roi = prev[y:y+h, x:x+w]
        cv2.imwrite(f'./faces/intruder/{i}.jpg', face_roi)


cv2.waitKey(0)
cv2.destroyAllWindows()
```

Block 8

```
n_filters=12
def learn_face(n_outputs=1):
        Conv2D   =   functools.partial(tf.keras.layers.Conv2D,   padding='same',
activation='relu')
    BatchNormalization = tf.keras.layers.BatchNormalization
    Flatten = tf.keras.layers.Flatten
    Dense = functools.partial(tf.keras.layers.Dense, activation='relu')

    model = tf.keras.Sequential([
        Conv2D(filters=1*n_filters, kernel_size=5,  strides=2),
        BatchNormalization(),

        Conv2D(filters=2*n_filters, kernel_size=5,  strides=2),
        BatchNormalization(),

        Conv2D(filters=4*n_filters, kernel_size=3,  strides=2),
        BatchNormalization(),

        Conv2D(filters=6*n_filters, kernel_size=3,  strides=2),
        BatchNormalization(),

        Flatten(),
        Dense(512),
        Dense(n_outputs, activation=None),
    ])
    return model

face = learn_face()

# Compile the model
face.compile(loss='binary_crossentropy',
             optimizer='adam',
             metrics=['accuracy'])
```

Block 9

```
detect=MTCNN()
#enroll new faces
def enroll_faces():
    n=1
    x=True
    cap = cv2.VideoCapture('http://192.168.8.168:81/stream')
    precentage=0
    while x:
        ret, frame = cap.read()
        faces = detect.detect_faces(frame)

        for face in faces:
            x, y, w, h=face['box']
            face_roi = frame[y:y+h, x:x+w]
            cv2.imwrite(f'./faces/user_1/img{precentage}.jpg', face_roi)
            cv2.rectangle(frame, (x, y), (x+w, y+h), (0, 255, 0), 2)
            precentage+=1

        cv2.imshow('frame', frame)

        if cv2.waitKey(1) & 0xFF == ord('q'):
            break

        if precentage<=100:
            print('=', end='')
        else:
            break

    cv2.destroyAllWindows()
    cap.release()

    train()
```

The following code was implemented to program the ESP32 to receive the data from PC using Platform IO.

```
#include <WiFi.h>
#include <WiFiClient.h>
#include <WiFiServer.h>
#include <WebServer.h>
#include <ESPmDNS.h>
```

```
const char* ssid = "Dialog 4G 071";
const char* password = "334Cc9e3";

String data;

WiFiServer server(80);

void setup() {
  pinMode(2,OUTPUT);
  Serial.begin(115200);
  WiFi.begin(ssid, password);

  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }

  Serial.println("");
  Serial.print("Connected to WiFi network with IP address: ");
  Serial.println(WiFi.localIP());

  server.begin();
  Serial.print("Server begin");
}

void loop() {
  WiFiClient client = server.available();

  if (client) {
    while (client.connected()) {
      if (client.available()) {
        data = client.readStringUntil('\n');
        Serial.println("Received from client: " + data);
      }
      if (data == "1"){
        Serial.println("nonintruder");
        digitalWrite(2, HIGH);
        delay(1000); // Wait for 1 second
      }
      if (data == "0"){
        Serial.println("NO");
        digitalWrite(2, LOW);
      }
    client.stop();
```

```
    }
  }
}
```