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Design and Development of a Cost-Effective Programmable Door Access Control System

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ABSTRACT

This research aims at the application of security esp32 camera and smart-phone for the design of a cost-effective programmable door access system. The system which is comprised of ESP32-cam which was successfully programmed with FTDI-232 USB serial interface adapter in order to carry out the desired assignment, sensor, and electromagnetic solenoid lock is designed to be dependent on the presence of an intruder or visitor within the sensor range, and to send photo notification to a smartphone for security enhancement. Telegram application setup installed in smartphone is used for building up WI-FI network interface, while Unified Modeling Language (UML) is the modeling tool applied to model the functionality and to describe all the activities of the system. Arduino Integrated Development Environment (IDE) which uses arduino code written in C++ programming language was applied to develop the source code. The system was later tested to ensure the following: the output voltage was sufficient enough to drive BC 547 transistor to saturation, TIP 122 darlington transistor was forward biased to supply 12v to the electromagnetic solenoid lock, as well as for recognition of pictures at the appropriate position on the smartphone, and for response to all the peripherals and mode of operation as desired in conformity with the software program,.The system which was unified by integrating all the modules in a main control loop, keeps track of those that enters sensitive areas, and also captures the pictures of intruders with real time feedback was tested and implemented to restrict unauthorized entry attempt in secured areas.

Keywords: security, door access system, esp32 camera, PIR sensor, smartphone, arduino, internet of things, smart lock

I. INTRODUCTION

Udu et al. (2022), explained that access control system is a great accomplishment that keeps rewarding the world with security of lives and property, as it allows access to authorized users, and also denies access to unauthorized persons. They pointed out that the need for a robust access control cannot be over-emphasized as the installation of key lock on doors has no restriction when entrance key falls into the hands of an unauthorized user.

According to Studycountry (2023), an ancient Egyptian made the first door used in the ruins of the palace of khorsabad near Ninevah over 6,000 years ago. However, in 1778, Robert Barron patented a double acting tumbler lock (Phillips, 1995). While Jeremaiah Chubb in 1818, incorporated detonator in doors for improving their security (Carlisle, 2004). With great skills and high degree of workmanship in 1848, Linus Yale patented a pin tumbler lock while working on an ancient Egyptian principle. The demand for locks increased with the emergence of industrial revolution.

Over the years, door locks have been constructed with many specialized functions ranging from resistance to explosion, shooting or stabbing by intruders, as well as seizing of hands. Some door control systems are designed with smart cards that provide information to authenticate an individual's claim of personal identification, using possession-based authentication such as passport, driver's license, credit card, or access card.

Smart lock is a device that contains electronic components and uses Bluetooth or WIFI connectivity for lock and unlock schedules without the need for traditional key. The early home

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automation began with labor saving machines and home appliances becoming viable with the introduction of electric power distribution (Siddanth, 2022). However, Hill (2015), observed that smart locks are considered part of a building automation for a home and due to its ability to use advanced technology and internet communication to enable easy access for users and provide enhanced security from intruders. Smart locks may monitor access and send alerts in response to the different events it monitors as well as other related events related to the status of the device. They allow users to grant access to a third party by sending alert to the recipient smartphone over standard messaging protocol via SMS, e-mail or dedicated application to enable door unlock. Some smart locks have in-built Wi-Fi connection which allows monitoring features like access notification and cameras capture for access.

II. THE SYSTEM'S COMPONENTS

Smartphone

A smartphone is the kind of phone that has additional functions when compared with mobile phone, such as improved camera, internet access for transmitting data, in addition to video call and the option to download applications. According to Smith (2018), The technology company IBM is widely credited with development of the world's first smartphone which was bulky but named Simon. He observed that it went on sale in 1994 and featured the following: a touchscreen, email functions as well as a handful of built-in apps, alongside a calculator and a sketch pad.

Smartphones have been found to increase productivity in the workplace, enhance school learning, and also build social capital (Park, Han and Kaid, 2012). Despite the advantages of smartphones, researchers are in dispute how they are perceived, as some people fully understand their advantages and utilize them, while others are skeptical or simply unaware of their possibilities (Elrod et al., 2011).

Arduino

Singh, Gerlot and Singh (2023), explained that arduino is an open source electronic prototyping platform founded on flexible, user-friendly hardware and software. The Arduino platform offers an integrated development environment that supports C, C++, and Java programming languages (Chatterjee, 2023), which are used to write the program code for arduino known as sketch (Singh et al., 2018). According to Singh, Gerlot, and Singh (2019), in 2005, the first ever arduino board was developed in the interactive design institute in Italy by a Columbian student HernamdoBaragan, he created devices that can serve the environment by receiving input from sensors and actuators, as well as affect its surrounding by controlling devices.

Arduino board have been used extensively in home activities with control system such as motion sensors, blower control, temperature sensors, garage door control, air flow control, sprinkler control and bill of material, heartbeat count, eye tracker, alcohol detection, supervising system, controlling traffic light, and other real time control system with programmable timings (Kaswan, Singh and Sagar, 2020).

Servomotor

Servomotor is a device based on Micro-Electromechanical Systems (MEMS) technology and features a closed–loop transducer with an analogue output. In order to integrate such sensors into existing system or design new ones, several interfaces are required by each application. Some need digital data while others require only an analogue signal. The two interface methods that can be used interchangeably depending upon the system requirements include direct connection via 12volt protocol, and indirect connection via voltage divider circuit that outputs suitable voltages between zero volt (0v) and two volts (2v), when no load is applied to the sensors terminals.

A system of this patent is a servo system that operates in accordance with position or speed command and it can control angular or rotatory actuating force at zero level. The basic configuration therefore utilizes the switching operation between main terminals of a circuit which consists of three phase bridge circuit containing six power transistors and six resistors.

Telegram

Launched on 14th August 2013, telegram is a messaging application with an overriding aim to enhance reliability, fast data transfer, and secured communication. The history of telegram demonstrates the evolution and development of applications for other platforms. Pavel Durov provided the financial and ideology of telegram while Nikolai built up its technology input to make telegram a reality. Telegram sustainability is a great way for engineers and developers ranging from sponsored message management to protecting private data of users from advertisers and telegram improvement for the future. With advancement in technology, engineers and developers have made telegram free and independent for users.

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Recently, telegram provides secured means of communication that works everywhere on the planet and supports independent researchers to verify the integrity of end to end encryption. Telegram prevailed more in developer's world and gained high performance that makes processes faster and reliable for security purposes because of its easier location sharing features.

Telegram bots are small program that runs right inside telegram. They are created by third party developers using telegram. Telegram becomes user friendly through bots' interactive interface ability to all manners of task and services because they are free for both users and developers. In order words, telegram bot provides many other tools via @Botfather, for building flexible interface to meets user's need. It supports multiple languages that adapts to user's language settings in the app known as command.

Telegram bots have offered consistent and user-friendly experience through developer's ability to make basic interaction more uniform such as /start which open a chat with the users' bot, /help returns a help message for the user, while /settings shows the bots settings for the user and suggest command to edit them.

Security ESP32 camera

Espressif system manufactured the chip esp32 which is capable of providing WIFI and dual Bluetooth connection. Esp32 is comprised of an OV2640 camera with support for onboard TF card slot. As a result of Internet of Things (IOT), Esp32-cam have gained massive popularity as it brought abrupt change in intelligent security system. Many manufacturers have used esp32-cam to express creativity mostly on digital door lock systems.

Today, Esp32-cam have become the future for manufacturers, as it provides different opportunities to building more advanced home automation projects including detections, taking photos and facial recognition, building surveillance camera, setting up wireless video monitoring, wifi image upload, as well as wifi video door-bell. Esp 32 chip has come to stay in manufacturing industry as it permits the addition of external memory of the micro-controller.

FTDI-232

Future Technology Device Interface (FTDI) was founded by Fred Dart in a Scottish based company specialized in Universal Serial Bus (USB) technology on the 13th of March 1992. FTDI chip is comprised of Input / Output (I/O) pins which is configured to operate at 5 volts. It supports the connection between USB to TTL interface devices because of its ability to convert a USB signal to UART signal for micro-controller to interpret.

With FTDI, manufacturers find it easy to transfer low bandwidth USB data from computer to external device, establish arduino and micro-controller compatibility, create interface devices to the USB port of computer, and also develop human-machine interface.

III. METHODS

The methods employed in the work include the following:

A. Design of the Hardware Components

This includes block diagram of the system, circuit diagram of regulated power supply, and the architectural design of the system.

Block diagram of the System

The block diagram of the system is shown in 1.

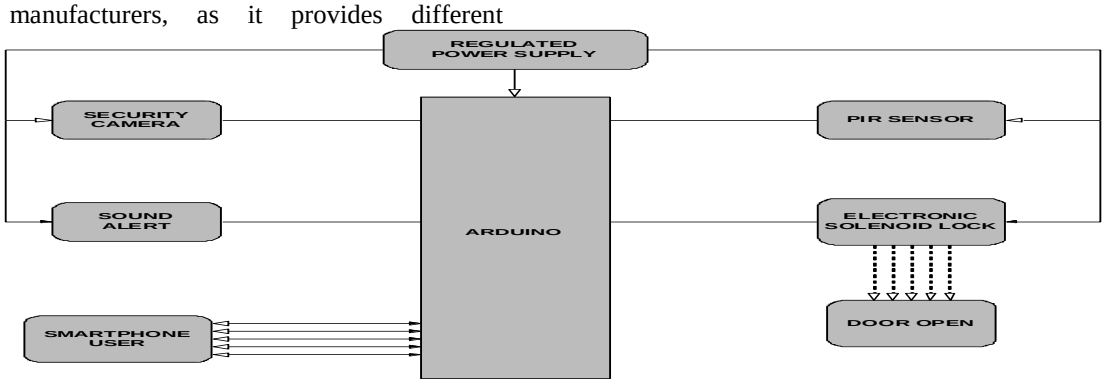

Figure 1: Block diagram of the system

Regulated Power Supply

In general, AC supply of 240v, and 50Hz is supplied for regulation as shown in figure 2.

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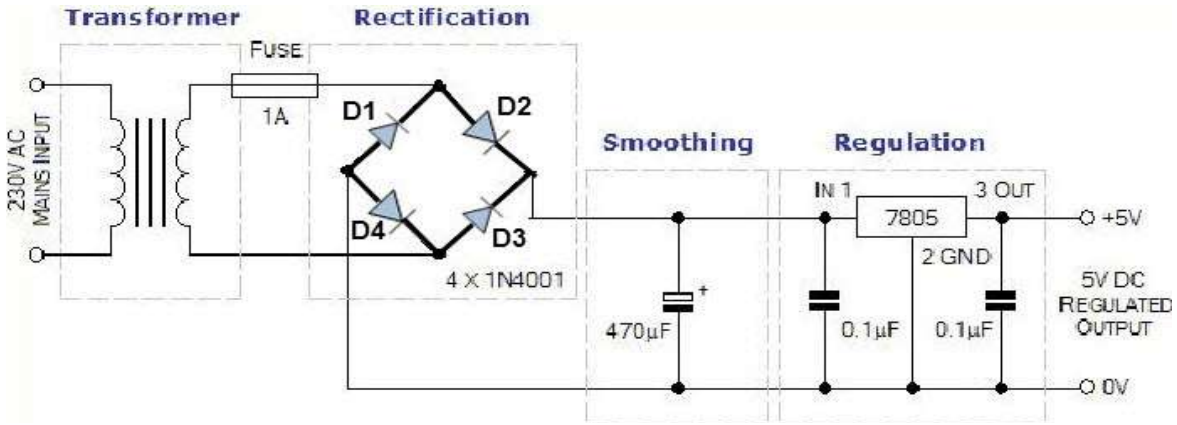

Figure 2: Circuit diagram of regulated power supply

Regulated power supply is comprised of 240v/12v step down transformer, rectifier, voltage regulator and capacitor. It energizes the entire system.

Transformer section

The 240v AC was stepped down to 12v AC using transformer. The resultant output voltage is given as: $Vp = \sqrt{2} \times Vrms$

1

Where Vrms is the root mean square value of the secondary transformer voltage. Vrms = 12
Therefore, Vp = 16.97v

Rectifier section

A full wave bridge rectification of 5A is chosen for the capacity to a load up to 2A using IN4001 diodes. The DC value of the rectified voltage is given by: $Vdc = {}^{2}/\pi \times V_P$ 2
Substituting V_P as 16.97, Vdc = 10.80v. The maximum load current (Imax) is given by:
$Imax = \sqrt{2} \times 500Ma$

3

Imax = 707.1mA. Hence the average load current (I_{dc}) can be obtained from:
$I_{dc} = {}^{2}/\pi \times Imax$

4

Therefore, I_{dc} = 449.72Ma. Hence, the specification of the transformer chosen is 12v, 500mA.

Filter section

The ripple voltage (V_r) is represented by the equation 5: $V_r = 0.308 \times Vdc$ 5

With the Vdc of 16.97, V_r becomes 5.22V
The ripple factor (r) = 0.1 is used to calculate the filtering capacitor. Hence the shunt capacitor is obtained from: $Vr(rms) = Idc / (4\sqrt{3}FC)$

6

From equation 6, $C = Idc / (4\sqrt{3}F\ Vr(rms))$
Where, Idc = load current (mA), f = frequency of supply (Hz), C= shunt filtering capacitor (microfarads) and Vr(rms) = root mean square value of the AC component ripple voltage.
Idc = 449.72mA, r = 0.1, f = 50Hz, and Vr(rms) = 7.84v
Substituting, C = 2487.03uf. Hence, the specification of capacitor chosen is 2200uf, 35v.

Voltage Regulation Section

The voltage regulator used is 7805 IC. Its current rating (Ic) = 1A, output voltage rating (Vmax) = 5.2v, (Vmin) = 4.8v while its input voltage ranges from 7v - 35v.

B. Design of the Software Components

The design of the software components includes system modeling, activity diagram and flowchart of the system.

System Modeling

In the use case diagram shown in figure 3, the system is door control system, while the actors are the visitor, PIR sensor, server and the smartphone user.

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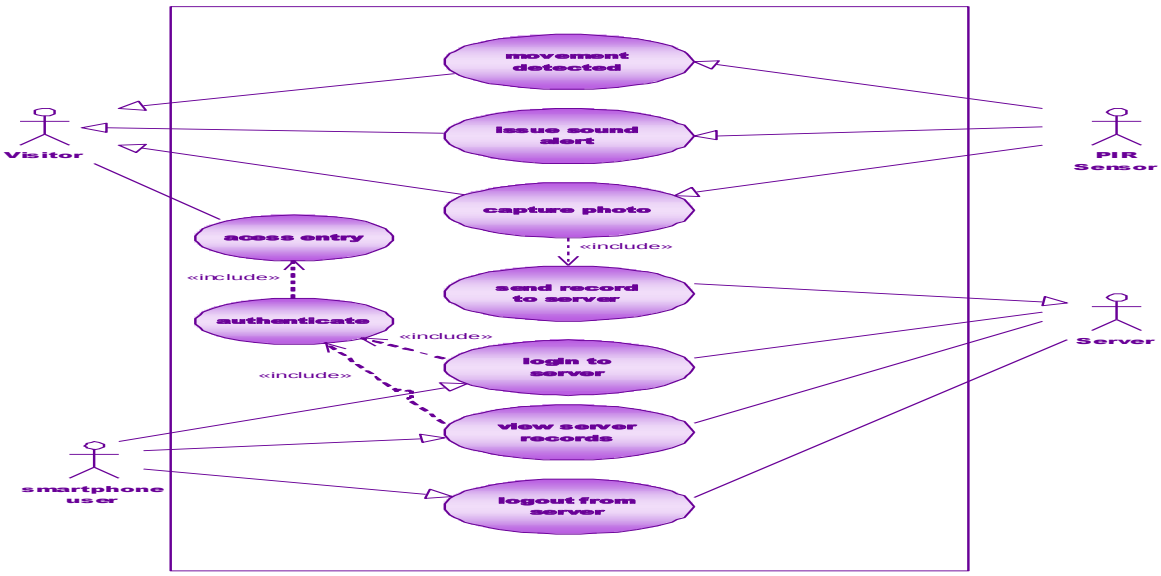

Figure 3.13: Use case diagram

Activity diagram of the system

Activity diagram of the system is shown in figure 4.

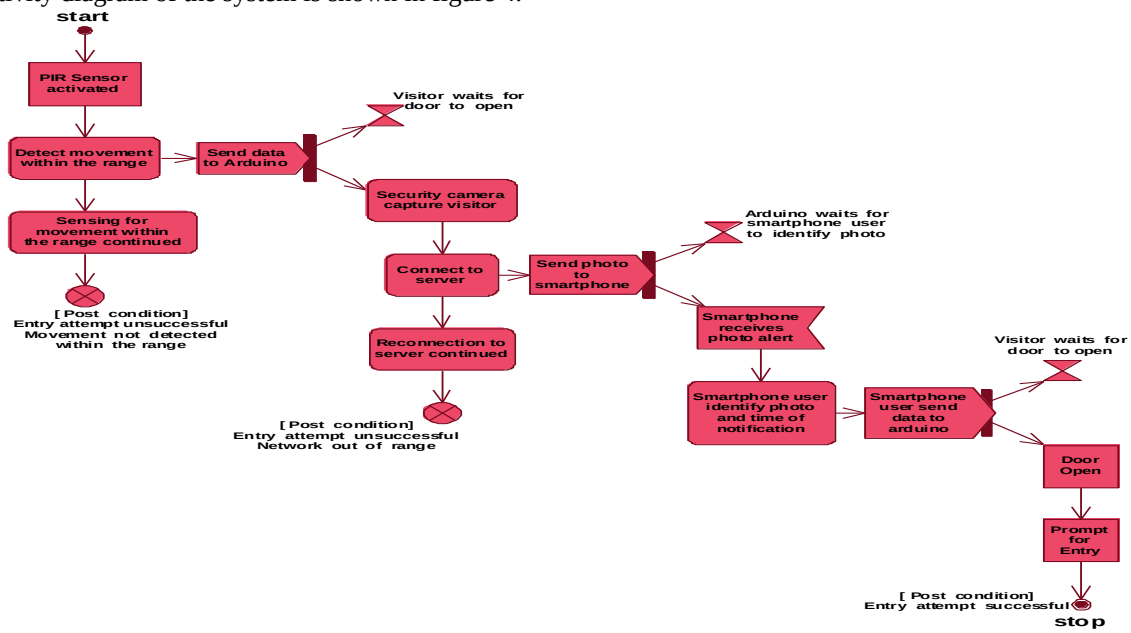

Figure 4: Activity diagram

System flow chart

In this design, the system flow chart is shown in figure 5.

International Journal of Advances in Engineering and Management (IJAEM)
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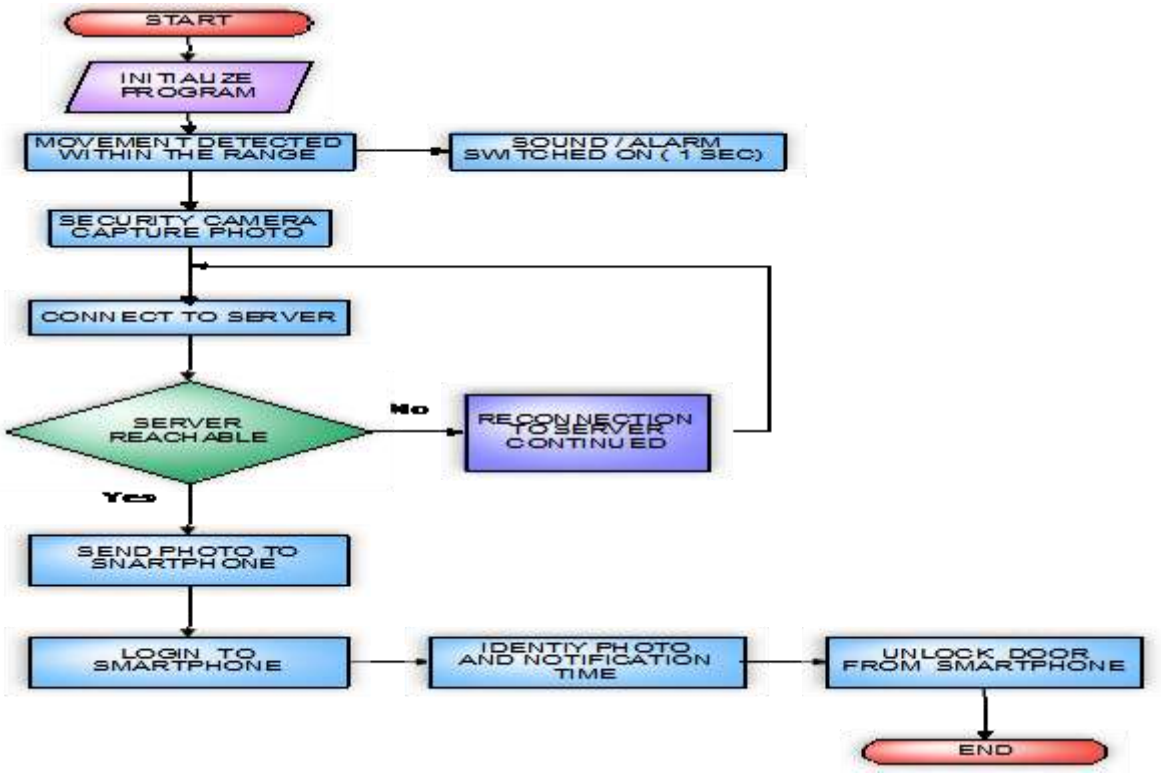

Figure 5: The System's flow chart

C. Architectural Design

Architectural design views play important role in communicating a building's spatial qualities through dimensional rendering. The use of these views allow clients to visualize the building in its entirety as well as specific details that may be difficult to see from one perspective as depicted in figure 6.

Figure 6: Front view and floor plan

Views in architecture are one of the fundamental components that make up a building where one can gain information about the space within it. They allow various aspects of space to be seen at once, thereby providing better understanding of its nature both from its exterior

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and interior perspectives, which includes the floor plan, frontal elevation and side elevation.

IV. RESULT AND DISCUSSION

The results from various sections of the design which involves the details of the system design, system implementations, and the results of experimental test are discussed here.

Details of System Design

The results obtained from the design of the system are presented using the use case diagram and the activity diagram as explained in methods. The system's external users and usage requirements are identified using the use case diagram in figure 3.The activity diagram in figure 4 described the operations carried out by the use case diagram in the system from start to stop, while architectural design view allows clients to visualize the various perspectives of the building in its entirety as shown in figure 6.

System Implementation

The various sections of the system are implemented with the application of different circuitry formulations and software coding for providing appropriate control in order to achieve the aim of the design. The implementation of the hardware subsystem was achieved unit by unit including PIR sensor interface circuit diagram and electronic solenoid interface diagram.

PIR sensor interface diagram is the input sub-system of the design to enable data entry and operation of the system. There is the need to design external circuit for PIR sensor to enable the transfer of output data. To achieve positive result, the output voltage of the sensor reads about 3v to 5v which was sufficient to drive BC 547 transistor to saturation, to switch ON the speaker, and to make GPIO 14 pin to be in high state. Esp32-cam was connected through the interface though GPIO 14 to access input using writing program.

From the writing program, Esp32-cam arduino makes GPIO 12 pin HIGH in order to unlock the door. The output voltage GPIO 12 pin read 3v from the voltmeter. However, it cannot in any way energize electromagnetic solenoid lock when the output pin was connected directly. The output voltage (3v) from GPIO 12 output pin was connected to the base terminal of TIP 122 Darlington transistor to drive 12v into the solenoid lock for the door to unlock.

To install an arduino core board, board cores already available in the Boards Manager are updated with every new release of the Arduino Software (IDE). To access these boards, one will click on Tools menu, then Board > Boards Manager. The Boards manager opens the list of installed and available boards, and the index file download may take some time. Once the list appears, the Arduino SAM Boards core as shown in figure 7 will be clicked on to enable one to choose the version in the drop-down menu, before clicking on Install.

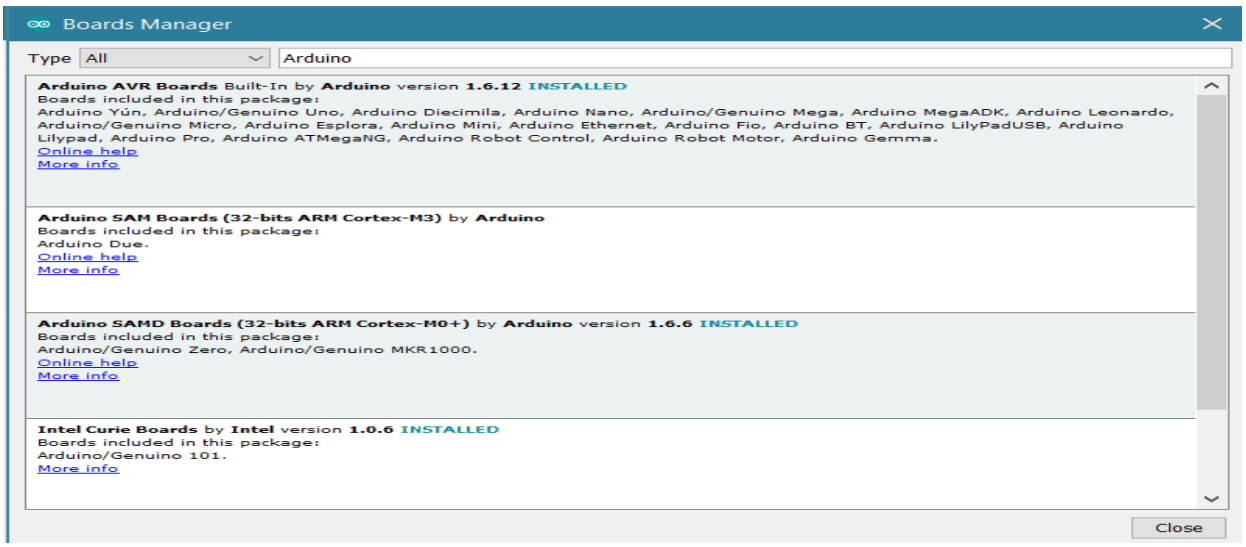

Figure 7: Arduino SAM boards core

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 03 Mar. 2024, pp: 355-365 www.ijaem.net ISSN: 2395-5252

The download time will depend on the connection speed. After installation is complete, an installed tag appears next to the core name as depicted in figure 8, and the Board Manager can be closed.

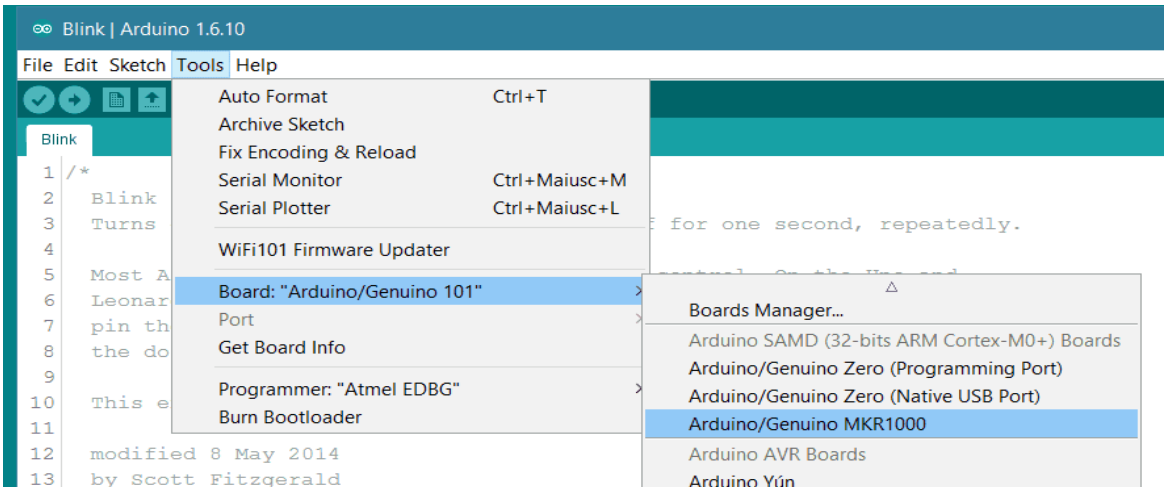

Figure 8: Installed tag

To install a third-party core, a specific file written in JSON format must be added to additional Board Manager URLs inside Arduino Software (IDE) Preferences.

As depicted in figure 9, to add more JSON files, click on the little icon on the right of the field and a window will open where URL's can be inputted one line at a time.

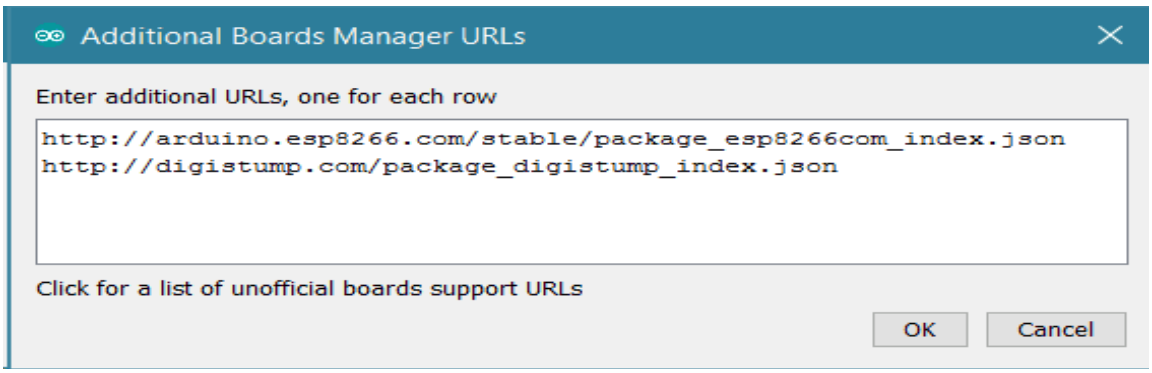

Figure 9: Entering of URL

After this procedure, the new cores will be available for installation in the boards manager.

Arduino Programming

The arduino IDE, Esp32 boards and arduino libraries were then in the computer, after whcih ESP32-CAM was attached to the computer with USB to TTL serial interface board. The installed arduino IDE in the computer was then opened and the right board was selected by choosing tools → port, followed by choosing the appropriate board from the board manager. This board can be programmed with the help of arduino programming language.

The board can be flashed to ensure program code is loaded successfully by selecting file → basic → flash for the program code to be dumped into the IDE, and then click on the upload button located at the top navigation bar. The LED on arduino board keeps blinking until the program load is complete.

The software program used for the programmable door system was written in computer system. The source code was developed and tested for error using the Integrated Development Environment (IDE). It is important to load computer written program into Esp32-cam board using USB to TTL serial interface board. The circuit connection for the interface is shown in figure 10.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 03 Mar. 2024, pp: 355-365 www.ijaem.net ISSN: 2395-5252

Figure 10: Esp32 programming circuit diagram Source: Techno-rev (2024)

During the loading process, LED indicator in Esp32-cam blinked repeatedly until sketch upload was completed before it stopped. This shows that the programming was successful. The control sub-system is implemented using telegram application setup installed in smartphone to create WI-FI connection. Esp32-cam is a WI-FI module integrated with in-built microcontroller, mini camera and 1MB flash. It permits all WI-FI networking functions including quick interface build up for controlling and monitoring from smartphone by the user. With the TCP/IP protocol stack, the module communicates to the smartphone with WI-FI network.

Telegram application is responsible for all the communications between the smartphone and Esp32-cam. This made it easy for Esp32-cam to send notification on the smartphone as a result of the interface build up by telegram app. With the setup on the smart phone, it was possible to capture another photo of a visitor for identification, and to unlock the door with a soft touch on the screen of the smartphone.

Working Principle of the System

Regulated voltage from power supply circuit is used to energize Esp32-cam and electronic lock of the system. PIR sensor at the entrance door detects infrared radiation from a visitor or an intruder within its range. It converts infrared input to output data for processing. With the written program, security camera is activated to take picture of a person standing at the entrance door.

At the same time, the smartphone user receives photo notification of the visitor or intruder on the mobile phone for identification. The smartphone user with a soft touch on the screen performs unlock and lock schedule from the smartphone without passing through the inconveniences of going to the door. After the error corrections were made, the appropriate power input and output were ensured. The active components were placed on the board one after the other and tested for their activeness and functionality. None responsive ones were replaced and the board was set to receive the control software for its proper operation. Telegram application was installed successful on the smartphone, With WI-FI connection, interface was established between Esp32-cam and smartphone.

Esp32-cam was tested to ensure recognition of photo at the appropriate position on the smartphone and for response to all the peripherals and mode of operation as desired in conformity with the software program. PIR sensor was tested to detect infrared radiation from visitor or intruder within its range. The output voltage of GPIO-12 pin was tested to ensure the supply of 12v to drive servomotor. Finally, the entire software was put together by integrating all the modules in a

main control loop and tested for conformity with the main control program.
On evaluation, it was realized that the research performed up to 98% of its proposition. However, with little adjustment of the error noted in the test result, a 100% performance can be achieved.

The Cost-Effectiveness of the System

The application of security ESP32 camera and a smartphone for access in the design of a programmable door access system is cost-effective compared to the ones available in the market due to several factors. Firstly, the ESP32 camera is an affordable and versatile option for image capture and video surveillance. It provides high-resolution video streaming capabilities, allowing for real-time monitoring of the door access area. The cost of the camera itself is relatively low compared to traditional CCTV systems. However, the total cost of acquiring the components of the system was one hundred and forty two Dollars, making it a budget-friendly choice.

Additionally, integrating a smartphone into the door access system eliminates the need for expensive physical access control devices such as key cards or fingerprint scanners. Smartphones are already widely adopted and owned by a large portion of the population, thereby reducing the additional costs associated with acquiring and distributing access control devices. Furthermore, using a smartphone as an access credential eliminates the need for dedicated infrastructure or additional wiring. It can utilize existing Wi-Fi or cellular networks for communication between the access control system and the smartphone. This significantly reduces installation and maintenance costs, as there is no need for complex cabling or extensive network setup.

Moreover, the programming capability of the ESP32 allows for customization and flexibility in the door access system design. It can be easily programmed to adapt to specific access requirements, such as different access schedules for various personnel or temporary access permissions for visitors. This flexibility eliminates the need for costly third-party software or system modifications often required with off-the-shelf solutions.

Additionally, the integration of the ESP32 camera and smartphone access system offer enhanced security features. For instance, the camera can be configured to capture images or videos whenever an access attempt is made, providing visual evidence for any potential security breaches. The smartphone access system can also incorporate multi-factor authentication, such as combining a unique access code with biometric verification from the smartphone's fingerprint sensor. These added security measures enhance the overall effectiveness of the access system while still remaining cost-effective.

V. CONCLUSION

The successful application of ESP32 Cam, PIR sensors, and smartphones for cost-effective access door control allows for real-time monitoring and surveillance of access points. This technology provides an efficient and cost-effective solution for maintaining security in different environments. The use of smartphones as a means of access control ensures seamless and convenient entry into restricted areas. This is because users can easily authenticate themselves using their smartphones, thus eliminating the need for physical keys or access cards.

The system allows for centralized management of door access control systems. This setup enables administrators to remotely monitor access, grant or revoke permissions, and track usage logs, thus providing greater control and flexibility. The integration of these technologies offers a more affordable alternative to traditional access control systems. ESP32 Cam and PIR sensors are relatively low-cost components, while smartphones are widely available.

The modular nature of ESP32 Cam, PIR sensors, and smartphones allows for customization and scalability of access control systems. Additional features and functionalities can be easily integrated, depending on the specific requirements of the environment. This adaptability ensures that the system can evolve alongside changing security needs. These findings demonstrate the potential benefits of utilizing ESP32 Cam, PIR sensors, and smartphones for cost-effective access door control systems, which can continue to advance and provide effective security solutions for various industries and settings.

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