TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Mechatronics and Autonomous Systems Centre

DEVELOPING INTERNET OF THINGS AND MACHINE LEARNING BASED BI-DIRECTIONAL PEOPLE COUNTING SYSTEM WITH PASSIVE INFRARED SENSORS

ASJADE INTERNETIL JA MASINÕPPEL BASEERUVA KAHESUUNALISE INIMESTE LOENDAMISE SÜSTEEMI ARENDAMINE PASSIIVNE INFRAPUNA SENSORITE ABIL

MASTER THESIS

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Tallinn 2021

(*On the reverse side of title page*)

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THESIS TASK

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main speciality: Mechatronics
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Thesis topic:
(in English) DEVELOPING INTERNET OF THINGS AND MACHINE LEARNING BASED BI-DIRECTIONAL PEOPLE COUNTING SYSTEM WITH PASSIVE INFRARED SENSORS
(in Estonian) ASJADE INTERNETIL JA MASINÕPPEL BASEERUVA KAHESUUNALISE INIMESTE LOENDAMISE SÜSTEEMI ARENDAMINE PASSIIVNE INFRAPUNA SENSORITE ABIL

Thesis main objectives:

1. Configuring the field of view of the PIR sensors for the people counting system
2. Writing the hardware program using the interrupt mode depending on the triggering time of the two PIR sensors
3. Real-time transfer of sensor data to the cloud system
4. Performing data analysis of the number of people data
5. Using the number of people data for prediction with machine learning algorithms

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Planning the software and hardware infrastructure of the system	February 2021
2.	Prototyping of electronic boards and 3D parts of the system	March 2021
3.	Ensuring the IoT integration of the system	April 2021
4.	Real-time testing of prototypes and analysis of the data	April 2021
5.	Using the data for prediction with machine learning algorithms	May 2021

Language: English **Deadline for submission of thesis:** "18" MAY 2021

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List of abbreviations and symbols

3D	Three-dimensional
AIoT	Artificial Intelligence of Things
ANN	artificial neural network
BLE	Bluetooth Low Energy
BPN	Back-Propagation Network
C-PIR	Chopped passive infrared
CNC	Computerized Numerical Control
dBA	A-weighted decibels
DT	Decision Trees
EN	Enable
GPIO	General-purpose input/output
HVAC	Heating, Ventilation, and Air Conditioning
I^2C	Inter-Integrated Circuit
I^2S	Inter-IC Sound
IDE	Integrated Development Environment
IFTTT	If This Then That
IoT	Internet of Things
IR	Infrared
kNN	k-nearest neighbors
M	meter
MCU	Microcontroller Unit
ML	Machine Learning

PCB	Printed Circuit Board
PIR	Passive Infrared
PWM	Pulse width modulation
RBF	Radial Basis Function
RF	Radio Frequency
RF	Random Forest
Ro-PIR	Rotationally chopped passive infrared
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SVM	Support vector machines
SVR	Support Vector Regression
TTL	Transistor–transistor logic
UART	Universal asynchronous receiver-transmitter
USB	Universal Serial Bus
WHO	World Health Organization
Wi-Fi	Wireless fidelity

PREFACE

With my eternal gratitude to the merciful God.

I would like to thank my supervisor Dmitry Shvarts for his great support and contributions to my master's thesis.

I would like to thank my parents Zeliha Arslan and Mehmet Emin Arslan and my brother Umut Arslan, whose love and support I have always felt in my heart throughout my life. And Beyza Capan, you are my inspiration, thank you for everything.

And finally, I would like to thank Sukru Bicakci, support for the machine learning part of this master thesis. My friend Gulsum Gurcan, thank you for all your support and assistance. I would like to thank everyone for their contributions to my education life and this important work.

This research work is the development of an internet of things and machine learning based low-cost, bi-directional people counting system using PIR sensors. The goal of this research work is to develop prototypes from scratch with the methods determined during the research, to test the prototypes in the field in real-time, and to make predictions using machine learning algorithms with the obtained data.

Keywords: 'people counting', 'PIR sensors', 'people counting for machine learning', 'IoT based people counting system', ‘master thesis’

1 INTRODUCTION

The goal of this research work is to develop internet of things (IoT) and machine learning based, low-cost, low energy consumption people counting device. The device aims to count the number of people on a single device while entering or exiting from a building or specific gate. In addition, this device will work with low energy consumption passive infrared spot detection sensors and will include a Wi-Fi connection for real-time data monitoring. With the data regarding number of people in real time and time-based human circulation data, the smart people-counting device aims to assist companies in their indoor energy management, companies' employee shift management and health management systems in the case of an emergency such as a pandemic.

The device may be of interest to the companies and stores where the volume of the sales based on the number of customers or the number of people in stores is restricted in accordance with the law caused by an unexpected event such as a pandemic. Also, those measurement can be used for optimizing area-based HVAC systems and lighting systems optimization based on the density.

In this research, we are going to proceed step by step for the prototyping of IoT-based, low-cost, low energy consumption people counting device. To conduct the research, the following steps will be taken: sensor research, developing algorithm, programming hardware, designing mechanic parts, 3D prototyping, designing printable circuit board, integrating of infrastructure of internet of things platform, laboratory tests and real-time tests.

Nowadays, passive infrared (PIR) sensors are frequently used for the control of ventilation, air conditioning and lighting systems based on the number of people [1]. According to the WHO (2020) considerations for the disinfection of environmental surfaces in the context of COVID-19, counting number of people in enclosed place is so important for avoiding virus contamination risk [2]. However, because of the detection method of the passive infrared (PIR) sensor, the measurement error margin of some of them is high and many systems do not include internet of things infrastructure [3].

Researches show that this is a common problem of similar solutions in which PIR sensors were used. This is due to the masking effect of the PIR sensors which does not allow it to detect any subsequent motion within a short period after it was triggered. In many projects, an extra sensor or a camera is used for solving this problem.

The device will be designed using passive infrared sensors to be cost-effective and measure input and output with a single device. These objectives can cause some problems such as an unsuitable sensor field of view and fluctuations in sensors' output because of the bidirectional measurement. Also measuring errors may happen due to consecutive human mobility, one after another within a short period of time (about 1-2 sec).

Advantages of our solution compared to other systems are measurement independent of human error, ability to measure input and output with a single device, low-energy consumption, not need cameras or other sensors and helps body-count based HVAC systems and lighting systems.

During the research and development, we are going to look for answers to these research questions. How can people counting devices, those consist of real-time data monitoring, be produced with low-cost and low power consumption? Are passive infrared spot detection sensors suitable for sensitive indoor people counting applications? How can the data obtained from the counter sensor, regarding the number of people, be used for energy management, companies' employee shift management and pandemic centred health management systems? In addition, it is required to check the accurate measurement of the number of people by passive infrared sensors, to keep data transfer uninterrupted with the Wi-Fi module and to maintain low power consumption of the device.

The success criteria for the subjects we work on in the research and development process are determined as follows. Multiple people pass one after the other within a short period of time should be smaller than 600 milliseconds and the success rate should be over 91% in a hundred consecutive measurement attempts. The continuous operation of the people counting device should be more than 6 hours with external power supply and internal battery. The device must be able to perform uninterrupted real-time data transfer and display for 6 hours via Wi-Fi connection. Measurement will be made for three days at different work places within working hours with the devices prototyped within the scope of the thesis. The received data will be analyzed with the data analysis methods, density of occupancy at work places will be determined. Also, the values of the number of people at certain time intervals in the workplaces will be processed by machine learning methods, and then, in coming days the time-based number of persons will be estimated.

2 LITERATURE REVIEW

2.1 Existing methods

In 2012, Wahl et al. [4] introduced a new approach to predict the count of the number of people per office area using distributed, strategically located PIR sensors and algorithms which are able to process the distributed sensor data is proposed by the author. This approach can be used for dynamic, occupancy-dependent HVAC and lighting and appliances' control of office areas. The probabilistic distance-based algorithms' ability to outperform a simpler direction-based counting is confirmed with the result of simulations. Both algorithms incur errors for insertion errors above 1%. However, as confirmed by measurements large error ratios do not appear in real systems. It is also stated that there might be errors due to measurement, but these errors are reduced by using multiple devices in the project. The simulation is found to be helpful in providing valuable insights into the algorithms' performance under varying concurrent occupant movement scenarios, which would be challenging to explore otherwise.

In the article, a multi-modal solution to the problem of counting the number of people in a given space is described by Erden et al. [5] Consisting in the multi-modal system are a differential pyroelectric infrared (PIR) sensor and a camera. The main equipment used for counting the number of people process is the camera. However, to make more accurate measurements differential pyroelectric infrared (PIR) sensors are used as auxiliary pieces of equipment. By using cascaded AdaBoost classifiers, the faces in the surveillance area are detected by the camera with the purpose of counting people. The camera is activated by the PIR sensor therefore it consumes less energy compared to the camera-only system. The average energy consumption improvement is 10% lower.

In this study, for correct occupancy detection an optical shutter driven by a Lavet motor PIR (LAMPIR) sensor is developed and analyzed. Since the PIR sensor can only detect incident radiation variation, this may lead to false-negative detections, improper lighting swings and waste of energy. The new system reduces by up to 89% of the consumption of power, up to 60% of size, up to 75% of weight, up to 31% of cost, and 12 dBA of acoustic noise. Experimental results show that for detecting immobile people up to 4.5 m and mobile people up to 10 m classification accuracy of 100% can be reached. These results show that there is a detection range advancement from both the C-PIR and the Ro-PIR sensors. [6]

In this article, in the search of finding a low-cost solution to detect the number of immobile people in a closed area, an innovative approach to mount a PIR sensor on a moving platform was developed. On the experimental results [7] it is seen that the system is able to detect the room classification with 99%, the occupancy count estimation with 91%, the relative location prediction with 93%, and human target differentiation with 93% accuracy.

In 2014, Yun and Song [8] introduced innovative methodology is used for detecting a relative direction of human movement (in uniformly distributed eight directions) via two pairs of PIR sensors whose sensing elements are orthogonally lined up. A data collection unit with four dual sensing element PIR sensors with modified lenses is developed. The data set is collected from six subjects whom were ambulating in eight directions each. Based on the collected PIR signals, a classification analysis with recognized machine learning algorithms, including instance-based learning and support vector machines is done. The findings show that with the raw data set captured from two orthogonally aligned PIR sensors with modified lenses, the correct detection of direction of movement was achieved more than 98%. It was also found that with the reduced feature set composed of three peak values for each PIR sensor, 89% to 95% recognition accuracy according to machine learning algorithms was achieved.

In addition to the articles mentioned above, the following of this section will share information on patent submissions about the studies related to developing a system to count the number of people using passive infrared sensors.

This patent file [9] belongs to Lutron Electronics Company. The device works as a counter and is configured to determine how many people have entered into or exited from an area. This device consists of a PIR detection circuit which is capable of generating different output signal patterns in response to a person entering or exiting the related area. The device also has a thermopile array, a radar detection circuit or a visible light sensing circuit. All of these circuits are capable of detecting a person's location or movements inside an area monitored by the device. Therefore is capable of determining, based on the detected movements, whether the person has entered or left the space.

According to patent file [10] belongs to Philips Electronics, this device is also used to detect the number of the person in an area. Moreover, it is actually used to measure the time that people have spent in an area. This device includes different data sets. The first data set is gathered from a motion sensor of the lighting system, and the second data set is gathered from a transceiver of an RF subsystem. This device is using PIR sensor and one or more RF transceivers comprise a Wi-Fi enabled router.

As demonstrated in the patent file [11] relates to a system for counting the number of people, the system contains a transmitting device and a receiving device. The transmitting device contains an IR transmitter and the receiving device comprises a counter. Moreover, the receiving device comprises a Passive Infrared (PIR) sensor to gather heat signals of the humans at the time instance. Counting the number of people in malls, retail stores or various other places are used for analysis purposes. Counting the number of people in such places used to calculate percentage of total visitors versus the number of people that make purchases. Maintenance of services are undertaken when the human traffic is less. Counting the number of people also helps to determine the popularity of various brands with different entrances in a shopping mall and this is the reason why this system is developed.

Many technologies are used in people counting systems, these technologies can be listed as ultrasonic sensors, infrared sensor array, infrared motion sensors, sensor fusion, and video counter.

People counting systems, which are operating with ultrasonic sensors, use a cluster of sensor nodes that are connected wirelessly. A large area is required to measure the number of people accurately, and a large area increases the needs of clusters. For an accurate measurement, the sensors must exchange the data simultaneously. Hence, clock synchronization is required at the millisecond level. Chen et al. [12] defined the biggest drawback encountered when using ultrasonic sensors in person counting systems is the protocol of clock synchronization.

People counting systems that are using infrared sensor array technology, require IR sensors matrix which forms the detectors. The sensor signals provided from the matrix and the pattern recognition algorithm detect people moving along the field of view. Such systems need power processing and synchronization to detect people. [13]

PIR sensors, which emerged as an alternative to previous technologies, are preferred in people counting systems. According to [14] PIR sensor-based people counting systems require three PIR sensors to detect the number of people. The coordinator connects to the sensors via a wireless RF connection and receives the motion events from the sensors simultaneously. The coordinator decides on the human count by correlating the phase, number and time difference of the signal peaks. The major drawback of PIR sensors is the effort and associated cost of installing multiple sensor nodes for each surveillance area.

Sensor Fusion consists of camera, CO2 and PIR sensors. The technology merges current sensor readings and historical data to predict the true state of the system. In addition, adjusts for stochastic processes and sensor noise. [15] In addition to all this information, in sensor-based systems, it is easier to protect the privacy of the individual than in camera systems. Also, the data obtained from sensor-based systems can be processed with a lower processing capacity while taking up less space. [16]

The video counter is defined by subtracting background images of people with the ceiling mounted camera. After the objects are determined, they are compared with the pixel dimensions of the previously created people, and counts are made as a result of this analysis. [17]

According to news [18], Schneider Electric has developed a human counter using LYNRED ThermEye thermal imager and STMicroelectronics' built-in artificial intelligence microcontroller STM32H723, according to the news published in November 2020. One of the main purposes of the developed prototype is to measure the occupancy levels of buildings, which became increasingly important to prevent Covid-19 infections.

In addition to the articles and patent applications mentioned above, the following of this section will share information about articles related to using a machine-learning-based approach for detecting occupancy and making predictions for energy efficiency in buildings.

To maximize revenue, minimize costs and save energy, the occupancy rate is very important. It has importance in planning and decision making for an area. For these reasons, in this work [19], different machine learning techniques were examined and compared about occupancy rate forecasting. Several models were trained using Ridge Regression, Kernel Ridge Ressession, Multilayer Perceptron and Radial Basis Function Networks.

To predict occupancy information, three occupancy models using machine learning algorithms, which are k-nearest neighbors (kNN), support vector machine (SVM), and artificial neural network (ANN), were selected. This study [20] also tested three data groups: environmental parameters only, Wi-Fi data only, and a combination of both. The results of this work showed which machine learning algorithm is more suitable for which model.

This work [21] is using thermostat data to detect and predict occupancy rates in buildings. The main aim of this work is to make decisions for energy usage, energy saving for heating and cooling systems.

In this work [22], the researchers performed a series of Monte Carlo simulations for several methods to determine the most efficient parameter combinations of machine learning techniques. The machine learning techniques were used such as Support Vector Machines (SVMs), Decision Trees (DT), Random Forest (RF) and Back-Propagation Network (BPN) along with the AdaBoost algorithm.

To optimize the usage of heating and air conditioning systems, the occupancy rate estimation is necessary. For this purpose, in this work [23], estimating the number of occupants in a room by leveraging multiple heterogeneous sensor nodes and machine learning models were searched. Also, the Internet of Things (IoT) was used.

2.2 Conclusion

According to the literature review that has been completed, all problems detected regarding the people counting systems are listed as follows:

- Some people counting systems can only count people in one direction.
- The majority of people counting systems do not include infrastructure of internet of things.
- Most of the people counting systems do not have real-time data monitoring feature.
- Most existing people counting systems require extra assembly costs for installation.
- Most of the people counting systems have measurement problems due to sensors' field of views.
- Some of the people counting systems need equipment such as cameras in addition to sensors.
- People counting systems which need equipment such as different types of sensors and cameras are not preferred due to their high cost, although they make more accurate measurements than other systems.
- The high cost of the existing person counting systems limits the possibility of making multiple measurements within the companies.
- Most of the existing people counting systems have high power consumption.
- In existing people counting systems, people crossing in groups cause measurement errors.
- Measurement errors may occur in sequential people crossings under 1-2 seconds.

- There are some studies which are mentioning that machine learning and deep learning utilization in such systems, but in practice, to make predictions about occupancy and energy efficiency, most existing people counting systems do not include a machine learning or deep learning approach to heating, cooling and ventilation systems.

2.3 Objective of the thesis

According to the detected problems, the problems planned to be solved within the scope of the master's thesis are listed as follows:

- High power consumption of existing people counting systems

- The high cost of existing people counting systems due to extra equipment such as cameras

- Some existing people counting systems only make one-direction people counting

- Most current people counting systems do not contain internet of things infrastructure and real-time data monitoring

- The large part of current people counting systems can not estimate the time-based number of persons for future with machine learning methods

- Measurement errors due to people crossing under 1-2 seconds in existing people counting systems

It is planned to develop a people counting system suitable for the indoor environment, with low power consumption, wireless connection, real-time measurement and monitoring, with the right sensor and communication module selection by making use of the people counting systems in the literature.

The result of the thesis is a prototype of the internet of things based low-cost people counting device. The project includes sensor research to set the right field of view optimization, development of people counting algorithm with passive infrared sensors, electronic components research and design of printable circuit board, hardware programming, integration of the internet of things and real-time data monitoring feature, device's mechanical design for setting sensor field of view and device box, 3d prototyping and test.

Advantages of our solution compared to other systems are measurement independence of human error, ability to measure input and output with a single device, low-energy consumption, not need cameras or other sensors and helps body-count based HVAC systems and lighting systems.

To perform the research, the author must know the printable circuit board (PCB) design (KiCad, Eagle, etc.) and hardware programming such as ESP32, ESP8266, Arduino, etc. 3D modelling is very important for sensor housing and covering to set the field of view of the sensor so experience of the mechanical design is beneficial for this project. For the internet of things (IoT) integration, the author should be familiar with the internet of things (IoT) cloud platforms such as Microsoft Azure IoT, Amazon WEB Service IoT, IBM Watson, etc. It is required that the author has knowledge about the machine learning methods (Regression algorithms, etc.) to make prediction by using the data of time-based number of person at areas.

2.4 Chapters review

This thesis consists of five chapters: introduction, literature review, methodology and device development, results, and summary. The contents of each chapter are explained below.

The introduction chapter, which is the first part of the thesis, includes general information about the thesis, problem statement, studies to be carried out within the scope of the thesis and success criteria.

The second chapter of the thesis is the literature review. This chapter includes articles and patent applications on current people counting methods, people counting systems working with PIR sensors, and machine learning applications in people counting systems. This chapter also includes the conclusion of the literature review, which includes all problems detected regarding the people counting systems, and the objective of the thesis.

In the third chapter, the general overview, hardware infrastructure and software architecture of the people counting system designed within the scope of the thesis are explained in detail. The hardware infrastructure section includes features of microcontroller and sensor, electronic design studies and mechanical design studies. In the software architecture section, hardware programming, IoT applications and machine learning applications are included.

In the results chapter, which is the fourth part of the thesis, the results of the studies carried out and their detailed analyses are included. This chapter includes configuration and calibration of the sensor, measurement results, analysis of measurement errors, real-time data obtained through IoT and analysis of this data, machine learning studies and results performed with the data obtained, and energy consumption analysis of the people counting system.

The last chapter of the thesis, summary, includes the summary of the studies carried out during the thesis process, the conclusion based on the analysis, and recommendations for future studies.

This thesis contains four appendices. Appendix A contains the electronic circuit design of the board. Appendix B contains the C++(Arduino) code in ESP32 . Appendix C contains Python code prepared for machine learning applications.

3 METHODOLOGY AND DEVICE DEVELOPMENT

3.1 General overview of the people counting system

As seen in Figure 1, the hardware and software infrastructures of the people counting system were developed and prototyped within the scope of the project.

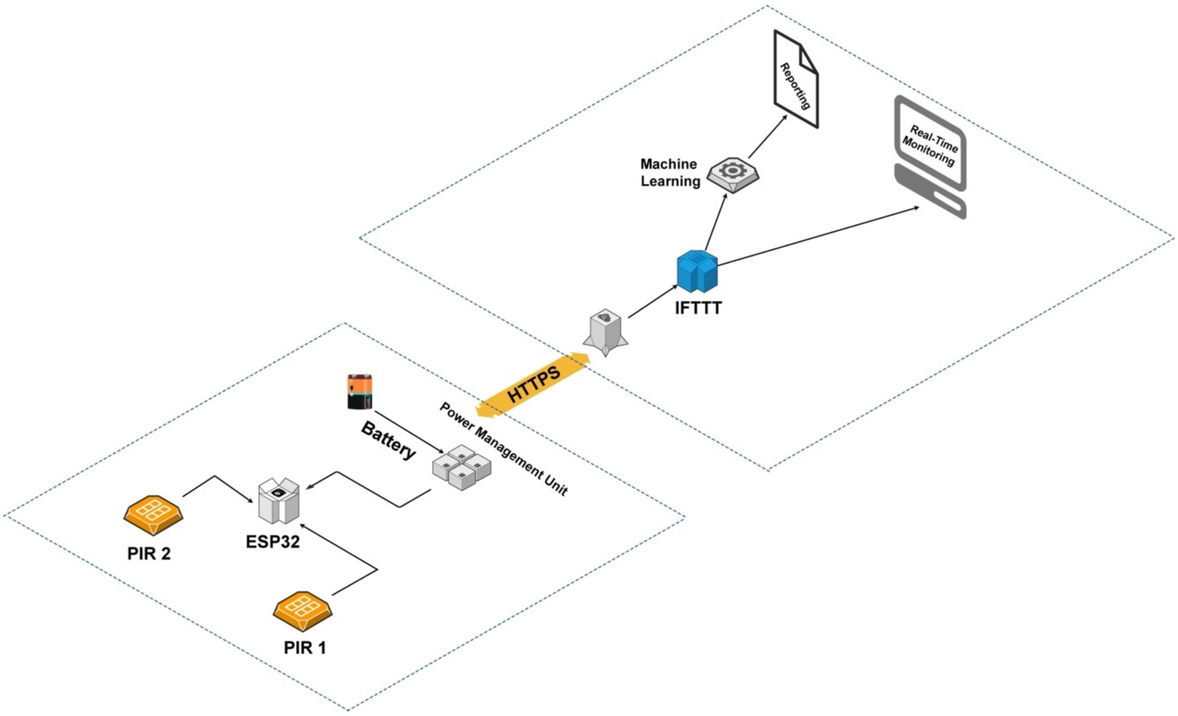

Figure 1 The hardware and software infrastructures of the people counting system

In the hardware part; ESP32 Wi-Fi, BT, BLE 32-bit dual-core Microcontroller (MCU) module developed by Espressif Systems, AMN33112 Spot detection type passive infrared (PIR) sensors developed by Panasonic and power management unit are used in the printed circuit board (PCB) specially designed for the project. According to the determined algorithm, PIR sensors detect individual entry-exit situations. Due to the ESP32 MCU, which has a built-in Wi-Fi module that operates according to the data received by the sensors, the data of the number of people is instantly transferred to the cloud platform via Wi-Fi. For the programming of the microcontroller, the CP2102 USB 2.0 to TTL UART serial convertor module developed by Silicon Labs is used externally. In addition, the electronic enclosure is designed to protect the PCB, to keep the sensor field of view stable, and to store the battery.

In the software part, firstly, entrance - exit tests were carried out depending on the detection priorities of PIR sensors. After the sensor data has been verified, the ESP32 module has been paired with local Wi-Fi networks. With the "Webhooks" service used on the IFTTT platform, which allows making or receiving a web request, the current number of people and the number of entrance-exit were recorded in the spreadsheet file created on Google Drive in real-time. Afterward, the data of the devices on spreadsheets will be processed using data analysis and machine learning algorithms. As a result of the analysis, the density of occupancy calculation of the workplaces and the estimation of the time-based number of people in the coming days are calculated.

3.2 Hardware infrastructure

3.2.1 ESP32 wifi & bluetooth compatible microcontroller

The important issue when developing IoT devices is the selection of microcontrollers and communication modules. Especially microcontrollers with integrated Wi-Fi and Bluetooth connection are used for a wide range of applications. Companies such as Texas Instruments, MediaTek and Espressif are among the major companies that develop and produce Wi-Fi microcontroller chips [24]. Espressif Systems' products are widely used in Internet of Things applications due to their low cost, low power consumption, open-source, single-core and dual-core MCUs options, and ease of use. Espressif Systems company has focused on developing low-power cutting-edge Wi-Fi and Bluetooth chipsets and AIoT solutions.

As seen in Figure 2, one of the most preferred Wi-Fi microcontrollers of this company is ESP32 Wi-Fi & Bluetooth MCU. ESP32 Wi-Fi & Bluetooth MCU is designed for wearable devices and IoT (Internet of Things) projects, and it includes wireless communication features such as Bluetooth and RF in addition to the Wi-fi protocol. This processor, which works with minimum power consumption, can work periodically in conditions determined for power saving, thus it can be used easily in projects that require batteries [25]. This microcontroller has been preferred to be used in the project due to all these features. ESP32-WROOM-32D module was used in the PCB design of the project.

Figure 2 ESP32-WROOM-32D module

ESP32-WROOM-32D module contains an ESP32-D0WDQ6 chip. The two CPU cores that can be controlled separately are designed to be scalable and adaptable. The clock frequency of the CPU is controllable from 80 MHz to 240 MHz. The module enables the developer to turn off the CPU and monitor the peripherals for changes via a low-power co-processor. The sleep current of the ESP32 chip is less than 5 µA, this situation provides good energy savings, especially in battery powered applications.

Although the old models of the ESP32 have an integrated temperature sensor, the new models do not have a temperature nearly since 2018, this MCU contains only capacitive touch sensors and Hall sensors integrated. In addition to integrated sensors, ESP32 contains SD card interface, Ethernet, UART, PWM, GPIO, high-speed SPI, UART, I²C, and I²S. [26]

The people counting device is developed for indoor use. Therefore, it is very important for the functionality and performance of the device that the ESP32 MCU contains Bluetooth, Bluetooth LE and Wi-Fi connection and allows to connect directly to the internet via Wi-Fi and also supports up to 150 Mbps data rate and 20.5 dBm output power on the antenna. Table 1 shows the key specifications of the ESP32, and Figure 3 shows the functional block diagram of the ESP32.

Table 1 Key specifications of the ESP32-WROOM-32D module [26]

TYPE	**DESCRIPTION**
Manufacturer	Espressif Systems
MCU Core	ESPG2-DOWD
RF Family/Standard	Bluetooth, WiFi
Protocol	802.11b/g/n,Bluetooth v4.2+EDR,Class 1,2,3
Modulation	CCK, DSSS, OFDM
Frequency	2.4GHz ~ 2.5GHz
Data Rate	150Mbps
Power - Output	20.5dBm
Sensitivity	-98dBm
Serial Interfaces	GPIO, I²C, I²S, PWM, SDIO, SPI, UART
Antenna Type	Integrated, Trace
Utilized IC / Part	ESP32-D0WD
Memory Size	448kB ROM, 536kB SRAM
Voltage - Supply	2.7V ~ 3.6V
Operating Current	80mA
Minimum Current Delivered by Power Supply	500mA
Mounting Type	Surface Mount
Operating Temperature	-40°C ~ 85°C

In this project, ESP32 has been programmed using Arduino IDE. For the programming of ESP32, CP2102 USB to TTL Serial Converter with CP2102 integrated, that is produced by SiLabs company, was used. In order to program ESP32, SPI boot mode must be turned on. This mode is first opened by pressing the EN (reset) button integrated on the card, then the Boot button. After the program is loaded to the MCU, it is possible to exit the SPI boot mode by pressing the EN (reset) button. Arduino IDE was used for hardware programming, and the microcontroller was programmed with C++ (Arduino) programming language.

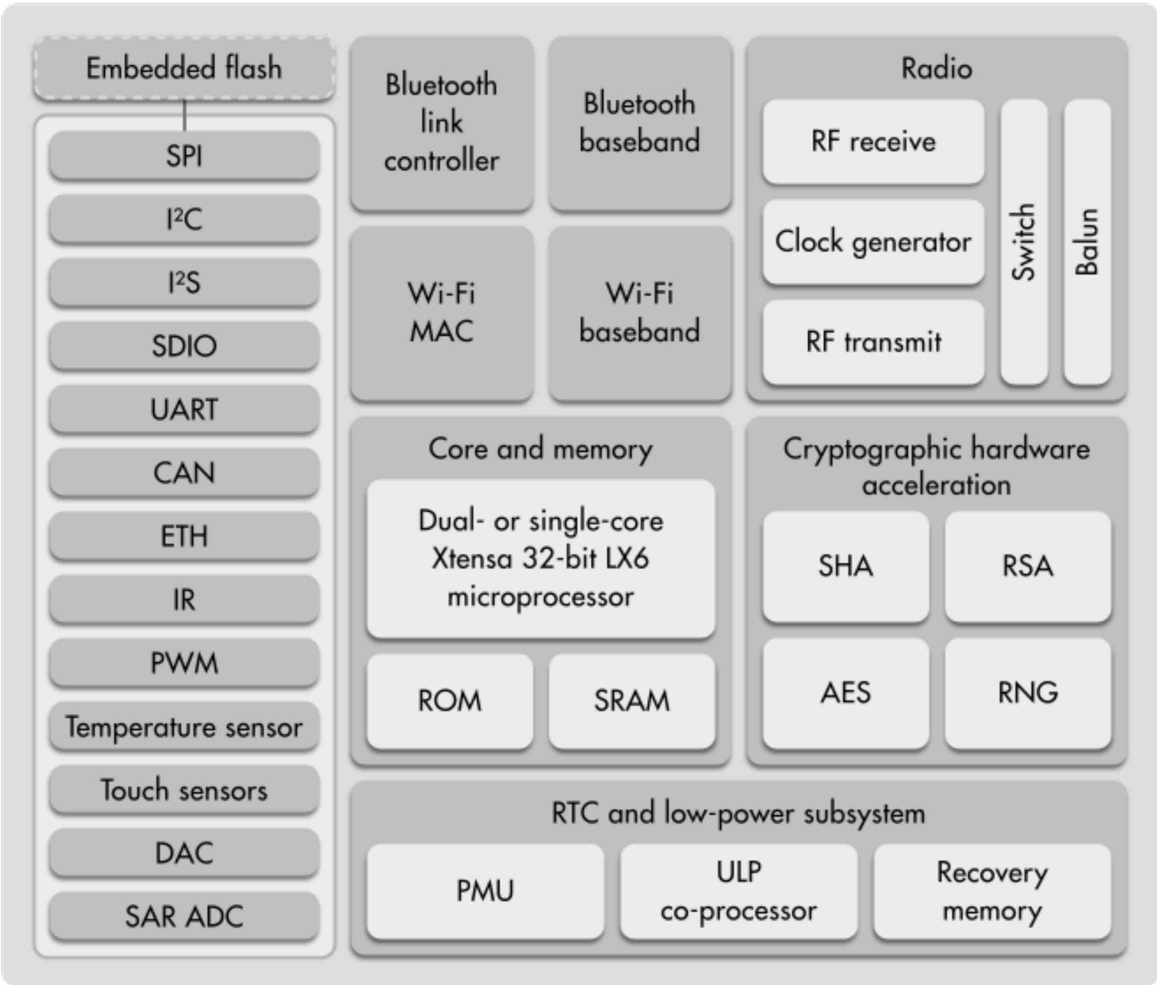

Figure 3 The functional block diagram of the ESP32 [27]

3.2.2 AMN33112 passive infrared motion sensor

Applications of passive infrared sensors can be listed as lighting controls in general, smart luminaires, smart LED bulbs, multi-function printers, video-conference systems, digital signage, vending machine, wake-up switch for LCDs and panels, IP cameras, intrusion alarms, thermostats, HVAC (heater, ventilator or air conditioner), smart home and IoT applications and people counting systems. The most important parameters for the selection of passive infrared sensor are field of view angle, response time and power consumption. Panasonic Electric Works company develops passive infrared sensors with fast response time, low power consumption (1μA, 2μA, 6μA, 170μA), and different field of view values for such applications [28].

In the project, it is planned to use two PIR sensors for bidirectional detection of person entrance and exit. The typical ceiling installation height of the PIR sensors to be used in the project must be suitable for overhead measurement applications. This height should be between 2 meters and 5 meters and should be suitable for measuring in small areas. The measurement method is to determine the entrance and exit states by measuring the two PIR sensors separately, therefore the sensor field of views should be narrower than other PIR sensors. In addition to all these features, it is expected that the object detection speed of the selected sensors can easily detect human movement speed and not detect creatures such as small-sized pets.

In the project, the Panasonic AMN33112 spot detection type sensor, shown in Figure 4, was chosen because it meets all these features adequately with its key features shown in Table 2 and is suitable for overhead measurement applications.

Figure 4 Panasonic AMN33112 spot detection type sensor

Table 2 Key specifications of the AMN33112 PIR Sensor [29]

Item	**Performance characteristics**
Lens Type	Spot Detection Type
Lens Color	White
Output Type	Digital
Detection Distance	5m
Standby current consumption	170μA

Detection Area (Vertical)	57°
Detection Area (Horizontal)	42°
Number of Detection Zones	24
Output Current (During Detection Period)	100μA
Sensor Type	NaPiOn 2nd generation
Sensitivity	Standard

The person counting system developed during the master thesis is based on the principle of increment or decrement the number of people value by the microcontroller according to the person perception order of the sensors within the field of view of the two PIR sensors, as seen in Figure 5.

Accordingly, the yellow arrow indicates the direction of entry into the indoor environment, and the orange arrow indicates the direction of exit from the indoor environment. If the (S1) sensor detects the person during the person transition, and then the (S2) sensor detects the person within the specified time, the increment process is performed here by the microcontroller. Besides, if the (S2) sensor firstly detects the person and then the (S1) sensor detects, the microcontroller performs the decrement process here. In order to limit the viewing angles to human size and speed, half of the PIR sensors are covered by the 3d sensor slots, this limitation ensures that the distance between the sensors on the board and the sensor viewing angles is equal.

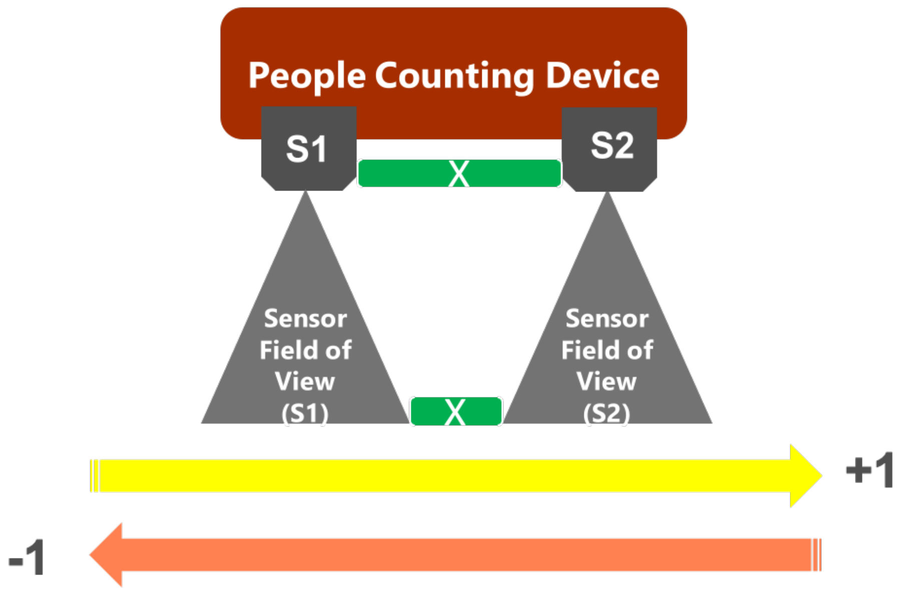

Figure 5 Working principle of the system

In Figure 6, the detection zones of the Panasonic AMN33112 Spot detection type sensor are shown within 24 squares in the x-y coordinate plane at a distance of 5 meters. [30]

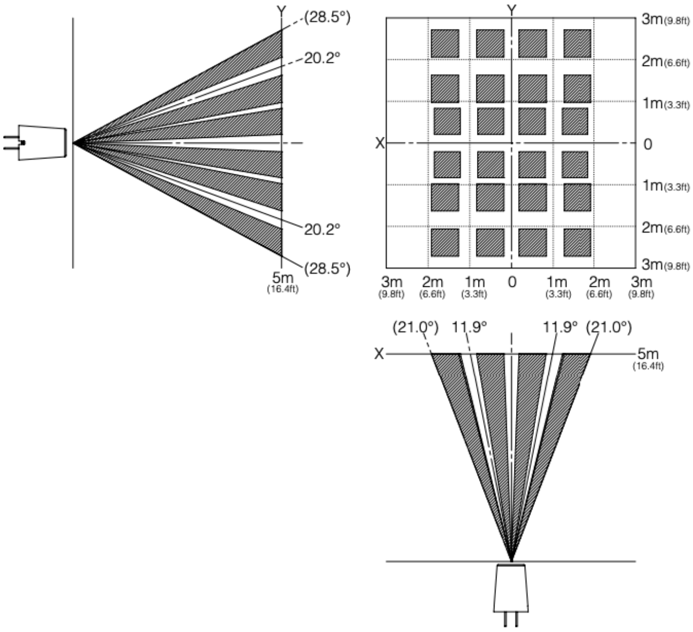

Figure 6 X-Y cross section at 5m [30]

The detection zones shown in Figure 6 are set up so that each sensor can detect 4 detection zones, as shown in Figure 7, by covering half of the sensors, limiting the field of view and positioning the device at a distance of 2.5 meters.

In Figure 7, the green plus sign indicates the detection zones of the first sensor, and the blue plus sign indicates the detection zones of the second sensor. The zones, which are marked with a red cross, are not detecting by the sensors. The distance between the two sensors is equal to the distance between the detection zones of the two sensors. Human icons represent the entrance-exit direction.

Trigonometric calculations were used in the calculation of detection zones adjusted according to the designed system, and the calculations are given below.

In Equation 2 and Equation 9, alpha and beta angles are divided in two to determine the field of view at 5 meters using trigonometric calculations. According to the Triangle similarity theorem, the length values at 5 meters in Equation 6 and Equation 13 are recalculated for 2.5 meters.

Since one side is covered, the sensors can measure in one way. So, it is calculated by physically dividing the area on the x-axis in half. However, the area on the y-axis was not physically affected and remained constant. Therefore, the positive value, which is found in Formula 15 to calculate the bidirectional field of view, is multiplied by two.

$$\alpha_{X_0} = 42° \tag{1}$$

$$\alpha_X = \frac{\alpha_{X_0}}{2} = 21° \tag{2}$$

$$\tan 21 = 0.3838 \tag{3}$$

$$\frac{X_{5meter}}{5} = 0.3838 \tag{4}$$

$$X_{5meter} = 1.92m \tag{5}$$

$$\frac{X_{2.5meter}}{1.92} = \frac{2.5}{5} \tag{6}$$

$$X_{2.5meter} = 0.96m \tag{7}$$

$$\beta_{Y_0} = 57° \tag{8}$$

$$\beta_Y = \frac{\beta_{Y_0}}{2} = 28.5° \tag{9}$$

$$\tan 28.5 = 0.5429 \tag{10}$$

$$\frac{Y_{5meter}}{5} = 0.5429 \tag{11}$$

$$Y_{5meter} = 2.71m \tag{12}$$

$$\frac{Y_{2.5meterPositive}}{2.71} = \frac{2.5}{5} \tag{13}$$

$$Y_{2.5meterPositive} = 1.357m \tag{14}$$

$$Y_{2.5meter} = 1.357m\ x\ 2 \tag{15}$$

$$Y_{2.5meter} = 2.71m \tag{16}$$

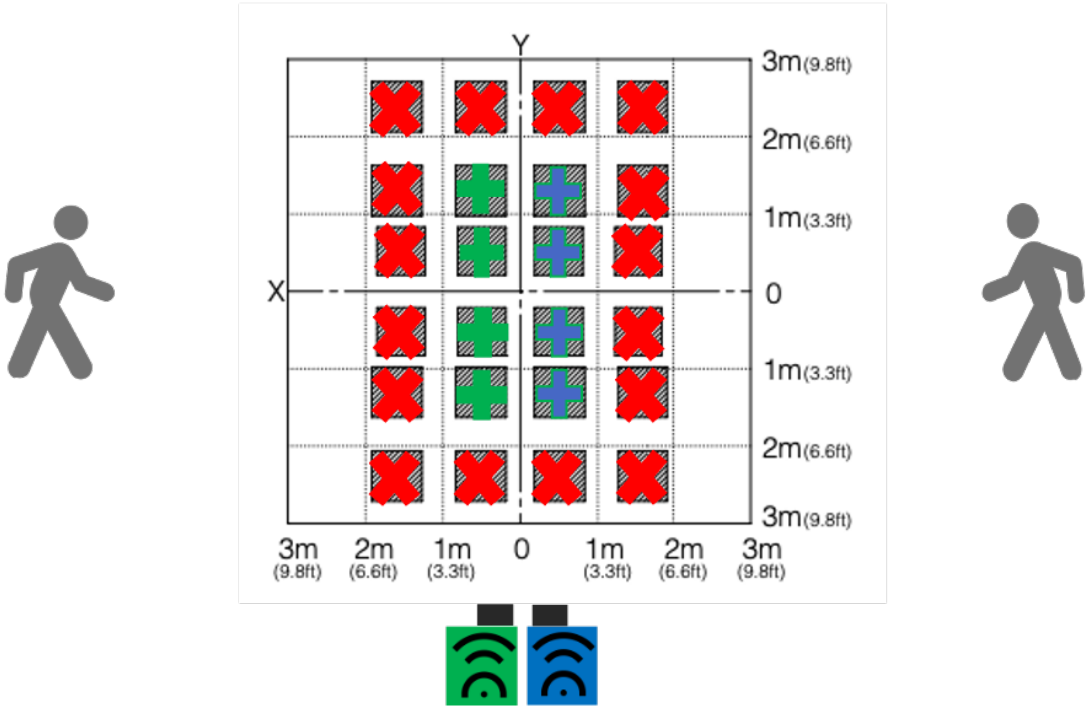

Figure 7 X-Y cross section with two half covered PIR sensors at 2.5m

3.2.3 Electronic circuit schematic design and PCB design

Another crucial subject is the printed circuit board design stage. After determining the processor and sensors required for the device, the printed circuit board is designed according to the requirements. Good planning of this phase is extremely important to ensure that IoT products operate successfully and reliably, avoiding unexpected delays and costs associated with manufacturing or assembly problems. Modern IoT designs should have a PCB design environment that includes pre and post-layout simulation, layout constraint management and verification. [31] KiCad EDA, Autodesk EAGLE, NI Multisim and Altium Designer are among the popular electronic design software. [32]

To briefly explain the electronic circuit design shown in Figure 8, a pull-down resistor of 10K is connected to the outputs of the AMN33112 PIR sensors to reduce noise. 1k resistors are connected to the LEDs to operate at a lower voltage. The enable pin on the microcontroller is connected to 3.3V VCC as specified in the datasheet. [26] Also, S1 and S2 buttons were connected to the Enable and GPIO-0 input pins respectively to open the programming mode of the microcontroller, and both buttons were connected to VCC with 10K resistors. A capacitor is connected to the VCC input of the microcontroller to provide a stable voltage input. The regulator reduces the input voltage to 3.3V and to protect the microcontroller from reverse currents, a diode is connected between the voltage regulator and the power connector. In addition, capacitors are used to provide stable voltage input. The programming connector is connected to pins 34 and 35, which are the RX and TX pins of the microcontroller.

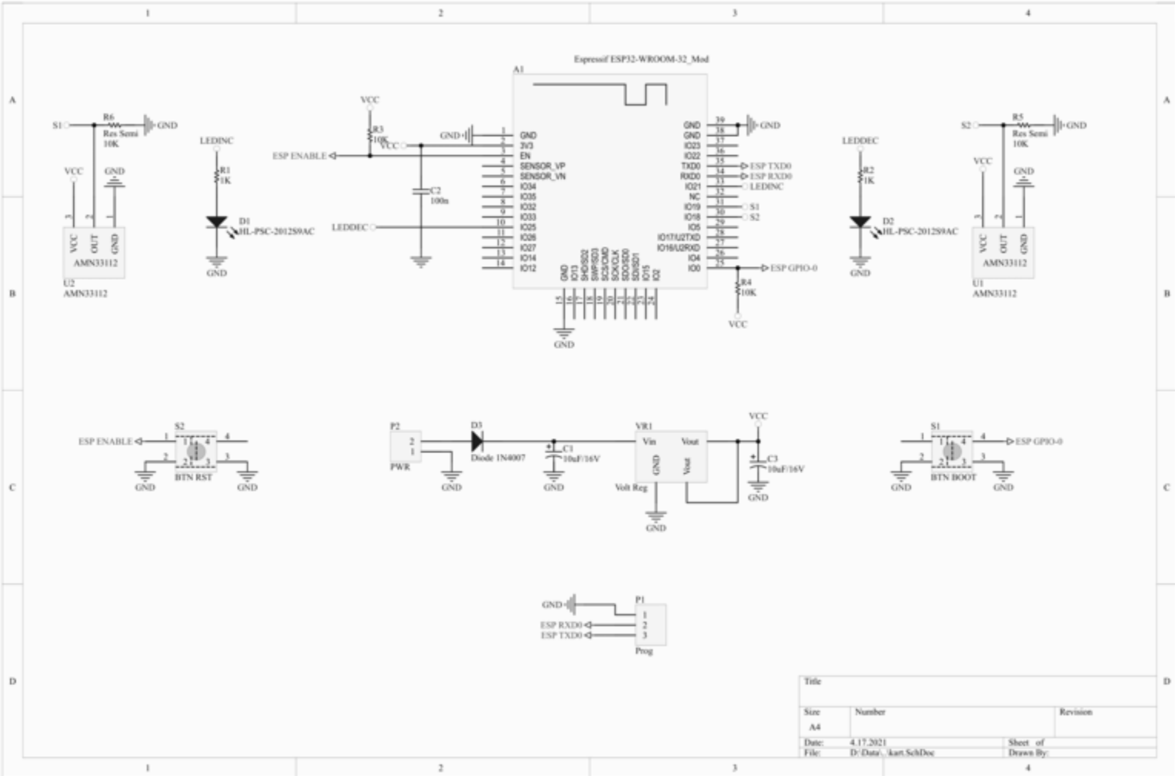

Figure 8 Electronic circuit schematic design

Figure 9 and Figure 10 show the PCB's top and bottom layout, respectively. Important issues in the PCB design process for this project are as follows.

- For the electronic circuit board to be small, all electronic components except the buttons are selected as surface-mount device (SMD) type.
- To increase the Wi-Fi connection quality and range, the bottom of the microcontroller antenna part is left blank.
- Based on the software and sensor calibration of the system, the distance between the sensors is set to 5 cm.
- Button and programming pins are located on the top of the board to be able to easily program the board without taking it out of the box.
- There are metric screw holes for easy mounting in the box.

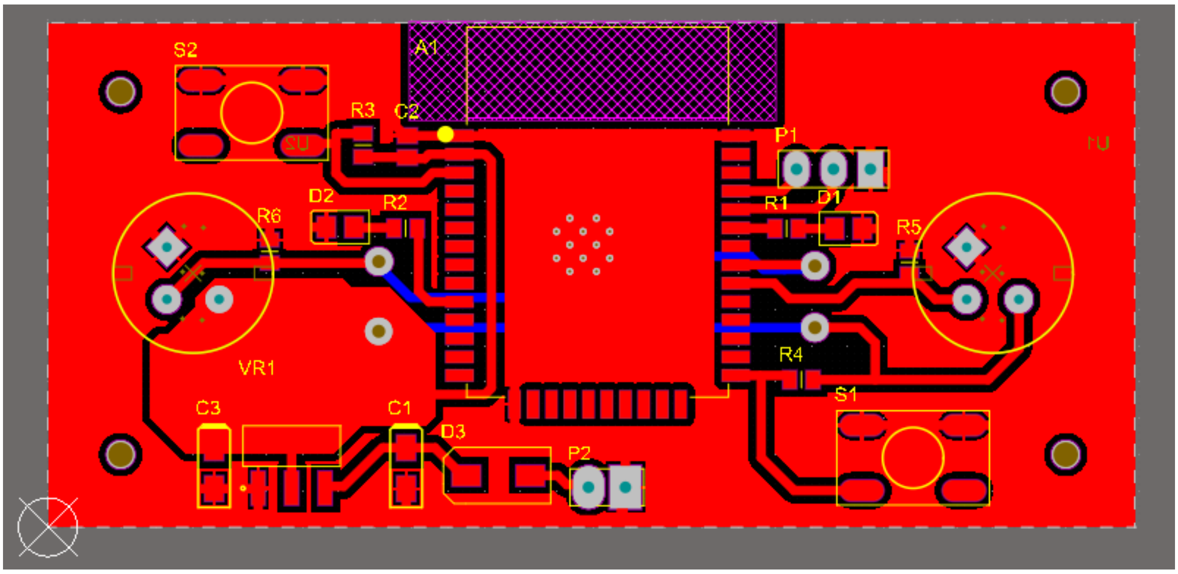

Figure 9 PCB design top layer

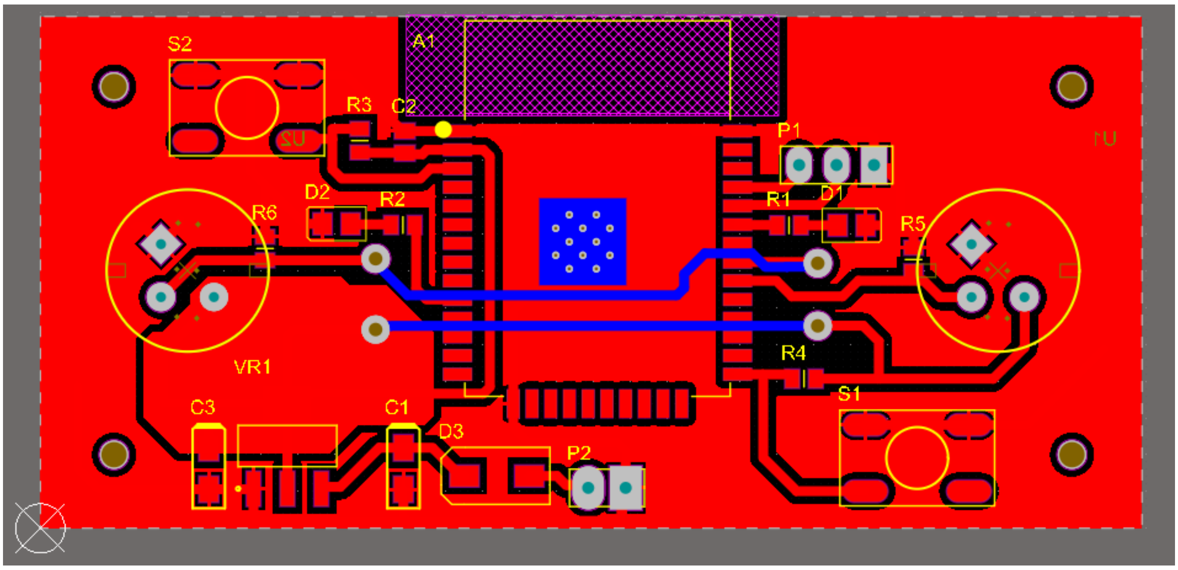

Figure 10 PCB design bottom layer

To better understand the electronic circuit and make mechanical designs more easily, 3D bottom layer and 3D top layer images of the PCB are shown in Figure 11 and Figure 12.

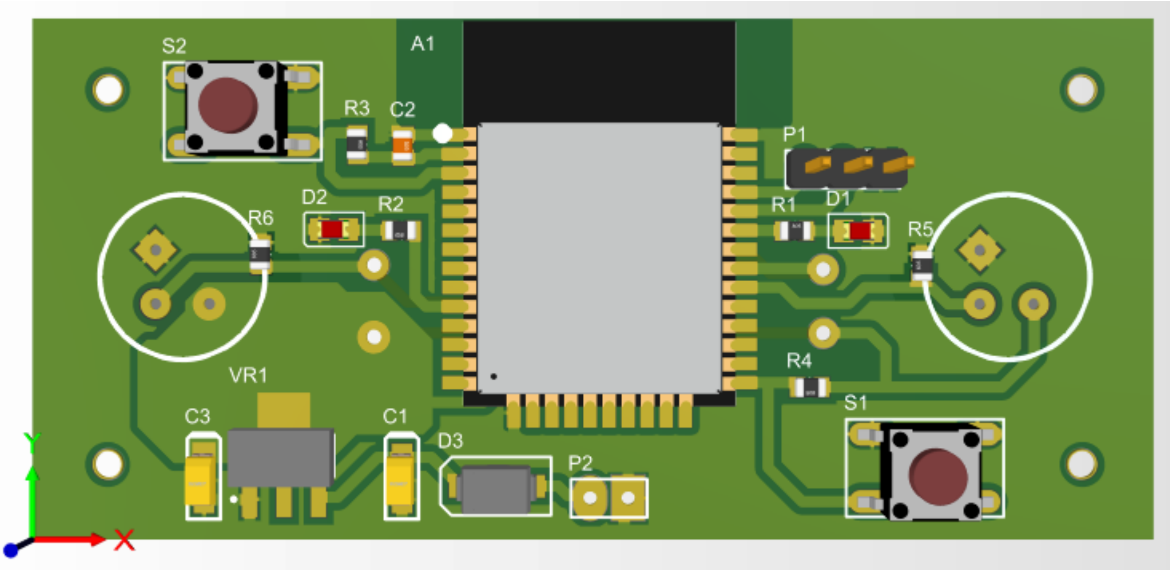

Figure 11 3D PCB design top layer

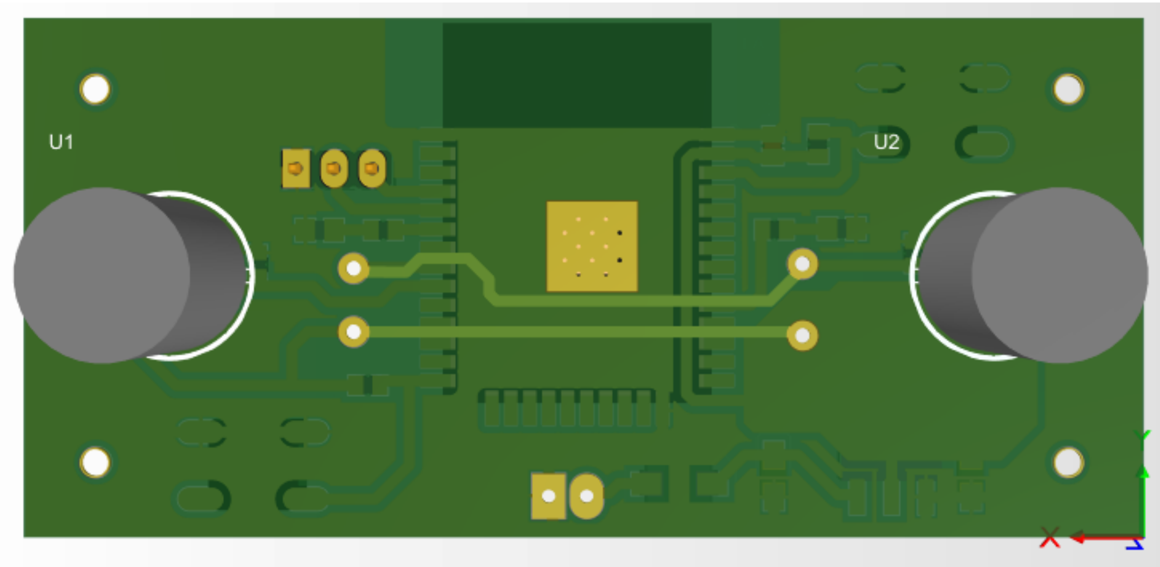

Figure 12 3D PCB design bottom layer

As shown in Figure 13 and Figure 14, the PCB design was produced with a CNC engravering machine, and then the electronic components were soldered.

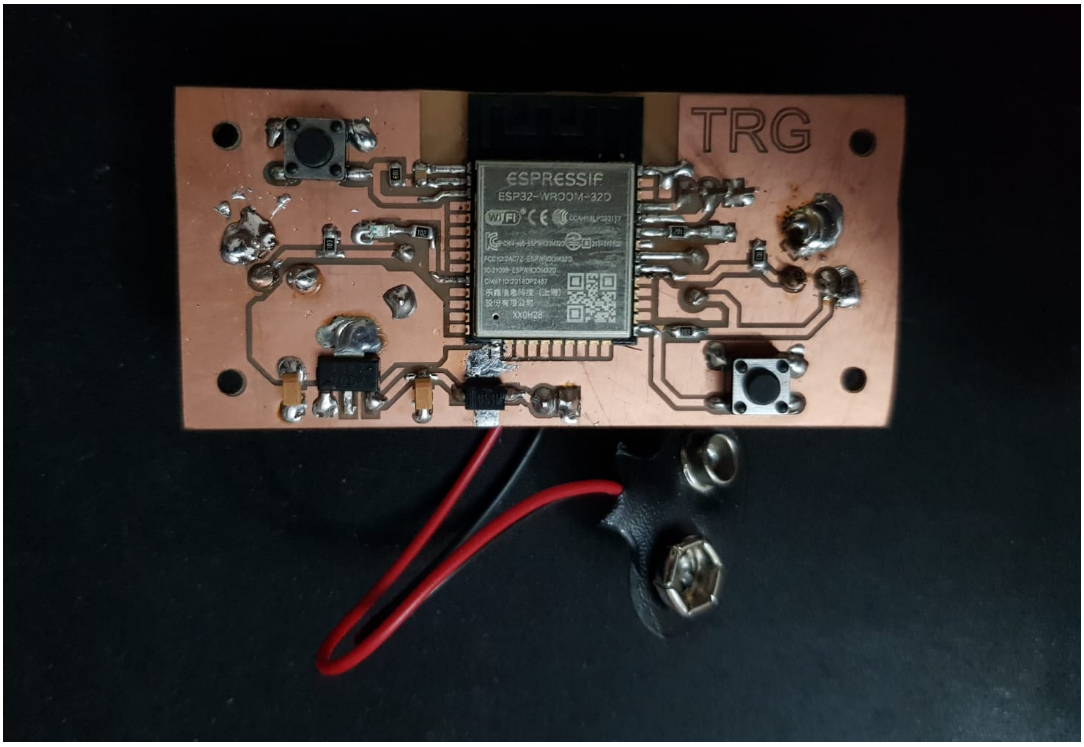

Figure 13 Manufactured PCB top layer

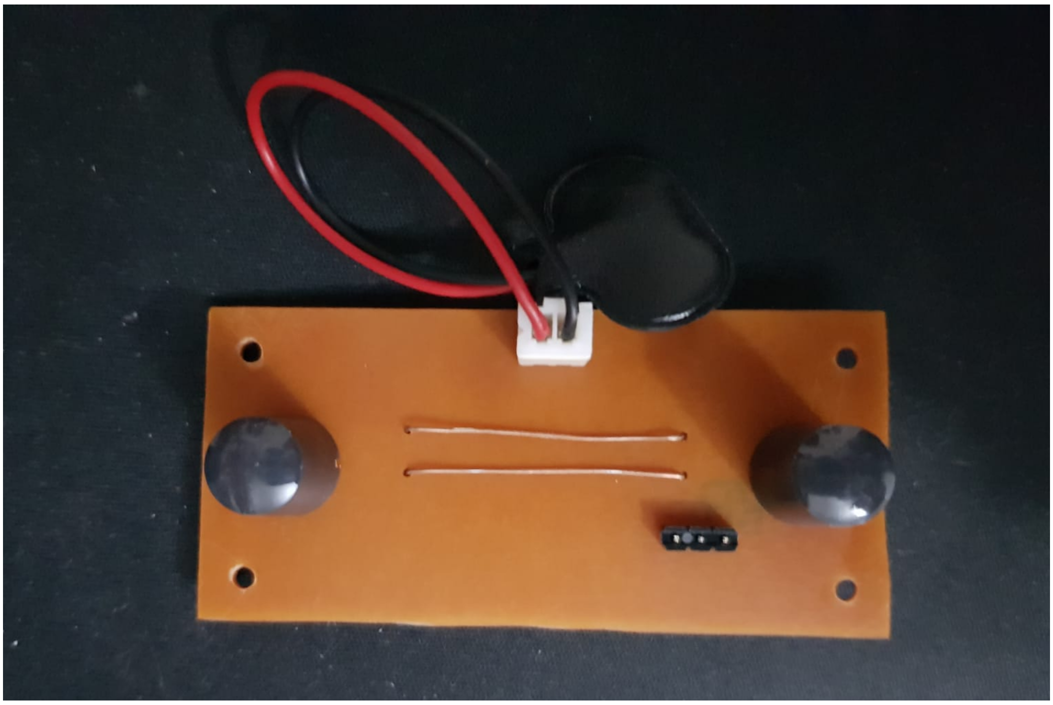

Figure 14 Manufactured PCB bottom layer

3.3 Electronic enclosure design and 3d prototyping

A different critical issue when developing a device is mechanical design. The mechanical design in this project includes device box design and prototyping. The IoT Device Box is significant to protect electronic parts from external factors and to hold them together, to create a sensor housing, to create a battery holder and to provide easy assembly. Besides many ready-made IoT enclosure solutions on the market, the developer can design a unique box for their prototypes. Various CAD applications are required for the design of the device box considering electronic design requirements [33]. Autodesk Fusion 360, SolidWorks, Blender, Autocad are among the popular CAD applications [34].

After the mechanical designs are completed, they can be prototyped and tested with 3D printing technology. The main 3D printing technologies are rapid prototyping, high temperature, high-quality surface finish, material Jetting, high accuracy, transparent and flexible material. 3D printing technologies have advantages and disadvantages compared to each other according to their usage areas. Prototyping the enclosures with 3D printing technology provides great cost and time savings to the developer compared to other production methods. 3D Printing results can be tested on the device and prints can be updated and reproduced quickly [35]. The electronic enclosure is designed using SolidWorks and prototyped using a FDM 3D printer and Polylactic acid (PLA) filament.

Figure 15 shows the bottom box design of the device. The bottom box contains a PCB housing of 75x35mm to match the PCB size. The sensor slot is designed for the placement of PIR sensors at the bottom of the PCB location. According to the project, half of the sensor circle on the floor is designed to be closed, as the sensors' field of views needs to be narrowed. In addition, a battery holder has been added to the design for placing the 9V battery.

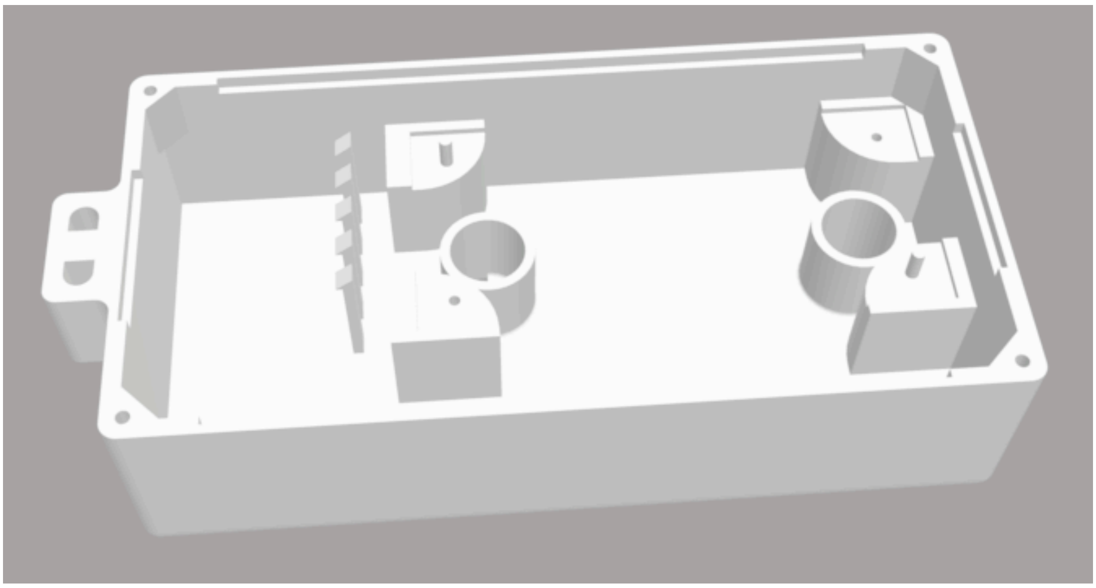

Figure 15 3D bottom box design

Figure 16 shows the design of the cover. The cover is designed to be suitable for the box and can be screwed with 4 pieces of M2 screw.

Figure 16 3D box cover design

As seen in Figure 17, a wall hanger is designed to mount the device on the top of doors. After the wall hanger is mounted on the top of the door, the device box can be easily hanged to the wall hanger.

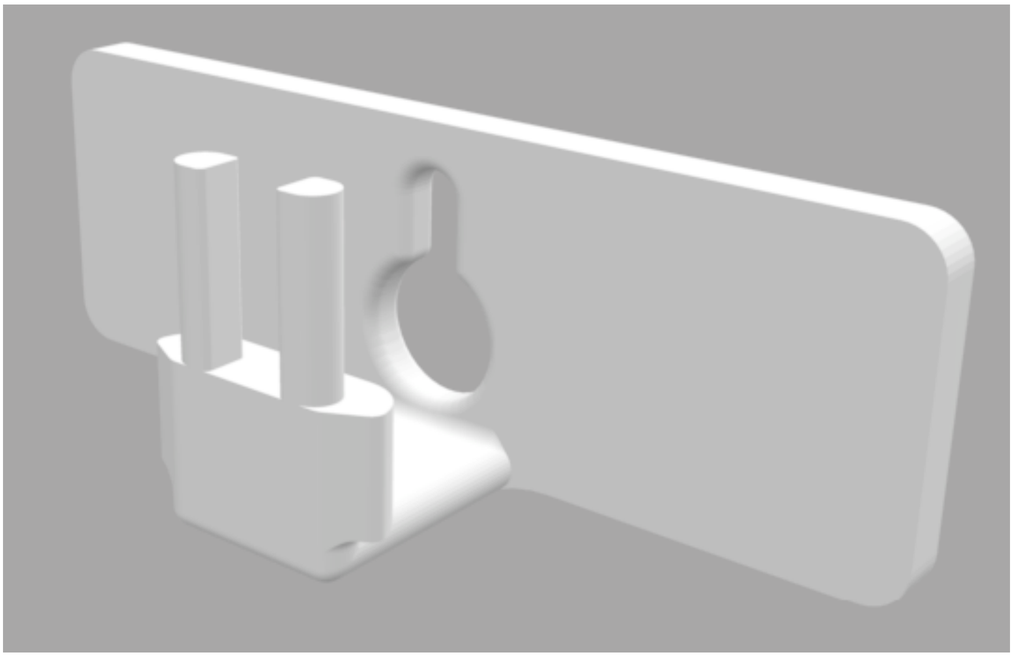

Figure 17 3D wall hanger design

As seen in Figure 18 and Figure 19, the enclosure design was prototyped with a 3D printer.

Figure 18 3D printed electronic enclosure design-1

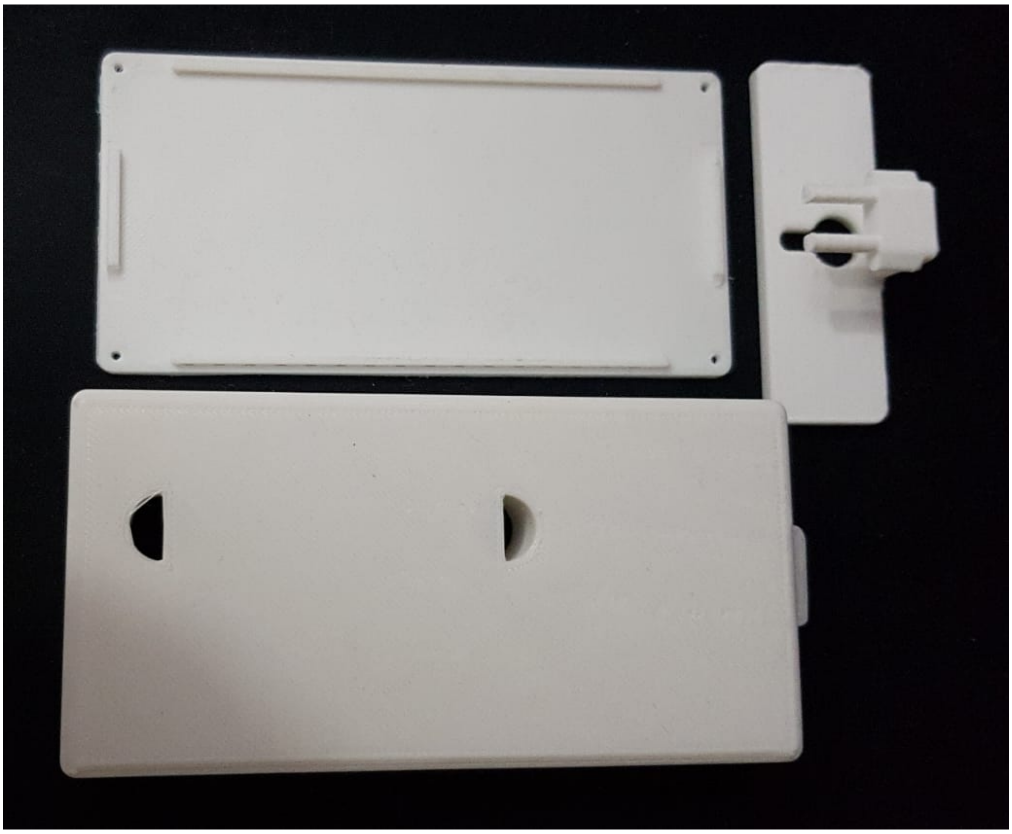

Figure 19 3D printed electronic enclosure design-2

3.4 Software design of the system

3.4.1 Programming of ESP32 for human Sensing

Hardware programming and cloud solution are other important issues that should be considered in IoT project development processes. Espressif Systems' microcontrollers can be programmed using many different development environments and code can be written in C++ (e.g. Arduino) or MicroPython [36]. Espressif Systems provides the Espressif IoT Development Framework to make use of all the ESP32 features [37].

First of all, before start programming the ESP32 microcontroller via Arduino IDE (Integrated development environment), it is necessary to install the ESP32 add-on on the Arduino IDE. [38] As seen in Figure 20, the link of the ESP32 JSON (JavaScript Object Notation) file was pasted into the additional board manager URL gap in the references section, and then the ESP32 board was selected from the Board managers section in Figure 21 and the installation process was performed.

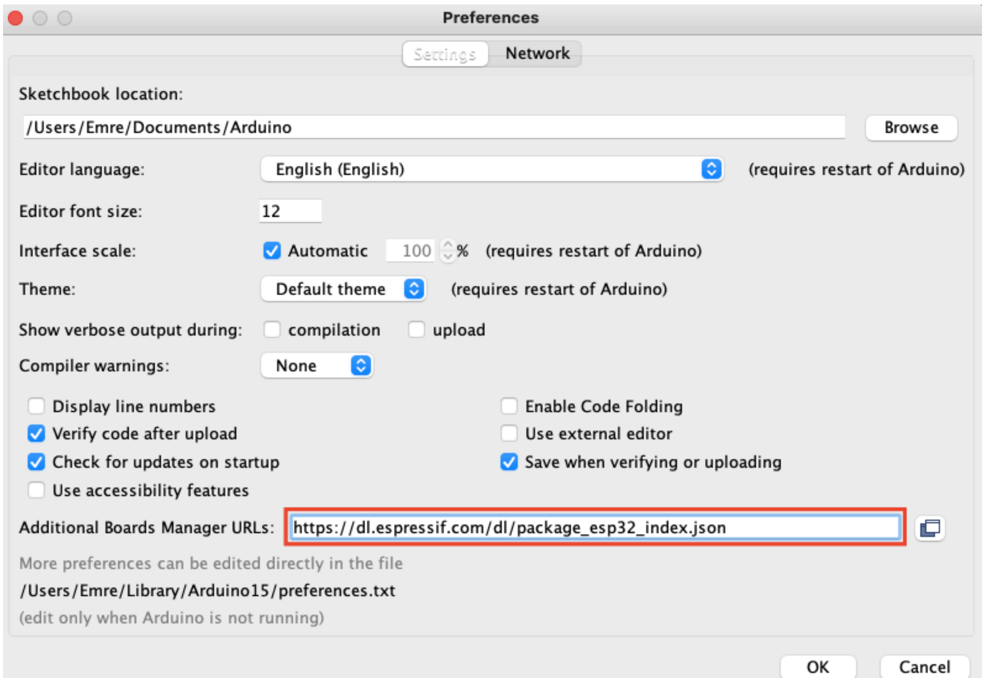

Figure 20 Arduino IDE preferences

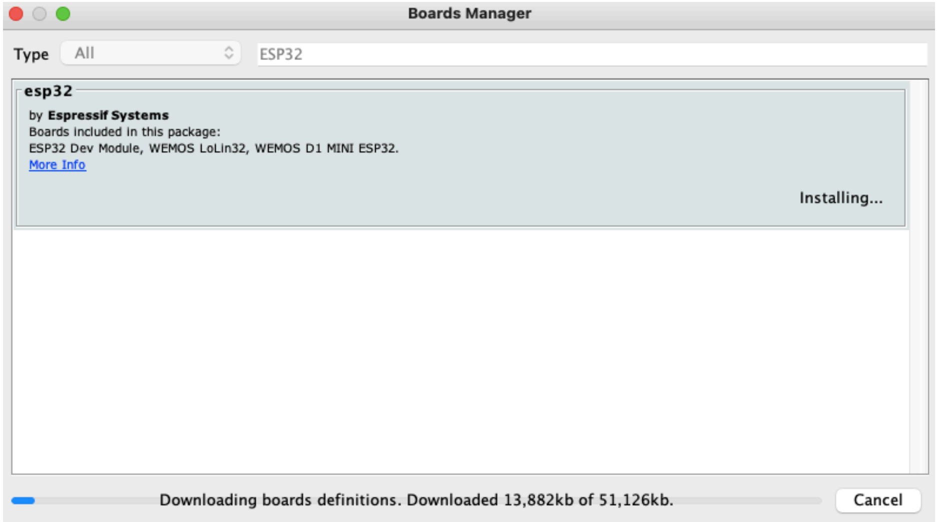

Figure 21 Arduino IDE board manager

The programming settings of the ESP32-WROOM-32D module used in the prototype are shown in Figure 22. After the processor is connected to the computer with a USB TTL converter, the port is selected and the code is uploaded to the ESP32 microcontroller.

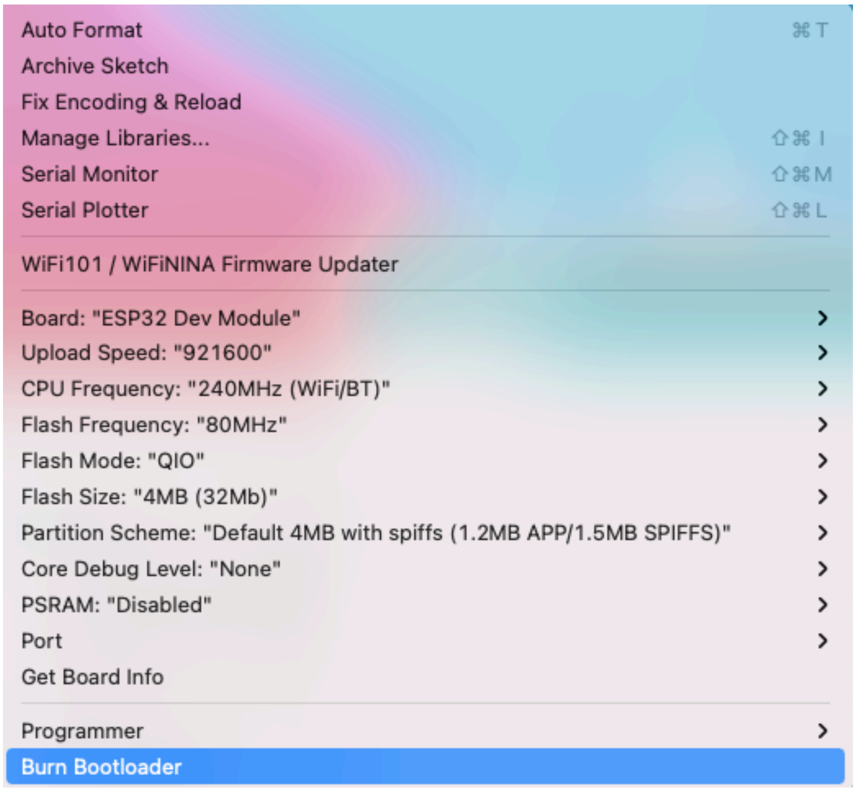

Figure 22 The programming settings of the ESP32-WROOM-32D module

In the code, 'AnalogWrite.h', 'WiFi.h' and 'HTTPClient.h' libraries are used. First of all, the 'ssid' and 'password' values of the wi-fi connection are defined in char type. The 'server', 'eventName', 'IFTTT_Key' and 'IFTTTUrl' values taken from the IFTTT platform are defined in string type.

The outputs of the first and second sensors are connected to pins IO18 and IO19 respectively. Outputs of LED1 and LED2 are connected to pins IO25 and IO21 respectively. The IO22 pin is defined as a buzzer and is available for testing. Therefore, there is no buzzer connected to the IO22 pin in the circuit.

The 'counting' variable defined in integer indicates the instantaneous number of people inside, 'x' variable indicates the total number of positive crossings and 'y' variable indicates the total number of negative crossings.

The 'calibrationTime' variable defined the time to wait for the calibration of sensors in the environment and the waiting time is determined as '30' seconds. A serial monitor is used to display the sensor outputs and operation results. The baud-rate value in the serial communication is determined as '115200'.

ESP32's flash is much slower than its Internal RAM. For this reason, when using interrupts in ESP32, they should be flagged with the 'IRAM_ATTR' attribute so that the code is placed in the Internal RAM (IRAM) instead of the flash of the ESP32. For this reason, ‘increment_’ and ‘decrement_’ interrupts in the code are flagged with 'IRAM_ATTR'.

Variables of volatile bool type such as 'SomeoneIN', 'SomeoneOUT', 'SomeoneReallyIN', 'SomeoneReallyOUT' and variables of bool type such as 'shouldIncrement', 'shouldDecrement' are defined as 'HIGH'.

In the ‘void setup’ section, the Wi-Fi connection has been checked and the states of the pins are defined. After the LEDs blink, the sensors are calibrated by waiting for the calibration time defined as 'calibrationTime'.

In order to use the interrupt function in ESP32, it is necessary to use the ‘attachInterrupt’ function to make settings. This function takes three parameters. The first parameter defines the pin to be used. The second parameter defines the name of the interrupt function and the third parameter defines the interrupt mode. Since the value of the pin voltage changes from Logic-0 to Logic-1 when Panasonic AMN33112 PIR sensors detect a person, the interrupt mode of the pins is set to 'RISING'. When pin voltage is Logic-0 in interrupt functions, it should be defined as 'LOW' mode. The change of pin voltage should be determined as 'CHANGE' mode and when pin voltage drops from Logic-1 to Logic-0, it should be defined as 'FALLING' mode. In this study, 'RISING' mode is used. 'DigitalPinToInterrupt' used in the ‘attachInterrupt’ function is a function that returns the interrupt number for the digital pin to be used.

When this function is used, if there is a change from Logic-0 to Logic-1 on digital pins, the program leaves the sequence in the main loop and passes the operations within the interrupt function.

When this function is used, in case of transition from Logic-0 to Logic-1 on digital pins, the program leaves the sequence in the main loop and passes to the operations within the interrupt function.

When the operations in this function are completed, the function continues from the place left in the main loop. The interrupt functions are defined as 'void increment_' and 'void decrement_'.

In the ‘void loop’ section, the ‘currentTime’ saves the beginning time of the cycle and it renews itself at the beginning of every cycle. When the sensor counts, ‘deflayflag’ provides the interruptions to wait for ‘timeinterval+200ms’. Hereby in ‘while cycle’, to prevent a wrong counting operation, it makes ‘delayflag’ high, stops interrupt and ignores the sensor output for a specific time. ‘Timesensor1 = 100ms’ is used as a timer to prevent interruptions that may occur consecutively when the sensor first interrupts. When this time is completed, it is reset by making ‘SomeoneIN’ and ‘shouldIncrement’ ‘HIGH’ in the else. All of this process, which is making in a positive-way passing (increment), is also using for negative-way passing (Decrement). Timers are used to prevent the sensors from counting in a wrong line, overcounting and taking a positive-a negative value consecutively because of the person's speed.

3.4.2 IFTTT Platform

There are many IoT cloud platforms such as Microsoft Azure IoT, Amazon WEB Service IoT, IBM Watson, Firebase, Google Cloud Platform etc. Despite having different features, all of them offer effective solutions for IoT solutions. In addition, many service providers provide free cloud service to students up to a certain usage limit. Platform selection can be made easily according to the requirements of the application to be implemented. In addition, multiple cloud services can be tested for performance checking for real-time monitoring [39].

After testing several IoT platforms for the thesis study, it was decided that the IFTTT (IF This Then That) platform was a convenient, easy and inexpensive solution to building the IoT cloud infrastructure of the prototype.

The IFTTT platform is a software platform that enables developers to connect apps, devices, and services to trigger one or more automation systems. There are many services in the IFTTT platform that allow you to easily develop projects. The most suitable service for the prototype developed during the thesis process is the 'webhooks' service in the "developer tools" category.[40]

'Webhooks' is a service that allows internet platforms to communicate with external APIs (Application Programming Interface). With the "Webhooks" service used on the developer tools in IFTTT platform, which allows making or receiving a web request, the current number of people and the number of people entrance-exit were recorded in the spreadsheet file created on Google Drive in real-time.

The IFTTT platform works with applets. Applets consist of triggers and actions and connect two or more apps or devices. Applets activate the action according to the triggers which are received from applications and devices.

First of all, a free IFTTT account was created for the project. After the account creation was complete, the applet was created. Webhooks is selected as a service, and "Receive a web request" is selected as the trigger. This maker service is triggered to notify the event when it receives a web request. As seen in Figure 23, the maker event is named 'per_count'.

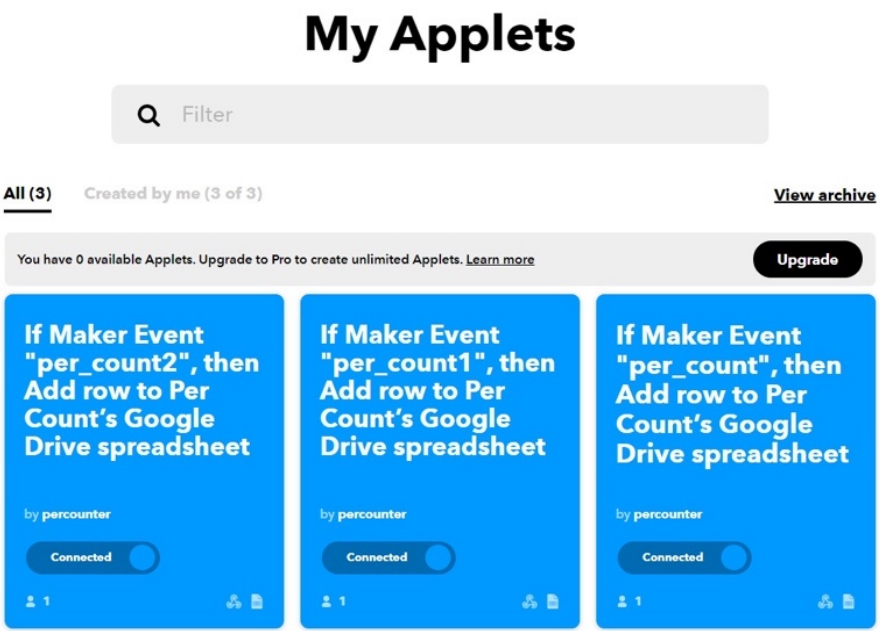

Figure 23 IFTTT applets

Google Sheets, which is in the category of services for action, has been selected. As seen in Figure 24, Google Sheets allows you to create spreadsheets on Google drive, edit these spreadsheets and save data. After the action selection was completed, rows were added to the spreadsheet. The event name, date and the variables of increment, decrement and number of current people are measured by the microcontroller and added to the action area. These values were added as columns on the spreadsheet with the creation of the action.

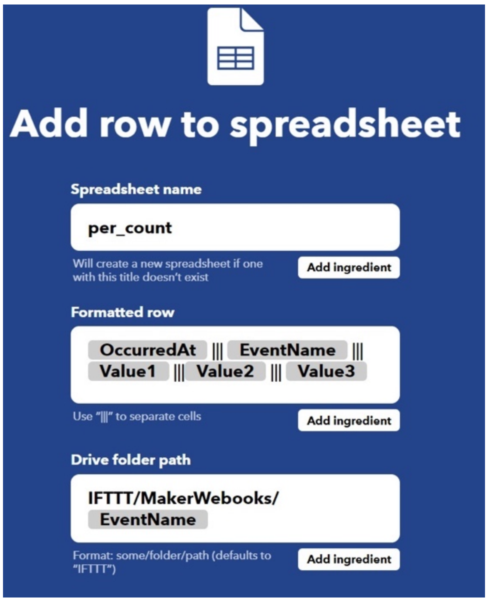

Figure 24 IFTTT settings - Google Sheet

This service records up to a maximum of 2000 rows for each file and creates a separate file in Google drive for every new 2000 measurement of data.

Before the API key values are imported into the code, the applet is tested in the Webhooks documentation section. Test results were checked and verified on Google drive. The **'server'**, **'eventName'**, **'IFTTT_Key'** and **'IFTTTUrl'** values in the unique API key provided by the Webhooks service are matched with the variables in the code.

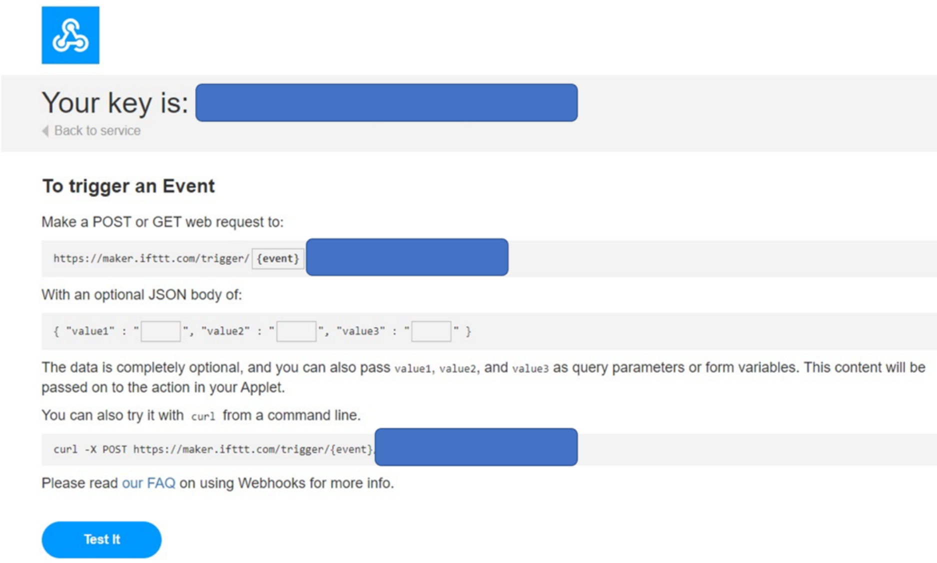

Figure 25 IFTTT secret key and test

3.4.3 Machine Learning for prediction

Figure 26 shows sample data recorded on Google Drive. The data can be saved to Google Drive at the end of each cycle or can be transferred to the cloud environment once a minute with the timer. In the field tests, the data was transferred to the cloud environment once a minute using a timer.

The data in column A shows the date and time, and column B shows the name of the device from which the data was taken. In addition, the data in column C shows the total amount of increment and the data in column D shows the total amount of decrement. And the last data in column E shows the total number of people indoors at the specified time.

	A	B	C	D	E
1	DATA DATE		INCREMENT	DECREMENT	COUNTING
2	April 20, 2021 at 03:21PM	per_count2	0	0	0
3	April 20, 2021 at 03:21PM	per_count2	0	0	0
4	April 20, 2021 at 03:21PM	per_count2	1	0	1
5	April 20, 2021 at 03:21PM	per_count2	1	0	1
6	April 20, 2021 at 03:21PM	per_count2	1	0	1
7	April 20, 2021 at 03:21PM	per_count2	1	0	1
8	April 20, 2021 at 03:21PM	per_count2	1	0	1
9	April 20, 2021 at 03:21PM	per_count2	1	0	1
10	April 20, 2021 at 03:22PM	per_count2	2	0	2
11	April 20, 2021 at 03:22PM	per_count2	2	0	2
12	April 20, 2021 at 03:22PM	per_count2	2	0	2
13	April 20, 2021 at 03:22PM	per_count2	2	0	2
14	April 20, 2021 at 03:22PM	per_count2	2	0	2
15	April 20, 2021 at 03:22PM	per_count2	2	-1	1
16	April 20, 2021 at 03:22PM	per_count2	2	-1	1
17	April 20, 2021 at 03:22PM	per_count2	2	-1	1
18	April 20, 2021 at 03:22PM	per_count2	2	-1	1
19	April 20, 2021 at 03:22PM	per_count2	2	-1	1
20	April 20, 2021 at 03:22PM	per_count2	2	-1	1

Figure 26 Sample data

The weekly, monthly, or annual data obtained as in Figure 26 shows that the total number of people on some days and some hours of the week are similar. While the density of the number of people is high on some days and hours of the week, the density of the number of people is low at other times.

Some companies optimize their ventilation, heating or cooling systems on an hourly, daily, weekly or monthly basis depending on the number of people in the environment. The prediction of the people density value will allow the companies to plan their heating, cooling and ventilation system in advance according to this density and provide to save energy. Therefore, machine learning algorithms are needed to estimate the number of people on an hourly, daily, weekly or monthly basis.

In order to predict with machine learning, Support Vector Regression (SVR) was preferred. Although the support vector algorithm is an algorithm that is used for classification, it is also used for regression. Thanks to these models, it is possible that some data problems can be easily solved. [41]

The possessed data may not always be suitable for using a linear model. In such situations, it is necessary to give a meaning to these data with other algorithms. When support vector regression is applied, it is ensured that the maximum point remains between the plotted range. The points, where these maximum intervals intersect, are called support points.

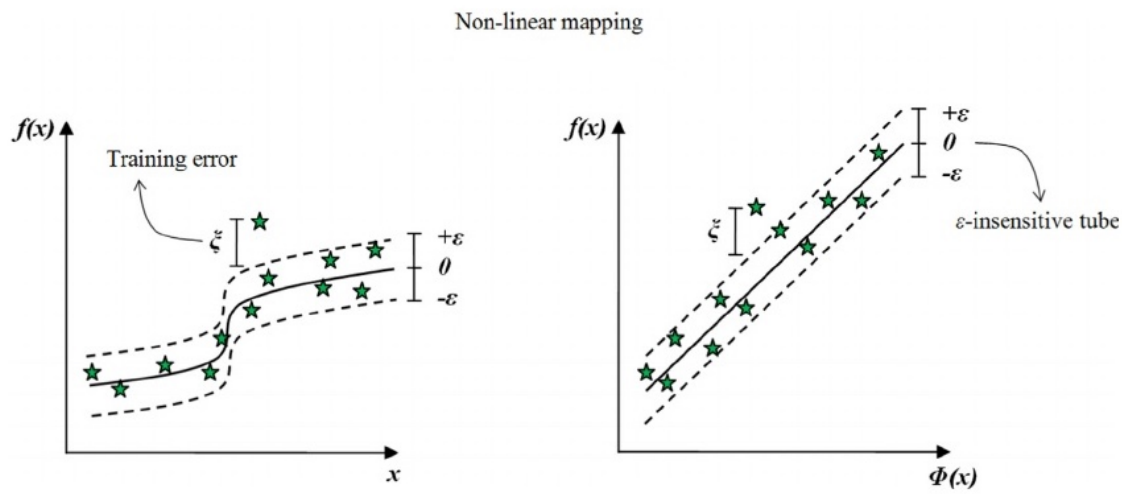

Figure 27 Linear and non-linear support vector regression

As seen on the left side of the Figure 27, when data is linear the linear SVR is using, and as on the right, when data is nonlinear the nonlinear SVR is using. In these situations, when the SVR model is applying with the Radial Basis Function (RBF) method, a nonlinear range is drawn.

In this study, the number of people is measured in three different environments for three days. By using these data with one of the machine learning methods SVR, it was tried to estimate the number of people for future.

The algorithm is written with the scikit-learn library in the Python programming language. At first, the data is divided into two, 70 percent for training the model and the remaining 30 percent for testing the model.

Then, feature scaling is required before creating a model. Because, while many regression classes take measures for feature scaling, there is no such measure in the less used SVR class. Finally, the model was trained with scaled training data. Here, RBF was chosen as the kernel, because the data has a nonlinear structure.

4 RESULTS

According to the workflow, firstly the number of people is measured with prototypes developed. After that, the measured number of people values are recorded on the cloud every minute. The data stored on the cloud can be displayed in real-time. And at the same time, this data is processed with a machine learning algorithm and the number of people is estimated on a daily, weekly, and monthly basis.

In this chapter, the tests performed to evaluate the operation of the device are given in detail.

4.1 Configuration and calibration of the PIR sensor

In the sensor detection test, the device positioned at a height of 2.5 meters, the distance between the detection point of the S1 sensor in the positive direction and the detection point of the S2 sensor in the negative direction was determined as approximately 1.80 meters. This distance shows the sensing distance on the 'X' axis.

In the tests performed for the sensor detections on the 'Y' axis, the detection width of the sensors was determined as 2.54 meters for the S1 sensor and 2.51 meters for the S2 sensor.

There may be errors due to the height and movement speed of the person participating in the test. Since the blind spot distance of the two sensors is very narrow, it is very difficult to detect by this test.

4.2 Measurement errors in different conditions

The prototype has to be tested under different conditions in order to determine measurement errors accurately. In the subsections of this section, normal crossings through the door and sequential crossings under 1-2 seconds through the door were tested.

4.2.1 Normal crossings through the door

In this test, the margin of error of the measurements was calculated by making 100 passes in the positive direction and 100 passes in the negative direction with a single prototype. The prototype is positioned at a distance of 2.5m.

In the positive direction transitions, 94 successful measurements were made in 100 trials. And the margin of error was determined as 6%. Meanwhile, in the negative direction transitions, 92 successful measurements were made in 100 trials. The margin of error was determined as 8%.

Table 3 Test result of normal crossings

Normal crossings	Total number of crossings	Incorrectly Measured Number of Crossing	Error Rate
Positive Direction	100	6	%6
Negative direction	100	8	%8

4.2.2 Sequential crossings under 1-2 seconds through the door

In this test, the measurement errors due to people crossing under 1-2 seconds have been detected. During the test process, for 400 times, in less than a second, person transitions were made in negative and positive directions. The test results are shared in Table 3. The margin of error was determined as %5.5 in positive sequential transitions, also the margin of error was determined as %10.5 in negative sequential transitions.

Table 4 Test result of Sequential crossings

Sequential crossings	Total number of crossings	Incorrectly Measured Number of Crossing	Error Rate
Positive Direction	200	11	%5,5
Negative direction	200	21	%10,5

4.2.3 Animal crossings through the door

In this test, it is monitored that the passage of a 50 cm cat under the device. At the end of a total of 50 passes in positive and negative directions, the sensor was triggered 33 times and made measurement correctly. As well as the accuracy of measurement changes depending on the size and speed of the animals, the device cannot stably measure animal passages.

4.3 Measuring the energy consumption of the system

All device tests have been done with 9V non-rechargeable batteries. The current value of the battery has been measured as 0.47mAh when the device is on standby and 0.53mAh while the sensor is triggered. According to the measurements made, the circuit can operate between 1094 hours and 1234 hours with a single 9V battery source.

$$\frac{Capacity\ of\ battery}{Power\ consumption_{Standby}} = \frac{580\text{mAh}}{0.47\text{mAh}}$$

$$Time = 1234h$$

$$\frac{Capacity\ of\ battery}{Power\ consumption_{Triggering}} = \frac{580\text{mAh}}{0.53\text{mAh}}$$

$$Time = 1094h$$

4.4 Measurement results of the field test

Within the scope of the field tests carried out, the number of people was measured between 12:00 and 16:00 for three days with three prototypes. In Figure 28, Figure 29, and Figure 30, the minute-based total number of people in indoor environments belonging to different days are shown. As a result of the field tests carried out, the device named 'Dev-0' became the device that measured the maximum number of people in three days. The device named 'Dev-1' was the device that measured the lowest number of people in three days.

As a result of the field test, the usage density of indoor environments was determined as 'Dev-0', 'Dev-2', 'Dev-1' from large to small. Using the graphics below, many values can be determined regarding the time-dependent density of people in indoor environments.

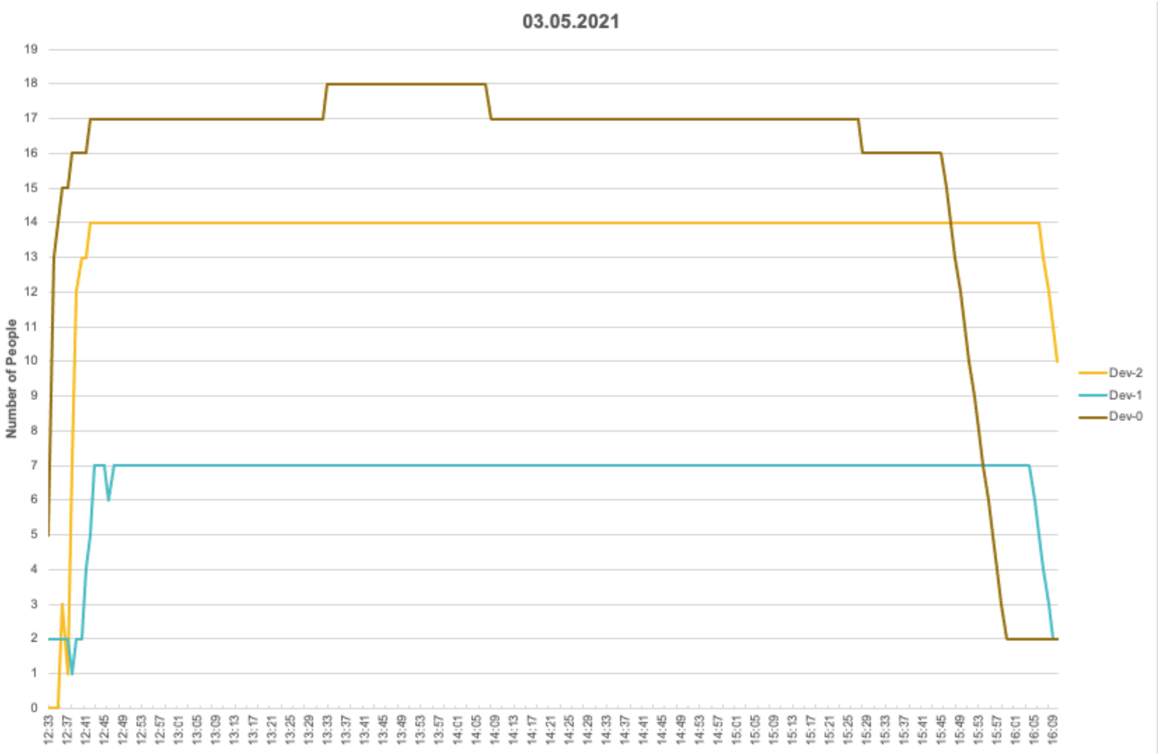

Figure 28 Field testing of devices (03.05.21)

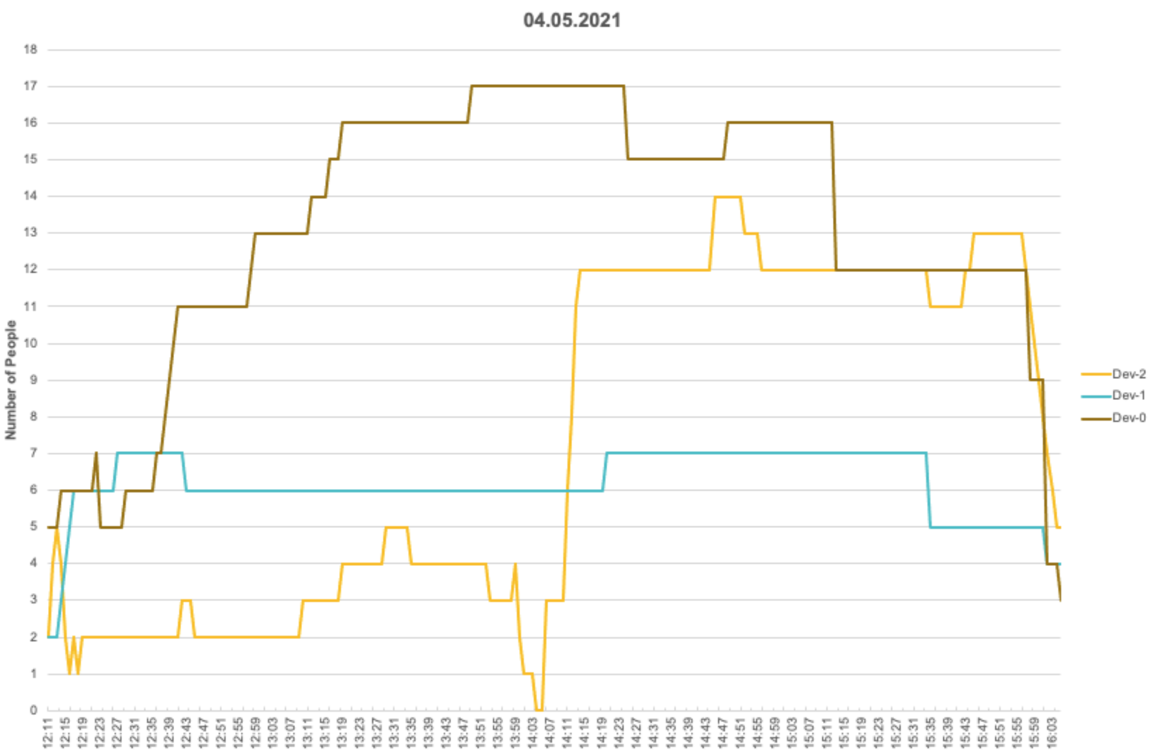

Figure 29 Field testing of devices (04.05.21)

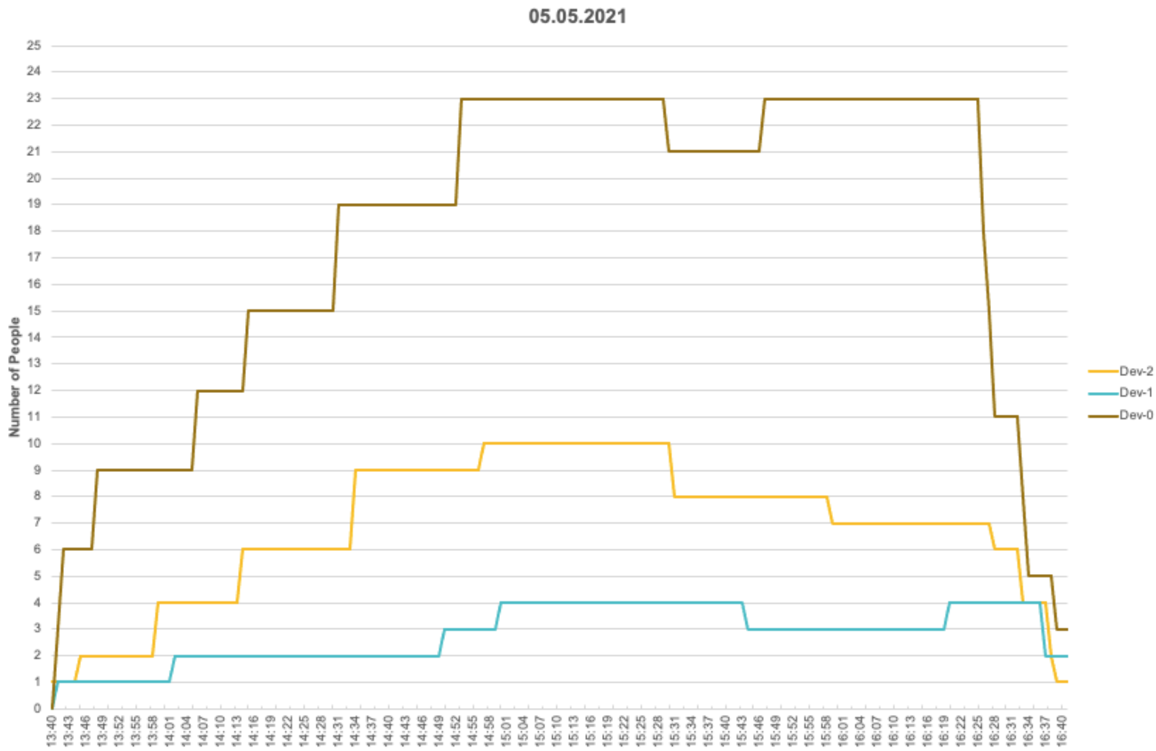

Figure 30 Field testing of devices (05.05.21)

4.5 Using machine learning to predict occupancy

When the model is tested with scaled test data, the results per device are as follows. In Figure 31, Figure 32 and Figure 33, the lines drawn in blue represent the actual data, while the lines drawn in orange represent the predicted data. As seen in Figure x, the predicted values for the first device do not match well with the values of 3rd day. However, it is observed that a very suitable estimate is made for the second and third devices in Figure 32 and Figure 33.

One of the most important issues in such studies is the amount of data. A basic estimation study has been made with the data kept for a limited time. It is possible to obtain more stable results if weekly, monthly and annual data are used.

The figures above show the estimation values of the number of people based on hours of the 3rd day. With these predictive values, companies can save energy by planning their heating, cooling and ventilation systems on a specific day in advance. In addition, businesses such as stores, where the number of daily and hourly customers are important, can plan the management of human resources by optimizing the number of employees according to these estimated number of people.

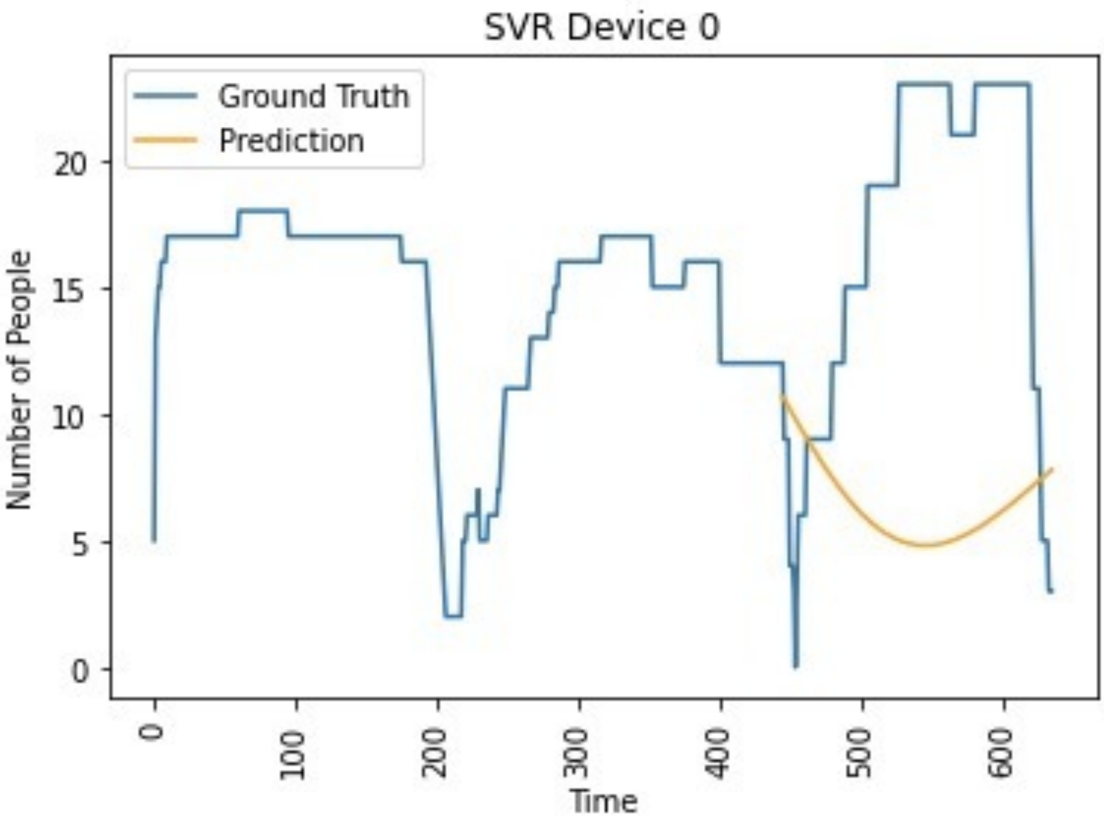

Figure 31 SVR Result Device-0

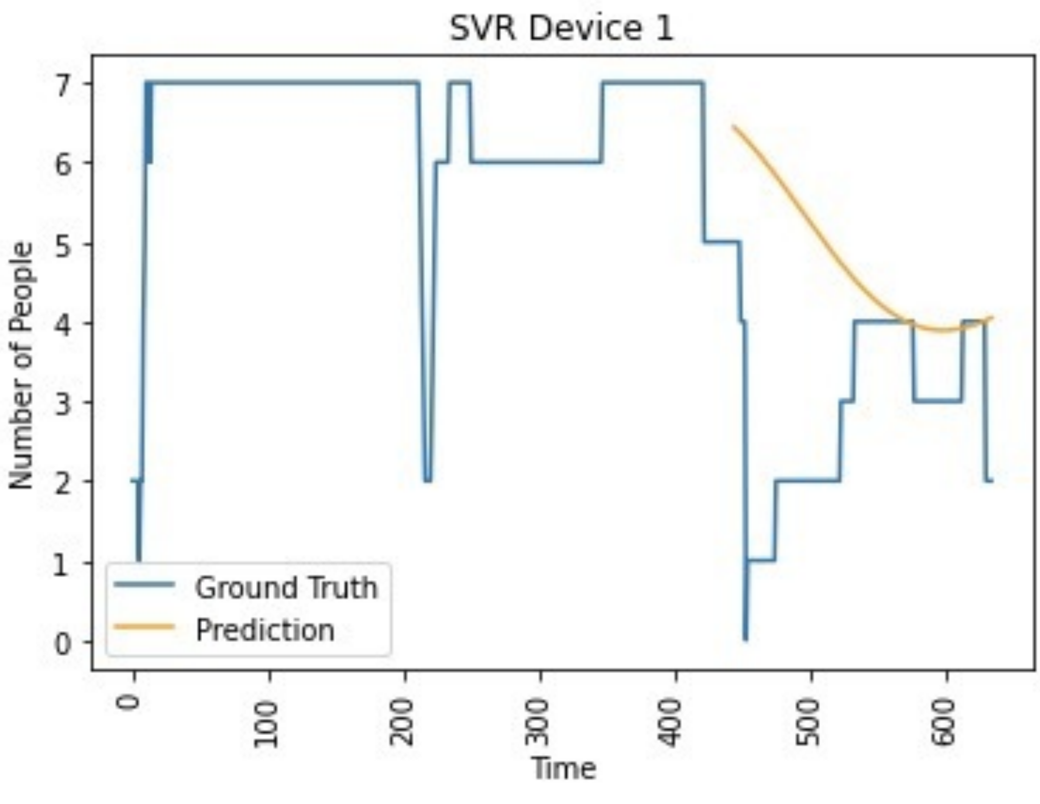

Figure 32 SVR Result Device-1

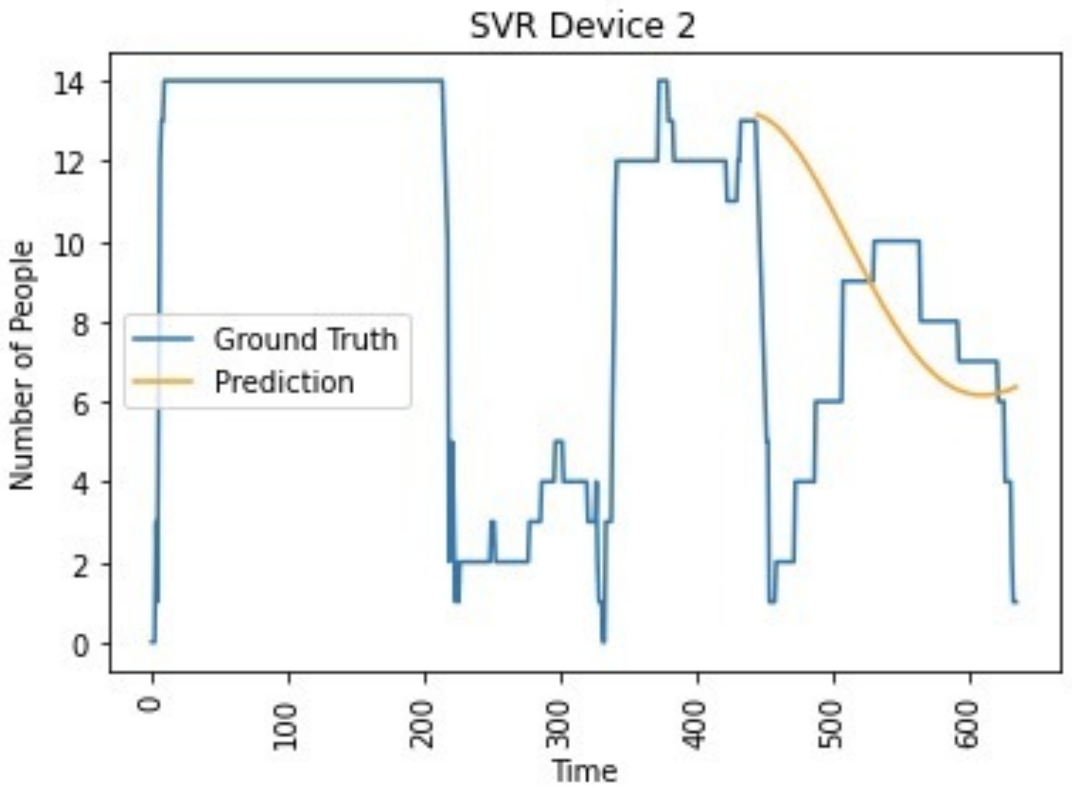

Figure 33 SVR Result Device-2

5 SUMMARY

5.1 Conclusion

Within the scope of the master's thesis, the Internet of Things and machine learning based people counting system has been successfully developed. Mechanical design, electronic design and software development stages were completed on the planned dates. According to the designs made, the prototypes were produced and the thesis objectives were fulfilled.

As a result of the tests carried out, it has been proved that the angles of the PIR sensors are calculated correctly. The prototype does not require any extra equipment for bi-directional people counting. In the C ++ based Arduino program, the prototype's counting people in bi-directional using interrupts was performed with a success rate of about 93%. Although the error rate is lower in normal crossings, the error rate increases even more in sequential crossings under one second.

The wireless network connection of each prototype was tested continuously for twelve hours, during that time, uninterrepted instant data transfer was performed from three prototypes, which are connected to the same network.

Production of mechanical and electronic parts for each prototype cost in total about 55 Euros. This price is valid for retail purchases and it is expected that this cost will decrease by 40% in mass production.

According to the battery test results, prototypes can be operated continuously for 1094 hours to 1234 hours theoretically with a single 9V battery source. Since the sleep modes of microcontrollers can affect sensor triggers, microcontrollers are used in normal mode in this study. As long as the sleep mode is properly integrated, the device will be able to operate for a longer time with a single power supply.

Due to the Covid-19 Pandemic, most of the workplaces are temporarily closed or open for a limited period of time. For this reason, it was difficult to find a suitable environment for field tests. Three-day field tests were applied to three R&D companies within the Erciyes Technopark campus located in the Central Anatolia Region of Turkey. Since companies employ short-term workers, all measurements were made in the afternoon at the specified times. The obtained data were used to make predictions with machine learning methods. Since the data are limited, a basic estimation study has been made. More consistent machine learning studies can be made by measuring monthly, quarterly and annual data.

In conclusion, the bi-directional people counting device, which works in accordance with the thesis objectives, was developed and prototyped from scratch. As a result of the tests performed, it was determined that the system worked successfully at a high rate. The components, methods and technology used in the prototype can meet the needs of companies and organizations, which are looking for people counting system solutions that do not require hyper precision.

5.2 Kokkuvõte eesti keeles

Magistritöö raames on edukalt välja töötatud asjade internet ja masinõppepõhine inimeste loendamise süsteem. Mehaaniline projekteerimine, elektrooniline disain ja tarkvaraarenduse etapid viidi lõpule planeeritud kuupäevadel. Vastavalt tehtud kavanditele, valmistati prototüübid ja täideti töö eesmärgid.

Tehtud katsete tulemusena on tõestatud, et PIR-andurite nurgad on arvutatud õigesti. Prototüüp ei vaja kahesuunalise inimeste loendamiseks lisavarustust. C ++ -põhises Arduino programmis, prototüübi inimeste loendamine kahesuunaliselt, kasutades katkestusi, viidi läbi umbes 93% edukuse määraga. Ehkki tavaliste ristamiste korral on veamäär madalam, tõuseb veamäär veelgi järjestikuste alla sekundi pikkuste ristamiste korral.

Iga prototüübi traadita võrguühendust testiti pidevalt kaksteist tundi, selle aja jooksul tehti katkematu kohene andmeedastus kolmelt prototüübilt, mis on ühendatud samasse võrku.

Iga prototüübi mehaaniliste ja elektrooniliste osade tootmine maksis kokku umbes 55 eurot. See hind kehtib jaemüügi puhul ja eeldatakse, et see kulu väheneb masstoodangus 40%.

Aku testitulemuste põhjal saab prototüüpe teoreetiliselt tööle panna ühe 9V akuallikaga 1094 kuni 1234 tundi. Kuna mikrokontrollerite unerežiimid võivad mõjutada andureid, kasutatakse selles uuringus tavarežiimis mikrokontrollereid. Senikaua kuni unerežiim on korralikult integreeritud, saab seade ühe toiteallikaga kauem töötada.

Covid-19 pandeemia tõttu on enamik töökohti ajutiselt suletud või avatud piiratud aja jooksul. Sel põhjusel oli keeruline leida välikatseteks sobivat keskkonda. Türgis Kesk-Anatoolia piirkonnas asuvas Erciyes Technopargi ülikoolilinnakus tehti kolmepäevaseid välikatseid kolmele uurimis- ja arendusettevõttele. Kuna ettevõtted võtavad tööle lühiajalisi töötajaid, tehti kõik mõõtmised kindlaksmääratud aegadel pärastlõunal. Saadud andmeid kasutati masinõppemeetoditega ennustamiseks. Kuna andmed on piiratud, on tehtud põhiline hinnanguuring. Masinõppe järjepidevamaid uuringuid saab teha kuu, kvartali ja aasta andmete mõõtmisega.

Kokkuvõtteks võib öelda, et kahesuunaline inimeste loendamise seade, mis töötab vastavalt lõputöö eesmärkidele, töötati välja ja prototüüp tehti nullist. Tehtud testide tulemusena tehti kindlaks, et süsteem töötas edukalt suure kiirusega. Prototüübis kasutatavad komponendid, meetodid ja tehnoloogia suudavad rahuldada ettevõtete ja organisatsioonide vajadusi, kes otsivad inimeste loendamise süsteemilahendusi, mis ei ole ülitäpsed.

5.3 Future Work and Recommendations

First of all, creating sensor nodes in IoT projects is very important both in terms of cost savings and energy savings. For this reason, establishing a sensor node in future studies will facilitate simultaneous data acquisition from more than one location in buildings, and abate wireless connection pollution and high energy consumption.

Another important issue in IoT projects is information security. While developing IoT projects, the issue of security is often overlooked. However, security vulnerabilities in IoT devices can damage businesses materially and spiritually. It is very important to take extra security measures in order to prevent cyber attacks that may occur during the use of wireless networks and sending data to the cloud.

The PIR sensors used in the prototype are especially limited for people counting applications at specific distances. Considering the variable door dimensions in workplaces, it is very important to make the device stable in every environment. For this reason, mechanical or software changes should be made depending on the working height of the device.

It is very important to use the sleep modes of microcontrollers to achieve more successful results in energy saving. During the study, the sleep mode of the microcontroller was not used because high sensitivity was aimed at the measurement. However, in future studies, the sleep mode of the microcontroller can be used in a way that does not affect the triggers of the sensors. In this way, the power consumption of the device can be further reduced.

In this study, since the author is not a professional software developer, errors that may occur due to interrupts and triggers of the sensors have been reduced by using certain waiting times. In order to solve these errors more professionally, it is very important that each process is carried out in a separate function. In addition, measurement errors that may occur due to data transmission can be prevented in this way.

In this study, PIR sensors with the narrowest field of view in their field were preferred. For this reason, the cost of selected sensors is relatively higher than other PIR sensors. In future studies, new solutions can be developed with lower-cost sensors with the same reaction time and technology but a higher field of view. More accurate measurements can be achieved by using more PIR sensors at a lower cost.

The fact that most of the workplaces were closed or limited work due to the Covid-19 Pandemic negatively affected the field tests of the project. For this reason, machine learning algorithms used for prediction gave limited results. More accurate estimates can be made with longer-term measurements. In addition, according to the forecast data obtained, the HVAC systems and personnel optimization of the workplaces can be planned more efficiently.

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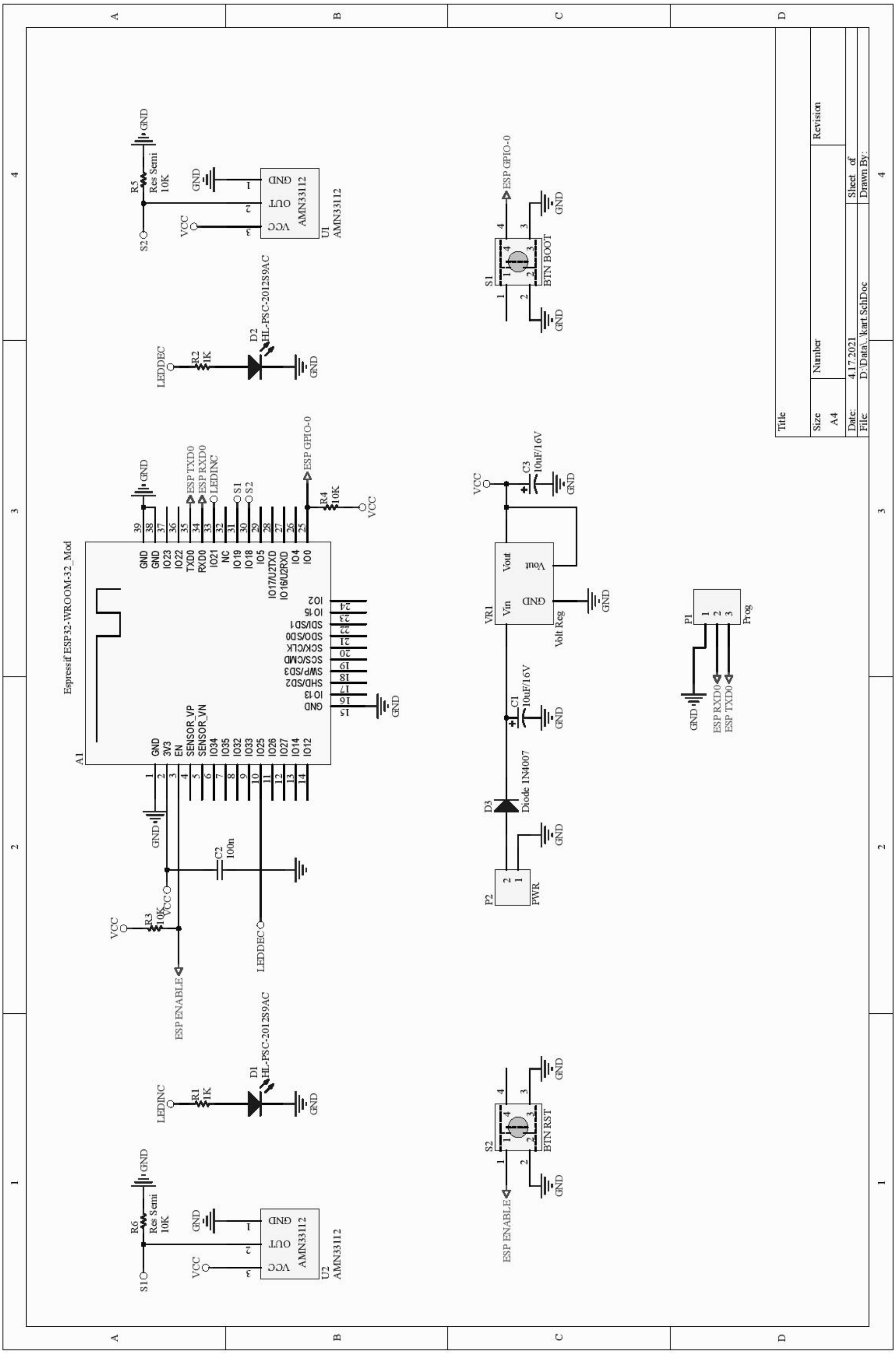
APPENDIX A


Espressif ESP32-WROOM-32_Mod
A1
U1
AMN33112
U2
AMN33112
R5
Res Semi
10K
R6
Res Semi
10K
D1
HL-PSC-2012S9AC
D2
HL-PSC-2012S9AC
R1
1K
R2
1K
R3
10K
R4
10K
C2
100n
LEDINC
LEDDEC
ESP ENABLE
ESP GPIO-0
ESP TXD0
ESP RXD0
S1
BTN BOOT
S2
BTN RST
VR1
Volt Reg
C1
10uF/16V
C3
10uF/16V
D3
Diode 1N4007
P2
PWR
P1
Prog
VCC
GND
Title
Size
A4
Number
Revision
Date:
4.17.2021
Sheet of
File:
D:\Data\..\kart.SchDoc
Drawn By:

APPENDIX B

```
#include <analogWrite.h>
#include <WiFi.h>
#include <HTTPClient.h>

const char* ssid = "XXXXX";
const char* password = "XXXXX";

String server = "http://maker.ifttt.com";
String eventName = "per_count";
String IFTTT_Key = "XXXXXX";
String IFTTTUrl= "https://maker.ifttt.com/trigger/per_count/with/key/XXXXXX";
bool sendHTTPrequest = LOW;

const int sendInterval = 5000;
float avg[3]={0,0,0};

char light_array[7];
char temp_array[7];


//PIN NUMBERS
uint8_t pirPin1 =  18;
uint8_t pirPin2 = 19;
uint8_t ledPin1 = 25;
uint8_t ledPin2 = 21;
#define buzzer   22

int counting,x,y = 0;   //Number of people in the room

int calibrationTime = 5; //10 secs    //Time required for sensor to be calibrated.
Sensors output until this time point is unstable

//Variables for holding the last checked time
unsigned long timeSensor1 = millis();
unsigned long timeSensor2 = millis();
unsigned long timeSensor4 = millis();
bool delayflag = LOW;
long timeInterval = 1400;        //Time interval for ignoring the output of other sensor

volatile bool SomeoneIN = HIGH, SomeoneOUT = HIGH;
volatile bool SomeoneReallyIN = HIGH, SomeoneReallyOUT = HIGH;    //Flags for
noting sensor outputs
bool shouldIncrement = HIGH;
bool shouldDecrement = HIGH;
void IRAM_ATTR increment_(); // ESP ürünlerinde kesme için belirtmek şart
void IRAM_ATTR decrement_();

void setup() {
  Serial.begin(115200);
  delay(1000);
  Serial.println("\nStarting....");
  WiFi.begin(ssid, password);
  Serial.print("Connecting to Wi-Fi");
  while (WiFi.status() != WL_CONNECTED) {
```

```
    delay(500);
    Serial.println("Connecting to WiFi..");
   }
   Serial.println();
   Serial.print("Connected with IP: ");
   Serial.println(WiFi.localIP());
   Serial.println();

   Serial.println("-----------------------------------");
   Serial.println("Connected...");

   pinMode(buzzer, OUTPUT);
   pinMode(ledPin1, OUTPUT);
   pinMode(ledPin2, OUTPUT);
   digitalWrite(ledPin1,HIGH);
   digitalWrite(ledPin2,HIGH);
   delay(1000);
   digitalWrite(ledPin1,LOW);
   digitalWrite(ledPin2,LOW);
   delay(1000);
   digitalWrite(ledPin1,HIGH);
   digitalWrite(ledPin2,HIGH);
   delay(1000);
   digitalWrite(ledPin1,LOW);
   digitalWrite(ledPin2,LOW);

   //give the sensor some time to calibrate
   Serial.print("calibrating sensor ");
   for(int i = 0; i < calibrationTime; i++){
     Serial.print(".");
   }
   Serial.println(" done");
   Serial.println("SENSOR ACTIVE");
   delay(50);
   attachInterrupt(digitalPinToInterrupt(pirPin1),increment_, RISING);
   attachInterrupt(digitalPinToInterrupt(pirPin2),decrement_, RISING);
}

void loop() {


  unsigned long currentTime = millis();
  delayflag = LOW;

//  Serial.print("Status of sensor 1 is: ");
//  Serial.print(digitalRead(pirPin1));
//  Serial.print(" and sensor 2 is: ");
//  Serial.println(digitalRead(pirPin2));

  if (SomeoneIN == LOW)
  {
    if ((currentTime - timeSensor1) < timeInterval) //if 2s has elapsed or entering
sequence not complete
    {
      if ((currentTime - timeSensor1) > 100)
      {
        shouldIncrement = LOW;
```

```
      Serial.println("shouldIncrement = LOW");
     }
    }
    else
    {
     SomeoneIN = HIGH;
     shouldIncrement = HIGH;
     timeSensor1 = currentTime;
    }
  }
  else
  {
    timeSensor1 = currentTime;
  }

  if (shouldIncrement == LOW && SomeoneReallyIN == LOW)
  {
     x = x + 1;
     Serial.print("Someone crossed the zone, pir reads low, was high, count now: ");
     Serial.println(x);
     Serial.println("Incremented");
     Serial.println("someone entered");
     currentTime = millis();
     unsigned long timeSensor3 = millis();
     analogWrite(buzzer, 1023);
     while (currentTime - timeSensor3 < timeInterval + 200)

     {

       currentTime = millis();
       delayflag = HIGH;

     }
     analogWrite(buzzer, 0);
     delayflag = LOW;
     Serial.println("Sensor2 is ready");
     currentTime = millis();
     timeSensor1 = currentTime;
     SomeoneIN = HIGH;
     SomeoneReallyIN = HIGH;
     shouldIncrement = HIGH;
     sendHTTPrequest = HIGH;
  }

  if(SomeoneOUT == LOW)
  {
    if ((currentTime - timeSensor2) < timeInterval)  //if 2s has elapsed or entering
sequence not complete
    {
     if ((currentTime - timeSensor2) > 100)
     {
      shouldDecrement = LOW;
      Serial.println("shouldDecrement = LOW");
     }
    }
    else
    {
```

```
    SomeoneOUT = HIGH;
    shouldDecrement = HIGH;
    timeSensor2 = currentTime;
   }
  }
  else
  {
   timeSensor2 = currentTime;
  }

  if (shouldDecrement == LOW && SomeoneReallyOUT == LOW)
  {
   y = y - 1;
   Serial.print("Someone crossed the zone, pir reads low, was high, count now: ");
   Serial.println(y);
   Serial.println("Decremented");


   Serial.println("someone exit");
   currentTime = millis();
   unsigned long timeSensor4 = millis();
   analogWrite(buzzer, 200);
   while (currentTime - timeSensor4 < timeInterval + 200)
   {

     currentTime = millis();
     delayflag = HIGH;

   }

   delayflag = LOW;
   Serial.println("Sensor1 is ready");
   currentTime = millis();
   timeSensor2 = currentTime;
   SomeoneOUT = HIGH;
   SomeoneReallyOUT = HIGH;
   shouldDecrement = HIGH;
   sendHTTPrequest = HIGH;
  }
   counting = x+y;
   Serial.println("the number of people inside:");
   Serial.println(counting);

  //if(currentTime - timeSensor4 > 60000){
  if(sendHTTPrequest == HIGH){
  String url = server + "/trigger/" + eventName + "/with/key/" + IFTTT_Key +
"?value1=" + String((int)x) + "&value2="+String((int)y) +"&value3=" +
String((int)counting);
  Serial.println(url);
  //Start to send data to IFTTT

  HTTPClient http;
  Serial.print("[HTTP] begin...\n");
  http.begin(url); //HTTP

  Serial.print("[HTTP] GET...\n");
  // start connection and send HTTP header
```

```
  int httpCode = http.GET();
  // httpCode will be negative on error
  if(httpCode > 0) {
    // HTTP header has been send and Server response header has been handled
    Serial.printf("[HTTP] GET... code: %d\n", httpCode);
    // file found at server
    if(httpCode == HTTP_CODE_OK) {
      String payload = http.getString();
      Serial.println(payload);
    }
  } else {
    Serial.printf("[HTTP] GET... failed, error: %s\n",
http.errorToString(httpCode).c_str());
  }
  http.end();
  timeSensor4 = millis()
  sendHTTPrequest = LOW;
  }
}


void increment_()
{
  if(delayflag == LOW)
  {
    //Serial.println("TEST INC");
    SomeoneIN = LOW; //random flag
    if (shouldDecrement == LOW)
    {
      SomeoneReallyOUT = LOW;
    }
    else
    {
      SomeoneReallyOUT = HIGH;
    }
  }
}

void decrement_()
{
    if (delayflag == LOW)
    {
        //Serial.println("TEST DEC");
        SomeoneOUT = LOW; //random flag
        if (shouldIncrement == LOW)
        {
          SomeoneReallyIN = LOW;
        }
        else
        {
          SomeoneReallyIN = HIGH;
        }
    }
}
```

APPENDIX C

```
#!/usr/bin/env python
import numpy as np
import pandas as pd

from sklearn.model_selection import train_test_split
from sklearn.preprocessing import StandardScaler
from sklearn.svm import SVR
from matplotlib import pyplot as plt


def support_vector_regression(X, y, print_text='support vector regression all in'):
    # scaling
    X_r = X
    y_r = y

    sc = StandardScaler()
    X = sc.fit_transform(X)
    y = sc.fit_transform(np.expand_dims(y, axis=1)).reshape(y.shape)

    # Split train test sets
    X_train, X_test, y_train, y_test = train_test_split(
        X, y, test_size=0.3, shuffle=False)

    X_r_train, X_r_test, y_r_train, y_r_test = train_test_split(
        X_r, y_r, test_size=0.3, shuffle=False)

    # SVR  all in
    reg = SVR(kernel='rbf', gamma="auto")
    reg.fit(X_train, y_train)

    plt.title("SVR " + print_text)
    plt.xticks(rotation=90)
    plt.xlabel("Time")
    plt.ylabel("Number of People")
    line1 = plt.plot(X_r,y_r, label="Ground Truth")
    line2 = plt.plot(X_r_test, sc.inverse_transform(np.squeeze(
        reg.predict(X_test))),color= "orange", label="Prediction")
    plt.legend()
    plt.show()

    return reg

if __name__ == '__main__':

    data = pd.read_excel('3day3device2.xlsx', index_col= None)
    df = pd.DataFrame(data=data)

    #X = df["Date-Time"].values.reshape(-1,1)
    X = np.arange(len(df)).reshape(-1,1)
    y = df["Dev0-Total"].values

    support_vector_regression(X, y, "Device 0")
print('Done')
```