Integrated Wireless Monitoring System Using LoRa and Node-Red for University Building

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RESEARCH ARTICLE

Integrated Wireless Monitoring System Using LoRa and Node-Red for University Building

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This paper aims to design and develop a network infrastructure for a smart campus using the Internet of Things which can be used to control different devices and to update the management with real-time data. In this proposed system, NodeMCU ESP8266 is interfaced with thermal and motion sensor for human, humidity and temperature sensor for the room and relay to control the lights and the air-conditioned. MQTT broker is used to acquire the data and control to and from NodeMCU ESP8266, Raspberry pi and LoRa, to be interfaced wirelessly with the Node-Red. Thus, the system is controlled and monitored wirelessly with the help of the developed integrated Graphical User Interface along with the Mobile application. The performance of the developed proposed system is analyzed and evaluated by testing the motion detection in the classroom, the LoRa range with the RSSI, the average time taken by the system to respond, the average time taken for the Graphical User Interface to response and update its data. Finally, the average time taken by the system and the Graphical User Interface to respond to the lights and air-conditioned control systems is less than 1 s, and for the security and parking systems is less than 2 s.

Keywords: Automation, Camera, Control, GUI, IoT, LoRa Gateway, LoRa, Monitor, MQTT, Node-Red, Real-Time, Security, Sensors, Raspberry Pi, Smart Campus, Wireless Sensors Network.

1. INTRODUCTION

Due to the rapid development in the uses for actuators and wireless networks, extensive studies on smart building systems has been carried out. The main objective of these systems is to intelligently control electric appliances based on the information collected by sensors from the surrounding environment. The smart control process can be done according to specific conditions. For example, a condition can be defined as an event where someone enters an office and the response being the lights automatically switching on. The condition is the engine rule in the smart building system, and it is an important factor which can results in flexible and easy control. The environment information is collected and reported to the server within a specified time by the monitoring region. In the server, the data will be analyzed and processed for identifying, matching the conditions, and executing the corresponding actions [1].

Internet of Things (IoT) will make a huge development and will provide new services to humans, public administration, and companies by enabling communication and interaction with different devices such as building appliances, monitoring sensors, surveillance camera, vehicles, displays, and many other devices which generate variety of data. This technology will be used in many different fields, such as industrials automation, buildings automation, mobile health care, medical aids, traffic managements, smart grids, and many other fields [2].

There are many ranges of protocols which have been used in IoT. Low-Power Wide Area Networks (LPWAN) is a new range of protocols and technology which has come to fulfill the communication requirements of the IoT. Generally, the LPWAN is supposed to be the IoT, as what WiFi was to consumer networking, and is offering radio coverage over a large area by means of base station and transmission power, adapting transmission rates, duty cycles, modulation, etc. LoRa is one such LPWAN protocol, it is a long range wireless communication system which was promoted by the LoRa Alliance [3]. LoRa system aims to be used in devices which are powered with long life battery where the amount of power consumption is very important. LoRa has two distinct layers which are physical layer using the chirp spread spectrum radio modulation technique, and the protocol which is known as a MAC layer. A specific access network architecture is implied for LoRa communication system. The layer which is known as physical layer was developed by Semtech, and

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it allows for long range, low throughput communications, and low power. It operates on the 915-MHz, 868-MHz, or 433-MHz ISM bands, and it depends on the region in which it will be used. Each transmission payload can range from 2–255 octets. When channel aggression is employed, the data rate can reach up to 50 Kbps [3].

University campus should be smart where many devices are connected to each other in a network, and where some actions will be done automatically based on real time data. When comes to the word automation, many challenges come to mind such as high installation costs, high maintenance cost, and complexity of the implementation. In this project, smart campus system will be developed by using Internet of things and with using different technologies and different communications protocols in order to make a smart system with low installation costs, low power consumption, and low maintenance and upgrading costs. The testing of the proposed system was done in Asia Pacific University (APU), Malaysia.

2. LITERATURE REVIEW

IoT based home design, which is using security and power management has been proposed. The design and the implementation of smart home system have been done which is an ethernet based intelligent system for controlling the power consumption. The system works based on the real time pursuing of the home appliances. The Intel Galieo Gen2 board was used to take the data from the sensors and forward it to the end user through the internet which will be displayed in a mobile application. Also, the user can send the commands from the mobile application through the internet to the development kit to control the home devices. Moreover, the development kit uses the sensors data to maintain the security of the smart home. The experimental results of the proposed system have shown better way of security and power management. The user can control the power usage and security of the home through friendly mobile application [4].

A smart home monitoring system which is using the principles of IoT and based on ZigBee has been proposed. LM3S8962 32-bit processor was used in the proposed design as central controller. ZigBee wireless communication was used for the local communication where it can send and receive the transmission data between the home devices and the main controller. The intelligent gateway LM3S8962 was used as main controller and through it, all process between the end user and the home devices can be done. The user can check and monitor the home appliances status through terminal devices with Web browsers. The local communication has been done through ZigBee and then the transmission data between the user and the local communication was done through the internet. The experimental results have shown that the remote monitoring devices based on ZigBee can be realized and the proposed system is feasible and simple [5].

IoT based control and monitoring system has been proposed which is for home automation and it uses the ambulant smart computers as a user interface. The communication between the network of the home automation and the end user is via internet gateway. It consists of 4 layers which are physical layer (devices), data link layer (gateway), network and transport layer (internet), application and presentation layer (webportal). The system is to control home devices using portable devices such as smartphone and through the Wi-Fi which has been used as communication protocol. In the proposed system, the raspberry pi was used as server system which is interfaced with relay hardware and which will allow controlling the devices through website. The experimental results have shown that the system is appropriate for remotely controlling home devices and for real time home security monitoring [6].

An integrated IoT-based cloud smart parking system has been proposed which provides real-time data about whether the parking spaces are empty or not in the parking area. It uses an on-site deployment of an internet of things module to signalize and monitor the status of each parking slot. The system has a mobile application which is used as a remote location and through this mobile application the end user can check the availability of the parking space and then can book the parking space through the application. The data of the parking space availability states are being obtained by using sensors and actuators, then the data will be transferred by the raspberry pi through the internet to the cloud. The results of the proposed system will enhance the parking systems and will improve the parking facilities in the cities [7].

An efficient embedded surveillance system that have facility of capturing image automatically and send it to email has been proposed. A surveillance system was designed and implemented by using sensors such as PIR sensors which is pyroelectric infrared sensors and ultrasonic sensors to detect stranger in house, storehouse, industries, bank locker room or ATM. The ultrasonic sensors were located vertically on the wall and the PIR sensors were placed on the roof. A camera was used to capture the area when there is someone entering the surveillance area then the captured images will be sent to the authorized person. The results have shown two different types of sensors that use the MVN to decrease the deficiency of PIR sensor and ultrasonic which is considered as enhancing the sensing probability. Also, the results have shown that system send the captured images to the user [8].

Smart home control system based on wireless sensor network and power line communications which reduce the effect of consumed power of a smart home and the effect of wireless interface on a smart home control network has been proposed. In the proposed system, segregated wireless sensor networks with integrated coordinator into the power line communications were established in each

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room. The responsibility of the coordinator is to transfer the environmental data which was obtained by the Wireless Sensor Network (WSN) through the Power Line Communications (PLC) to the management. A smart control algorithm was used in this proposed design to control the lighting system. The WSN was used for data sensing and the PLC was used as network backbone. The proposed system reduced the effect of wireless interfaces and it simplified the problem of setting up relay in WSN. The results of this system have shown that the power cost will be reduced. This system can be developed and implemented for intelligent buildings [9].

IoT based smart security and home automation system alerts the user via voice call using the internet in case of any sort of human movement in any area where the security system has been installed. It allows the user to control different appliances via the internet. User can control different applicants such as opening the door and switching on several appliances which are connected to the microcontroller inside the house. It uses the motion sensor to detect any motion, and the microcontroller sends the user alerts through the internet based on the collected data. Also, the microcontroller was connected to various appliances which enable the user to control them. This system has low installation costs as it uses the minimum requirements to take care of both home automation and security as well. This system does not use any type of graphical user interface or any phone application to control the appliances, it uses only digits from the keypads on the phone. The system is independent platform and it can be accessed from different phones with various operating systems [10].

3. SYSTEM IMPLEMENTATION

3.1. Overall Block Diagram

The smart campus system is an integrated system that consists of 4 systems which are light control system, air-conditioner control system, parking status system, and real-time alarm security system. This integrated system was built with the use of different types of electrical and electronic components and with different types of communication mediums.

Figure 1 shows the overall block diagram of the smart campus system. It shows how the system was implemented and it shows the involved electrical and electronic components, the communication mediums, and the end user applications.

The overall block diagram which was shown in Figure 1 has shown that the system has different types of inputs that will be acquired from different types of sensors which are thermal and motion sensor, DHT 11 sensor, ultrasonic sensor, and camera. The thermal and motion sensor and the DHT 11 sensor (humidity and temperature sensor) were connected to the NodeMCU ESP8266 microcontroller. The NodeMCU ESP8266 acquires the data from the sensors and transmits it to the MQTT broker through the internet. There are four relays which are connected to the NodeMCU ESP8266. This microcontroller controls the relays based on the acquired data from sensors and based on the input of the user. The four relays control the lights

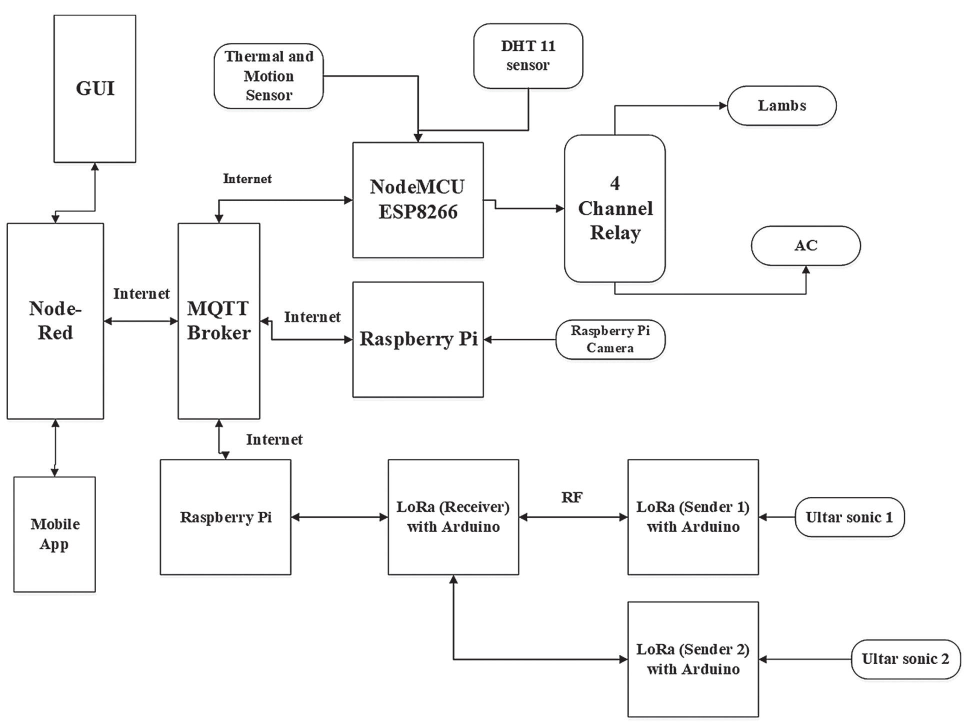

Fig. 1. Overall block diagram of the smart campus system.

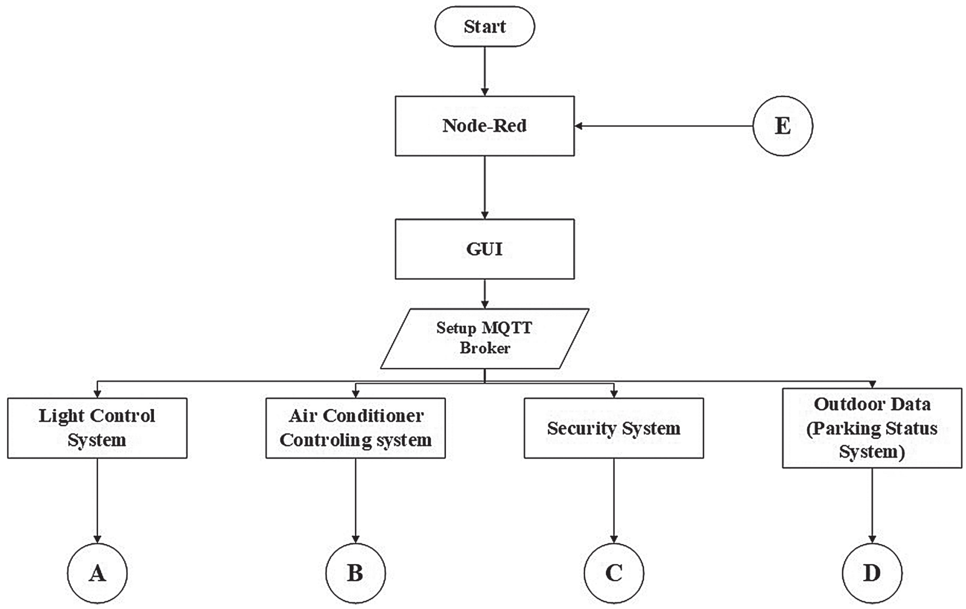

Fig. 2. Main flowchart of the integrated system.

and the Air Conditioner (AC) which are represented in the prototype by a fan to show the working principle. The ultrasonic sensors were connected to the Arduino microcontrollers with the LoRa transceiver to detect the availability of the parking slots and send it to the LoRa receiver. The raspberry pi with the LoRa transceiver was used as a gateway to receive the data from the LoRa senders then transfer it to the node-red through the internet. The raspberry pi camera was used as a motion detector and it captures the area when there is any motion detected in the surveillance area. The camera was connected to raspberry pi 3 microcontroller that sends the data to the MQTT broker through the internet.

3.2. Working Principle

There are two controlling systems in the smart campus system which are light control system and air conditioner control system. The two controlling systems use wireless

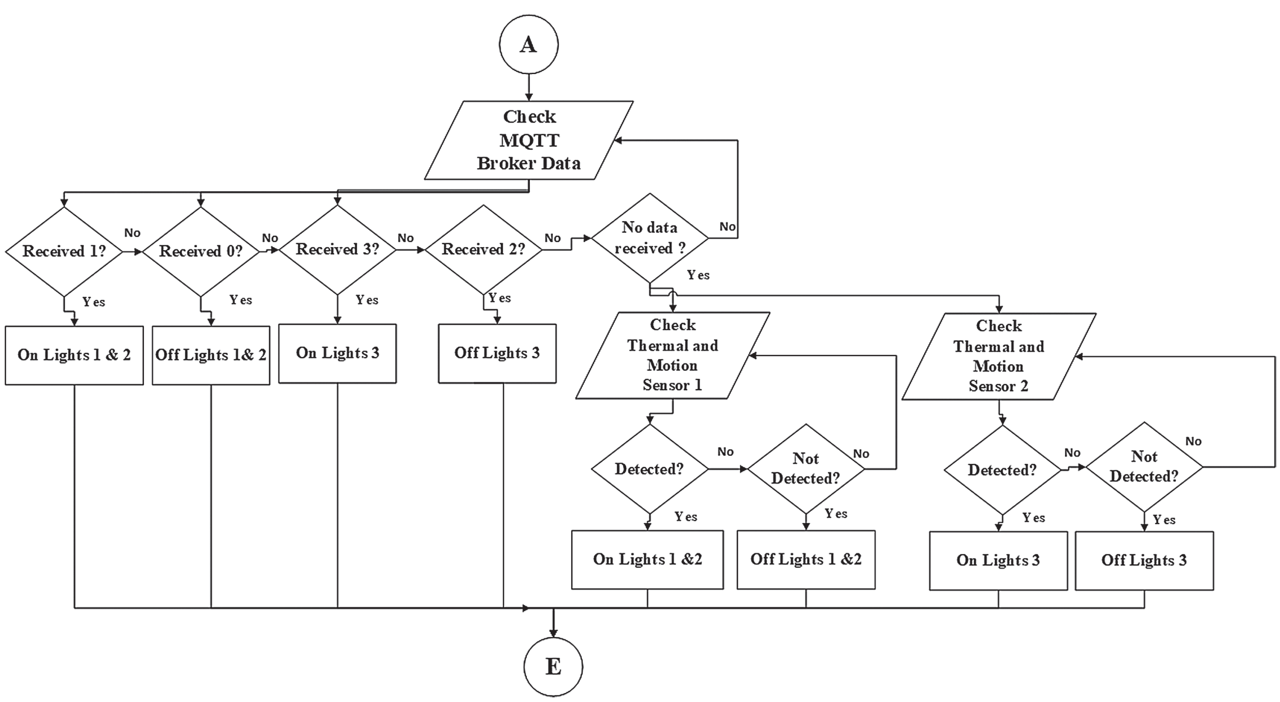

Fig. 3. Light control system flowchart.

Wi-Fi as a communication medium to transfer the data and the commands between the microcontrollers and the IoT platform. There is also security system which is a real-time alarm system, which uses OpenCV image processing to detect any motion in the surveillance area and to capture the area when there is any motion detected. The real-time alarm system uses a wireless Wi-Fi as a communication medium between the raspberry pi and the Node-Red platform. The parking status system uses LoRa to transfer the data between the LoRa nodes, then it uses the LoRa gateway which was developed in this system with the help of raspberry pi to transfer the data from the LoRa nodes to the Node-Red platform through the internet.

Figure 2 shows the main flowchart of the integrated system. It shows that the system starts with the Node-Red platform which is an IoT platform and it was fully hosted in a private server for this system. This platform contains all the codes that process the data which are coming from the sub-systems, then it sends commands to the sub-systems through the MQTT broker via the internet. The MQTT broker is the channel that made this system flexible when transferring data or commands which was done by the user.

Figure 3 shows the light control system flowchart and it shows that it can be controlled remotely based on the input of the user or automatically based on the data collected by the thermal and motion sensor. There are three lights in the classroom and there are two thermal and motion sensors. When the user turns ON light one and light two, digit 1 will be sent to the NodeMCU ESP8266 through

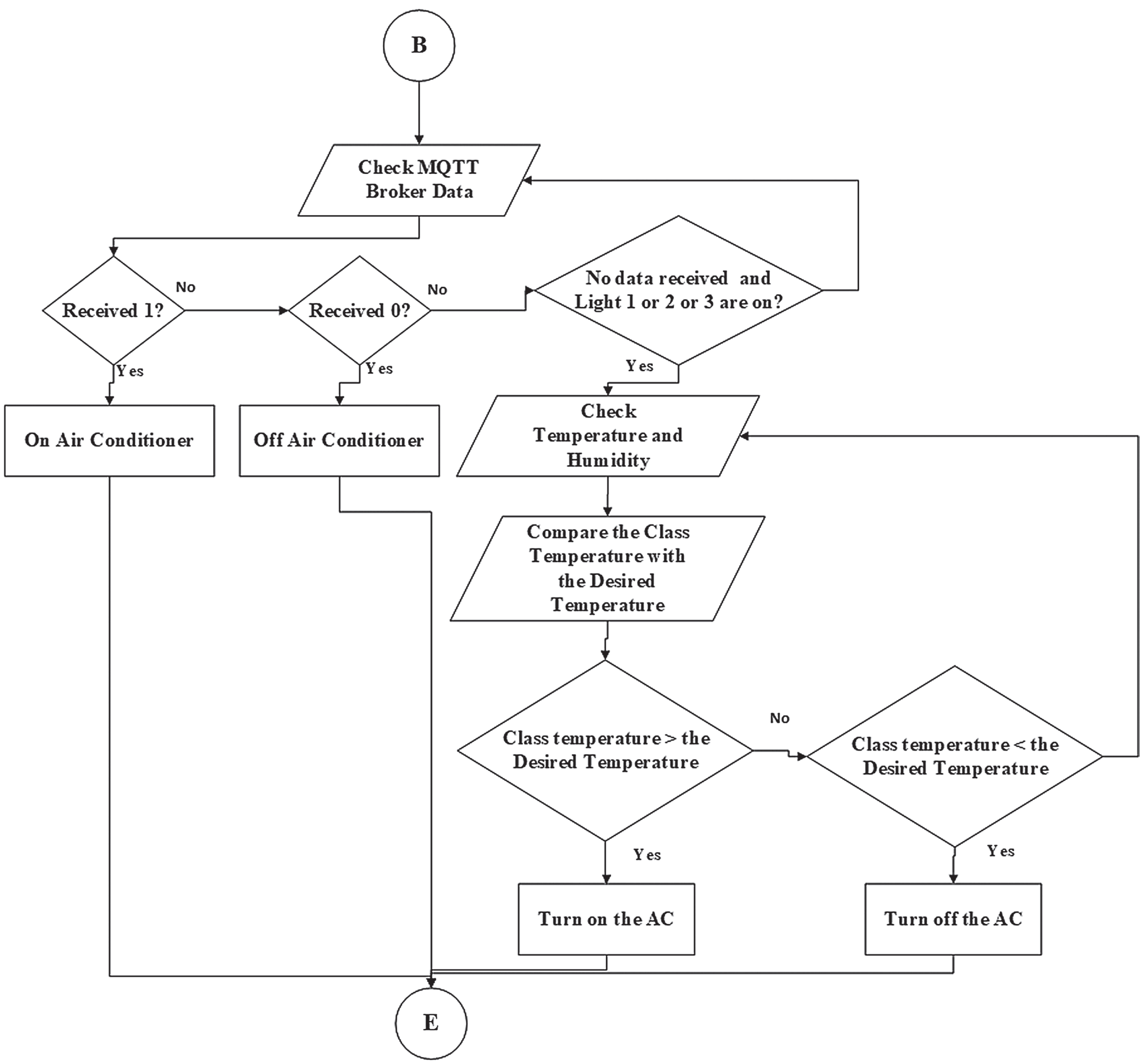

Fig. 4. AC control system flowchart.

the MQTT broker then light 1 and light two will be turned ON. When the user turns OFF light one and light two, digit 0 will be sent to the NodeMCU ESP8266 through the MQTT broker then light 1 and light two will be turned OFF. When the user turns ON light three, digit 3 will be sent to the NodeMCU ESP8266 through the MQTT broker then light three will be turned ON. Also, when the user turns OFF light three, digit 3 will be sent to the NodeMCU ESP8266 through the MQTT broker then light three will be turned OFF. In case if the user did not send a command to the NodeMCU ESP8266, the light system will work automatically and if there is any motion detected by motion sensor 1 then light one and light two will be turned ON automatically and if there is any motion detected by motion sensor 2 then light three will be turned ON automatically. In case if there is no input by the user and no motion detected by motion sensor one and motion sensor 2, then all the lights will be turned OFF automatically.

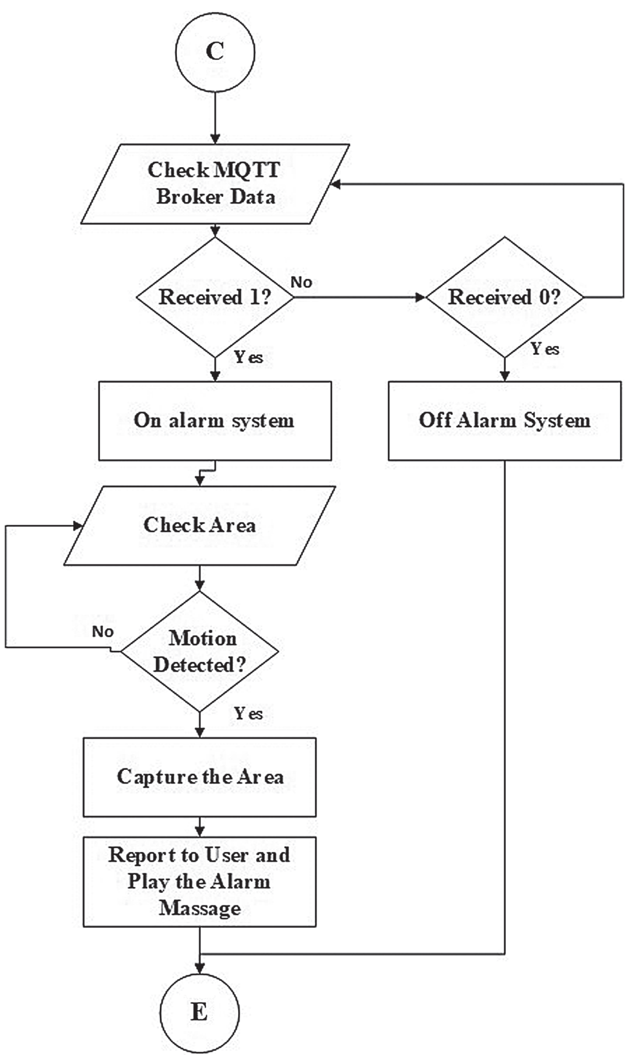

Fig. 5. Real-time alarm system flowchart.

Figure 4 shows the AC control system flowchart and it shows that the AC can be controlled automatically and it can be controlled by the user remotely. The AC was represented in the prototype of this project by a fan.

When the user turns ON the AC, digit 1 will be sent to the NodeMCU ESP8266 through the MQTT broker then the AC will be turned ON, and when the user turns OFF the AC, digit 0 will be sent to the NodeMCU ESP8266 through the MQTT broker then the AC will be turned OFF. In case if the user did not send any command from the GUI and if any of the lights is ON, then the system will compare the classroom temperature that was acquired by the DHT 11 sensor with the desired temperature which was set by the user and based on that the AC will be turned ON or turned OFF automatically. There were two cases set in the system which are when the classroom temperature is higher than the desired temperature and if any of the lights is ON then the AC will be turned ON automatically, and when the classroom temperature is lower than the desired temperature and if any of the lights is on then the AC will be turned OFF automatically. Figure 5 will show the real-time alarm system and it will show that the system works only when the user turns ON the security system. When the user turns ON the security system, digit 1 will be sent to the NodeMCU ESP8266 through the MQTT broker then the real-time alarm system will be turned ON and if there is any motion detected in the area, the area will be captured and will be sent to the user. There will be audio alarm message played in the office as an audio

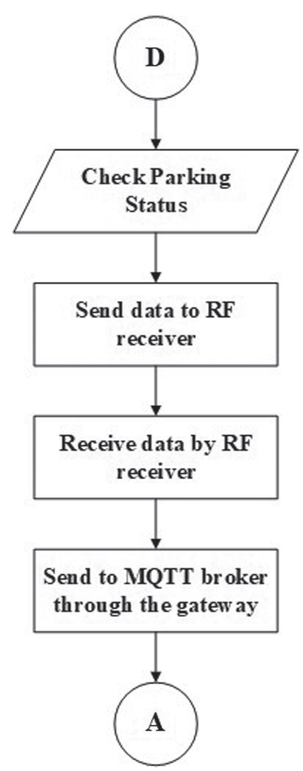

Fig. 6. Outdoor parking system flowchart.

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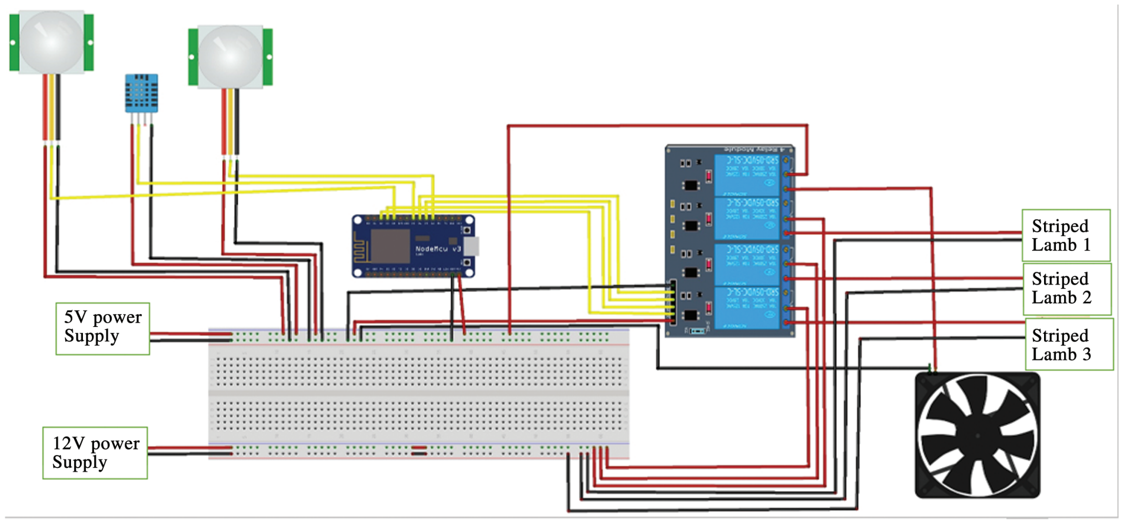

Fig. 7. Wiring circuit of the light and air conditioner control systems.

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when there is motion detected as well and the user can send any message to be played as an audio. When the user turns OFF the security system, digit 0 will be sent to the NodeMCU ESP8266 through the MQTT broker then the real-time alarm system will be turned OFF.

Figure 6 shows the outdoor parking system flowchart that uses LoRa technology to transfer the outdoor parking data. The parking slots will be checked using the ultrasonic sensor and the data will be sent regularly through the LoRa sender and it will be received by the LoRa receiver. The data which received by the receiver will be sent to the MQTT broker through the gateway.

3.3. Wiring Circuit

The construction of this system was done according to the proposed methodology. This integrated system consists of four systems and every system was constructed based on its proposed methodology and its selected components.

Figure 7 has shown the wiring circuit of the lights and air conditioner control systems. The NodeMCU ESP8266 is a microcontroller and it was chosen to be used for the indoor systems which are the light control system and the air conditioner control system. It is a Wi-Fi module that was programmed using Arduino to process the data which are acquired by DHT 11 sensor and PIR sensor. It was

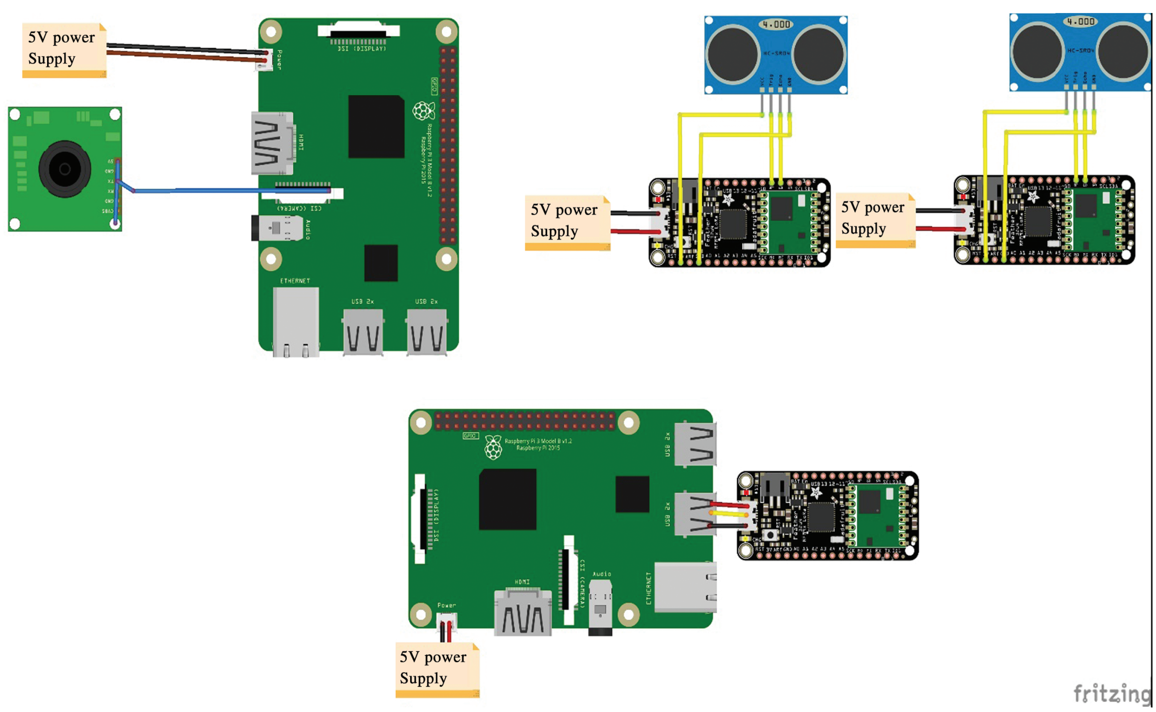

Fig. 8. Wiring circuit of real-time alarm and parking status systems.

Fig. 9. Software results 1.

programmed to process the data, to send the acquired data to the IoT platform through the Wi-Fi, to receive and process the data which are coming from the IoT platform, and to control the relays based on the processed data and based on the input of the user.

Figure 8 shows the wiring circuit of the real-time alarm system and the parking status system. Raspberry pi camera was connected to the raspberry pi through strip wire that contains 15 pins. Two ultrasonic sensors were connected to the LoRa shield which were connected to Arduino where the LoRa shield with the Arduino were represented in Figure 8 by using Adfruait LoRa because the LoRa type which was used in the prototype was not found in fritzing parts. The ultrasonic sensor is a distance detector sensor and it was used to detect whether there is a car in the parking slot or not. The LoRa transceivers which were connected to the ultrasonic sensors were programmed to send the data acquired by the ultrasonic sensors and the data will be received by the LoRa receiver. The LoRa receiver was connected to the raspberry pi through a serial connector and it was programmed with the raspberry pi to work as a gateway.

The LoRa type which was used in this project is Cytron LoRa shield RF95. Raspberry Pi 3 was used in the real-time alarm system. It was used to control the system, process the data, and send the picture which was detected and captured by the camera when there is any motion being detected in the area.

3.4. DEMO

APU smart campus system has different types of results as it is an integrated system which consists of 4 sub-systems. For every system, there are results which will be displayed in the GUI of the integrated system and there are some results which show more detailed results which can be displayed in the information box which shows the real-time data. Also, for the real-time alarm system, the results are shown in the GUI and in a mobile app which is telegram.

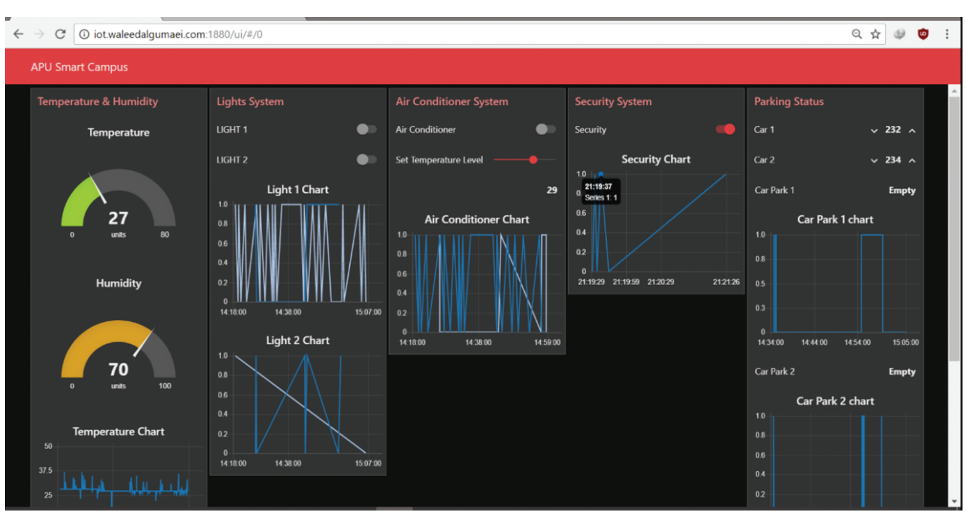

Fig. 10. Software results 2.

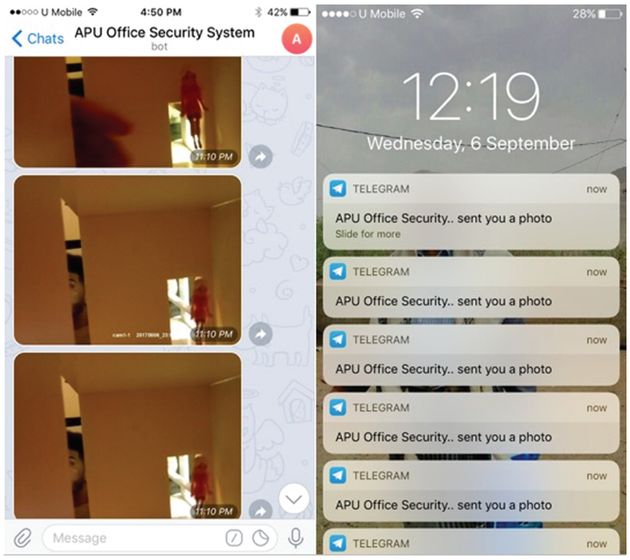

Fig. 11. Software results 3.

Figure 9 shows simulation results 1 which is the GUI of the system. In this GUI, there are two status systems which display data only for the humidity and temperature and for the parking status. Also, there are 3 control systems which are for lights control, AC control, and security control. In the light control system, there are two switch buttons which are light 1 button that controls the first and the second lights in the classroom and light 2 button which controls the third light in the classroom.

There are two charts for the light control system that shows the lights status (ON or OFF) for the entire day and that can be used for data analysis. For the air conditioner control system, there is one switch button which controls the AC (ON or OFF) and there is a slider to represent the levels of the remote control of the air conditioner. There is one chart for the air conditioner control system which shows the status of the AC (ON or OFF) for the entire day and that can be used for data analysis.

For the security control system, there is one switch button that turns ON or OFF the real-time alarm system and

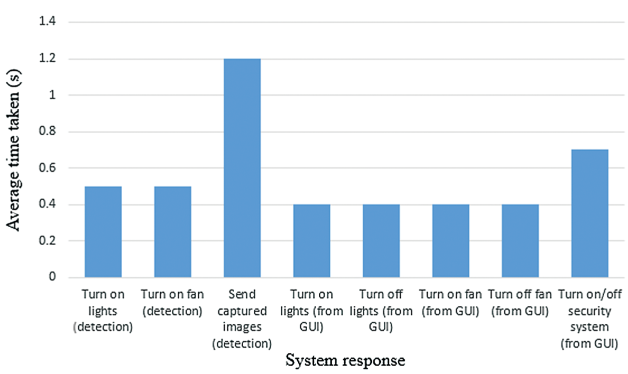

Fig. 12. Average time taken for the system to response.

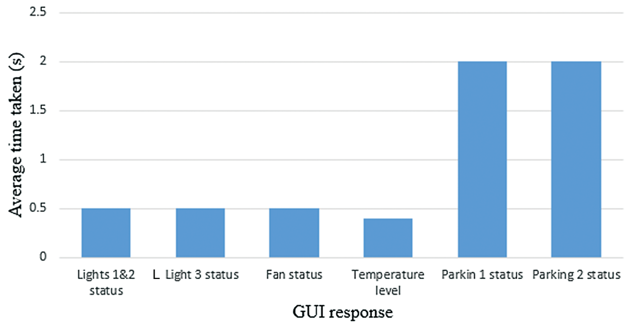

Fig. 13. Average time taken for the GUI to response.

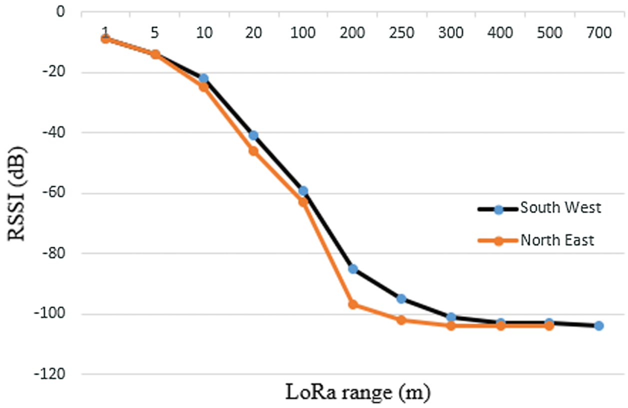

Fig. 14. LoRa range versus RSSI.

there is a chart which shows the status of the real-time alarm system status (ON or OFF) for the entire day.

Figure 10 shows software results 2 which is the GUI of the system, it shows that the user can know the status of the systems with the exact time as it shows in chart of the security system. By pointing to any point in the chart, the status of the system at that time will be displayed in a small box as it shows in the security system chart.

Figure 11 shows software results 3 which is the real-time alarm system results. In the right side of Figure 11, it shows when the captured images were received by the telegram app in the phone of the user in the real time of motion detection. In the left side, it shows the captured images that were received by the telegram bot which was named APU office security system. In the received images, the time and the date of the moment when the motion was detected and when the image was captured is displayed in the lower part of the image as shown in Figure 14.

4. EXPERIMENTAL RESULTS

Testing have been done to evaluate the overall performance, and to ensure that the working principles of the proposed methodology of the system have been implemented properly.

4.1. System Response

This test is about evaluating the system response by measuring the average time taken for each sub-system to response in the different situation. The system collects the environment data from the wireless sensors network and based on the collected data, it responses and some actions will be done automatically. Also, the system can be monitored remotely from the GUI of the system.

Figure 12 shows the time taken for the systems to respond to the collected data by the wireless sensors network and to the commands done by the user from the GUI. It shows that the sub-systems take different time to response and different situation (detection or command from GUI) take different time even for the same subsystem. The light control system takes 0.5 s to respond based on motion detection when the students enter the class whereas it takes 0.4 s to respond based on the commands which come from the GUI. That difference is because in the first situation (detection) there are two-way communications which are from the microcontroller to the GUI then from the GUI to the microcontroller whereas in the second situation (command come from GUI) there is only one-way communication which is from the GUI to the NodeMCU ESP8266 microcontroller which controls the light and the AC.

In the first situation (detection), the data collected by the motion sensors will be sent to the IoT platform then it will be analyzed and based on the analyzed data, a command will be sent to the NodeMCU ESP8266 to turn ON/OFF the lights. In the second situation (command from the GUI), when the user turns ON/OFF the light control system a command will be sent directly to the NodeMCU ESP8266 microcontroller.

Different processes take different time and different types of data take different time to be transmitted. The internet network connectivity is an important factor which directly affects the data transmission and influences on the system response.

4.2. GUI Response

This test is about evaluating the GUI response by measuring how fast the data will be updated in the GUI when there is new data being collected by the wireless sensors network of the system. For evaluating the GUI response to update its data when there is a change in the system status and data, a bar chart was plotted and is shown in Figure 13.

Figure 13 shows the average time taken for the GUI to response when there is a change in the system status and response. It can be observed that the average time taken for the GUI to response and update its data when there is a change in light 1 status, light 3 status, and fan status, is 0.5 s and this is because these three statuses are being controlled by the same sensors and microcontroller. The temperature level data for the classroom environment was updated in the GUI within 4 s which is faster than the lights and system status response time and this is due to the fact that there is no controlling process to be processed and the temperature level data, which was only collected by the DHT 11 sensor and then it was transmitted to the GUI directly. It can be observed that the parking status updates in the GUI have taken 2 s which seems to be high as the system uses MQTT broker which is a high data rate transmission, but the delay is due to the LoRa gateway which transmits the received data from LoRa receiver to the internet. This gateway was built using a raspberry pi microcontroller which is only for testing purpose. Different processes take different time and different types of data take different time to be transmitted and to be updated in the GUI. The internet network connectivity is an important factor for the GUI to response fast where it directly affects the system transmission data and this influences on the GUI response time.

4.3. LoRa Range with RSSI

The relative received signal strength in a wireless environment which is in arbitrary units is known as RSSI and it indicates the level of the power being received by the receiver where the higher the RSSI, the stronger the signal. This experiment is about evaluating the LoRa range with the RSSI where the RSSI is influenced by the environment, the distance between the sender and the receiver, and antenna type of the sender and the receiver. LoRa RF95 was used in this project to create a wireless communication network for outdoor data transmission and it was tested for transmission outdoor parking status.

Figure 14 shows LoRa range versus RSSI where the range was tested in two different directions which are in the south–west direction and north–east direction. It can be observed from Figure 11 that when the distance increases the received signal strength decreases as well. When it comes to comparing the coverage range with the RSSI values in the south–west and north–east directions, it can be observed that the RSSI readings in the south–west direction from APU campus is better than the RSSI readings in the north–east directions and is because the obstacles and barriers in the north–east direction are more than in the south–west direction of APU campus. The data transmission in the south–west direction becomes weak when the distance between the sender and the receiver is more than 700 m and it was observed that at that range the data delay and losses occurred. Whereas the data transmission in the north–east directions becomes weak when the distance between the sender and the receiver is around or more than 500 m and that is because the obstacles and the barriers in this direction were more than the south–west direction. The lowest value of the RSSI readings was −104 dB and after that reading the data losses occurred which means that the antenna of the receiver cannot sense any signal has more than −104 dB RSSI as the antenna which was

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used, was for testing only and in the real implementation there are some other antennas which can receive data with lower than −104 dB RSSI. The performance of LoRa coverage becomes weaker when there are obstacles and barriers between the LoRa sender and receiver. Also, the received signal strength becomes weaker when the distance increases between the LoRa sender and receiver where the higher the RSSI the better the speed and the quality of the communication.

5. CONCLUSION

A network infrastructure for a smart campus has been designed and developed using internet of things which can be used to control different devices and to update the management with real-time data. It is an integrated system that has light control system, air conditioner control system, real-time alarm security system, and parking system. From the experimental results, the average of the time taken for the system and the GUI to respond to the lights and air-conditioner control systems are less than 1 s, and to the security and parking systems is less than 2 s.

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