Smart Office: Implementing IoT for Enhanced Efficiency and Connectivity

Yuliana Prastiwi[1], Hudiono[2], Azam Muzakhim Imammuddin[3]

[1,2,3]Digital Telecommunication Network Study Program,
Department of Electrical Engineering, State Polytechnic of Malang, Malang City, 65141, Indonesia

[1]yulianaprast37@gmail.com, [2]hudiono@polinema.ac.id, [3]azam@polinema.ac.id

***Abstract* — In office buildings, control of electrical devices is still carried out manually using a switch, namely by turning off and turning on electrical devices directly or manually, the result is inefficient and ineffective. So far, smart building research on offices that has been carried out can only control the use of lights and fans in rooms that are monitored and controlled via the web, but smart office buildings should include more than just controlling electrical devices. To overcome this problem, it is necessary to develop so that electrical control can be carried out automatically and more broadly at the same time can be monitored via a cellphone by utilizing Internet of Things technology. In this study, the implementation of the Internet of Things made in this smart building includes a gate control system using an ultrasonic distance sensor, monitoring light intensity using an LDR light sensor and the condition of the lights in front of the building's terrace, monitoring movement in the room using a PIR motion sensor for control. using lights and fans, scheduling watering for the garden by scheduling it using a Real Time Clock and soil moisture sensors to determine whether the garden has been watered or not. The use of this technology also covers the field of building security by using fingerprint sensors for office employees. Tests in this study used LDR light sensors which produced a small average error of 0.062%, ultrasonic sensors which produced a percentage of success values of 50% on ultrasonic sensors outside the building, and 70% on ultrasonic sensors in the building area. In testing the PIR motion sensor can detect up to 51 cm which is more than enough to detect movement within the building area. In the soil moisture sensor synchronization test that can test the differences in soil before watering and after watering. As well as a fingerprint sensor that can be read with a delay of 6 seconds to read fingerprints, update fingerprint sensor data to the database and relay.**

***Keywords* — *ESP8266, Ultrasonic Sensor, LDR Sensor, PIR Sensor, Soil Humidity Sensor, Realtime Database*.**

I. INTRODUCTION

In office buildings, control of electrical devices is still done manually using a switch, namely by manually turning off and turning on lights or other electrical devices. Controlling electrical devices manually is not efficient in time because the office guards must check one by one the room from floor to floor just to check the state of the electrical devices. In addition, wasting energy that should be used for something more important. In this case, it is necessary to develop so that electrical control can be carried out automatically and at the same time can be monitored via a cellphone.

This condition can be overcome by the presence of automatic control. However, in 2022 there are research that controls only electrical devices, such as lights and fan [1]. However, in this study, office building security was not applied, but only focused on the use of electric lights and fans, even though office buildings should have strict security. In addition, office buildings certainly have electrical devices other than lights and fans, such as garden watering pumps in front of the building, as well as office gates that should be able to apply automation systems. For this reason, it is very important for an office building to implement a system that can run automatically. Buildings that have this system can also be called smart buildings [2] [1].

Research on control of smart building systems by utilizing the Internet of Things has been carried out by Tata Sutabri, Muhammad Bahrul Lutfianto, Yohanes Bowo Widodo, and Rio Andriyat Krisdiawan in 2022 with the research title Design and Build of Wemos-Based Smart Building Control Tools at PT. Citra Solutions Primary [1]. This research was conducted because the office still uses a manual system in terms of turning off and turning on electrical devices, one of which is lighting and air conditioning. In this case, employees must move from one floor to the next using the stairs, so that a manual system like this becomes less efficient in terms of time. For this reason, this research makes a device for controlling electrical devices in office buildings using a web-based control Wemos D1 mini. In this study hardware devices such as Wemos D1 mini, relays, jumper cables, lights, and laptops were used for web control [1].

Based on the explanation above, this research will further develop smart building devices that are supported by the Internet of Things technology [3] [4] [5] [6] [7] by using NodeMCU microcontroller [8] as the main processor in this research. This smart building system will be enriched by controlling gates using ultrasonic sensors, controlling electrical devices automatically in the room by utilizing Passive Infrared Receiver (PIR) sensors [9] to detect human movement in the room, Light Dependent Resistor (LDR) light sensors as usage controllers. lights in front of the building, securing the door when entering the building using a fingerprint sensor [10], and watering the garden [11] [12] [13] using a scheduling system using the Real Time Clock (RTC) [14] module and soil moisture sensors [15] to monitor soil moisture conditions in the garden after and before watering [16]. The entire value of sensor monitoring, and control of electricity use in the prototype office building is regulated in the smartphone application that is developed using Kodular [17] [18]. The sensor data is then stored in the Firebase database [19] and then a Quality of Service (QoS) [20] [21] test is carried out to test the reliability of the internet network in sending sensor monitoring data and the ability to control electricity use via smartphone.

II. METHOD

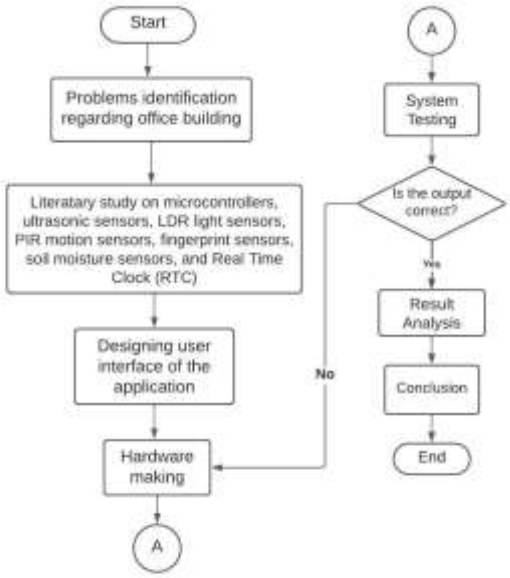

Figure 1 Flowchart Design

Fig. 1 depicts the planning of the research method that is shown as follows:

1. The first stage is problem identification about office building.
2. The second stage is literature study about Node MCU ESP8266 [4] [8] microcontrollers, ultrasonic sensors, LDR light sensors, PIR motion sensors [11] [9] fingerprint sensors [10], soil moisture sensors [15] [5], and Real Time Clock [14] (RTC).
3. The third stage is designing user interface for the android application software using Kodular [17] [18] [18] as an application builder.
4. The forth stage is making the hardware designs to clarify the concept of the tool to be made, programming the Arduino application considering that the main microcontroller to be used is the ESP8266 NodeMCU, as well as determining the variables and parameters to be analyzed.
5. The fifth stage is system testing is carried out to re-ensure whether each tool on each sensor node in the smart building has run as planned. If it is not appropriate or there are errors, it is necessary to return to the prototype design stage.
6. The next stage is analyzing the data, an analysis is carried out on the accuracy of sensors readings, application process delays, and comparison of results according to other parameters.
7. The last stage is making the conclusions of the entire test to be carried out as well as suggestions for development in further research.

A. Block Diagram System

Fig. 2 depicts a system overview that describes the entire system of the hardware.

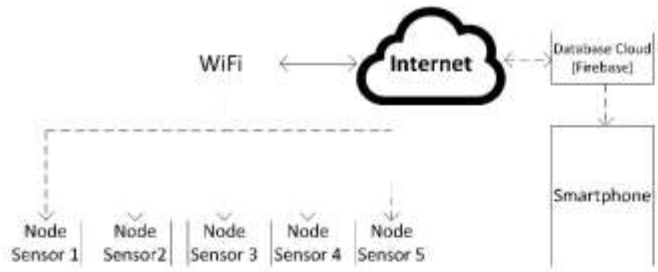

Figure 2 Block Diagram System

There are 5 sensor nodes scattered in various corners of the building, where sensor node 1 to control the movement of the building's gate, sensor node 2 to control garden watering [16] using the Real Time Clock (RTC) module, sensor node to control the use of lights in front of the building using the LDR module light sensor, sensor node 4 to control electricity use in the building using the PIR motion sensor and the LDR module light sensor. Sensor data from each sensor node will be sent to the Firebase Database [19] then displayed to the application.

B. System Planning

Fig. 2 to Fig 4 depicts the planning design for the physical form of the Smart Building prototype. The design is seen from the top view as shown in Fig. 2, the front view as shown in Fig. 3, and front view with a fence in Fig. 4.

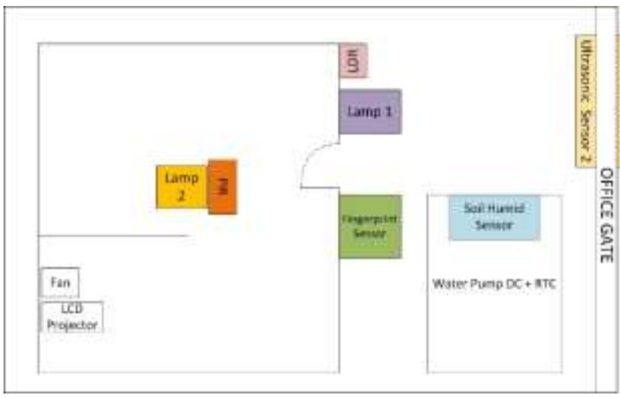

Figure 3 Top view of smart building prototype

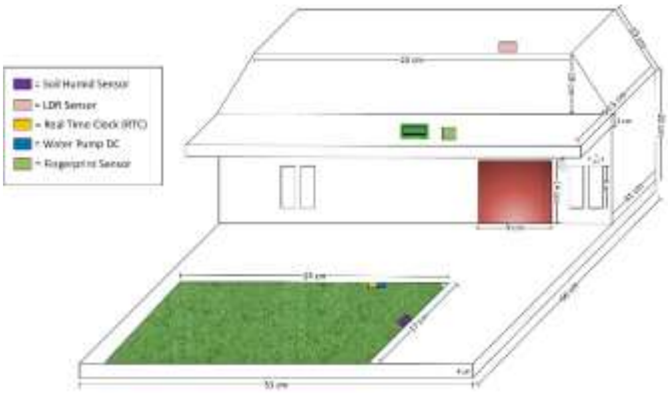

Figure 4 Front view of smart building prototype without a fence

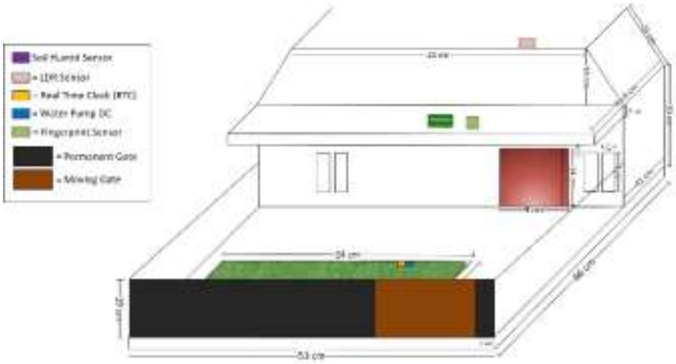

Figure 5 Front view of smart building prototype with fence

III. RESULTS AND DISCUSSION

The following is the finished form of a building prototype that has been installed with sensor nodes around the building. The resulting images are shown on various sides of the prototype, the front, left, right, top, and back sides.

Figure 6 Front view of the smart building prototype

Figure 7 Top view of the smart building prototype

Figure 8 Left view of the smart building prototype

Figure 9 Right view of the smart building prototype

Figure 10 Back view of the smart building prototype

A. Testing on Ultrasonic Sensors.

Testing of the ultrasonic sensor aims to detect whether there are objects at a certain distance. This test needs to be carried out to determine the accuracy of the distance measurement on each ultrasonic sensor used to detect object distances as evidenced by manual measurements using a ruler and compared to the distance read on the ultrasonic sensor.

The ultrasonic sensor is connected to the NodeMCU ESP8266 microcontroller which has uploaded the program code supported by the library of the ultrasonic sensor itself. The process of uploading the program code to the ESP8266 NodeMCU using a micro-USB cable or Universal Serial Bus to connect between laptops that have Arduino IDE installed as software to carry out the process of uploading program code with the NodeMCU ESP8266 microcontroller. This ultrasonic sensor distance detection measurement is placed at the top of the gate with the sensor position facing down so that it can detect whether there is an object in front of the gate. At this gate there are two ultrasonic sensors which are installed on the outside of the gate and on the inside of the gate respectively. Testing on these two ultrasonic sensors starts from 1 cm as the closest distance and 20 cm as the farthest distance.

The measurement starts from 1 cm, that is, the object is very close to the sensor, separated only by the ultrasonic sensor support with a width of 1 cm. The ultrasonic sensor has been set so that it can read the distance of objects with a maximum distance of 20 cm, and the distance so that the gate can open automatically is at 10 cm.

Measurements were made to measure the distance of object detection on this ultrasonic sensor by using a ruler that has a measuring length of 30 cm. The test was carried out 20 times for each sensor starting from the closest distance to the object and the sensor as shown in Table I and Table II below.

TABLE I
RESULTS OF DISTANCE DETECTION TESTS ON ULTRASONIC SENSORS OUTSIDE THE GATE

No	Ruler (cm)	HC-SR04 (cm)	Error (cm)	Error (%)
1	1	1	0	0
2	2	2	0	0
3	4	4	0	0
4	8	8	0	0
5	10	9	1	0.1
6	12	11	1	0.08
7	14	13	1	0.07
8	16	16	0	0
9	18	17	1	0.05
10	20	19	1	0.05
Average (%)				0.035

TABLE II
RESULTS OF DISTANCE DETECTION TESTS ON ULTRASONIC SENSORS INSIDE THE GATE

No	Ruler (cm)	HC-SR04 (cm)	Error (cm)	Error (%)
1	1	1	0	0
2	2	2	0	0
3	4	3	1	0.25
4	8	7	1	0.12
5	10	9	1	0.1
6	12	12	0	0
7	14	14	0	0
8	16	16	0	0
9	18	18	0	0
10	20	20	0	0
Average (%)				0.047

The percentage results of calibration testing on both ultrasonic sensors with a success percentage of testing on ultrasonic sensors outside the office area is 0.035% while ultrasonic sensors in the office area are 0.047% indicating that out of 10 tests on each ultrasonic sensor, the ultrasonic sensor The inner ultrasonic sensor can only detect the distance of the object accurately 7 times, while the external ultrasonic sensor can only detect the distance accurately 5 times. Based on the test results table in Tables I and II, some of the test results have a difference of 1 cm between the manual calculation and the calculation of the distance from the ultrasonic sensor. This distance difference can occur due to human error which causes inaccuracy in distance readings. This distance reading can be affected due to unstable object positioning so that the distance reading on the ultrasonic sensor is less than optimal and produces a slight difference in value with the manual calculation. However, the difference in this value difference is very small so it will not affect much the performance of the ultrasonic sensor used as the gate controller.

B. Testing on Light Dependant Resistor (LDR) Sensor Module

The calibration process for this light sensor module needs to be carried out so that a value that is in accordance with the standard or a linear value can be obtained. Calibration can be done by comparing the results with national standards and international standards to obtain accurate and consistent measurement results for a component. The process of calibrating a sensor is important because whether the quality of the sensor used in a study can affect the data taken during the research or not. The level of accuracy in the sensor reading results is also an important factor because if the value read by the sensor is far adrift with the reading value on the measuring instrument, it will affect the quality of the data collection process in a study.

TABLE III
LIGHT SENSOR MODULE TEST RESULTS

Test	Light Condition	LDR Sensor Module	Luxmeter	Error (%)
1	Bright	49	44	0.114
	Dim	171	140	0.221
	Dark	236	224	0.054
2	Bright	8	8	0.000
	Dim	117	104	0.125
	Dark	364	360	0.011
3	Bright	0	0	0.000
	Dim	181	176	0.028
	Dark	273	272	0.004
Average Error (%)				0.062

Based on Table III for sensor node 3, the sample test was carried out 9 times with the results of reading the light intensity value by the light sensor module compared to the standard Luxmeter application measuring instrument installed on the cellphone. Based on the results of the tests that have been carried out, the result is a small difference in value between the luxmeter measuring instrument and the reading on the light sensor module with an average percentage error of 0.062%. The average percentage error value is obtained from the total percentage error divided by the number of sample tests to produce an average percentage value of 0.062%.

The calculation formula used to get the sensor calibration percentage value is as follows:

$$\text{Error (\%)} = \frac{\text{LDR Sensor Module} - \text{Luxmeter}}{\text{Luxmeter}} \times 100\%$$

$$\text{Average Error (\%)} = \frac{\text{Total error}}{\text{Total test}}$$

From the results of the average percentage error, it can be shown that the light sensor module is linear or in accordance with predetermined standards because the overall calibration results are of small value. So that this light sensor module is feasible to use in this study.

C. Testing on Passive Infrared (PIR) Sensor

Calibration testing of the PIR motion sensor aims to determine whether the sensor can be used to detect movement in the room or not. Tests on this sensor are carried out using a ruler comparison to determine whether the motion sensor can detect movement correctly at a certain distance or not. The results of testing the PIR motion sensor are shown in Table IV.

TABLE IV
PIR MOTION SENSOR TEST RESULTS

No	Ruler (cm)	PIR Sensor	Motion
1	10 cm	1	Motion detected
2	20 cm	1	Motion detected
3	30 cm	1	Motion detected
4	40 cm	1	Motion detected
5	45 cm	1	Motion detected
6	48 cm	1	Motion detected
7	50 cm	1	Motion detected
8	51 cm	1	Motion detected
9	52 cm	0	Motion not detected
10	53 cm	0	Motion not detected

Based on the test results data in Table IV, for sensor node 4 for controlling electrical devices with PIR motion sensors, it can be seen that the PIR motion sensor can only detect movement up to a distance of 51 cm. With this distance, it is more than enough to detect movement in the room.

D. Testing on Soil Moisture Sensor

Soil moisture sensors were used to check the current soil moisture conditions with the soil moisture categories used, namely dry and wet soil moisture categories. Based on research conducted by [5], the results showed that soil moisture included in the dry category was in the percentage range of 0-49% with an ADC value of 520-1023, while for the wet soil category it was in the percentage range of 50-100% with an ADC value of The ADC is 0-510.

Table 5 shows the results of the garden watering test which will be displayed in tabular form below. Watering is done for 15 seconds on each schedule.

TABLE V
SOIL MOISTURE SENSOR TEST RESULTS

Time Schedule	Moisture (%)	Moisture Level	Relay Status
Outside the specified time	1.17	Dry	LOW (inactive)
	3.2	Dry	LOW (inactive)
	3.6	Dry	LOW (inactive)
	2.1	Dry	LOW (inactive)
Within the specified time	1.9	Dry	LOW (inactive)
	33.2	Dry	HIGH (active)
	49	Dry	HIGH (active)
	50.24	Wet	HIGH (active)
	57	Wet	HIGH (active)
	70	Wet	HIGH (active)

Based on the test results in Table V for testing sensor node 2, namely watering the garden using a soil moisture sensor, the relay will be in LOW status or not watering the garden if it has not entered the specified time. Meanwhile, when it has entered the specified time, the relay will have a HIGH status and do the watering. Soil moisture sensors are used to determine whether the garden has been watered at the specified time and duration or not.

E. Fingerprint Sensor Testing

Testing on the fingerprint sensor node is carried out by accessing it using 10 fingers, 5 fingers on the left hand and 5 fingers on the right hand as shown in Table VI.

TABLE VI
FINGERPRINT SENSOR NODE TEST RESULTS

Finger Position	Storage State	Access State	Number of Access
Right Hand			
Thumb	Successfully Saved	Access Granted	1 times
Index Finger	Successfully Saved	Access Granted	1 times
Middle Finger	Successfully Saved	Access Granted	1 times
Ring Finger	Successfully Saved	Access Granted	1 times
Little Finger	Successfully Saved	Access Denied	2 times
		Access Granted	
Left Hand			
Thumb	Successfully Saved	Access Granted	1 times
Index Finger	Successfully Saved	Access Granted	1 times
Middle Finger	Successfully Saved	Access Granted	1 times
Ring Finger	Successfully Saved	Access Granted	1 times
Little Finger	Successfully Saved	Access Denied	1 times
		Access Denied	2 times
		Access Denied	3 times
		Access Granted	4 times

Based on Table 6 for the sensor node 5, namely the reading of fingerprints on the right and left hands, it has been able to read fingerprint biometric data quite well. The number of denied accesses occurred on the left and right little fingerprints. The little finger of the left hand failed to access 1 time, then the next access was acceptable. The little finger of the right hand failed to access 3 times, then on the fourth access test it was acceptable. This can be caused because the biometric data on the finger is not read correctly on the system, so access permission is repeatedly denied.

F. Quality of Service (QoS) Measurement

- Throughput

Throughput is the calculation of the total value of the arrival of a successful packet that is observed at the destination during a certain time interval then divided by the duration of that time interval.

$$Throughput = \frac{Packet\ receive}{Lobservation\ time}$$

$$= \frac{10963909\ bytes}{217.217\ s}$$

= 50474.452 Bytes/s

= 50.474 KB/s

Because the Throughput value is measured in bps or bits per second, the Kilobytes/s value needs to be converted into Kilobit/s units with the following equation:

$$Throughput = 50.474\ \mathrm{KB/s} \times 8$$

$$= 403.792\ \mathrm{Kb/s} = 403\ \mathrm{Kb/s}$$

Based on the results of the calculations that have been done, the result is that the throughput value is 403 Kb/s. From these results, it can be concluded that the quality of the network used is included in the Medium Throughput category based on TIPHON [20] with a Throughput percentage of 40.3%.

- Packet Loss

Packet loss can describe the total number of lost packets caused by data collisions on the network that can affect all applications. This has resulted in reduced overall network efficiency even though the amount of bandwidth is considered sufficient [21].

$$Packet\ loss = \frac{Packet\ data\ sent - Packet\ data\ received}{Packet\ data\ sent} \times 100\%$$

$$= \frac{16801-473}{16801} \times 100\% = 97.18\%$$

$$= 100\% - 97.18\% = 2.82\%$$

Based on the results of the calculations that have been carried out, the percentage of packet loss obtained is 2.82%. This result is included in the good category based on the TIPHON standardization category [20].

- Delay

Delay is the time value required by the data to cover the data distance from origin to destination.

$$Average\ delay = \frac{Total\ delay}{Packet\ data\ received - 1}$$

$$Average\ delay = \frac{214.9209}{16801 - 1} = 0.01279291\ second$$

From the delay data that has been obtained, the total delay is carried out so that in this test the results are 0.127 seconds with the Very Good category based on TIPHON [20].

G. Sensor Value to Application Testing

Fig. 11 shows the value of the PIR motion sensor and the LDR light sensor on the light menu so that they can appear in the application.

Figure 11 The results of the PIR and LDR sensors display in the lamp control menu

Fig. 12 shows the value of the ultrasonic sensor outside the gate and inside the gate on the gate control menu

Figure 12 The results of the ultrasonic sensor display on the office gate control menu

Fig. 13 shows the value of the PIR motion sensor on the fan menu so that it can appear in the application. Fig. 14 shows the value of the soil moisture sensor in the garden watering menu.

Figure 13 PIR sensor displays results in fan menu

Figure 14 The display results of the soil moisture sensor on the garden watering menu

Based on Fig. 11, an application with a light control menu has been able to display PIR motion sensor data and LDR light sensor data in the form of numbers in real time based on data displayed in the Firebase database. The on and off status of the relay connected to the lamp can also be displayed in real time by showing the result "ON" or "OFF".

Fig. 12 shows the result of the fan state control display with the PIR motion sensor value that appears is 0 which means there is no movement, whereas if there is movement, the PIR motion sensor value is 1.

Fig. 13 shows the gate control menu in the application by displaying data from ultrasonic sensor readings both outside and inside the gate with ultrasonic sensors outside the gate having a value of 16 cm, and ultrasonic sensors inside the gate having a value of 15 cm.

Fig. 14 shows the results of the soil moisture sensor readings on the garden watering menu with the results of reading the soil moisture content of 57%. Under the sensor result value, there is a garden watering schedule that is set at 08.00.00-08.00.15 and 16.00.00-16.00.15 which means watering is done every 8 am to 15 seconds ahead, and the next watering schedule will be performed at 4 pm until 15 seconds later.

This shows that the sensor value data on the sensor nodes can be displayed properly in the application and can be updated in real time following the sensor value data in the Firebase Database. The status of the relay on or off can also be displayed according to the current situation.

IV. CONCLUSION

The results of the accuracy of the sensors at each sensor node can be used to properly monitor and control electrical devices, namely with the results of the PIR motion sensor node test which can detect up to a distance of 51 cm which is sufficient to detect movement in the room, LDR light sensor nodes which can detect light intensity with an overall average error value that is sufficient to produce a value of 0.062%, garden watering sensor nodes can be used to control the use of water pumps automatically following a predetermined schedule, ultrasonic sensor nodes that can be used to control gate movements, and fingerprint sensor nodes that can read fingerprint biometric data properly. The system for sending sensor node data to the Firebase database can work well as evidenced by the results of a Throughput percentage of 40.3% which is in the Moderate category, 2.82% packet loss percentage in the good category, and the average delay is 0.0127 seconds in the Very Good category. The Android application can display the data sensor in real time on the application in the form of LDR light sensor data values, PIR motion sensors, soil moisture sensors, ultrasonic sensors, as well as data on whether electrical devices inside and outside the building are on or not.

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