THE DESIGN AND ANALYSIS OF AN INTERNET OF THINGS PROTOTYPE PRODUCT

Technical Report

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SUMMARY

The report contains detailed information on an IoT device prototype design, which is needed to measure the temperature and handle it over the network to the server. The ESP8266 has been chosen, as a core of the device, as it is easy to work with Arduino development environment as well as it supports functionality such as HTTP server deployment, WiFi connection and MQTT protocol, which are need for in our design. The detailed design, verification, commercial social analysis carried out after verification. Deployment cost scenarios of the device are also shown.

Contents

1. Introduction

The Internet of Things is a new stage in the development of the Internet, significantly expanding the possibilities of collecting, analyzing, and distributing data that a person can turn into information, knowledge and, ultimately, wisdom. In this sense, the Internet of Things is gaining in importance and it will have huge popularity shortly.

Nowadays, health issues related to COVID-19 become the main topic, and government, organization and companies implementing different methods and rules to stop the spread of the virus among the population. That's why the IoT device prototype with specification such as 2.4 GHz wifi connectivity, long durability, remote control is demanded by the market. And the following section describes each aspect of such a device.

2. Design and implementation

2.1. Design

The prototype was designed according to the given requirement. There three main tasks:

1. Measuring the temperature.
2. Sending measured values over the network
3. Opening the door if the temperature of a person in acceptance range, or display that he should go home.

There are other extra-functionality are also implemented such as mDNS and IP broadcasting, showing local IP on LCD and also setting the range of acceptable temperature over HTTP server or MQTT.

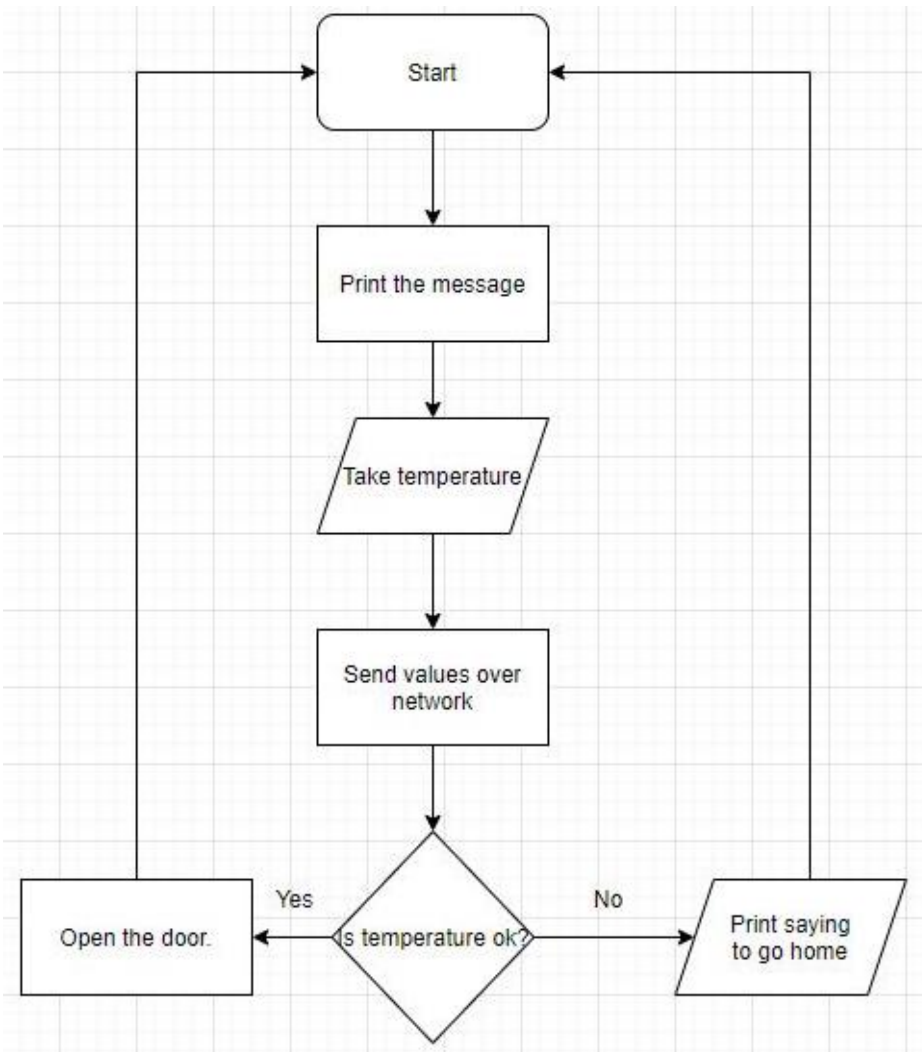


Figure 1: Main block flow chart

Figure 1 shows the main flow chart of the program. As stated above program starts with displaying the message to present the id card. Upon approving the ID, the temperature is measured, and these values are sent over the network to the MQTT server and the HTTP server's values are updated for the client to see. After that temperature is checked whether it is in 36.5°C-38°C. according to the check, further action is taken.

2.2. Implementation

2.2.1. setup State

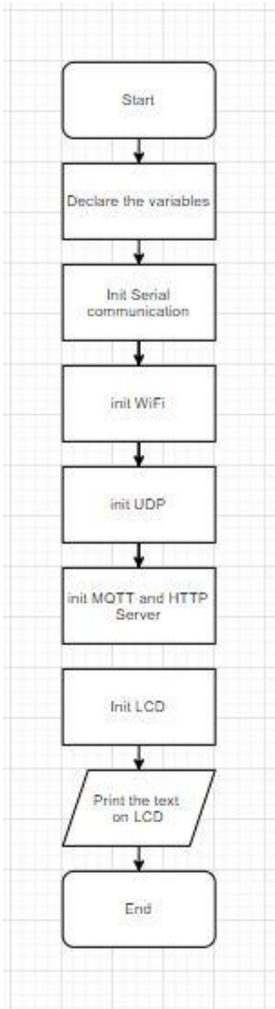


Figure 2: Setup section

Before all, after declaring the variable, the serial monitor connection is established as it is crucial to debugging while writing the code step-by-step. The serial monitor tries to connect to the PC with a baud rate of 115200 bps. The next most important thing is WiFi communication, which pillar of our communication. Here is the code snippet of both.

```
#include <ESP8266WiFi.h>

void setup()
{
  Serial.begin(115200);
  Serial.println();
  WiFi.begin("network-name", "pass-to-network");
  Serial.print("Connecting");
  while (WiFi.status() != WL_CONNECTED)
  {
    delay(500);
```

```
    Serial.print(".");
  }
}
```

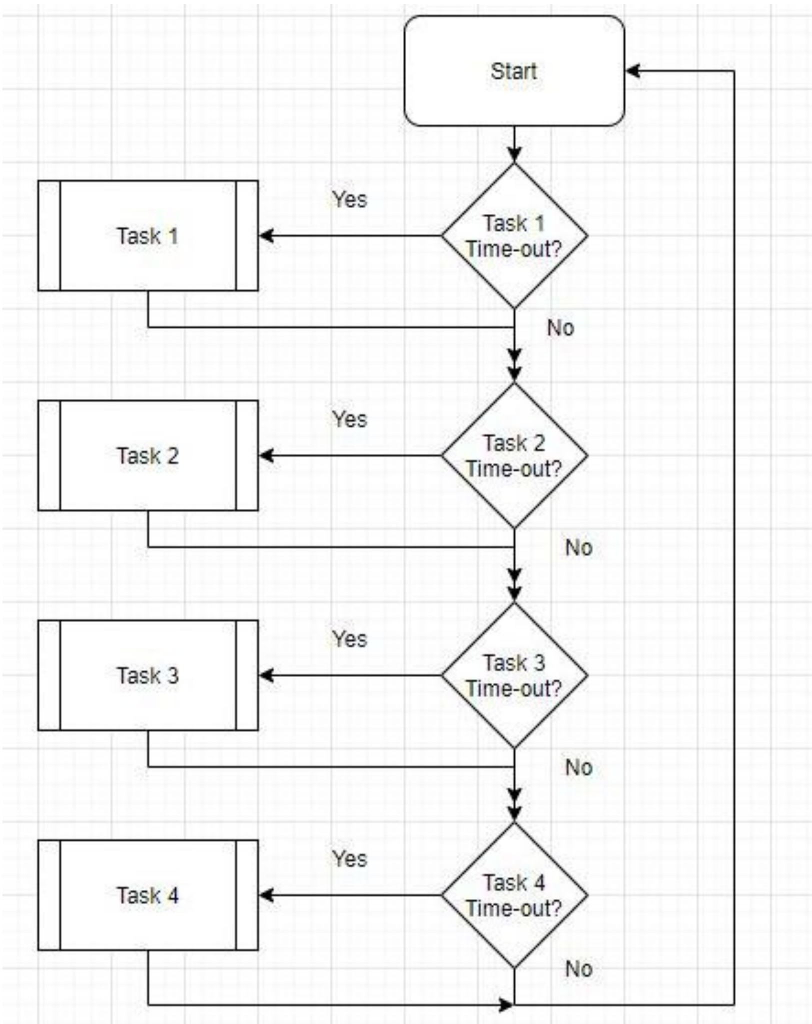
The UDP initialized as a fundament of our communication for MQTT and device discovery. There is a separate library for UDP functions(WiFiUDP.h). The class instantiation is required for UDP communication as RFID, HTTP server and MQTT. Then calling begin function from class object starts our UDP communication.

MQTT and HTTP are also implemented as above but one major change, MQTT requires a fingerprint and a secure WiFi client to connect to adafruit[1] with SSL/TLS.

RFID initiation requires SPI protocol to start first so there is a separate library SPI.h and then calling init() function on RFID class give access to integrate it into our prototype.

There are potentiometer works as an infrared thermometer, and also LED which can be manipulated by only one function so, no extra effort is needed.

2.2.2. Loop part



The design consideration of the loop part is carried out thoroughly to give the user smoothness and avoid and lagging in a user interface.

The loop contains four tasks that utilize a time-driven scheduler. To increase the efficiency of the CPU cycles and power consumption.

a. **Task1**:

Task one is the implementation of the rfid function, it is called each 100ms seconds. If I card is present it takes the reading displays it, records it and checks for temperature range if it is in the range, then it illuminates the LED as pretending door opening. The efficient side can be said, instead of wasting the CPU cycle with pooling, the waiting part implements an MQTT subscription check for two seconds. That's kind of increasing the efficiency.

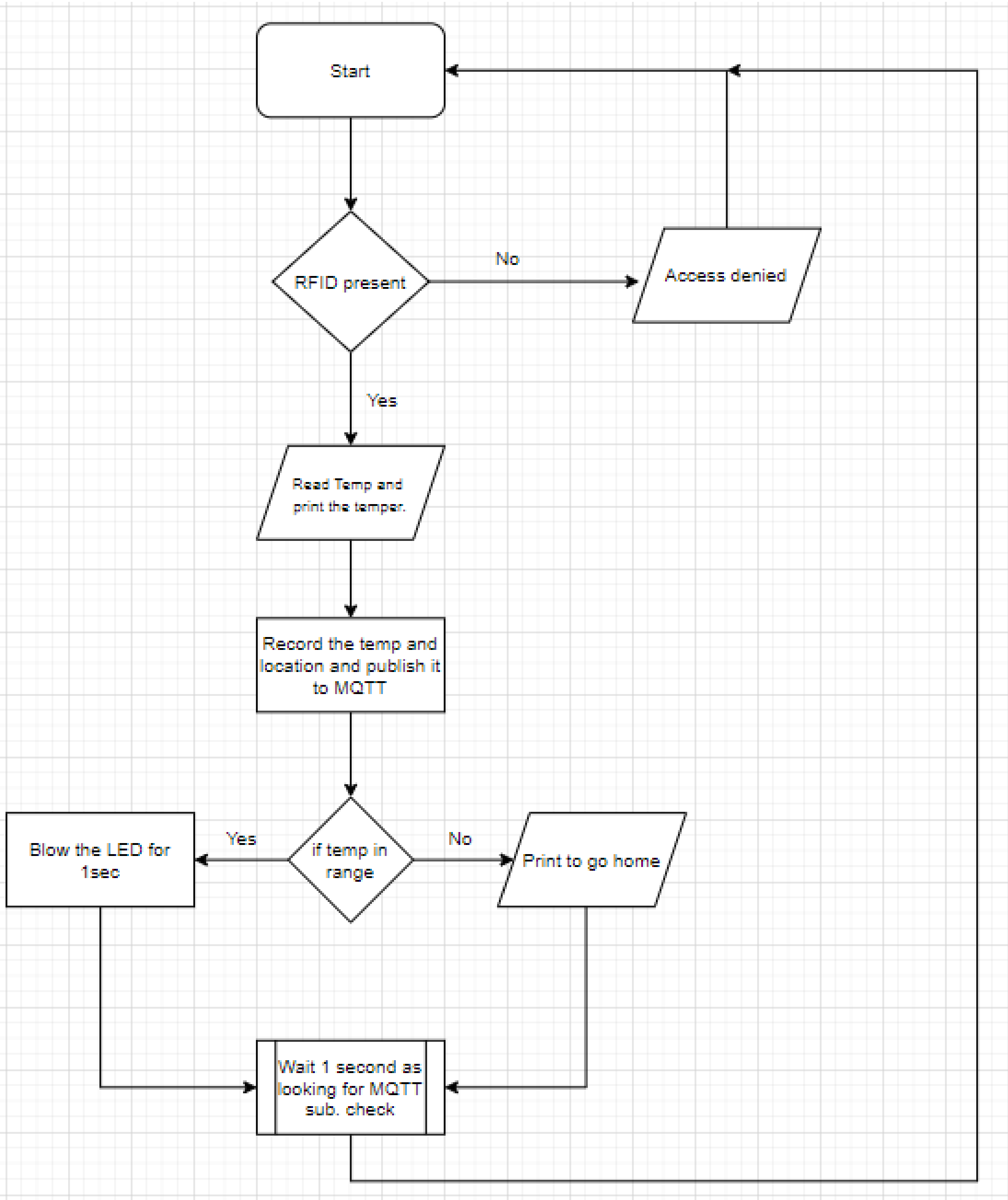


Figure 3: RFID function implementation

b. **Task 2:**

Task 2 is a basic implementation of HTTP client-server, It waits for the availability of the client if there is client reads the request. And keynote should be done here, function after reading request parse the text, It looks for variable min temp and max temp in case it finds it, then those variables are updated. That's setting a range of temperatures from the web.

Below, figure 4 shows a flow-chart of this function.

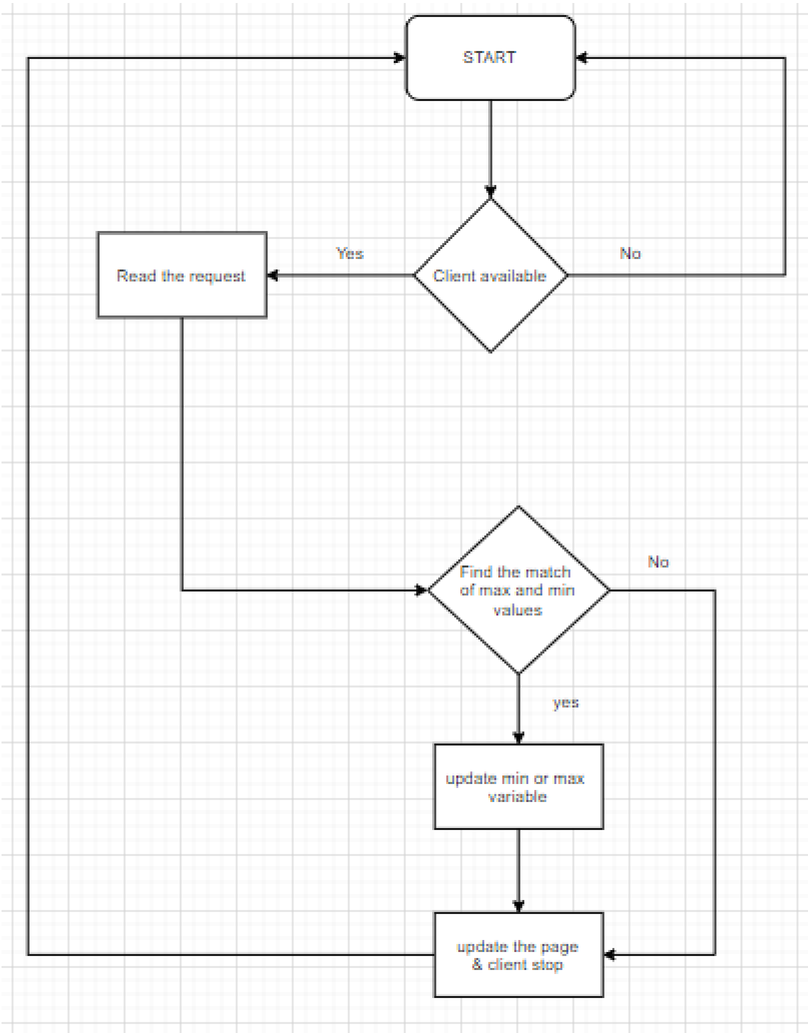


Figure 4: HTTP server

c. MQTT function

The MQTT operation is the simplest one among all. It waits for subscription data to be received in a certain amount of time, in our case it is the min and max temperature range changed from adafruit web site. There are two sliders responsible for range lower one is in the 25°- 38°C range and the upper one in 38.1°- 45°C. The operator can easily change the range to adjust the device to cold and warm temperatures.

d. Device discovery function:

The device discovery is used to announce about current IoT prototype to other users. It waits for the packet to array in UDP buffer from broadcast address, once it matches with it its IP address then it sends this IP to the address from where the packet is received.

The timing is taken as follows:

1. Task1 – 100ms
2. Task2 – 2ms
3. Task3 – 10ms
4. Task4 – 1000ms

The task1 timing is given in requirement the task 2 is purposely chosen to be 2ms as it gives smoothness while working with the HTTP server. Task 3 is should be large to capture incoming packets from adafruit, however, I set it to as low as 10ms, since I have used this function inside of task1 with 2*1 seconds delay, overall it gives 2100 ms decent enough to handle the updates from the server. Task 4 is 1 second because it only needed once when the UDP packet arrived as I have tested UDP packet stays in buffer, so it is decided not to over-spent processor power.

2.3. Verification

The below figure shows that the code successfully uploaded to the memory of the microcontroller. And it is running:

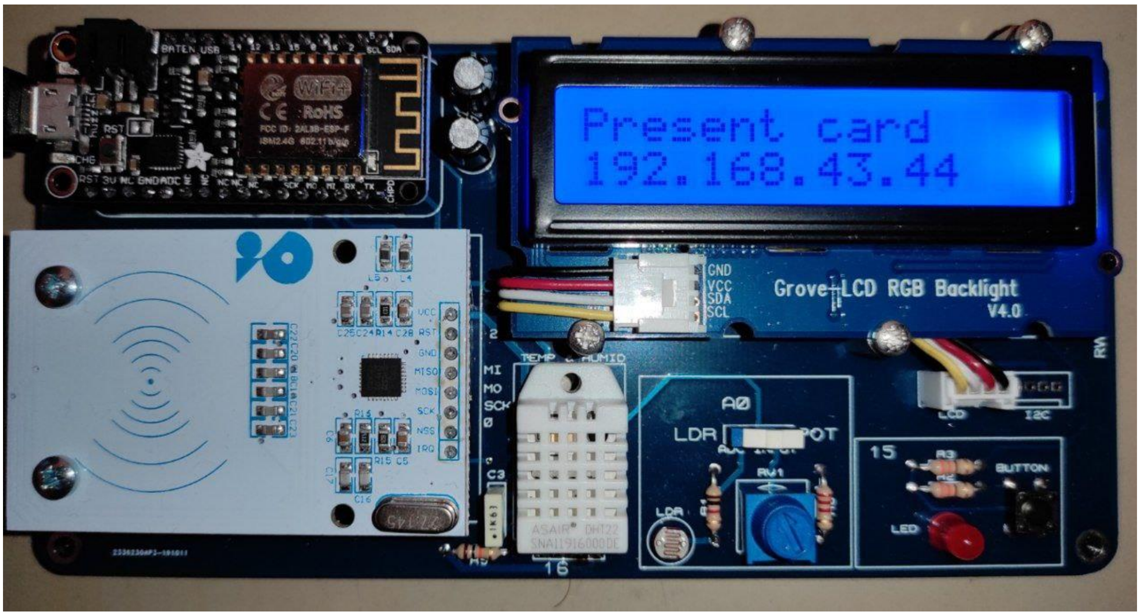


Figure 6: Requesting the card to be present

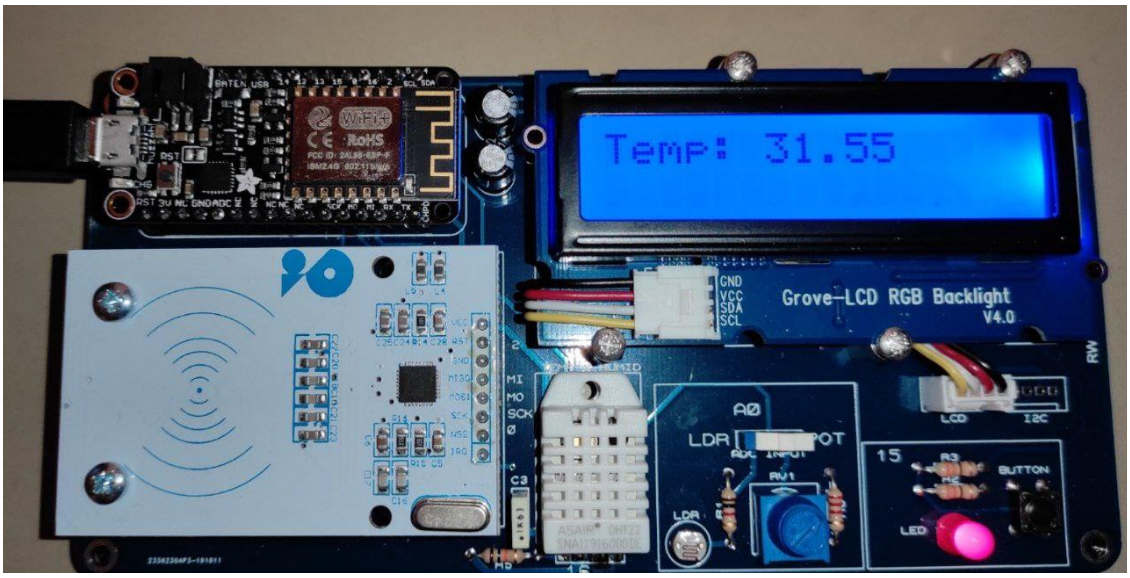


Figure 5: Showing the temperature and illuminating the LED

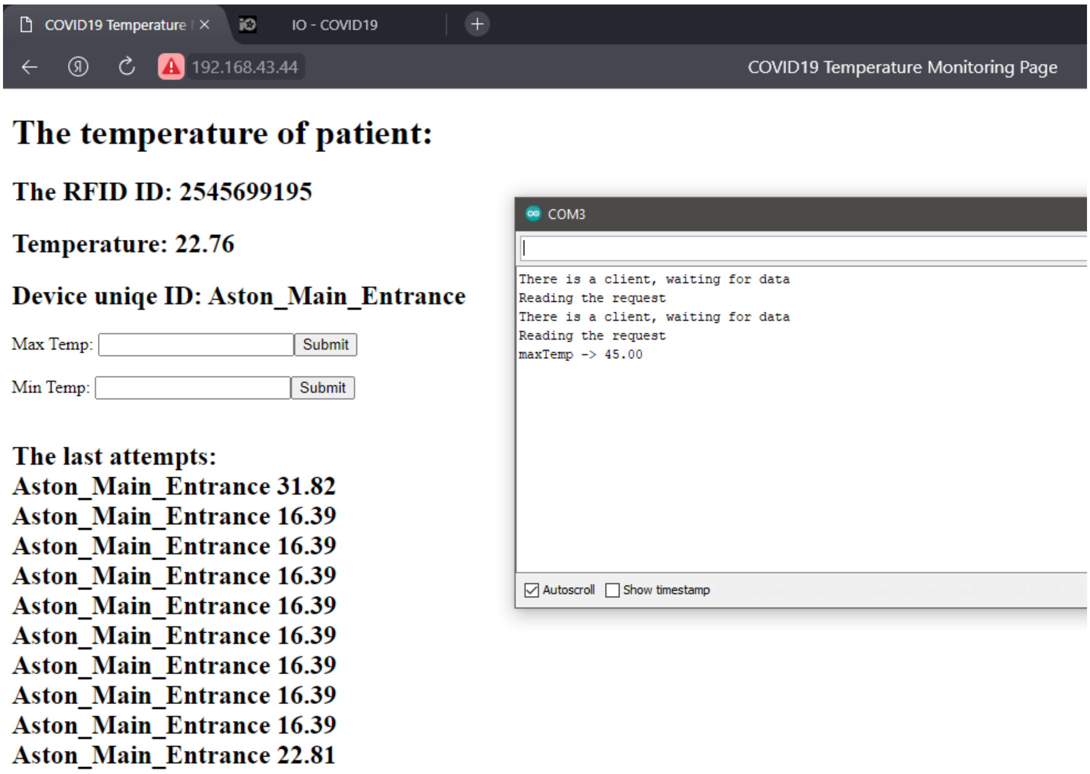


Figure 7: Updating measuring temperature range from HTTP client

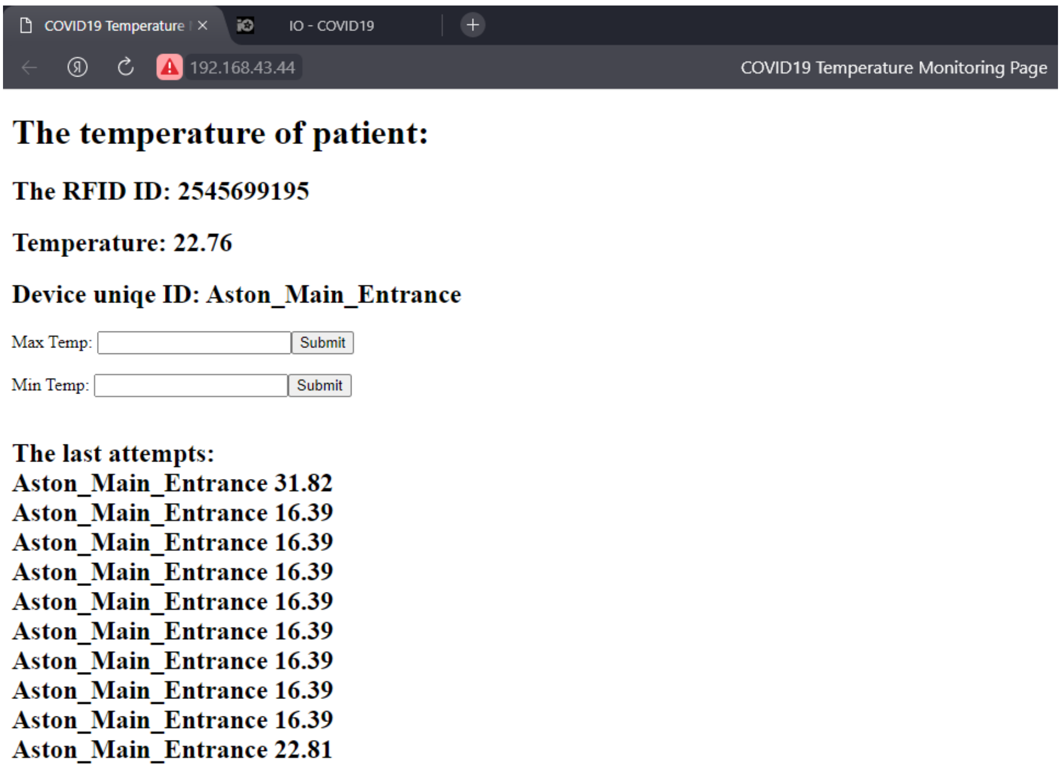


Figure 8: HTTP server client side look with 10 last record

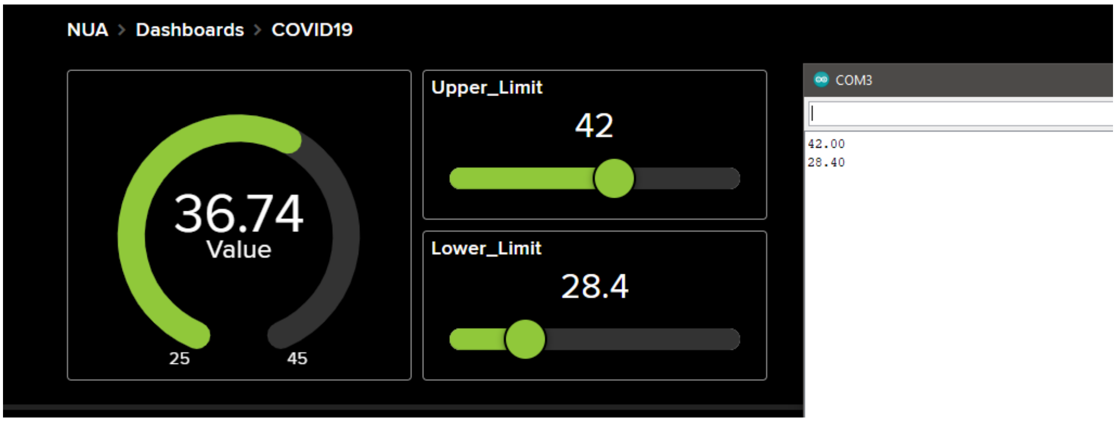


Figure 9: MQTT server look and updating temperature range from the server.

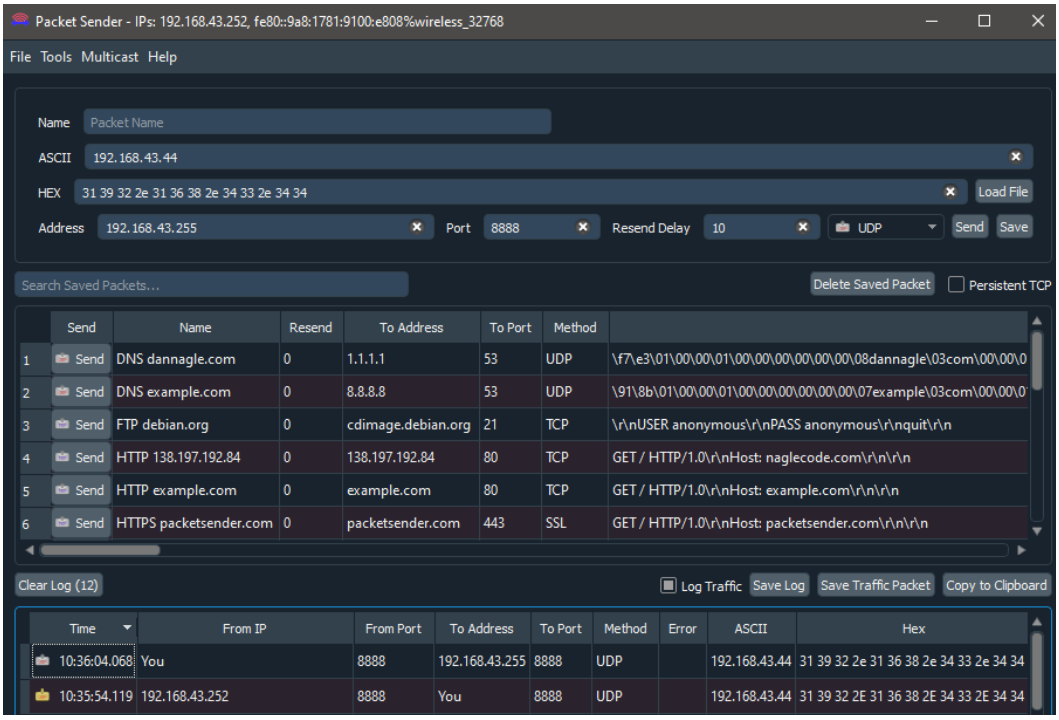


Figure 10: Device repsponse to the broadcast message

In figure 7, the recorded temperature is shown on the LCD and it is in the updated range, so LED is also illuminating. Figure 8 and figure 9 perfectly verify our code where the last 10 records are shown on the HTTP server, and also values can be updated from HTTP. MQTT communication is presented the temperature value in gauge, and also temperature ranges are changeable remotely via two sliders, the functionality verified in figure 9. Additionally, the broadcast messages are addressed correctly by the device.

3. Societal, privacy, and commercial impact analysis

3.1. Societal impact

The electrical characteristics of the component are shown in table 1. From that the power can be calculated as below:

Table 1: Electrical characteristics of components

Item name	Voltage supply(V)	Current draw(mA)	Power Supply(W)
ESP8266[2]	3,3	0,08	0,2640

Grove – LCD[3]	5	0,06	0,3000
RFID-RC522 Reader[4]	3,3	0,026	0,0858
MLX90614 IR Infrared Temperature Sensor[5]	5	0,0013	0,0050

$$P_T = 3.3 * 0.08 + 5 * 0.06 + 3.3 * 0.026 + 5 * 0.0013 = 0.65(Watts)$$

The computed power value is 0.65(Watts), which a really small power drawn from the device. However, from design and implementation, it is clear that even if a time scheduler is used, the loop section of the code continuously, execute the code which adds up to the code powering. This is not the efficient way of doing that, putting a microcontroller into sleep or deep-sleep[2], can improve the situation. Since, the device needs to work only a certain amount of time in a day, make it sleep helps to save power. Additionally, batteries such as Li-ion polymer have a long cycle life[6], implementing the above method longevity of many years.

The device contains a liquid crystal display, battery, capacitors, which is according to WEE directives harmful to the environment and need to be collected free of charge, and disposed of separately[7]. Since device dimensions are small and many parts can be easily replaced as plug and play manner, then the prototype should last longer, even if the malfunctioning component is found can be returned almost free of cost, and restored in a special place. From this aspect, the IoT kit is environmentally friendly.

3.2. Privacy analysis

The data transmission fully complies with the Privacy by Design framework, namely, the only data is collected from the patient is body temperature and location of IoT device, as know as, data minimization, it is considered at the development stage. This data is transmitted over the internet and local network, in the sense it's transparent to use. However, the data is destroyed after some time or when the device is restarted. Nevertheless, ID card details are hardware into the memory, as ID is provided by the organization, doing so is legal by the rules[8]. The only weak point of the design of the prototype it uses an insecure connection over a local HTTP server, it could be fixed by replacing it with a secure version like HTTPS.

The purposed IoT device helps to prevent the spread of the covid among the population, it is done so, first of all by:

1. Remote control of the terminal is done
2. While measuring the temperature IR sensor, help the keep 2m COVID safe distance
3. The LCD gives clear instruction to follow the rule, depending on measured data.

3.3. Commercial impact

There are many companies, who produce a similar product as proposed one, the comparison is done, the one of the world's leader in the field, company called "ThermoWorks", head-quarter is located in Lindon, UT, the USA, Annual Revenue is estimated $34.8 mil., and the number of employers is around 10-49 personal[9]. The selected product to compare is "**WAND™ - No Touch Forehead Thermometer (FDA-Cleared)"** [10], below a detailed comparison, is done.

Table 2: Product Comparison Table

Features	Proposed IoT product	WAND
Forehead Range	25°- 45°C	34°- 42.2°C
WiFi connection	Available	N/A
Setting range remotely	Available	N/A
Accessing the last 10 records	Available	N/A
Battery last	1 year with 15000mAh	3000 hours with 2xAAA

Cost	~27GBP	~50 GBP

From the above table, it can be seen that the COVID19 IoT device overtakes it is a competitor in aspects such as cost 46% cheaper, longevity 65% more, functional availabilities. And, that's for the majority of the market holders have similar devices in this segment. From that, it can be concluded that the purposed device can be brought to the market, it will have huge market popularity.

4. Deployment considerations

The IoT prototype needs one access point that can router with wifi or wifi transmitter with internet access which can create a local network. So, in most cases, a modern router will have all in one, from that it needs at least one router and one of our IoT prototypes at one location.

So, ESP8266 has[2] :

$$\mathrm{RSSI} = -91 \text{ dbm} @ 11(\mathrm{Mbps})$$

$$\mathrm{P}_T = +20\mathrm{dbm}$$

$$f = 2.4\ Ghz$$

lets consider $G_T = G_R = 1$ then from FSPL can be written as

$$d = \sqrt{\frac{P_T * G_R * G_T}{P_R}} * \frac{\Lambda}{4 * \pi} \rightarrow (\mathbf{1})$$

$$P_T = \frac{10^{\frac{20}{10}}}{1000} = 0.1\ Watts \quad \rightarrow (\mathbf{2})$$

$$P_R = \frac{10^{\frac{-91}{10}}}{1000} = 7.94 * 10^{-13}\ Watts \rightarrow (\mathbf{3})$$

$$\Lambda = \frac{c}{f} = \frac{3 * 10^8}{2.4 * 10^9} = 0.125m \rightarrow (\mathbf{4})$$

Substituting above in 4, 3, 2 in 1, we get:

$$d = \sim 3.5\ km$$

With free space loss exponent following formula can be re-written as[11]:

$$P_R = P_T * \frac{G_R * G_T}{L} * (\frac{\Lambda}{4 * \pi})^2 * (\frac{1}{d})^\gamma \rightarrow (\mathbf{5})$$

For office buildings free space exponent constant is $\gamma = \sim 2$, and insertion loss L = 1 for easy calculations so substituting above in 5 we get:

$$P_R = 2.1196 * 10^{-11}\ (or)$$

$$P_R(dBm) = -106 @ 3.5km$$

From this, it can be concluded that an inbuild environment rarely will be as large as 3.5 km, so considering a small office, this range is well enough to cover not only a single room, despite it has given small Pr value than RSSI. And also it should be noted that Gr=Gt=1, normally, it is 2-6dBi, linear scale it is in between 1.5 - 4 so, it means our system has a good coverage area.

The deployments cost of the product per unit can be summarized as table 2:

Table 3: Component and their cost

Item name	Cost(GBP)
ESP8266[12]	4,95
Grove – LCD[13]	13,32
RFID-RC522 Reader[14]	3,95
MLX90614 IR Infrared Temperature Sensor[15]	12.5

The prices are taken from eBay which offers quick delivery to the place inside the UK, and while purchasing a large amount discount can be requested from the seller. So, for only one IoT prototype cost can be ~30-40 GBP including PCB and wires. And also fixed and direct cost should be added per prototype.

The IoT prototype has the following power consumption characteristics:

$$P_T = 3.3 * 0.08 + 5 * 0.06 + 3.3 * 0.026 + 5 * 0.0013 = 0.65(Watts)$$

And it is powered by a Lithium Polymer battery or through the socket. Considering the integration of battery technology will be less expensive in terms of both complexity and cost, then we can purchase a 1500 mAh battery from the market at the price of ~12.98 GBP [16], to achieve a charge time of once a year.

$$Batter\ life = \frac{Battery\ capacity(mAh)}{Current\ draw(mA)} = \frac{1500(mAh)}{0.1675(mA)} = \sim 1\ year$$ [17]

So, this particular battery costs 12.98 GBP, and our cost per components is 27.17 GBP, overall, the total cost of one-time installation of the prototype is 40.15GBP. This calculation is done roughly not taking into account the other major components.

The device functionality is limited compared to the hardware capability. Despite firmware checked thoroughly, some functions might be improved and it might possible that many features may be changed, later by customer preferences. With scalability in mind, the efficient way of upgrading and extending the functionality of the device is over the air programming.

There are numerous publications and proposals about vulnerability and security concern of OTA update. However, Secure Over – the – Air Programming of IoT devices (SOTA) can be implemented to overcome security concerns. [18] If security is omitted in the process of OTA update, then the device can be reprogrammed by hackers or stealing the software on the air may happen. SOTA has the following components:

a) **Remote programmer:** To send the firmware to the IoT device which needs to program.
b) **IoT device communication module:** It is a WiFi transmitter between the programming device and programmer. Supports two modes of operation transparent mode where the header is sent while keeping it as it is and normal mode, in which the header of sending packet modified and information about the sender is included.
c) **IoT device:** it has a bootloader and program space, bootloader uploads the firmware if a special command is received from the remote programmer, otherwise it loads the usual program.
d) **Provisional Security:** implements in itself symmetrical encryption algorithm – AES 128 Bit CBC. A special key is hardwired into the device memory, well – protected from hacking.

Last but not least it should be noted that STOA is designed to scale up to a large number of devices.

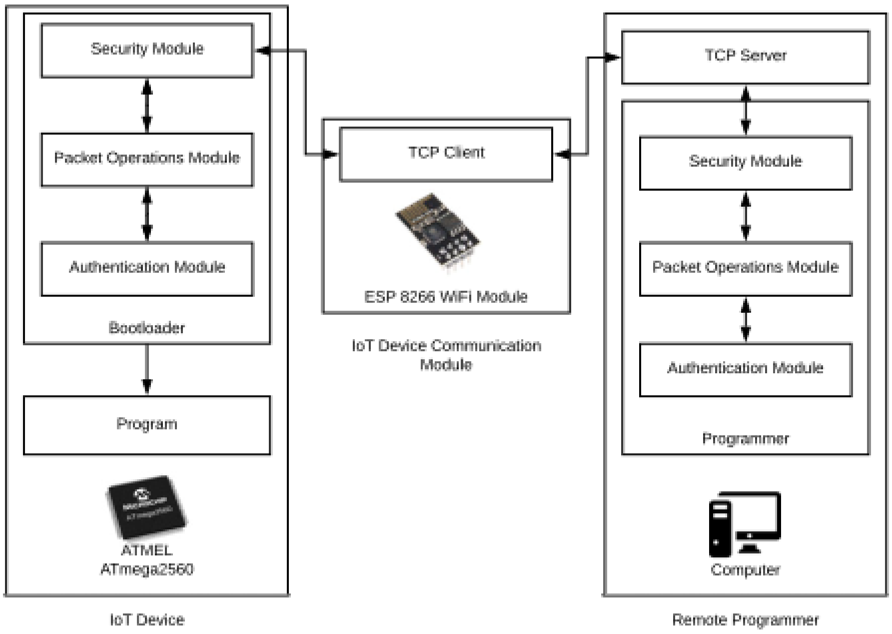


Figure 11: Major component of SOTA framework[18]

5. Conclusion

Nowadays, in a pandemic situation, it is necessary to have a well-functional IoT device, to prevent the spread of the virus. The purposed system was shown from the commercial and social analysis that it fully complies with current trends in the industry, don't violate data privacy laws, and fully functional for given requirements while the price is cheaper than competitors. Future updates can be easily done through the air, to add extra features.

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[5]*MLX90614 family*. 2021, p. 7.

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