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An Effective and Inexpensive IoT-based Home Automation and Security System

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Draft Version

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***Abstract*— Modern homes are rapidly transitioning away from manual switches to centralized control systems that incorporate remote-controlled switches. As we enter the age of artificial intelligence and ubiquitous computing, home security and management have become a critical issue to address. In this project an inexpensive, IoT-based home automation and security system is developed that can be used to control various switches inside the home and to protect the house during the absence of owners from the premises. The proposed system utilizes an Arduino board, Node MCUESP8266MOD micro-controller and security system incorporating RFID, motion detection, flame and gas alarms. An android mobile application with voice command feature is developed to control the system. The proposed system is then tested to perform optimally with the average operating delay found to be less than that of similar devices that are currently available in the market. In a cost analysis comparison with competing devices, our proposed system at only USD 31 costs significantly less in terms of module and sensor prices.**

***Index Terms*—Arduino, micro-controller, security system, voice recognition, mobile application**

I. Introduction

A home automation system monitors and controls several aspects of the home such as lighting, temperature, entertainment systems and electronic home appliances. Additionally, it may encompass residential security measures such as access control and alarm systems. When connected to the Internet, household appliances form a critical component of the Internet of Things (IoT) architecture. This enables the user to remotely manage panel infractions. Home automation is gaining popularity because of its convenience and the capacity to monitor and manage infections and other things according to the user's comfort and demands. People may be away on holidays and might get worried about the safety of their home as intruders may get in. Some may also forget if the gas connection has been left on, an accidental fire has broken out, or if the temperature setting is not appropriate. In the very least, people often forget to turn off their lights when they are away.

In the prototype, keeping in mind all the issues people may face, a cost-effective solution has been developed. In our developed prototype, RFID and motion detection will ensure overall safety and security in the house. The temperature and humidity sensors will inform the user if there is an unusual temperature and humidity inside the premises. Users can also be physically away and informed the status of their front door if any movement is detected inside the house. Information on fire alarm and gas leakage are also integrated in the prototype. The user will be notified remotely via an Android-based application. Lights, fans, and switches can be turned on or off remotely using the user interface of the app.

Though many home automation systems are already widely available, we demonstrate that our proposed system is robust in performance and inexpensive compared to other similar devices in the market. For ease of access, a voice recognition feature is added to control the overall system. Additionally, the electricity consumption is expected to be significantly lower.

II. Related Work

There are numerous number of works that have been conducted on home automation and security systems. Researchers in [1] have focused on a system where an alarm will be sent if the observed MAC address doesn't match with the owner's one. Farzana et al. [2] focused on a demand based optimum energy harvesting and management IoT system with additional monitoring feature that uses web interface which is connected to the hardware. Padma et al. also proposed a similar design, the only difference being the way of implementation and absence of demonstrated data on energy management [3]. In another investigation [4], Sivanathan et al. proposed an idea of low cost IoT based smart home automation system. It demonstrated a flow-level method to detect intrusions for security and mirrored data plan to make it low cost. However, none of the investigations stated above comprised a completed setup of automation and security system and a comparative cost analysis of the proposed design.

Our proposed prototype has following attributes and contributions:

- The system is designed in a way that it is unified, it needs only a single app to control the whole system and for different features, no different apps or systems are required.
- Our proposed system is significantly cost effective, costing only around USD 31.00 to build, which comprises of automation and security features like fire and gas alarm, movement detection, temperature and humidity measurements, RFID based door lock etc. Similar system suggested in the market costs more than our proposed system, as explained in section V [5]–[7]. Our proposed system is specially targeted for customers of developing countries where energy is scarce and competitive to acquire. Consumers can easily build and distribute the proposed system as per their demand.
- Systems that only incorporates individual automation or security measures are often available in the market. It is rare to see unified implementation of automation and security in a single system in such a competitive price range.
- In our system, we have shown a direct comparison of Shamim et al. [8] where their proposed system takes 5-7 seconds to execute the user commands whereas our proposed system takes maximum of 5 seconds to execute commands and the lowest time of execution is 2 seconds.
- As the system is IoT based, it can be controlled from anywhere. The app is designed in such a way that it could be user friendly, for example, it utilizes voice command feature for the convenience of the system owner.

The rest of the paper is organized as follows. Section III of this paper describes methodology where working of the system is mentioned along with short description of the modules that have been used. Section IV presents project implementation explaining hardware and circuits, the software development, the firebase database and the overall security system. In Section V performance evaluation of our prototype is demonstrated. Lastly, in Section VI, a conclusion was given with a layout of the future works involved with the project.

III. System Workflow

In our prototype, NodeMCU, an open-source and widely used IoT platform [9], [10] was used to control all switches, fans and lights. The Arduino Nano was used to control the RFID module. A servo motor was connected with the RFID module to enable control for the gate when RFID card is punched. Sensors are connected to the NodeMCU for carrying environmental information to the user app using real time Firebase database. The android app is providing ease of access for the user to control various features remotely.

When the system is turned on, we'll see a Wi-Fi named "IoT Home Automation" in our mobile which we've to connect using the credentials in order to make the system operational. If the credential is successfully given, all the lights and fans which were initially on will be turned off, notifying that the system is now connected with the internet. Once connected, now we can control the system using our android based mobile app. All kinds of automation such as turning on switches to on and off of lights/fans can be done within our fingertips using the app. The app also shows us all the current system status like if the door is opened or not, the current temperature and humidity of the home, any movement inside the house, fire and smoke status and also the status of the switches.

Now, if RFID card is punched which is provided with the system, the door will be unlocked and the user can get in. In case of unusual temperature inside the house, cases like fire or gas leakage, the system will instantly notify the user giving an alarm in the app. In such cases, steps can be taken accordingly. Also, if intruders are present, the app will notify the user by showing that there are movements inside the house. Thus, the home is ensured to be secured alongside making most of the works to be automated.

IV. Implementation

A. Hardware Implementation

The NodeMCU Wi-Fi module will manage all of objectives of the hardware section. Here, an application will be used to control the light and fan. The NodeMCU micro-controller is a 32-bit device. However, it cannot connect the light and other devices directly due to voltage congestion. That is why a relay will be utilized as a switch in this instance. Now that the network is connected to the NodeMCU board, it will act as an input for the switch relay. The relay lights and other devices will be attached to the output side. Thus, the devices will be operable through mobile application. Fig. 1 demonstrates the algorithm of the overall system.

Step-1: Start

Step-2: Initialize all devices.

Step-3: Connect to Firebase database.

Step-4: If connected then proceed otherwise go to step-2.

Step-5: Fetch data from Firebase Realtime database.

Step-6: If data=1 then turn on the load otherwise turn off.

Step-7: Check whether the load is on or off.

Step-8: Retain temperature, humidity, motion, fire, smog data.

Step-9: Obtain security data of entry side and send load conditions data to database.

Step-10: Update data on client-side Application.

Step-11: Take unit input on interactive interface.

Step-12: Update data on database.

Step-13: End

Fig. 1. Algorithm of the system showing how our system works.

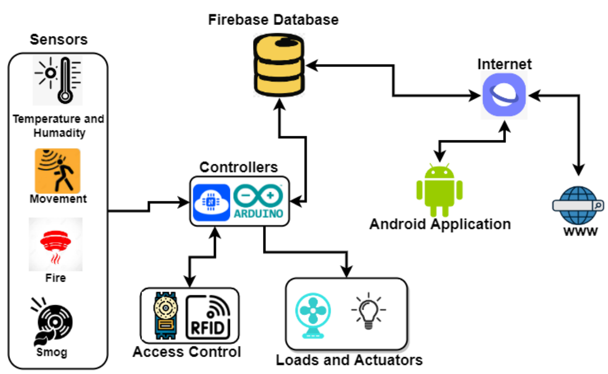

Fig. 2. Block diagram showing how the components and modules are connected to the controller.

Fig. 2 demonstrates the block diagram of the proposed system. The major controller component is the NodeMCU, which acts as an input for the signal. In contrast, the other component connects the LED and fan modules. The Firebase database is continuously exchanging data from the NodeMCU controller on the status of the electrical components using sensors. The data from Firebase is used by the application to enable the user to control the loads by turning them on or off. Arduino Nano has been used to control the overall RFID mechanism. Fig. 3 shows the hardware of the system after implementation.

B. Software Development Operation

1) Front View of the Application: Here an application was created using MIT App Inventor [11] by which the user can easily control system's lights, fans and other switches, alongside get updated about the other status like temperature, humidity, door lock status, motion detection, fire alarm, gas leakage and much more. Below, Fig. 4 demonstrates the front view of the application.

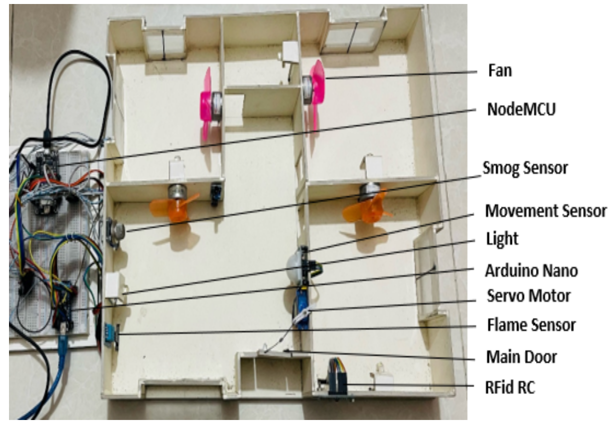

Fig. 3. Real picture of the hardware using all the modules we've mentioned in section II.

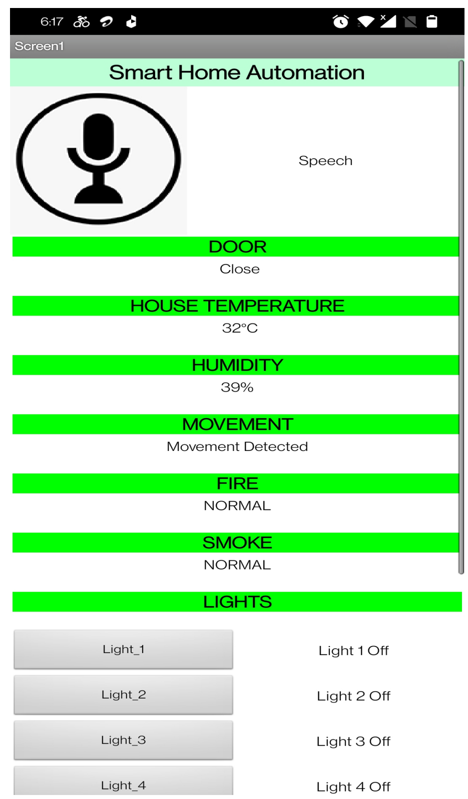

Fig. 4. Front view of the app, here door status, house temperature, humidity, movement status are seen along with voice recognition feature.

2) Voice Recognition: As mentioned earlier, a set of voice commands were added with the software to work perfectly with the system. Some of the voice commands are given: i) Turn on light 1, ii) Turn off light 1, iii) Turn on fan 1, iv) Turn off fan 1, v) All fan on, vi) All fan off, vii) All light on, viii) All light off etc.

C. Firebase Database Observation

The admin/user will have complete authority over the database. Only the administrator will have access to the database and will be able to add or remove elements. Admin can add new members to the database or delete existing members at any moment. Additionally, the administrator can alter the notice board from this page. Owner can quickly install the program and navigate the system. Using the Firebase database, all the commands given on the app will be updated real time using the internet, and thus get implemented in the system as per the command. Data will be updated using the Firebase in real time, only if the mobile app is connected to the internet, it doesn't matter even if the system is turned off. In the Firebase database, door, temperature, light/fan, PIR, smoke and fire, along with voice commands are constantly getting updated after each changes happen in the system.

D. Overall Security System

When the system is turned on for the first time, it has to be connected with the internet using Wi-Fi. When connected, the lights and fans will be turned off indicating that the system is now connected with the internet. Using the mobile app, user can see the overall status of the system like the door status, temperature/humidity, movement, fire alarm and smoke in the house along with the lights and fans. When someone enters the house using the RFID card, or breaks into the house, the app will show that the door status is open. Then movement will be detected inside the house and the app will let the user know about it as well. In events such as fire inside the house, the fire alarm will be activated and it will alert the mobile app that there's fire inside the house in turn increasing the temperature level at the same time, which can also be observed using the temperature status. Smoke inside the house will be detected using the MQ2 sensor and will be notified in the app. All of these will ensure the proper security inside the house, and the user can immediately take action according to it.

V. Prototype Performance Evaluation

The performance evaluation is checked by measuring the activation time/the response time of our prototype. Here, the activation time is the delay time of a sensor activation after receiving the activation command from the user end. The delay time is plotted in figure 5, by splitting the result in three sections: System (time taken for the command to get accepted in the hardware device), Database (time taken for the command to get updated online) and App (total time taken from the inception of user command to command execution) respectively. As can be observed, for system, light and fan switching using buttons takes lesser time (3-4s) than light and fan switching using voice commands (4-5s, around a second more). For the case of database; light, fan turn on/off using buttons, RFID and movement sensors are updated within around 2-3.5 seconds except for Fire and Gas sensor which takes around 4-5 seconds to get updated in the database. Overall, for the user, RFID and movement sensor works in around 3s, fan and light switching around 4.6s and fire and gas sensor within 5 seconds of command in the app. To be noted, delay might increase due to network issues, but at optimal condition, all the modules and features are observed to work perfectly. In all intents and purposes, we wanted to show how stable the device is for different test runs (1-40) where the delay is calculated for aforementioned sections of our system. As noted, the reading defers for 1 to 1.5 seconds for different runs, but not more than that.

In the second phase of our test, we analysed the standard error variation for each working part to check the reliability of the prototype. Here we take the mean value of 40 attempts to calculate the standard deviations in each categories of user operation (light using buttons/voice, fans using button/voice etc.). A bar chart of mean standard deviations in delays for each category (light using buttons/voice, fans using buttons/voice, RFID, Fire Gas sensor and Movement sensor) was plotted (Figure 6). To be added, the delays were further categorised for System (the delay of command to get accepted in the hardware), Database (time taken for the command to get updated online) and App (total time taken from the inception of user command to command execution). The plots demonstrates better stability (delay fluctuations are less) for light and fan commands using voice command system than button systems (delay fluctuations are more). The plots also shows high fluctuations in database delays (time taken for the command to get updated online) than system and app delays. Furthermore, RFID, Fire Gas sensor and Movement sensor's app and database delays are observed to be more than the system delays.

Shamim et al. designed a home automation system depended on mobile GSM technology which takes 5-7 seconds to execute the user commands [8]. The total initiation to command execution time was also depended on the mobile data operator. Within the knowledge of the authors of this paper, in comparison, the delays for the proposed design of the prototype is lower than the total time taken for similar commands in other proposed designs in the market.

Different models of similar IoT based home automation system has previously been suggested where features such as temperature, humidity and appliance con-

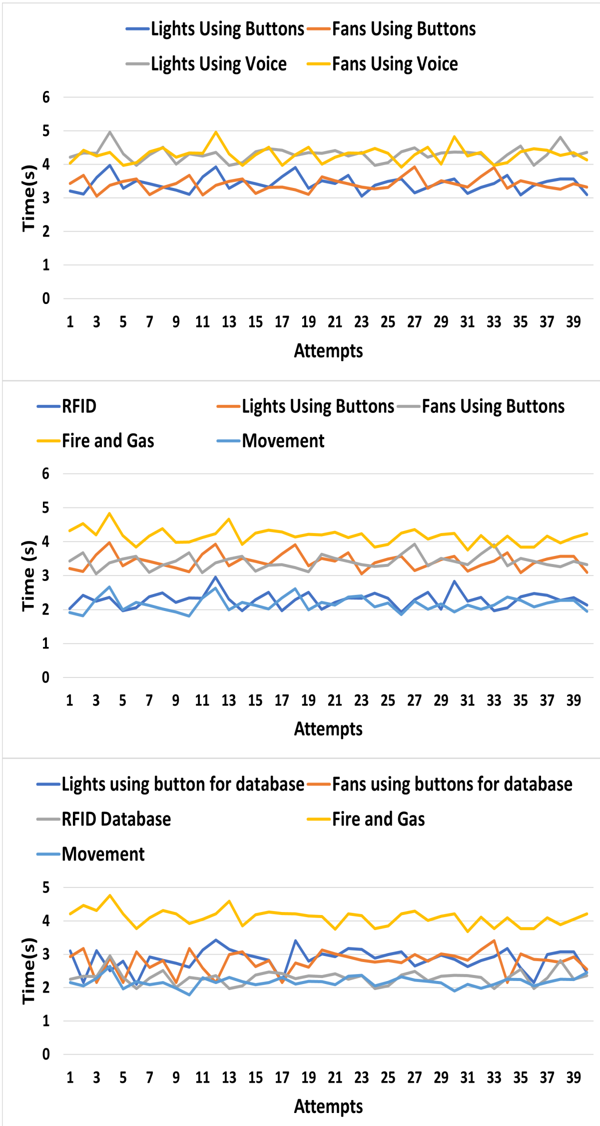

Fig. 5. Graphs of delays for App, System and Database (in order) demonstrating the time taken in each segment for around 40 attempts.

trol has been added for ease of accessibility. Compared to the suggested design in this investigation, these models are non-comparable to our system in terms of system cost. For example, Nader et al. proposed automation system which costs more than USD 66 including security systems [5]. N. Vikram et al. also designed a similar system which costs USD 100 [6]. Other systems available in the market is reported to cost 76 USD initially and 28 USD for the consecutive years [7], leading available systems to be expensive compared to the proposed system requiring only 31 USD initially.

Table I demonstrates the cost analysis of the proposed design showing individual component cost.

As can be observed from the Table I, the total cost

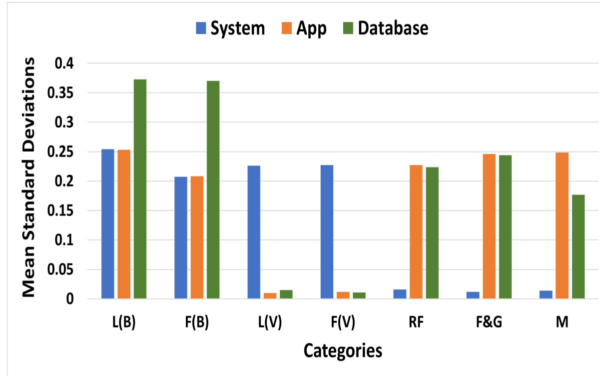

Fig. 6. Bar chart demonstrating average fluctuations/deviations in delays for each category of commands (light/fans using buttons/voice, RFID, Fire Gas sensor and Movement sensor) found from previous figures in 40 attempts of command execution in terms of system, app and database delays. Category L(B) represents lights using buttons, F(B) represents fans using buttons, L(V) represents lights using voice, F(V) represents fans using voice commands and lastly RF represents RFID sensor, F&G Fire and Gas sensor and M represents movement sensor respectively.

TABLE I
TOTAL COST OF THE PROJECT IN USD($)

Product List	Price (USD Approx.)
Arduino Nano(1)	7.92/-
Node MCU v3(1)	4.96/-
Servo Motor SG90(1)	2.06/-
RFID RC522(1)	2.09/-
DHT11(1)	1.90/-
PIR Motion(1)	0.84/-
Breadboard(1)	0.90/-
Relay 4-Channel 5V(1)	3.06/-
Jumper Wire (3 set)	3.01/-
Gas Sensor MQ2(1)	1.69/-
Flame Sensor(1)	0.93/-
Cable	1.65/-
Total	**31.00/-**

TABLE II
COST CALCULATION BEFORE AND AFTER IMPLEMENTING THE SYSTEM

Appliances	Load (W)	Avg. time daily Before (hours)	Avg. time daily After (hours)	Monthly Consumption Before (kWh)	Monthly Consumption After (kWh)
Refrigerator	150	24	22	108	99
Water Pump	360	.33	.33	3.6	3.6
Air Condition	1000	4	3	120	90
Light	30	5	4	4.5	3.6
Fan	50	14	12	21	18
Desktop	50	8	6	12	9
Total				**269.1**	**223.2**

of the whole system cost about USD 31. It can be seen that the proposed design is significantly less expensive compared to models already available in the market. The suggested model is additionally compact compared to other designs as the model utilizes a single NodeMCU and Arduino Nano, controlling the switches from one single system. This makes the proposed system compact and inexpensive compared to currently available models.

To understand how cost effective the proposed system is, an arbitrary cost analysis is done considering normal daily electricity consumption of an individual. As can be observed from Table II, the proposed system is effective in reducing the electricity consumption, as users can readily control the switch through the app in the home automation system.

VI. Conclusion and Future Work

The proposed system costs around USD 31 to build. In terms of the implementation at home, for a single room, it will cost analogous to the prototype, for multiple rooms, as per the sensors count, the price will increase accordingly. Compared with the other solutions out in the market, this is significantly less which makes the system stand out from the rest. Additionally, the system is cost effective in terms of standby/vampire consumption [12], as when the switches are on during non-usage time, some electricity is continuously being consumed. Using the proposed system, it is saving the hidden cost in the electricity bill that is often overlooked. Thus, the proposed system is cost effective and can be useful in the market. The system can be controlled from anywhere once connected to the internet. All the switches can be remotely controlled using the app. It is a compact system with a lot of modules implemented at as low cost as possible. Voice command implemented here is an interesting feature to interact with the system. Along with the different advantages mentioned the system comprises of the following identified weaknesses.

- The database is only accessed by the admin. Thus, in situation where the admin's information is hacked, the total system will be in risk. But the issue is minimized as the primary security measures are present and additional measures will be implemented later as future work.
- The mobile app used is only developed for Android, but the authors intend to release their own app for both android and iOS version alongside web version of it in future.

With the enormous scope of future development, the authors are currently thinking about using machine learning algorithms to add more features. The authors have intention to add Covid-19's vaccination verification to the door lock system for better security. Parking systems will be included in the system to ensure proper measurement. More efficient modules will be built to future proof all-in automated home security system which can be used from personal houses to large extent, ensuring a proper utilization of IoT for home automation systems.

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