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Design Low-Cost IoT Smart Home System with Comfort and Humidity Control using NodeMCU ESP 32 Microcontroller

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ABSTRACT

More recently, there has been growing interest in research about energy consumption, improved energy efficiency and saving electricity due to sustainability growth and improved quality of life. This paper aims to propose a Smart Home System built with a NodeMCU ESP 32 microcontroller board that allows for remote control and monitoring of electrical devices using App Blynk. This system operated with a sensor such as PIR Sensor to detect humans dan DHT 11 to detect temperature and humidity. The Smart Home System also support solar panel as renewable energy to reduce electricity usage. The prototype of the Smart Home System can control and monitor electrical appliance, sockets, air-conditioning, fan, comfort and humidity through a smartphone with the help of an internet connection via Blynk App. The results revealed the difference reading of the temperature and percentage of humidity in room before and after trigger the sensor with hair dryer. The humidity results in a room and hall before testing is higher than after triggering the sensor with a hair dryer, which from 79% to 53% and 72% to 48%.

1. Introduction

From the past few years up to the present, the research on building energy consumption has increased due to the growing concern about energy efficiency. Based on the World Energy Markets Observatory (WEMO) 2017 report, Malaysia's energy usage is projected to increase up to 4.8% by 2030 [1]. The research design about energy consumption and the Internet of Things (IoT) proliferated due to the Industrial Revolution 4.0 (IR4.0).

IoT is the acronym for the Internet of Things (IoT) introduced by Kevin Ashton [28] and is something familiar to the technologically increasing world. IoT is the system where computer systems will connect the internet to real-world objects or things without the human to human or human-to-computer interaction [3,4]. The objects or things will share and record data such as wireless sensors, radio frequency identification (RFID), cloud computing and smart home systems [3,5,6]. The data

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obtained then will be processed through any microcontroller, for instance, the commonly used Arduino Uno, ESP8266, and Raspberry Pi.

A Smart Home system, also known as home automation, promotes an easy, convenient and technological system. Smart home systems may include home security, monitoring temperature, climate and humidity, auto-controlling doors and others [3,7]. Some papers have highlighted the advantages of Smart Home applications [2,3,7,8]. For the concept smart home system, it is built mostly using Arduino as it is an easy microcontroller, as well as a low price. But in recent years, as IoT concepts become advanced, other microcontrollers with communication systems such as Bluetooth, ZigBee, MQTT, IFTT and Blynk Application have been developed [7]. Another design proposed by Hagejärd *et al.,* [9] in a recent publication in 2023 evaluates a smart home energy management system, Ero 2.0, which was tested by households in a multi-residential building in Sweden. The author concludes that the future system must be designed in such a way that it can adapt to users' varying levels of knowledge and interest, as well as adjust as users' ability changes over time. To avoid the system becoming merely a monitoring device, emphasis should be placed on making the information meaningful and relatable to one's own daily practices. IoT and smart home systems are becoming increasingly important in today's technological landscape and their impact on our daily lives, businesses and society as a whole is profound. They provide a wide range of benefits, from increased convenience and energy efficiency to improved security. These systems impact not only our daily lives but also various industries and sectors such as business application, data analytics, health and wellness and emerging technology like 5G and AI.

Another proposed paper presented a low-cost project about home monitoring systems and device control using the Internet of Things (IoT) and control home devices using ESP32 by Pravalika *et al.,* [10]. The paper proposed a new method different from other previous work, which is for storing data and displaying data status by using cloud storage and MIT app inventor, respectively. As the input, the project used four different inputs; temperature sensor, PIR sensor, gas sensor and water level sensor while the outputs are a buzzer, servo motor, fan, light and DC motor. The project is run according to three phases: first phase, second phase and third phase. In the first phase, it only monitors room temperature, gas leakage, tank water level and person detection. The monitoring data will be saved in cloud storage while the MIT app inventor will display the data or output value performed by different sensors. In the second phase, the author creates a system to automatically control the gas knob and water pump of home appliances at a certain level. Lastly, the third phase is where people can automatically and remotely control their home devices through mobile applications; such as controlling lights and fans. This project is a low-cost project but it may be easily implemented for home appliances.

Next, a researcher designed and fabricated a low-cost Smart Home application [7]. This paper used Arduino as a microcontroller with its compatible module. It proposed two ideas for smart homes which are home security and home automation. For home security, the researcher makes this system to prevent thieves from entering the house by using the laser ray (LDR) sensor and infrared sensor and thus sending a signal to the buzzer as an alarm system if the thief successfully passes by the laser sensor. Besides, home automation is designed to automatically detect fire and gas leakage in homes by using a flame sensor and MQ-05 sensor, respectively. In order to successfully run the project, the researcher programmed and designed the project using the MIT app inventor (installed through a smartphone) with Bluetooth module so that it can display and control devices from an Android smartphone. The project also used other sensors to complete the term of smart home which are humidity sensors which detect the home moisture or condition.

The following paper created a control system based on mobile for Smart Home [11]. The project uses the method of waterfall model which is a software development that is the process in sequential and linear [11]. The details of waterfall design can be obtained from previous research by Van Casteren [12]. The author uses the model where the overall project is designed and implemented step by step and repeated ten times to achieve good system performance. The project uses proteus as simulation software, Arduino with WIFI module ESP8266 as the project microcontroller and MIT app inventor to design systems in Android smartphones. The project used four lights and was tested repeatedly; with ten trials as the output for home appliances. It is tested by simulation and monitoring using a mobile application (MIT app software). The author prefers to use the WIFI module instead of Bluetooth to connect an Android smartphone with the Arduino. A comparison has been made between the Bluetooth module, Zigbee and the proposed module which is the WIFI module. The results presented from the paper show that the relationship between smartphone and Arduino is best implemented using the WIFI module as it obtained no error [11].

Other research discussed improving smart home concepts with IOT using Raspberry Pi and NodeMcu [2]. Unlike other researchers, this proposed project is to focus on automation, controlling, monitoring and security using Raspberry Pi and NodeMcu. The research creates a system that can calculate the power from electronic devices used by users so that it can save electricity bills. The smart home from this project builds three modes; auto, manual and secure mode with different functions. It employed rain sensors, door sensors, PIR sensors and DHT22 sensors (temperature and humidity) as inputs and light as output. The on and off of the light is decided by the function of the sensors in this project as well as the air conditioning is on and off according to the humidity sensor. The communication signal between Raspberry Pi and NodeMcu is using message queue telemetry transport (MQTT) while the user and Raspberry are by telegram bot. The research observed the advantages and disadvantages of smart home implementation from the project [2].

Smart energy-efficient home automation systems using the Internet of Things (IoT) are presented by Vishwakarma *et al.,* [13]. The research proposed a smart home by controlling using Google Assistant as a controller and Adafruit with IFTT ('If This Than That') as a communication link throughout the project. A low-cost smart home automation system has been proposed by Tayef *et al.,* [14] using MQTT and IFTT communication systems with the designation of Cayenne application. The paper proposed a security system for the project by the implementation of fingerprint authorization. Besides, it implemented a system that can monitor the temperature and humidity of the home that will show the alert message through the Cayenne application when each condition exceeds the desired temperature and humidity. As for the demand-side energy management system, another study suggests designing two type-2 fuzzy logic controllers. A combination of renewable energy sources, including fuel cells, photovoltaic solar panels, vertical axis wind turbines with helical savonius rotors, electric vehicles, energy storage systems and an external grid are used for this purpose to supply the electricity consumption of home appliances in a smart home [15].

Two research studies were found to design smart home systems for elderly people [16,17]. The researcher created a system for ease of use to control the home environment including humidity and temperature conditions and to detect intruders. It created a WIFI based system which connects an Arduino controller with a smartphone application and thus displays text notifications (humidity, temperature reading and motion) on the phone using the IFTT communication function [16]. Next, a smart home is designed for physically disabled people, especially those with disabilities spoken using voice commands [17]. The research by the Institute of Electrical and Electronics Engineers [18], digital assistants to record spoken instructions, including Google Home, Amazon Alexa, Google Assistant, Apple Siri or Microsoft Cortana to capture voice commands. Development of the Smart Home system plays a significant role in the development country because the demand and need for technology have driven in recent centuries.

In 2020, Artiyasa *et al.,* [19] will be doing a comparative study of IoT for smart homes using Thingspeak and Blynk applications for Smart Home which is the devices that can turn on and off house lights via laptops and smartphones. Research can compare their pros and cons. NodeMCU resembles the Arduino ESP8266 board. NodeMCU is a compact board with ESP8266, a microcontroller, Wi-Fi access and a USB data cable extension chip that can charge and transfer data from Android smartphones. Blynk's creation and operation are simpler and more efficient than the other two platforms, according to the analysis results. Table 1 summarizes previous research using the app Blynk for IoT applications and the contribution of this paper.

Table 1
Summarize previous work smart home system design

Author	Method	Finding/ Application
Durani *et al.,* [20]	Control fan, light, water pump, gardening with help of coding and hosting online with web server with ESP8266, IOS app, app Blynk	a prototypical system is applicable to real-time home security, automation, monitoring and controlling of remote systems.
Osman [21]	fan, light, water pump, gardening and meter reading with help of coding and hosting online with the web server	prototypical system is applicable to real-time home security, automation, monitoring and controlling
Ram *et al.,* [22]	safety system is capturing the picture and sends it e-mails to the user using Arduino uno, raspberry pi and app Blynk	raspberry pi module is associated with the raspberry pi camera which catches the pictures of the gate crasher
Bawono *et al.,* [23]	smartphone home IOT using smartphone using Wi-Fi as the Arduiono Mega 2560 communication protocol as a server that integrates	ESP8266 wifi module, internet network and Blynk app make monitoring room temperature and controlling lights easier
Sahrab *et al.,* [24]	Arduino Nano and the Arduino Leonardo microcontroller boards.	stealing and a safety system for detection of the blaze and LPG leakage
Rosli*et al.,* [25]	wireless technology and infrared sensor to detect the motion and a microcontroller to control the usage of appliances in the home for educational purpose	the Blynk application, login the email and pushing several buttons.
Suwartika *et al.,* [26]	Wi-Fi module ESP8266 controlled via Blynk App	Gas leak detector, alarm and temperature
Hussain *et al.,* [27]	Google Assistant-controlled Home Automation	Google Assistant's voice input is connected to Adafruit's IFTTT account.
This paper	nodeMCU 32, esp8266, app Blynk with internet protocol connection	control all electrical appliance, socket and added with comfort and humidity control for human comfort and needs

Based on the discussion above, this paper proposes to design a low-cost smart home system using a NodeMCU 32 with App Blynk control through bright with the help of an internet connection. The proposed design is easy to operate and install and equipped with auto mode.

This paper consists of four sections, which are as follows. The introduction presents the background of IoT, smart home systems and related reviewed research papers about smart home systems. Methodology is the next part, which explains the methodology for the development of the IoT smart home applications including the hardware and software of the applications. The results and discussion explained the results analysis of testing and evaluation of hardware and software of smart home applications. The last part presents the conclusions of the project and some novelty and contributions.

2. Methodology

Up to recently, the development of IoT applications for Smart Home increased rapidly due to advanced technology movement to IR4.0 and awareness of energy efficiency. This project proposed a Smart Home System to control electrical appliances, temperature and humidity and the whole device using Blynk IoT. For this project, two types of sensors have been used as input of the project which are the DHT 11 temperature and humidity sensor and the PIR motion sensor. Both of these sensors will be equipped in the room and hall of the house. The temperature and humidity sensor will sense the temperature and humidity level in the room and hall area. The PIR motion sensor is installed in the room and detects human motion. The sensors will produce an output signal and trigger the microcontroller to display the temperature and humidity readings of the room and hall on the screen.

An IoT application will be used to control the devices such as lights, fans and other electrical appliances. Plug outlets and humidifiers will turn on or off remotely through the internet connection. Blynk IoT application is used as the IoT application for this project which is able to be accessed from a smartphone, tablet, personal computer or laptop. The automatic mode also can be activated from this IoT application and is able the turn off every device by using the emergency stop button from the Blynk IoT app. The Smart Home System has a reset button and power button to reset the whole system and the microcontroller and to turn on or off the whole system and the devices.

2.1 Block Diagram

Refer to Figure 1, In the input section, the room temperature and humidity sensor, hall temperature and humidity sensor and room PIR sensor are the input components because this sensor will produce signals to receive by the microcontroller. The microcontroller will reset when the reset button is pressed. When the switch is switched off, the system will be turned off. To control the devices or output components, the Blynk software will send data to the server by Wi-Fi/internet connection. The power supply components such as solar panel, regulator, charging circuit and battery are placed under the input section because the input power for the system goes from the battery and other power source components.

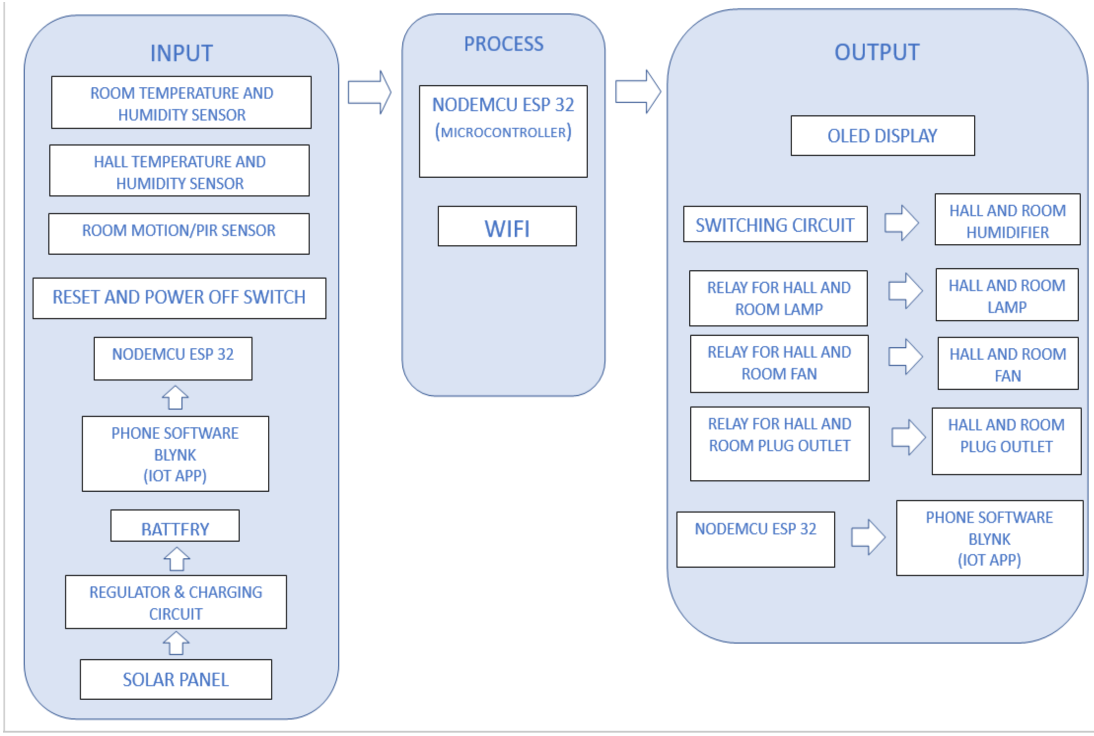

Fig. 1. Block diagram

In the process section, the NodeMCU ESP32 microcontroller board will process the input signal from the input components to generate the output signal. Wi-Fi is a medium to transfer a signal to the NodeMCU ESP 32 and receive a signal from the Blynk server or to transmit a signal to Blynk to control the temperature and humidity level in the room and hall. The microcontroller sends signals to switching circuits and relay modules to control or turn on or off the lights, fans, plug outlets and humidifiers in the hall and room. The Blynk app will show the temperature and humidity level in the room and hall. Figure 2 shows the flow chart of the system operation.

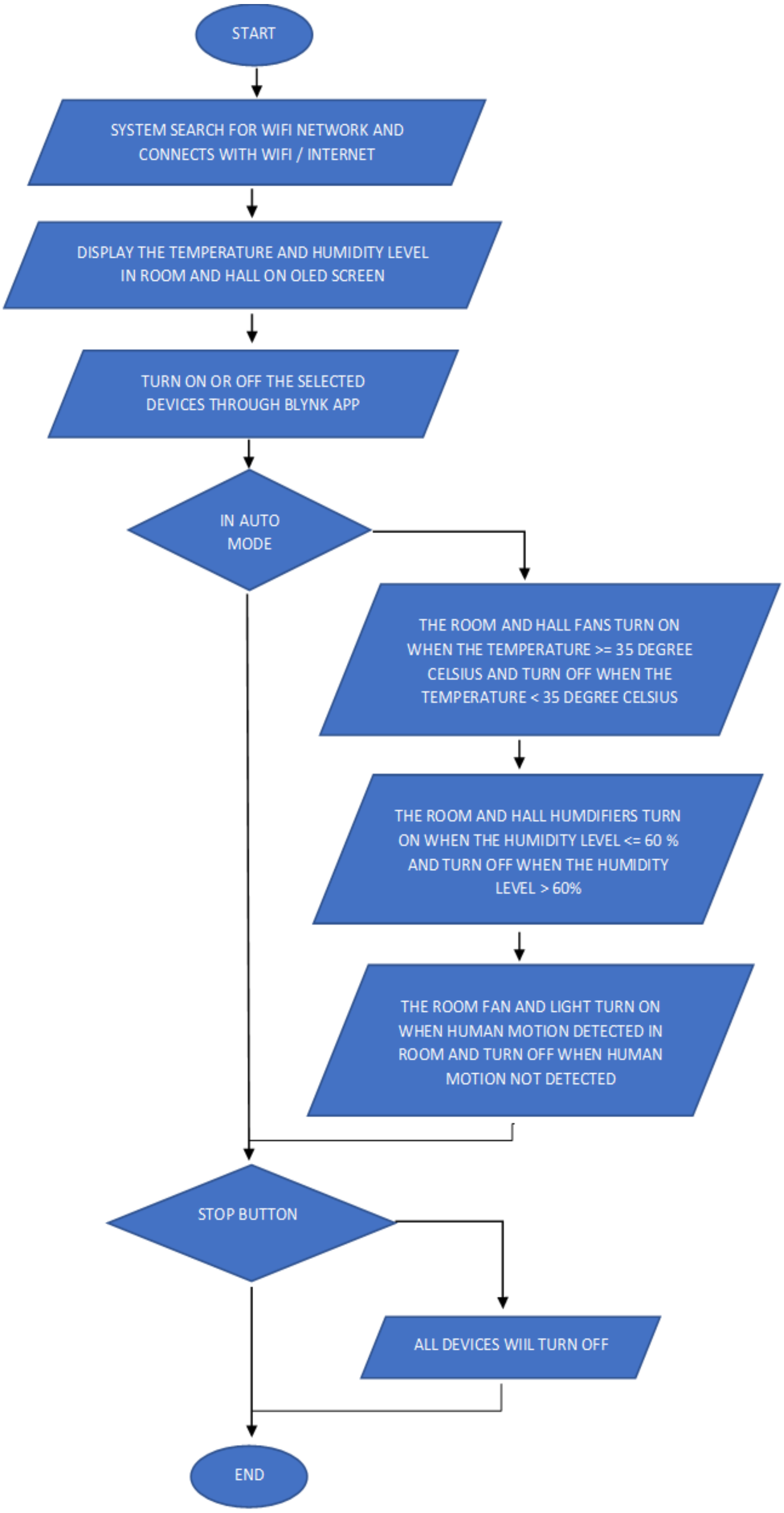

Fig. 2. Flow chart of smart homes design

Table 2 presents the specification of NodeMCU and the requirements used in the design prototype of the Smart Home System. Wireless connectivity is needed to connect the system to the internet and control the electrical device using the App Blynk through the phone.

Table 2
Features of NodeMCU ESP 32

Processors	• CPU: Xtensa dual-core 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS • Ultra-low power (ULP) co-processor
Memory	• 320 KiB RAM, 448 KiB ROM
Wireless connectivity	• Wi-Fi: 802.11 b/g/n • Bluetooth: v4.2 BR/EDR and BLE (shares the radio with Wi-Fi)
Peripheral interfaces	• 34 × programmable GPIOs • 12-bit SAR ADC up to 18 channels • 2 × 8-bit DACs • 10 × touch sensors (capacitive sensing GPIOs) • 4 × SPI • 2 × I^2S interfaces • 2 × I^2C interfaces • 3 × UART • Infrared remote controller (TX/RX, up to 8 channels) • Pulse counter (capable of full quadrature decoding) • Motor PWM • LED PWM (up to 16 channels) • Hall effect sensor • Ultra-low power analogue pre-amplifier
Security	• IEEE 802.11 standard security features all supported, including WPA, WPA2, WPA3 (depending on version) [5] and WLAN Authentication and Privacy Infrastructure (WAPI) • Secure boot • Flash encryption • 1024-bit OTP, up to 768-bit for customers
Power management	• Internal low-dropout regulator • Individual power domain for RTC • 5 µA deep sleep current • Wake up from GPIO interrupt, timer, ADC measurements, capacitive touch sensor interrupt

2.2 Project Software

The software used in this project are Blynk IoT app and Arduino IDE. Blynk IoT app and website were used to create a template for the project to control the devices remotely from a smartphone. Arduino IDE is used to write the coding and upload the program of the project into the microcontroller.

2.3 Mechanical Design

The Smart Home System was built with a prototype house model to demonstrate the system. The prototype is 3D printed with PLA plus material which is durable and looks neat. Figure 3 and Figure 4 show the prototype of the Smart Home System design.

Fig. 3. Prototype of smart home system

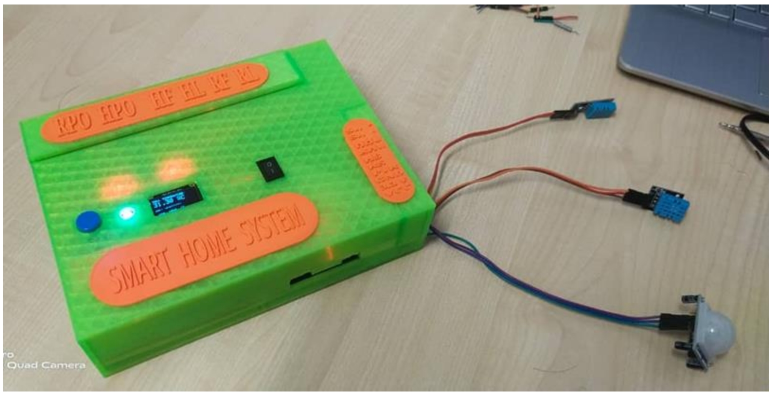

Fig. 4. Prototype of the controller for smart home system

Figure 5 shows the electrical appliances and devices installed in the smart home system.

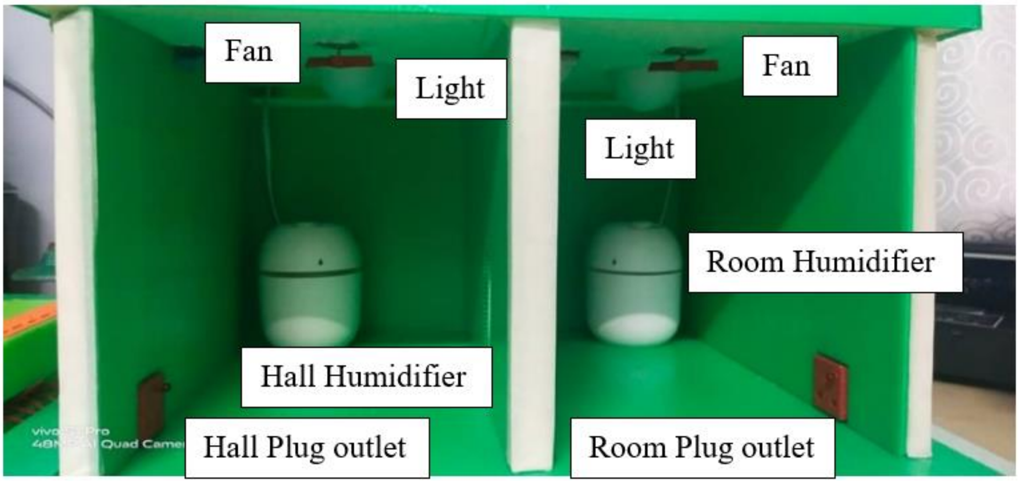

Fig. 5. Electrical appliance and device install in smart home system

Based on Figure 6, one is the main circuit board which consists of a microcontroller, charging circuit, transistors and resistor. Another board is soldered with an OLED screen, blue LED and reset push button. The relay modules, microcontroller and charging module are able to connect and disconnect from the main circuit board. The Smart Home System also install Solar panels as alternative renewable energy to support the Smart Home System.

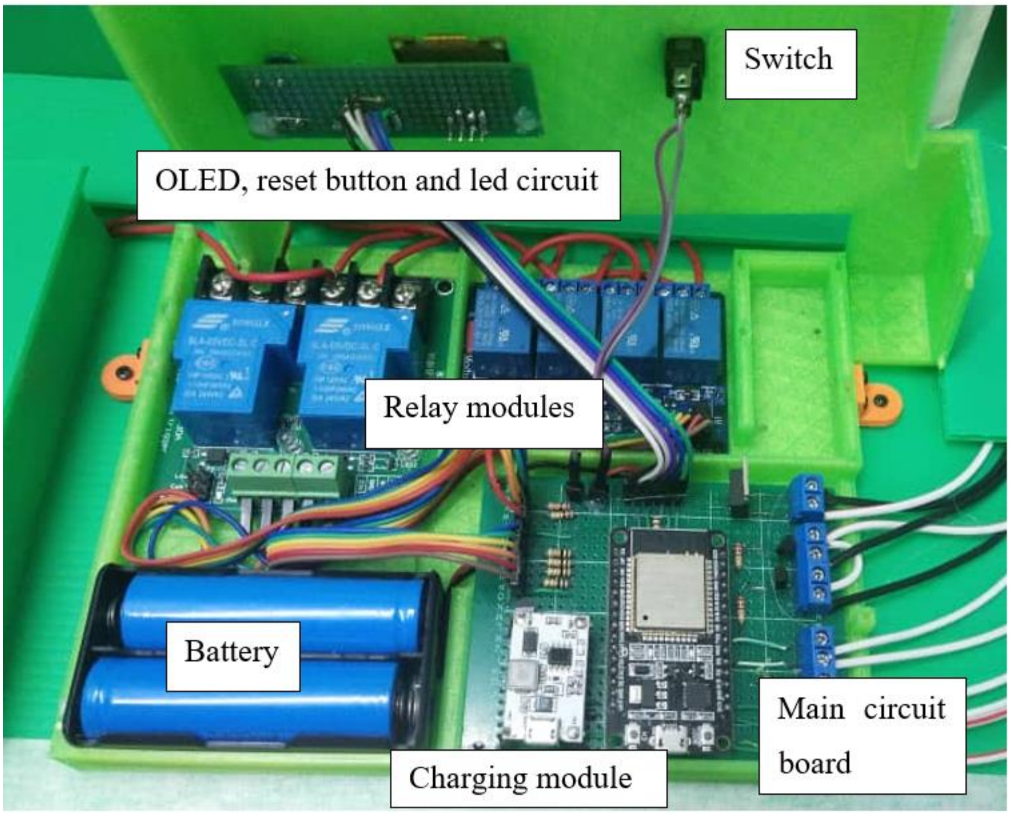

Fig. 6. The arrangement of relay modules and other components

In this Smart Home System, there will be two types of sensors have been used as input for the project which are the DHT 11 temperature and humidity sensor and PIR motion sensor. Both of these sensors will be equipped in the room and hall of the house. The temperature and humidity sensor will sense the temperature and humidity level in the room and hall area. The PIR motion sensor equips in room and detects human motion. The sensors will give an output signal to the microcontroller to display the temperature and humidity readings of the room and hall on the screen.

An IoT app will be used to control the devices such as lights and fans. Plug outlets and humidifiers to turn on or off remotely through the internet connection. Blynk IoT app is used as the IoT app for this project which can be accessed from a smartphone, tablet, personal computer or laptop. The automatic mode can also be activated from this IoT app and is able to turn off every device by using the emergency stop button from the Blynk IoT app. The Smart Home System have a reset button and power button to reset the whole system and the microcontroller and to turn on or off the whole system and the devices.

The relay modules and switching circuit are used as output for the Smart Home System which acts as switches for the devices to open and close the circuit for the devices. The Smart Home System first will connect to a Wi-Fi/internet connection to receive the signal from the IoT app server to which devices to turn on or off. After receiving the signals, the microcontroller sends the signal to the relay modules and switching circuits to turn on or off the devices. The microcontroller also will transmit readings of the temperature and humidity level of the room and hall to the IoT server via a Wi-Fi/internet connection.

To power the Smart Home System, rechargeable batteries are used and it can be charged from the power supply from the solar panel The rechargeable batteries also can be charged from other external power supply such as a power bank or 5v adapter. The Smart Home System has a reset button and power button to reset the whole system and the microcontroller and to turn on or off the whole system and the devices.

3. Results and Discussion

3.1 Testing and Evaluation

The prototype of the design was tested using 3 types of testing methods to test manual operation, automatic mode and emergency stop function. The testing method also includes testing of components and modules. Table 3 shows the result of the testing method and the effect of temperature and humidity. In order to assess the performance of the temperature and humidity sensor, a hair dryer was utilized to induce temperature changes and observe the system's response to this stimulus (Figures 7 and 8).

Table 3
Method of testing

Method of testing	Result	
	Temperature	Humidity
Before testing (room)	31	79%
Trigger the sensor with a hair dryer	35.10	53%
Before testing (hall)	31.80	72%
Trigger the sensor with a hair dryer	39.5	48%

Fig. 7. Temperature and humidity level of room before hair dryer placed

Fig. 8. Temperature and humidity level of room after hair dryer placed

The second testing procedure is devices controlling test from the Blynk IoT app. This testing method checks whether the devices such as lights, fans, plug outlets and humidifiers turn on or off when controlled from the Blynk app. Figure 9 shows the manual operation of the devices from the Blynk IoT app.

Fig. 9. Hall humidifier, hall plug outlet, room light and room fan are switch on

The third testing procedure is for the automatic mode. When the automatic mode is activated in the Blynk app, the room light and fan, hall fan and humidifiers cannot be controlled because it will turn on automatically. When the temperature is higher than 35 degrees Celsius, the fans will turn on and turn off when the temperature is lower than 35 degrees Celsius. Figure 10 shows the fans turned on condition in auto mode. When the humidity level is below 61%, the humidifier will turn on and turn off when the humidity level is higher than 60%.

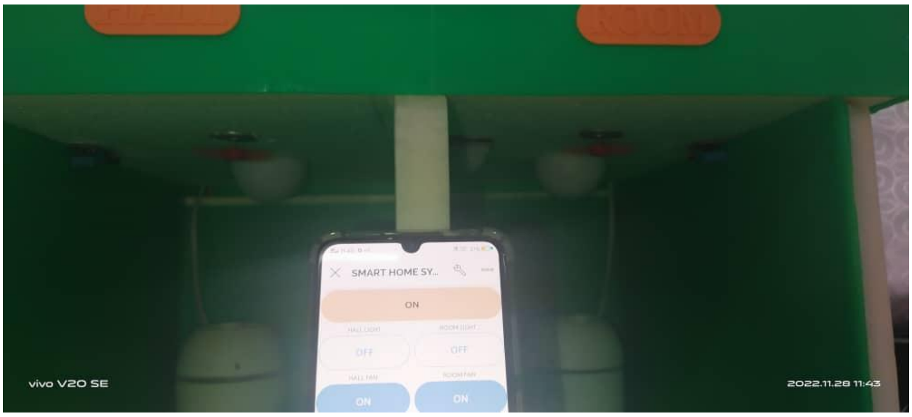

Fig. 10. The fans in room and hall switch on

Figure 11 shows the humidifiers turned on in auto mode. In auto mode, when the temperature is high and equal to 35 degrees Celsius in room or hall, the relay for the fan will energize either room or hall. If the temperature is below 35 degrees Celsius the relay for the fan will de-energize. When the humidity level is below and equal to 60% in the room or hall, the humidifier in the room or hall will turn on and turn off when the humidity level is higher than 60%. When the PIR sensor detects human motion in the room, the microcontroller will send the signal to energize the relays for light and fan of the room making them turn on. When the PIR sensor doesn't detect any human motion for 40 seconds, the relay for the room light and fan will de-energize making them turn off.

Fig. 11. The humidifier in room and hall switches ON

The temperature of the room and hall are also displayed in the form of a graph with live readings in the Blynk Iot app. Figures 12 and 13 show the temperature graph for the room and hall in the Blynk app and Table 4 represents the testing result of the Smart Home System.

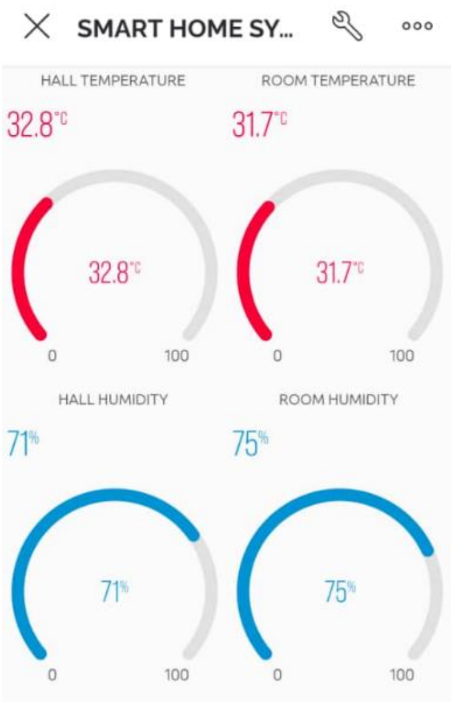

Fig. 12. Temperature and humidity level of room and hall displayed in Blynk app

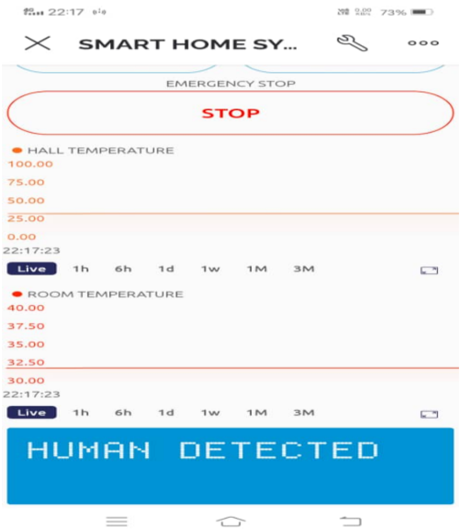

Fig. 13. Graph temperature of room and hall

Table 4
Prototype test results according to the conditions

Condition	Result
Power switch of the prototype switched on.	The blue led blinks fast and blinks slow after connects to Wi-Fi network. OLED displays the temperature and humidity level of room and hall. All devices in off state. In Blynk app, the temperature and humidity level of room and hall displayed.
Hall light button is pressed in Blynk app	Hall light turned on
Room light button is pressed in Blynk app	Room light turned on
Hall fan button is pressed in Blynk app	Hall fan turned on
Room fan button is pressed in Blynk app	Room fan turned on
Hall plug outlet button is pressed in Blynk app	Hall plug outlet turned on
Room plugs outlet button is pressed in Blynk app	Room plugs outlet turned on
Hall humidifier button is pressed in Blynk app	Hall humidifier turned on
Room humidifier button is pressed in Blynk app	Room humidifier turned on
Emergency stop button is pressed in Blynk app	All the devices turned off
Auto mode button is pressed in Blynk app	Room light, room fan and hall fan turned off
User enters hand in the room	Room light and room fan turned on
User remove hand from the room	After 40 seconds, Room light and room fan turned off
Room temperature is 35 degrees Celsius	Room fan turned on
Room temperature is 34 degrees Celsius	Room fan turned off
Hall temperature is 35 degrees Celsius	Hall fan turned on
Hall temperature in 34 degrees Celsius	Hall fan turned off
Room humidity is 60%	Room humidifier turned on
Room humidity is 61%	Room humidifier turned off
Hall humidity is 60%	Hall humidifier turned on
Hall humidity is 61%	Hall humidifier turned off
Reset button is pressed and released	All devices turned off. The blue led blinks fast and blinks slow after connects to Wi-Fi network. OLED displays the temperature and humidity level of room and hall.

	In Blynk app, the current temperature and humidity level of room and hall displayed.
Power switch of the prototype switched off	All the devices turned off The whole system shut down
Batteries are low	All the devices remain in current state Prototype won't connect to Wi-Fi network Display same temperature and humidity readings
Prototype is charging	Red light emitted from bottom of the prototype
Prototype fully charged	Blue light emitted from bottom of the prototype

3.2 Discussion

The prototype of the Smart Home System functions properly. The prototype accomplished the objectives such as controlling the electricity for lights, fans and all plug outlets of a home automatically or manually by using relays, sensors and microcontroller. The prototype needs to connect 2.4 GHz of Wi-Fi connection, IEEE 802.11 standard security features including WPA, WPA2 and WLAN, 2400mAH of battery capacity, high contrast OLED display, fast response with Blynk app in less than a second, work manually and automatically and emergency stop function and reset function included in this prototype. This prototype will control all the devices to turn on or off manually using the Blynk app and automatically using sensors. On the other hand, the prototype displays the temperature and humidity readings on an OLED screen and the Blynk app. This prototype is installed with a solar panel to charge the batteries which has the alternative of renewable energy. This smart home system provides an efficient means of conserving electricity by automatically turning off lights, and fans and unplugging devices when they are not in use. Additionally, it offers a convenient solution for individuals of all ages, including children, the elderly and those with disabilities, allowing them to easily control their appliances without the need to physically reach them. Furthermore, the system can be a lifesaver in emergency situations, as it can swiftly disconnect circuits from the main power supply, reducing the risk of electrical fires.

The implementation of this Smart Home System can lead to significant cost savings for households, as it effectively lowers electricity bills. Every homeowner is encouraged to consider installing this system to transform their residence into a smart home, enhancing both comfort and safety while mitigating electrical hazards.

4. Conclusions

This proposed Smart Home System was undertaken to design a Smart Home System with IoT application App Blynk, nodeMCU ESP 32, solar panel as renewable energy and comfort and humidity for human comfort. This system was designed by controlling using a smartphone with an internet connection is efficient in reducing electricity for users. The system can also be equipped with an alarm system as security for humans. Still, the focus and contribution of this project is to design a system that will control comfort and humidity other than automatic control of electrical appliances in the house. All the electrical appliances can easily be controlled and monitored using a smartphone through the App Blynk. In auto mode condition, if there's no human detection in the area the device will automatically turn off. The finding of this design indicates that IoT will support energy efficiency, reduce electricity and help humans monitor and control electrical devices installed in the house. For future recommendations, the development of a Smart Home System will equip with a security system with a flood or disaster warning system, and a rain harvest system to support water saving and quality monitoring system in the house.

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