Design of low cost IoT enabled embedded control system for covid free smart home

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Abstract. In the era of automation, the Internet of Things (IoT) has come up as a solution and innovation for many applications to improve the basic facilities required in the day-to-day routine. IoT, itself is the interconnectivity of different physical devices with the help of wireless networks e.g., Bluetooth, Wi-Fi without human intervention. The low-cost embedded control unit for Covid free Smart Home is based on the idea of home automation by keeping the current situation of the Covid pandemic in mind. Irradiation of Ultraviolet C (UVC) spectrum is used to sanitize household goods, where conventional sanitization process is not suitable. Simple home automation means controlling or monitoring different electronic/electrical home appliances, devices, and other such things with smartphones or by doing sensor-based operations. All the required devices are connected with one embedded control unit which is managed through a mobile app. This functionality can be accessed either by manually operating a mobile app or with voice assistants e.g., Alexa or Google Assistant, etc. The basic point of communication among devices is based on real-time sensor inputs, which trigger the devices for action and react as per requirements. Ambient light sensors are used to control the on/off functionality of lights based on the intensity of light present naturally. In this scenario, lights will be switched off in day mode and switched on in night mode. Advancement in wireless technologies enables the researchers to apply various modes of communications among the sensors, gateway, and applications. Bluetooth, Wireless sensor network (WSN), Wi-Fi, Global system for mobile communication (GSM) are a few of them, which are being used either in sensing nodes or in communication gateway to make home automation free of the wired network.

Keywords: Smart house, Home automation, Covid, Internet of Things (IoT), UVC Sanitizer, Access control

1. Introduction
Bluetooth enabled embedded devices are getting wide applications in home automation. 2.4 GHz ISM band gives secure short-range communication. It exhibits a secure communication range from 10m to 100m with a bandwidth of up to 3Mb. Various home appliances are controlled using smartphone and Bluetooth gateway [1]. Home automation makes home functioning more energy efficient with reduced efforts. Sensors based actuator control, save lots of electricity bill by reducing unwanted uses of lighting, cooling or heating systems [2].
Various IoT technologies like Bluetooth, Wi-Fi, GSM are being used widely in smart home applications. Sensors are used to detect environmental parameters like ambient light, room temperature, etc. to automate the lighting, heating, and cooling systems [3]. Machine to Machine (M2M) communication, IoT protocol reduces the need for human interventions in data communication and related computing work for decision making. Intelligent embedded devices are programmed to operate on predefined threshold values of the sensor’s inputs [4]. IoT enables home monitoring from remote locations at any time. Real-time sensor data are uploaded to the cloud and can be accessed by the end-user mobile application. One can monitor his/her home without physically being there [5]. IoT-based home automation is trending these days. It allows users to securely control and monitor home appliances with ease [6]. Appliances can be controlled remotely in autonomous mode or through user inputs. In autonomous mode, action is taken based on real-time sensor data [7]. The Bluetooth enabled embedded control unit for covid free smart home is developed which is paired with Mobile App to access functionality. The smart home control unit has inbuilt sensors which can monitor different parameters of devices e.g., motion, temperature, and ambient light to gather basic information. [8]. This unit also provides contactless access control by controlling the switching of power supply of the electromagnetic locking system for safe, almirah, or any restricted area at the home [9]. During Covid, it is need of the hour to have a covid free smart home to avoid contact with the virus and to stop further spread of the pandemic. In a normal routine, one must sanitize all the goods, items brought in-house on daily a basis before keeping and using them at home [10]. To simplify and verify the process of sanitization of products purchased on a daily basis, a smart cabinet is developed, in which sanitization can be done with the help of ultraviolet C (UVC) irradiation in a controlled manner. Arrays of UVC LED are fitted in cabinets and its operations are controlled by mobile app.

Smart cabinet is a simple cabinet made of metallic, plastic, or wooden materials in which UVC lights are fitted. Items to be sanitized are placed inside the cabinet and UVC lights are switched on for one or two minutes. Received UVC radiation inside the cabinet chamber is measured and displayed on an OLED display positioned outside the chamber to ensure accurate and efficient operation. After switching off the UVC supply, sanitized items can be taken out for use. A Smart home control unit will definitely ease the life challenges and secure from diseases too. Such a simple smart home is itself a money saver in means of heating, cooling, and saving electricity bills by optimized control of the appliances. This also provides greater safety with security modules, locks, and other systems. Automations of the electrical devices make them intelligent devices as human interventions to operate them are reduced to a minimum.

Existing home automation systems do not offer such a comprehensive solution in one unit, whereas the developed unit exhibits various functions like appliance control by Mobile App, smart lighting, activity-based lighting, day/night mode-based lighting, smart access control, and Covid19 free sanitization chamber in a single unit. Developed low-cost IoT enabled embedded control system for Covid free Smart Home is a comprehensive solution, it is controlled and monitored by Mobile App, using Bluetooth wireless interface, so it is not dependent on the availability of the mobile network. Bluetooth enabled smart home control unit is developed around a low cost robust 8051 microcontroller which can operate in Indian conditions very effectively. An Android Mobile App is developed to communicate with developed Embedded Device over Bluetooth Interface. The device has IoT (Bluetooth-SPP) capability and can receive instructions on UART. Electrical loads are connected to the control unit using suitable relays through the ULN relay driver. Home Appliances can be switched ON/OFF using Mobile App, without physically touching the switch. Integration of Google voice assistant to the developed unit, makes it more user-friendly. Convensional sanitization process which is based on isopropyl alcohol is not suitable for sanitization of household goods. The Smart cabinet is fitted with UVC LED arrays for sanitization against Covid19 viruses or any other microbes and bacteria. Sanitization is controlled by mobile app to avoid any accidental exposure of
UVC to human skin. Experiments are performed by switching on UVC led arrays for pre-defined duration and the received UVC radiation index is measured to ensure the effectiveness of the sanitization process. Cascading of 14W UVC panels is done to meet desired 10 mW of UVC irradiation inside the chamber, which is essential to destroy viruses, bacteria, and microbes.

2. Literature Review

Home automation systems are mostly controlled by embedded devices. It is built around a microcontroller interfaced with various sensors for monitoring environmental parameters. Mobile application is used to send switching instructions to embedded devices for controlling loads through actuators [11]. There are few approaches, where control is done through web pages or cloud-based client applications. Sensors data from home is fed to the internet cloud and computing is done at the server end for decision making before sending the control signal back to the control unit [12]. The smart home is an intelligent home these days. IoT makes it very convenient to use various wireless protocols like Bluetooth, Wi-Fi to connect with home and user applications. [13].

Home security is the key concern when a person is out from his/her home. Security sensors like the PIR motion sensor alert when any motion is detected in the house. It works seamlessly in daylight and in night mode. A Security camera can be used to click and send images if any motion or activities are detected. Motion or activities-based function of camera reduces the need for high bandwidth or more cloud storage spaces [14]. Things in IoT, i.e., sensors are for real-time inputs of what they sense in the environment, it depends on what critical parameters are to be included in the design of smart home systems. Sensors like gas sensor, air quality sensor, CO2 sensor, fire sensor, or sensors for ambient parameters are selected as per need of the information which is required to be collected for decision making. Information collected from the sensor terminal is transmitted to a server in real-time or periodically or in polling mode depending on application requirements [15].

Few smart home solutions use wireless sensor network (WSN) deployment for real-time sensing of parameters and remote monitoring. WSN allows using 255 sensor nodes in a single network, although cascading of such networks is possible. Such a solution is feasible in big-size deployments, where sensing locations are more and wireless networking is most suited. WSN technology allows sensing motes to operate in sleep mode at an ideal time between two consecutive samplings of input data. This saves battery life and power consumption. Such deployment can run for months on a single battery. The Self-healing feature of WSN allows to add or drop any node as per requirement and the routing table is updated accordingly without rebooting the network. WSN based smart home system is best suited for remote monitoring, where data payload is less. Monitoring of room temperature, humidity, gas leakage, ambient light, human activities one few use cases of such solutions [16].

3. System Architecture

Embedded system is built around an 8-bit 8051 microcontroller NXP89V51RD2, Bluetooth Module (SPP), ULN Relay driver, and Relays. Home appliances are connected to Embedded Devices through Relays. UVC LED arrays are fitted in the Smart Cabinet and it is controlled by the mobile app.

Bluetooth module is connected to the serial port of the microcontroller, which is paired with mobile application to receive instructions for controlling electrical loads. The use of an 8051 microcontroller makes the design suitable to operate in Indian conditions. The system block diagram is depicted in figure 1.
Figure 1. System Architecture

System receives instructions from Mobile App using wireless Bluetooth protocol and based on predefined instructions, Embedded System will be switching ON/OFF a particulate home appliance.

Microcontroller NXP89V51RD2 is used in the design. It is an 8051 based microcontroller, having more code memory and ease of flashing options than traditional 8051 microcontroller. It is having an on-chip bootloader with 32Kb of flash memory. Its port 1 pins are interfaced with the ULN relay driver to have the required current support. Output pins of ULN are connected to relay ports. All the electrical home appliances, which are to be controlled, are connected to relays.

RN42 Bluetooth module is connected to the UART of the microcontroller. RN42 Bluetooth module works on Serial Port Profile (SPP) protocol. It is used for serial communication between user applications and the microcontroller’s UART. It is configured for required baud rate, authentication mode, and user name using AT commands. The transmission and reception range of this Bluetooth modem is approximately 100 meters. Relay’s specifications are decided according to the requirement of electrical loads which are to be attached to the control units. Relays of 220V AC/16A rating are widely used in home automation applications. It can handle loads of most of the electrical appliances which are used in the home environment. The required number of relays depends on the number of electrical loads to be connected.

4. Hardware Specification and Features

4.1. Activity-Based Lighting
Activity based lighting is used to reduce the load of lighting as per the requirement of lights. It is achieved by sensing the human activities in the target area to either increase/decrease or turn on/off the light automatically. This is done with the help of PIR sensors which are commonly used in these day’s basic appliances and gadgets. PIR motion sensors are used to detect the motion of humans in the targeted area under the range of sensors. Based on human activity, these sensors react in the system. PIR motion sensor is available in 3 PIN configuration, beside VCC and Ground PIN, it has output PIN, which is interfaced to the microcontroller.
4.2. Day/Night Mode Based Lighting

In development of Day/Night mode lighting, Light Dependent Resistor (LDR) based light sensors are used. Most of the light sensors are developed using light dependent register (LDR) and LM393 voltage comparator unit. It is available in two versions, first one produces continuous analog voltages corresponding to ambient light falling on it, which is called an analog light sensor. Another one, the digital light sensor, produces logic Low/High signal corresponding to day/night mode. LDR works as a variable resistor and changes its values depending upon the intensity of light falling on it. When there is no light surrounding or falling on it, its resistance becomes very large and vice versa in absence of light. Our circuit makes use of this feature to automatically switch on or off the light. The main advantages of such type of lighting are low energy consumption, longer life of electric bulbs/tube lights and very economical in long term.

4.3. Ultraviolet C Spectrum (UVC) Irradiations Based Sterilizer\Sanitizer Cabinet\Chamber

To overcome the fear and protect the family from covid-19 virus, Ultraviolet C Spectrum (UVC) Irradiations Based Sterilizer\Sanitizer Cabinet\Chamber has been developed. The cabinet can be switched on using the Smart Home Controller unit and Mobile App for a predefined duration of two minutes to successfully carry out sanitization. The Irradiation of UVC has the ability to destroy RNA and DNA of micro-organism which disables them to reproduce and survive. This ability of UVC enables it to sanitize items and reduce the infections due to them. It uses a pure physical sterilization method. As the UVC spectrum of light can destroy the viruses and bacteria from items that are exposed to UVC irradiations, so irradiation of UVC rays is used in smart cabinet in which items are placed for sanitization. The sanitization process can be carried out whenever any items are brought home, to reduce the risk of infection. Irradiation in UVC chamber can be switched on/off through mobile app. It irradiates UVC light on the target area for a predefined duration of 2 minutes at 20mW which is enough to destroy Viruses, microbes, and bacteria. In comparison with recommendations from WHO and US-FDA to use 10 mW of UVC exposure for a minimum of 10 seconds, it is quite effective. The Block diagram of the Smart cabinet is shown in figure 2.

Figure 2. Block diagram of UVC Sanitizing cabinet
5. Experimental Setup

Working Prototype is assembled around 8051 microcontroller NXP89V51RD2. Six relays are interfaced through the ULN relay driver for isolation of the microcontroller from Relays. PIR motion sensor is interfaced with the microcontroller for implementation of activity-based lighting. RN42 Bluetooth module is configured before interfacing it to the UART of the microcontroller. Picture of the developed prototype is shown in figure 3. RN42 Bluetooth module is configured using USB to Serial converter and some terminal communication software like Realterm. Terminal software is opened at the default baud rate of the Bluetooth Module and AT commands are used to configure the required baud rate, authentication mode, switching timer, and other required parameters. The configured module is ready to be used for serial communication between the embedded control unit and mobile phone.

PIR motion sensor HC-Sr501 is used in the design to detect human activities in the target area of the home. It works on detecting IR signals which depend on the body temperature of living things. It sends a high signal to the microcontroller when motion is detected and lights are switched on by the control unit. In case of no activity in the target area, lights are switched off to save electricity. Light Dependent Resistor (LDR) based Digital light sensor with LM393 is interfaced for detection of ambient light. Resistance of LDR changes with changes in ambient light. Sensors send logic high to the microcontroller when dark mode is detected. Sensor’s night mode detection can be adjusted using onboard variable resistors. When night mode is detected by the microcontroller, it switches on the lights and the same is switched off when day mode is detected. Positioning of LDR is done in such a way that it detects ambient light only, lights installed in the home should not illuminate it, otherwise false day mode detection may disturb the switching operation.

![Figure 3. Setup of hardware Prototype](image-url)
Ultraviolet C Spectrum rays use 270-280nM irradiation-based sanitization. Its irradiation can instantly destroy the molecules of Covid19 viruses and prevent pandemic to spread further. It can be used for UVC disinfection of any object which is kept in the smart cabinet very effectively. IoT-enabled systems are developed, to control and monitor UVC irradiation systems. UVC-LED arrays are deployed inside the cabinet and it is switched on for a predefined duration when disinfection is to be carried out. UVC light destroys the viruses and bacteria from inside surfaces of Public Transport. The sanitization process can be carried out whenever any suspected item is bought home. The embedded control unit is paired with mobile app using Bluetooth SPP protocol.

6. Results

Prototype is assembled using a Microcontroller, ULN relay driver, Relays, Light sensor, PIR sensor, and RN42 Bluetooth module. An android mobile app is developed to interact with the control unit. Mobile app Bluetooth connection manager API is used for creating a wireless connection with devices. Google voice assistance APIs are used to control devices with voice commands. The Prototype has achieved 100% Switching Control without any noticeable lag time.

Mobile app is developed using Bluetooth connection manager and google voice assistant APIs. Buttons are placed in App GUI corresponding to each electrical load and some command instructions are defined and programmed for switching ON/OFF of every appliance. The Mobile app sends these predefined commands to the microcontroller through Bluetooth for switching operations. Mobile app interfaces are shown in figure 4.

![Mobile App Button Setting Screen](image1)

![Mobile App Button Control Screen](image2)

![Mobile App Voice Assistant Screen](image3)

**Figure 4.** Mobile app for smart home

Google voice assistance’s speech-to-text conversion module is used to generate predefined text commands against predefined voice commands for switching operation of every port. When user inputs voice command like “Switch on Light”, corresponding ASCII character of text command is transmitted to microcontroller and the microcontroller calls pre-programmed subroutine and light is switched on. Switching instructions are received from mobile phone and the corresponding electrical
device is switched ON/OFF. PIR Motion sensors are used to exhibit activities based on lighting. When human activities are detected in the target area then lights are switched on. In absence of activities, lights are switched OFF. Day/Night modes are detected using LDR light Sensors and Lights are switched ON in night mode and switched OFF in day mode.

For access control, the electromagnetic lock is interfaced with the microcontroller through the relay. The electromagnetic lock consists of two parts, an electromagnet part that needs to be energized to close the lock, and the second part is a metallic plate that is attracted by the magnet to close the door. It works on 12 V DC, which is switched ON/OFF by the control unit based on switching instruction generated by the mobile app. To allow access to Safe or restricted areas, the power supply of the electromagnetic lock is switched off to de-energize the magnet, and hence lock is opened to grant the access. Sanitization process is tested in a smart cabinet with mobile App using Bluetooth wireless interface. Desired UVC switching is achieved with 100% accuracy. Received UVC irradiation inside the cabinet is measured by a self-developed UV index meter, which is more than 11.5 on average in 50 samples (UV index >=5 for more than 10 seconds is desired for sanitization of covid infected items). Received UVC power inside the chamber is constantly more than 20mW, which is much more than desired 10mW UVC irradiation for 10 second for killing for viruses, bacteria and microbes.

When the prototype is powered on, RN42 Bluetooth module turns on in discoverable mode using device discovery protocol. It is paired using mobile app running on Smartphone. Based on user input through button or voice command, the mobile app sends pre-defined switching commands to the embedded device. Signal transmitted by mobile app is received by onboard RN42 Bluetooth module and it further sends the command to Rx pin of Microcontroller. Based on received instruction, Microcontroller calls specific subroutines and specific home appliances are switched ON/OFF. If any human motion/activity is detected in target area then PIR motion sensor sends logic High signal to the microcontroller and corresponding lights are turned ON, else activity-based lights are turned OFF. Day/Night mode is detected by Light sensor, it sends logic Low/High signal to the microcontroller and respective lights turn OFF/ON.

7. Conclusion

Developed prototype is a low-cost IoT-enabled embedded control unit and worked as per expectation with any noticeable latency and exhibited 100% switching operation with full electrical load. Voice command-based switching makes it more convenient to use. The Bluetooth-based operation makes it free from the need for internet availability for local applications. PIR motion enabled activity-based lighting kept lighting in off mode when no activities are detected, it is a good measure to save electricity. Such lighting is more useful in the wider area, where more lights are fitted and switching off the lighting of the unused area is required. Light sensors-based lightings are found more useful as it automates the lighting and reduces human intervention. IoT enabled access control system enables keyless entry to restricted areas.

Smart cabinet achieved desired ultraviolet index inside the chamber, which is essential to destroy Covid19 like viruses, bacteria, and microbes. Mobile app-based operation makes its monitoring very easy and user-friendly.

Thus, IoT enabled low-cost embedded control unit for covid free smart home, demonstrated home automation and home monitoring application with added advantages of sanitization of household things in no time. Hardware unit is tested successfully for 12 hours without failure. Standardized security modules can be added in the future for digital safety. Further cost reduction may be undertaken in future work to make it more economical.
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