Design and Implementation of a Low-Cost Home Automation and Monitoring IoT System Using Message Que Telemetry Transport protocol: South Africa context

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ABSTRACT

Home automation is a fast and growing industry in South Africa, because in recent years almost everything home and office electrical and electronics appliances are been connected to the internet and human mobile devices. There is an increase in demand of time from the working class and hence the busy time schedule. This necessitate the home automation and monitoring systems which enable homeowners to remotely monitor and control appliances in their houses and offices without being present in the device physical location. The designed system host the integrated intelligent unit functionalities that enable communication between the controller and remote end-user units of the system. It is important to ensure that home automation systems have a low cost to enable user adoption. Home automation systems should also incorporate latest technology, portability and also have internet connectivity capabilities. This paper proposes a design of low-cost home automation system that incorporates internet access and delivers internet of things (IoT) connectivity services in a smart home application. The designed system provides access to an internet connected home automation systems. The system is accessible via mobile devices and provides remote access to home appliances. In conclusion, during measurement and testing of the designed system, device full duplex connection for one round trip was less that 5seconds to relay a message packet between the transmitter subscriber device and the publisher receiver device. The performance of the designed device is satisfactory at first iteration prototype designed.

Keywords

Home automation, Internet of Things, End-user, Control unit, Microcontroller, Relay, Message que telemetry transport, Subscriber, Publisher, Python

1. Introduction

A significant number of home appliances require physical contact for switching purposes. This makes the remote control of household appliances challenging for people who spend a significant period of time away from home. Appliances that are left on in the absence of homeowners consumes a lot of electricity leading to high energy bills. Different methods have been proposed to address the challenge of reducing the power consumption and high electricity bill. Existing methods that can be used to reduce high energy bills are the use of light sensors [1 – 2], voice commands [3 – 4], and sound signals [5]. The methods in [1-5] have the drawback of depending on the distance and weather conditions for proper operation. The use of these existing approaches is not suitable when the homeowner is far away from home.

The home automation system enables remote control and provides a better performance in comparison to existing methods in [1-5]. This is because the remote controlled home automation system addresses the problems associated with non-remote control methods in [1–5]. In addition, remote control home automation systems add extra functionalities that make its use convenient for the subscriber. The homeowner deploying a remote controlled home automation system does not have to be in physical contact with the appliances. In addition, the individual can turn appliances ON or OFF regardless of his location at any point in time. In this case, there is no limitation to how many times or when the appliances are controlled provided that the home has electrical supplies at all time. This approach is embodied in internet of things (IoTs) that are becoming increasingly available.

The design of IoT systems should consider the specific use contexts of intending subscribers. The income levels of different subscribers should be considered in the design of IoT systems. The focus of this paper is the design of an IoT system suitable for a South African subscriber. The context being considered is that of a low income South African subscriber. The case of a South African subscriber is considered similar to that of a subscriber in a developing country.

The proposed design presents approaches that enable the realization of a low powered and low cost IoT system. This is investigated by considering the use of embedded and non-embedded components in system realization [6]. The proposed IoT system also incorporates the message que telemetry transport (MQTT) communication protocol. MQTT is a messaging protocol, designed to support communications in IoT applications. The MQTT protocol functions in a network comprising clients and brokers. The clients publish messages. The broker receives and filter all messages. It decides the clients that should receive a message; and also coordinates the transmission of messages on different aspects to clients. The MQTT protocol enables the remote control of home appliances that are connected to the internet.
The rest of the paper is structured as follows. Section 2 describes aims, objectives and functionalities expected of the proposed solution. Section 3 focuses on the presentation of the system design and set up. Section 4 presents results discussing on the performance of the proposed IoT system.

2. LOW-COST INTELLIGENT HOME AUTOMATION SYSTEM-monitoring and control

The proposed solution provides IoT functionalities to homeowners at low cost. It comprises hardware and software components. These components interact with each other through protocol connectivity to enable the homeowner control home and office appliances remotely. In addition, it is intended that homeowners incorporating the proposed solution will be able to control home appliances from any location in the world and at any time without the need for physical contact.

The proposed solution comprises a control circuit, a microcontroller and computing resources software for hosting the MQTT communication protocol. The system is designed in the following steps: (i) control circuit design, (ii) microcontroller programming, and (iii) MQTT support implementation.

The control circuit enables the switching ON or OFF of appliances in the homeowner residence. The control circuit receives signals from the homeowner at a remote location through a smart mobile device. The transmission of data by the homeowner is preceded by a switching command. The instructions in the switching command is done via the internet. The functionality of the control circuit is realized via relays and microcontrollers as the core components of the control sub-section system.

In the IoT system, the micro-controller enables the translation of homeowner switching instructions. The switching instructions enable the control of different devices to yield the desired command outcome. The microcontroller is programmed using the C++ language, and in addition, the microcontroller supports the universal synchronous receiver transmitter, which incorporate serial communication support.

The proposed solution incorporates support for the MQTT protocol. The MQTT protocol is implemented to support the relaying of messages from the end-users to the control unit sub-section of the designed circuit system. This differs from the functions executed in the microcontroller. In the microcontroller, the communication ensures that user commands are directed to ensure that the switching is executed for the desired device.

Communications and signal transmission takes place as follows. The homeowner subscriber in our consideration sends a signal indicating the desire to turn an appliance ON or OFF to the control system. This transmission is done via a user interface through the internet via the MQTT protocol.

The MQTT protocol handles interactions between the homeowner and the control unit. Homeowner switching preferences are transmitted from the homeowner to the module hosting the MQTT protocol. The information on the homeowner switching preferences is transferred to the microcontroller unit. The microcontroller unit interfaces with the appliances in the homeowner residence and can also turn selected devices either ON or OFF. This is done considering the homeowner preference and switching instruction.

The role of the MQTT broker in the proposed IoT system is shown in Figure 1. In Figure 1, the MQTT broker receives data from the homeowner i.e. subscriber with access to different end-user devices. The homeowner request is sent to the MQTT broker via an internet based entity. The MQTT broker transmits the homeowner requests to the central unit with bidirectional links to controlled appliances. The MQTT broker transmitting requests to the home, sends the messages to the control unit via a wireless module [8-9]. The control unit then activates (Turn ON) or deactivate (Turn OFF) the homeowner device in satisfying the homeowner's request.

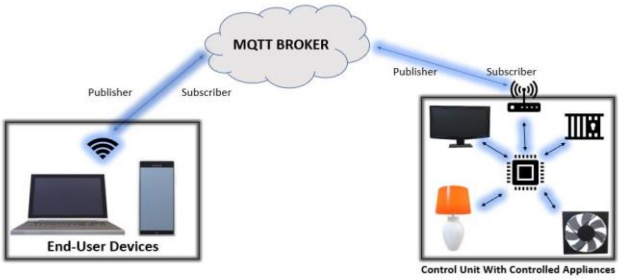

Figure 1:: Role of the MQTT in the proposed solution

3. DESIGN OF PROPOSED SOLUTION

This section focuses on the design and implementation of the proposed IoT solution. The design of the proposed system considers two design approaches. Each design differs on the basis of the type of components used in the realization of an IoT system delivering the expected functionality.

The control unit is realized via a computer and a microcontroller i.e. the Carambola 2, relay unit, controller appliance and the power supply unit. The MQTT broker entity is realized via an intermediate server that relays commands between the end-user and the control unit. The MQTT broker is capable of bi-directional communication. In addition to the microcontroller, and the MQTT broker the proposed system comprises the end-user.

In the proposed IoT system [10], the microcontroller program is compiled using MikroC, a C++ code compiler by Mikroelektronika. The binary file compiled by the compiler is flushed on the microcontroller in the circuit running on the simulation software to ascertain that it works properly. The code on the microcontroller is responsible for controlling the output signal transmitted by the relay to the controlled appliance. This will help with simulating the control unit circuits operation by using terminal emulation software to send commands corresponding to the written code running in the microcontroller.

The preliminary practical model will be built on a breadboard and connected to the control computer using a universal serial bus to serial DB9 cable. This will help test the control unit practically using a live terminal.

When the serial communication is working and the setup is operating as expected the implementation and support of the MQTT protocol is demonstrated successfully. Initially, this is achieved via a computer connected to the microcontroller that functions as the subscriber device. The computer is connected to the internet for testing.

Scripts used to activate, generate and transmit commands are written in Python. Python will be installed on both the remote and control computers. The published script running on the remote computer will open a command write window to send predefined commands to the control computer in the form of messages. The control computer will receive the homeowner's commands from the MQTT broker and pass them to the microcontroller which executes them using the instructions specified in its installed code running. After executing the messages, the control computer unit sends an acknowledgement message to the remote or end-user computer via the MQTT broker. In this design both the controlled device and end-user act as publisher and subscriber simultaneously as they must send messages from each side, messages for control and acknowledgement messages or of current status in request.

The rest of the discussion in this section is divided into two aspects. The first aspect presents the first design concept for the proposed system. The second aspect discusses the second design concept and implementation for the proposed system.

3.1 Proposed IoT System – First Approach

The first approach to the design of the proposed IoT system is presented in this aspect. In the first design approach, the control entity i.e. the control computer (control PC) and the microcontroller are separated and not embedded in one entity. The scenario describing the system design is shown in Figure 2.

In Figure 2, the computer is a part of the main control unit. The computer receives the homeowner's commands (e.g. On, Off and Status) from the end user through the MQTT broker. The received signals are sent to the microcontroller unit (MCU) that executes actions related to the homeowner's preferences.

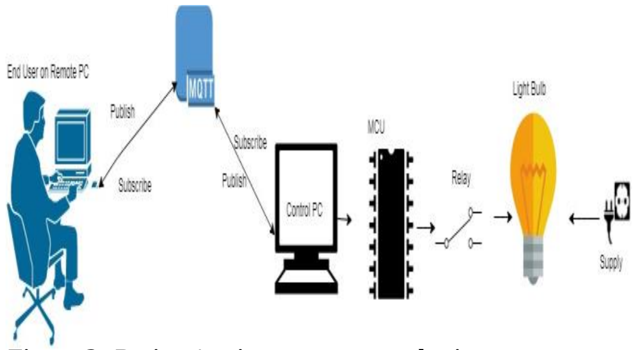

Figure 2: Design-1 using computer and microprocessor as the control unit.

3.2 Proposed IoT System – Second Approach

The second approach to the design of the proposed IoT system is presented in this sub-section. In this design approach, the control entity i.e. the control computer (control PC) and the microcontroller are integrated and embedded in one entity. The system design is shown in Figure 3.

In the second design (design 2) the control computer and microcontroller are replaced with an embedded device called the Carambola 2. Carambola 2 is a surface mountable embedded device. The Carambola 2 has IEEE 802.11 networking capability and utilizes the Linux operating system. In addition, the Carambola 2 entity has the benefits of low power consumption, portability (enabling ubiquitous mounting and installation) [6-7]. A high level set-up for the design in the second approach is shown in Figure 3. In Figure 3, the entity integrating the functionality of the control computer unit and the microcontroller unit has the features of portability and low power consumption.

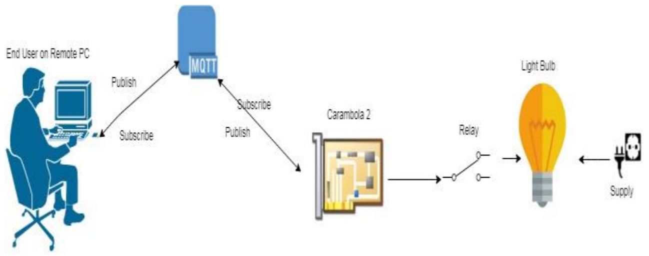

Figure 3: Second design approach for the proposed IoT system.

4. IMPLEMENTATION OF PROPOSED SOLUTION

The discussion in this section focuses on the implementation of the proposed solution. It is divided into two parts. The first part focuses on the design aspects and considerations in system realization. The second part presents details on system simulation. The implementation of the system results in the design of a wireless network enabled IoT home automation system. The system wide area wireless networks such as the GSM. This manner of application is considered feasible as seen in [8-9]. The protocol of interest is the MQTT communication protocol.

4.1 Design Aspects and System Realization

The performance of the systems presented in Figure 2 and Figure 3 is initially investigated via simulations. The conduct of simulations is important to determine the appropriate code that can work well on the microcontroller unit in system realization. Simulations also enable the determination of the suitable voltage values and specifications to be applied on the components and circuits.

The implementation also considers the design and realization of the core control circuit. This helps in determining the architecture of the whole circuit i.e. knowing the components required to realize the control circuit. The conduct of this design task also enables the determination of which components constitute the control circuit and how these components should be placed. Information on knowing where to place the components comprising the control circuit is determined using knowledge acquired from component's data sheet. Information obtained by reading datasheets enables the system designer to know where to place and align the components based on their power and current requirements. Knowledge of the placement is important in determining the type of household appliances that can be remotely controlled in the proposed IoT system i.e. the design approaches shown in Figure 2 and Figure 3.

The control unit is realized via a development board for the second design approach that is shown in Figure 3. Tera-term was used to access the interface of the board and to install Python on the development board. Python is used to execute the subscriber script and receive predefined commands from the remote computer.

The development board has internet connections to the MQTT broker. The connection between the development board and the MQTT broker is necessary to ensure that the development board can receive instructions on homeowner subscriber preferences. The architecture of the development board is shown in Figure 4. Figure 4 presents the design and architecture of the board. The board uses the general input output pins to control the state of appliances being controlled [6-7].

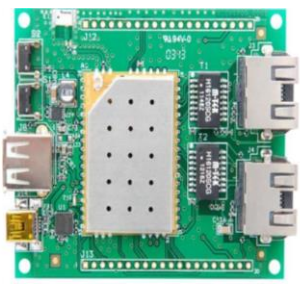

Figure 4: Structure and Architecture of Carambola 2 Development Board.

4.2 Simulation Details

The simulation of the proposed system is done using the Proteus Design Suite 8 software. Proteus Design Suite 8 simulation software is used to test the control unit side, this was done to see how the circuit will perform when assembled practically on a breadboard and to have a suitable system design. Figure 5 shows the windowpane of the simulator while testing the operation of the control unit.

In the simulation, the control unit comprises the control computer, microcontroller, relay unit, controlled appliance (Light bulb) and the power supply, the other section is the MQTT broker: which is just an intermediate online tool that relays commands from the third section, the end user. Proteus Design Suite 8 is the simulation software that was used to test the control unit side, this was done to see how the circuit will perform when assembled practically on a breadboard and to have a suitable design for the whole system.

The code running on the microcontroller was compiled using MikroC, a C+ code compiler by Mikroelektronika. The binary file compiled by the compiler software was flushed on the circuit running on the simulation software to see that it works properly. This helped with being able to control the control unit side by using terminal emulation software called Tera-Term, Figure 5 shows the window pane of the simulator while testing the operation of the control unit. The practical model on a breadboard was connected to the control computer using a universal serial bus to serial DB9 cable, to be able to also test the control unit practically.

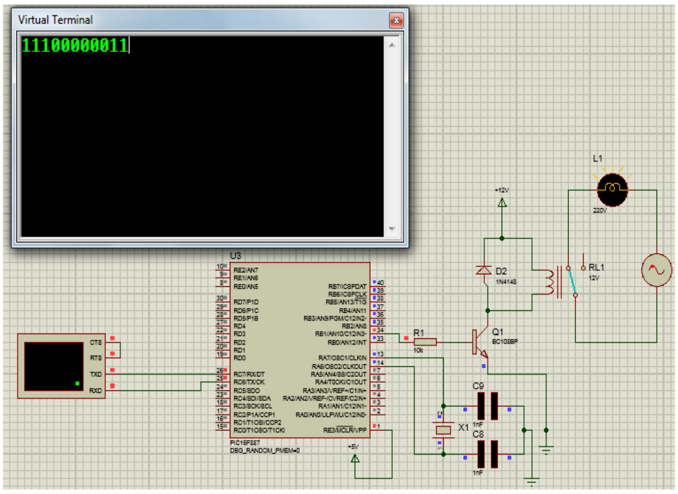

Figure 5: Proteus Simulation Circuit for the Proposed System.

In realizing the first form of the system design (where the control circuit and microcontroller unit are separate entities), Python was installed on the remote computer and control computer and used to write and run the MQTT scripts. The python script running on the remote computer opens a command window to send predefined commands to the control computer in the form of messages. The control computer that receives the message opens a terminal interface to pass the commands to the microcontroller which executes them according to the code running on it. After executing the messages, the control computer sends back an acknowledgement message to the remote computer via the MQTT broker.

5. Hardware Design

The realization of the proposed IoT system via hardware design is also considered in this paper. The hardware components that are used in the realization of the proposed IoT system are shown in Table I. The aim of the hardware is to demonstrate a remote switching control of home appliances from any location.

Table I: Components of the system.

Equipment	Manufacturer	Value
Microcontroller	**Microchip**	**PIC16F887**
Relay	**Communica**	**HF36F 10A 250VAC**
MAX232	**Texas instruments**	**MAX232N**
Crystal Oscillator	**Communica**	**NSK 5F 10.000 ALH**
Capacitors	**Communica**	**10 uF and 2.2 pF**
Diode	**Communica**	**1N4001**
Resistors	**Communica**	**10 kΩ**
DB9 connector	**Communica**	**Serial : Female**
Light bulb	**MAX LIGHT**	**100 watts**
DC power Supply	**Metronix**	**NITR 922**
AC power Supply	**Wall plug**	**220 VAC**
Breadboard	**Communica**	**N\A**
Transistor	**Communica**	**BC108**
Proteus Suit 8	**Labcenter Electronics**	**Release 8.5 SPO**
MikroC Pro for Pic	**MikroElectronica**	**Version 7.1.0**
Python	**Python Software**	**Version 2.7.13**
Carambola 2	**8 Devices**	**Version 2**

The set-up of the control unit for the case of the first system design (without integration of control computer and microcontroller unit) and the second system design (integrated control computer and microcontroller unit) is shown in Figure 6 and Figure 7 respectively. Figure 6 and Figure 7 present the prototype of the system for the first design and second design respectively.

Figure 6: Implementation of system design – Design Case 1.

Figure 7: Implementation of system design – Design Case 2.

The implementation of the proposed system also involved the implementation of the control system being hosted by the control computer unit. This design is done using python programming tool.

The Python based control window on the control computer is shown in Figure 8. Python 2.7 was used in the micro-controller set up and for all associated software development related tasks.

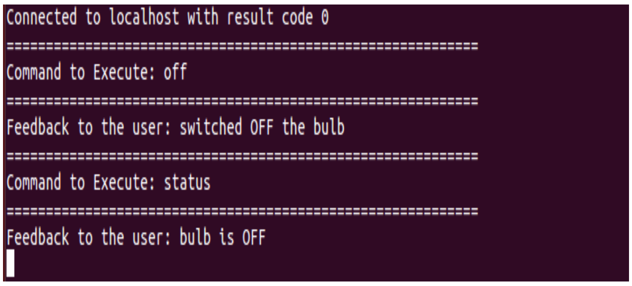

Figure 8: Python based interface for the control system hosted on the control computer.

The Python based interface shown in Figure 9 does not enable the homeowner to provide inputs on switching preferences on household appliances. This functionality is hosted on the interface with which the homeowner interacts. This interface is also designed with Python and shown in Figure 9.

The interface in Figure 9 allows the homeowner to issue instruction on switching appliances ON or OFF. It also enables the homeowner to check the status of household appliances and also disconnect some household appliances as deemed necessary. The interface also enables the homeowner to obtain feedback information on the status of household appliances.

Figure 9: Python based interface for the computer system interacting with the homeowner.

The second approach proposes the use of an entity that integrates the control computer and microcontroller unit. This single interface is realized via the Carambola 2 entity in the realization of the proposed IoT driven home automation system. The interface for Carambola 2 is shown in Figure 10.

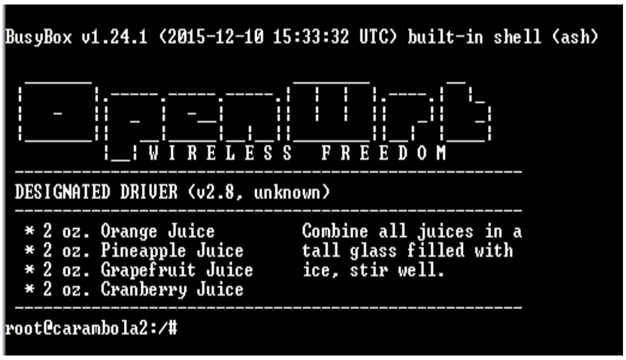

Figure 10: Control Interface for the Carambola 2 entity used in the second design approach.

The designed system functioned in the following manner. The homeowner issues a command by interacting with the interface (on the remote computer) shown in Figure 9. The issued commands from the remote computer are received by the control computer [11-12]. The control computer executes the command received from the remote computer via the MikroC code hosted on the microcontroller. In the system set-up in demonstrating the performance of the proposed concept, the set up worked perfectly as expected. This shows that the proposed system is able to remotely receive homeowner commands and execute the required instructions. Therefore, it can be concluded that the MQTT protocol is suitable for the proposed network.

The demonstration of the design project was considered a success. This is because the two designs are able to deliver the expected functionalities. In our consideration, the second system design i.e. design 2 (integrated control computer and microcontroller unit) is chosen. This choice is made to address the issues of power savings, money and ensuring compatibility with other IoT components and associated electronics. However, the system design in the case of the first design approach separates the control computer and the microcontroller unit. System design 2 is also chosen because it is easier to design. The costs associated with the design of the proposed system considering Design 1 (first design approach) and Design 2 (second design approach) is presented in Table II.

Table II shows some of the factors that influenced the decision to identify design 2 as the suitable design for this project. The number of components and price played a significant role in the choice of the design strategy. Analysis of the information in Table II shows that the second design approach i.e. Design 2 has the lowest cost of realization.

TABLE II. DESIGN COMPARISONS FOR SYSTEM 1 AND SYSTEM 2

Component	Price (ZAR)	Design 1	Design 2
PIC KIT3	495.00	X	
Microcontroller	385.00	X	
Max232	8.41	X	
DB9 Connector Female	5.81	X	
Light-bulb	5.00	X	X
Light-bulb holder	9.50	X	X
Resistors, Capacitors	24.00	x	X
IC Holder	8.00	x	
Wires	9.00	X	X
Relay	28.00	x	X
Carambola2 board	801.30		X
PC Desktop	7 000.00	X	
Linksys modem	2 000.00	X	X
Total		9,977.72	2,876.8

6. CONCLUSION

The discussion in this paper recognizes the importance of designing home automation systems with remote access capability. This is necessary to enable home-owners remotely monitor the devices in their homes. The paper proposes the design of a remote access IoT based system that utilizes the MQTT communication network protocol. In addition, the paper examines two system design methods with a view to selecting the system design approach with the lowest cost. In the first system design, the microcontroller unit and the control computer are separate entities. The second system design approach considers the microcontroller unit and the control computer as integrated entities. The second approach is used predominantly due to the benefits of low power consumption and low cost of realization and implementation. Based on our research observation, substantial demographic of the homeowners and the working class in SA don't have acess to the internet, and many struggle with data to connect to the internet. This design system functionality relies on the use of data. In future, we proposed that the Internet Service Providers (ISP) or the cellular companies in the country should reduce the cost of data for this group of subscribers.

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