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Design, Specification and Implementation of a Distributed Home Automation System

T. A. Abdulrahman[a,*], O. H. Isiwekpeni[a], N. T. Surajudeen-Bakinde[a], A. O. Otuoze[a]

[a]*Department of Electrical & Electronics Engineering, University of Ilorin, P.M.B. 1515, Nigeria*

Abstract

This work presents the design and model implementation of a novel home automation system applying the Internet of Things (IoT) technology. It seeks simplified design protocols for developing a robust home automation system to deal with the problems of complexity, multiple incompatible standards and the resulting expenses in the existing systems. The embedded system features the ubiquitous low-cost 32-bit ESP8266 System-on-chip (SoC) module interfaced to some sensors and actuators for interaction in the home. Flexibility in the remote access, operation and management is achieved through HTML5 based intuitive mobile and web GUI applications. Web Application Messaging Protocol (WAMP) is deployed to ensure that individual applications and systems seamlessly communicate with a relatively high level of security using robust web service security protocol. This system offers a cost-effective and efficient solution, because the costs of a dedicated public IP address and a high-end computer are excluded, which are present mostly in other solutions.

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Keywords: Internet of Things; Websocket; ESP866 SoC; HTML5; Distributed System

1. Introduction

The use of smart devices in daily activities increases the quality of life and offers high productivity in turn. This has led to the increased calls for benefits such as comfort, centralized control of appliances, cost reduction, energy

* Corresponding author. Tel.: +234-7069-214-332
E-mail address: abdulrahman.tabdulhakeem@gmail.com

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saving, security and safety which are basically the driver of the growth of automation technology in both homes and industries. As a result, the intelligence of such devices is developing exponentially while offering much higher affordability and simplicity through their connectivity[1]. The interconnectivity of virtually every object is now possible through the Internet; human social networks and machine-to-machine communications. The concept of the "Internet of Things", tied closely with the popularization of home automation[2], is an evolving technology which has received quite a lot of attentions from researchers following the vision of a global infrastructure of networked physical objects. While this vision is enthralling, no consensus exists about its realization[3].

IoT involves integrating smart objects; embedded devices with sensors and actuators connected to the Internet. These devices are intelligently interconnected thereby necessitating new forms of communication between things and people, and between things themselves[4]. It is noted in[5] that with increased device processing power and storage capabilities, their sizes tend to be smaller making them suitable to be equipped with different type of sensors and actuators. The greater power and capabilities of such embedded devices further enable them to be stacked up with the desired network protocols for seamless communication. Home automation started long ago with labour-saving machines and the term "smart house" was first coined by the American Association of House Builders in 1984[6]. However, early smart homes suffered poor performance, high cost of ownership, complicated set-up and operation, poor management and maintenance, and in many cases, the need to rewire the home[7]. While novel home automation is fast evolving, consequently, there have been different procedures with vast of them based on the wireless and Internet technologies relating to the concept of "Internet of Things".

This work addresses the problems of complexity, multiple incompatible standards and the resulting expenses in these recent systems by providing a simplified design protocol and developing a robust distributed home automation system. The system's independent computing units collaborate together in order to achieve the desired automation functionalities by exchanging only terse messages as opposed to human-human communication[8], to synchronize their current states in addition to the input and output data operation of the individual systems and applications[9].

2. Related works

Several works have been done with various approaches deployed towards realizing home automation. Bluetooth based solutions were explored in[10,12] for the home automation technology using Bluetooth enabled devices to provide the control without internet connectivity. Here, the appliances which are wired to the embedded controller are accessed and controlled by devices with built-in Bluetooth connectivity. However, Bluetooth has a maximum range of operation of about 100 m and this limitation renders the systems incapable of coping with long distance mobility and by this means restricting the system control to within the neighbourhood. Also, Global System for Mobile (GSM) based solutions for the communication and control of home appliances have also been offered in[13,14] where a mobile phone (or GSM modem) is incorporated to the home controller and receives different AT commands for the control. These systems suffer lack of graphical user interface (GUI) for supple operation. Thus, the users have to remember different short codes for different operations. Also, a message can be delayed due to failure of mobile network operators; hence, the solution is not suitable for real-time monitoring as well as long distance data logging (telemetry).

With the popularity of Internet gateways at homes such as broadband modem and mobile hotspot, remote access to control home appliances is becoming practicable. In[15,16], Wi-Fi based home automation solutions utilizing localized systems which manage the connected appliances were presented. Such arrangements usually pose a resource bottleneck as they require complicated network traffic routing for remote operations. Similar architectures were offered in [7,17] where local web servers are deployed at home with applications developed to manage the devices over the Internet. The drawbacks of these setups are that, deployment of a high-end computer will not only increase the cost of installation but also the energy consumption and space by the virtue of its size. The developed interface applications running on the home servers are not easily upgradable and the data communication protocols employed are not robust and scalable to support the future demands.

While there are no dedicated severs at the client premises in [4,18], the allotment of a public IP address makes the system expensive and chokes the limited addressing resources. Moreover, the deployment of Representational State Transfer (RESTful) based Web service, as an interoperable application layer does not offer a full-duplex communication for real-time operations. To improve the previous designs, a Cloud-Enhanced Home Controller (CEHC) architecture where the localized resources are augmented with cloud scheme is proposed in[19]. Although, the work attempted to provide a flexible ecosystem of rich applications in the growing automation technology, it overlooked the associated pressing security issues. Also, an implementation of a fully cloud based solution is presented in[20] leveraging on the Google Cloud Messaging (GCM) service for communication between the distributed cloud platforms. GCM is a free service that allows messages transfer in server-client based applications[21], and uses Extensible Messaging and Presence Protocol (XMPP). Although, the Push technology outsmarts the polling and long polling techniques, it is a heavyweight protocol streaming Extensible Mark-up Language (XML) and its big specification sees no complete implementation. In addition, unless a particular contract with Google is considered with some charges applied, there is no restriction from using the system's data for other purpose than storage without users' consent.

Our work utilizes ultramodern Internet technologies realizing a distributed home automation system with the processes as services. We deployed robust and scalable protocols to ensure seamless communication between the individual applications and systems. The principal and novel protocol (WAMP) implements Websocket full-duplex and persistent connection and JSON data serialization. Additionally, flexibility is induced in the automation operations and management through HTML5 web based applications and services development for intuitive GUI mobile and web applications. Generally, this architecture provides a simplified paradigm for a supple home automation realization and it eliminates the costs of a dedicated public IP address as well as of a high-end computer, thereby providing a cost effective solution to home automation.

3. System architecture

Fig. 1 shows the distributed home automation system which comprises mainly two components, the hardware interface and the software control components.

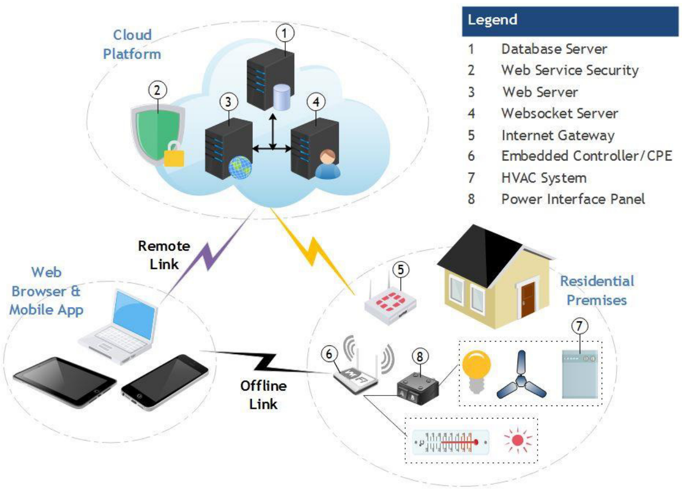

Fig. 1. Overall system layout

3.1. Hardware interface component

The hardware forms the client premises equipment (CPE) which provides the appropriate interfaces to sensors and actuators in the home. These modules are coordinated by a 32-bit ESP8266 system-on-chip running a firmware written in C++ programming language. It is required that the CPE provides control of lightings, HVAC appliances, security locks and others, as well as monitoring of the house environments such as the room temperature, humidity and light intensity[22]. It must also provide interfaces for user interactions as well as Internet connectivity. As a result, the embedded hardware is further divided into: controller, power device actuators and integrated sensors.

The controller is a ubiquitous low power 32-bit CPU based ESP8266 Wi-Fi module which is a self-contained SoC with integrated Transmission Control Protocol/Internet Protocol (TCP/IP) stack used as an application processor and allows our embedded unit to communicate over wireless network. This module is chosen because of its powerful on-board processing and storage capabilities that allow for interfacing with the sensors and other application specific devices through its General-purpose input/output (GPIOs) with minimal development upfront and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry while it also contains a self-calibrated RF allowing it to work under all operating conditions, and requires no external RF parts. It has features such as 802.11 b/g/n, Wi-Fi direct (P2P), soft-AP, 81 Mb RAM, up to 160 MHz speed, 1 Mb flash memory and+19.5 dBm output power [23].

The home appliances are controlled by the power actuators which are majorly relays; electromechanical elements that switch high-voltage, current or power devices with small electrical signals (pre-amplified through transistors) usually from digital controller circuits. An 8 channel relay module is interfaced via a shift register to allow the control with fewer pins from the controller. While light emitting diodes (LEDs) serve as the indicators for the states of the digital output pins and for configuration. For monitoring the ambient meteorological conditions, quantities such as temperature and light intensity are measured. Such measurements enable the system to interact with its environment and as a smart device should be able to control the environment based on these measurements. Temperature is measured using a precision LM35 IC with an output voltage linearly proportional to the centigrade temperature[24]. The chip outputs 10 mV per degree centigrade and it is read by the analogue pin of the ESP8266controller. Passive Infra-red (PIR) Motion Detector detects the animated movement in the vicinity. As soon as any gesture is detected, the digital output pin of the device rises digitally high and can be optionally delayed so as to be read by a digital pin of the controller[25].

3.2. Software control component

This consists of web servers, client applications and embedded software. The web servers present the core for managing, controlling, authenticating and monitoring the distributed system processes. While the client applications provide graphical user interfaces (GUIs) for client's operations. Structural design involving the operational use of design patterns and frameworks is deployed in the software system development. The frontend applications include the web and mobile applications which provide graphical interfaces for the control and monitoring of user's equipment and sensors. The web application is open-source using the HTML5 technology – HTML, PHP, JavaScript, CSS and MySQL. It is launched through the web browsers of smart gadgets such as personal computers, tablets, PDAs, smart phones etc. The mobile application is an adaption of the web application using the cross-platform development framework, PHP Cordova (or Phonegap). Features as flexibility, intuitiveness, memory efficiency and uncluttered operation were considered for greater user experience.

The embedded software is written in C/C++ and coordinates the input and output devices interfaced to the ESP8266 controller. It also runs embedded mini web and Websocket servers to support offline operations taking advantage of the dual-mode (access point and station) of the on-board Wi-Fi radio. This is to augment the system in case of link interruption to the cloud services and to enable independent use within the home.

3.3. Communication interface

Websocket is found to be the most suitable for real-time bi-directional, full-duplex, persistent connection from a web browser to a server. The web application communication protocol (WAMP) is an open standard Websocket sub protocol which provides application routing that works with different languages[26]. WAMP allows a distributed system with loosely coupled applications components communicate in soft real-time. It is built over Websocket communication protocol and JSON data serialization. JSON is an open, language-independent, human-readable, data interchange format to ideally inter-operate, store, and transfer data between systems. It is designed to be simple, generic, structured, human and machine readable, and used over the Internet. It uses a textual data format with Unicode encoding and it is fat free as opposed to its XML counterpart. A typical example of a JSON formatted packet is given as; **{"user_id": "1", "port": "2", "state": "0"}**.

3.4. Web service security

We employed standard web service security techniques in the applications as well as in the communications between them. These include authentication system built into the web and mobile applications and as such, an unauthorized user cannot gain entrance into the mobile and web applications. To further secure the Websocket implementation, a one-time password (OTP) mechanism is deployed. Upon valid authentication on the application console, a randomly generated 50-character long token is firstly sent to the Websocket server for communication authorization to allow further exchange of messages.

4. Implementation

Most of the hardware components are modules by the virtue of the integrated design and development adopted for the work. Therefore, standards data bus and jumper wires are used in routing all the network paths for the embedded hardware. Also, at each stage of construction, the modules were tested and each was confirmed to work as required independently as well as conjointly. For efficiency in software development, some frameworks were used in this work. They include Laravel PHP framework[27], Rachet PHP Websocket framework[28], Phonegap mobile apps framework, and Twitter Bootstrap CSS framework. The design pattern employed is Object-Oriented pattern while the higher level design architecture is the Model-View-Controller (MVC) pattern. Generally, the software applications were developed to be reliable and really user-friendly. This was achieved through sophisticated built-in tests (BIT) embedded in the applications. The applications as well as the services are up and running now and this prototype is accessible via [http://cb.djade.net].

5. Results

The robust and scalable architecture involves a Websocket and JSON based communication protocol that saves a great deal of bandwidth with terse messages exchanged and exhibits a very low latency needed for a real-time home automation operations saving time, money and space. Although, the actual link characteristics depend on the available Internet connection strength, even at relatively poor connection situations, the system performance is guaranteed. While, in the event of total Internet interruption or offline use, the embedded mini web and Websocket servers running on the CPE suffice for continual operations. It is worth mentioning that this model distributed automation system has been tested to fully work as designed and even won an exhibition award at the Engineering Projects Exhibition (EPEX) 2015, University of Ilorin, Nigeria.

6. Conclusion

In this work, the up-to-date web technologies were utilized to render the whole home automation system a distributed type with the processes as services. The cloud portion of the distributed system involves the web applications integrated with data management and repositories as well as communication interfaces. We induced great flexibility in the automation operations through HTML5 based web applications and services development for intuitive GUI mobile and web applications. Similarly, modular design concept was adopted in the embedded hardware development for better functionality and greater reliability. A robust data communication protocol to ensure seamless communication between the individual applications and systems was deployed. Relatively, a high level of security by the virtue of the robust web service security protocol deployed was realized. Overall, the system provides a cost effective solution to home automation as the costs of a dedicated public IP address and a high-end computer, as present mostly in other solutions, are removed. In future work, we intend to further improve the performance by incorporating a higher layer communication protocol, Message Queuing Telemetry Transport

(MQTT), an extremely simple and lightweight machine-to-machine, messaging protocol built on Websocket for constrained devices and low-bandwidth, high-latency or unreliable networks[5,29].

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