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Towards Home Automation System Framework and Design

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Abstract: Home automation system is the process of embedding technology into home with a goal to improve quality of life, increase comfort, and save time or energy. Many home automation systems have been proposed and implemented, however, most of them have been focusing and leveraging different mediums of communication. As a consequence, each of these systems has been targeting to optimize only one of the aspects of overall home automation system structure. The study of existing systems indicates that there is no well-known framework to guide the design and implementation of home automation system. In this paper, we propose a framework to guide the design and implementation of home automation system. We also present the design of home automation system based on the proposed framework and, finally, validate the design by building a proof-of-the-concept implementation of the system.

Keywords: Home Automation Framework, Home Automation Design, Smart Home

1. INTRODUCTION

Home automation is the process of embedding technology into the home with a goal to improve quality of life (Kumar *et al.,* 2012). Creating a sort of automation for interactive control of household appliances provides comfort, saves time and energy (Gill *et al,* 2009). The underlying idea is to have a central interactive control of household appliances ranging from mechanical devices to consumer electronics. The persuit to exploring such possibilities is to add value to the quality of life in different possible ways, such as energy conservation, e-health, remote control of appliances, and security systems.

Home automation systems have been proposed and implemented leveraging different mediums including power lines (Shwehdi and Khan, 1996), telephone lines (Ardam and Coskun 1998), Internet (Al-Ali and Al-Rousan 2004), Bluetooth (Anwarullah and Altaf, 2013; Javalee, *et al,* 2013; Ramlee *et al,* 2013; Sriskanthan *et al,* 2002), zigbee (Gill *et al,* 2009), WiFi (ElShafee and Hameed, 2012), and Short Messaging Service (SMS) over Global System for Mobile Communications (GSM) network (Khiyal *et al,* 2009; Teymourzadeh *et al* (2013). Each of these systems targets optimizing only one facet of overall home automation system structure. There exist some standards on network message specification that define the message specification for inter-device communication (Kim *et al.,* 2002). However, to the best of our knowledge, there is no well-known framework to guide the design and implementation of home automation system.

In this paper, we propose a framework to guide the design and implementation of home automation system. We also provide a prototype design of home automation system based on the proposed framework. The design of the system uses multi-layered architecture. Finally, we substantiate the effectiveness of the home automation design by building a proof-of-the-concept implementation of the system.

The rest of the paper is organized as follows. Section 2 provides overview of the related work in home automation, which eventually arises the need of an established framwework for guiding the design of home automation. Section 3 elaborates the proposed framework, followed by discussion on illustrating the prototype design of a home automation based on the proposed framework. The design is implemented into proof-of-the-concept system in Section 4. Finally, Section 5 concludes the paper along with some future directions.

2. RELATED WORK

The endeavour to building home automation systems dates back to seventies. In 1975, the first standard named as X10 was proposed for the communication

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between devices through power lines of the home as a medium (Gill *et al,* 2009). The subsequent home automation systems proposed in literature have strived for improving the medium of communication. These systems have used Internet, Bluetooth (Anwarullah and Altaf, 2013; Javalee, *et al,* 2013; Ramlee *et al,* 2013; Sriskanthan *et al,* 2002), wifi (ElShafee and Hameed, 2012; Dickey *et al,* 2012), and GSM (Khiyal *et al,* 2009).

A home automation system using hand gestures was presented by Bundel and Beaudouin-Lafon (1993). The system captures the gestures of human arm in order to control the devices. Some of the fixed arm movements are received as commands. The system faced a major problem by misinterpreting the normal normal arm movements commands.

Ardam and Coskun (1998) proposed a home automation system in which communication took place through landline that supports Dual Tone Multiple Frequency (DTMF). Although this system did not require any other medium but phone lines, yet it had several disadvantages including no graphical user interface and requiring the users to memorize the access codes. This renders the system less user friendly.

Sriskanthan *et al* (2002) presented a Bluetooth based home automation system. The authors mentioned a few issues in home automation system, nonethless did not address all of them. The system was designed with an initial controller and a number of other sub-controllers that supported Bluetooth. The home devices were physically integrated with Bluetooth supported sub-controllers through wired communication medium. All the sub-controllers communicate with primary controller through Bluetooth medium. This proposed system incurred long-lasting access latency when several devices simulatneously accessed the Bluetooth module.

Al-Ali and Al-Rousan (2004) presented a home automation system based on Java technology. A personal computer along with the web based server supports the remote management of the system. Yet, the devices at home are physically connected to control board.

Teymourzadeh *et al* (2013) presented a GSM based home security and automation system. A short message service was used in the system in order to implement security or control of the devices. This system used mobile network as a communication medium. Amongst others, one of of the disadvantage was daily operational cost of short messaging service.

It can be easily inferred from the above discusion that early efforts to home automation systems have been designed and implemented in an ad hoc manner. Moreover, the main focus of the early work leans more on improving merely one facet the communication medium. Hence, we recognize a need for a multifacted fraemwork that guides the design and iplementation of home automation system. We propose and elaborate such a framework in next section.

3. MATERIALS AND METHODS

From our literature survey on home automation systems, we discern that there is a lack of a framework that guides the design and implementation of a home automation system. The existing systems have been designed and implemented in an ad hoc manner. Thus, these systems are rigid in design (Ardam and Coskun 1998; Sriskanthan *et al,* 2002), costly to build (Teymourzadeh *et al,* 2013), or are fragile and vulnerable to changes (Bundel and Beaudouin-Lafon 1993). Consequently, we recognize four key factors, which characterize the effectiveness of the design and implementation of home automation system. Finally, we consolidate these factors into a framework.

In this section, initially, we provide some definitions of the basic terms. Next the details of the proposed framework follow:

Client Module: Any household appliance which is connected to the system for automation is referred to as client module.

Central Controller: All the client modules are connected to a central controller. It is a means to communicate with the client modules, such as turning an appliance on or off.

Host Controller: A host controller is a human to machine interface. More technically, it is a means of user control to client modules. It communicates the user commands to central controller, the central controller in turn transfers these commands to client modules.

We identify some key factors involving the decision about design and implementation of the home automation system. In particular, four factors are identified related to all the three entities of the home automation system (i.e. Client Modules, Central Controller, and Host Controller). As a guidline, any home automation system should take into account these factors for the design of home automation system. These four factors include (i) Scalability and Flexibility (ii) Robust to changes (iii) Cost effectiveness and (iv) User-friendliness.

The first factor concerns at the level of client modules and central controller. More specifically, it recommends how the client modules and central controller be connected. This dictates that there should be no bound on the upper limit on the number of client modules to be connected to the central controller. At the

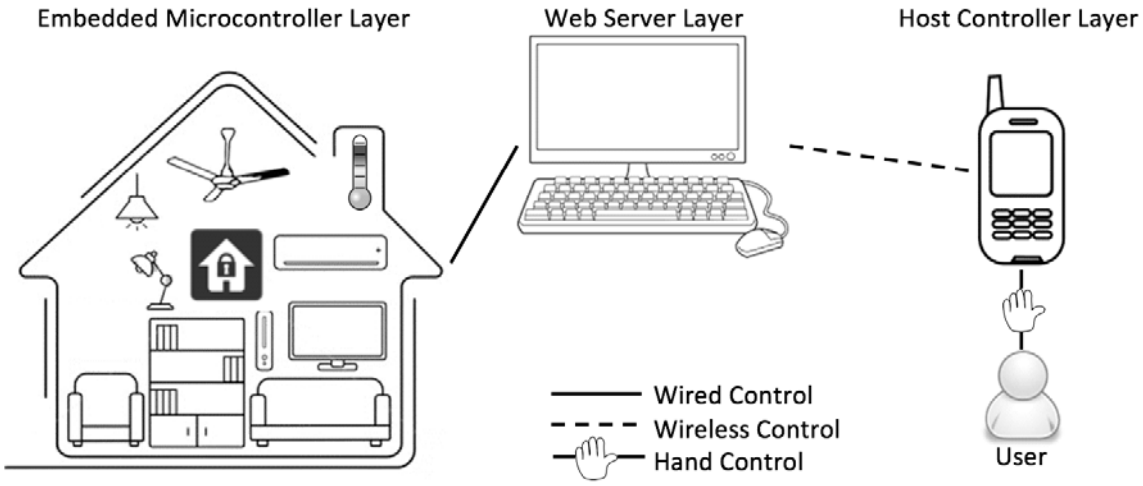


Figure 1. Three layered architecture of proposed home automation system

same time, the system should allow addition of distinct types of client modules to the system.

The second factor is generally a universal concern to every system. In the context of home automation system, it involves at all three system entities. The system should be stable enough in face of adding new and removing old client modules, as well as, changing or adding new host controllers.

The third factor also involves at all three system entities. The design decision should minimize the cost at each three entities, so as the system can effectively be implemented in practice.

The fourth factor concerns about the design decision on user interface to the system and is significant indicator on system usability. The interface to home automation system should be easy to use, not be restricted to a particular device configuration, and be accessible across multiple devices.

Home Automation System Design based on Proposed Framework

The design of home automation system is finalized by taking into account the key factors proposed in the framework. A multi-layered architecture for the design of home automation system is projected in Figure 1. It has three layers, namely; Embedded Microcontroller layer, Web Server Layer, and Host Controller layer.

The Embedded Microcontroller Layer is a main control board that connects to the Client Modules and, coupled with Web Server Layer which operates as a Central Controller Layer. The Client Modules are connected through the wires to the Embedded Controller. There are systems that advocate the use of wireless medium for interconnecting the Client Modules and Central Controller. These systems use WiFi, Zigbee, or Bluetooth (Sriskanthan *et al.,* 2002). Although, these systems benefit from wireless means of connectivity, yet they incur an additional cost of a dedicated adapters for each Client Module or an adapter per small cluster of Client Modules. Furthermore, the adapter at the Central Controller side poses a limitation on the number of Client Modules that can be connected. Thus, these systems increase the installation cost, constraint the system scale, and at the same time make the system fault prone neither of which is desirable. On the contrary, our design choice of using a wired connection reduces the cost of additional adapters and also eliminates the scalability issue. In summary, this makes the system scalable and fault tolerant.

The Web Server Layer is a dedicated computer running a web server and a light database server. The web server hosts a server application that provides a mapping between Host Controller commands to actions on Client Modules. On the other hand, the database server hosts a database primarily meant to store authenticated users' information. The server application, before delegating the Host Controller command to Client Modules, first ensures through database that the user is actually a registered user. The decision of introducing a Web Server Layer in between Embedded Microcontroller Layer and Host Controller Layer follows the Law of Demeter (Lieberherr, 1988). Notably, it follows the "do not talk to strangers" principle, creating a loose coupling between Host Controllers and Embedded Controller. On one hand, it makes the system resilient to changes in any Module without affecting the others effectively adhering to second factor of our framework robust to changes. On the other hand, the use of web server allows to use any

device as a Host Controller that can speak the language of HTTP (Fielding, 1999). As a result, several devices such as computers, java based phones, android phones, and iphones can be used as Host Controller effectively adhering to fourth factor of our framework user friendly interface. Furthermore, the advantage of controlling the system through diverse devices is also gained.

The Host Controller Layer in our design permits the use of heterogeneous devices. The Host Controller needs to be a device that can interact with the web server over HTTP protocol. This is easily achieved by using web browsers in computers and writing apps in android or iphones. The possibility of accessing and controlling the system through several diverse devices already alleviates the need to purchase dedicated devices as Host Controllers. In addition, it does not restrict to a particular device configuration for interacting with the system, allowing several devices to be used. This design choice complies with our framework cost effectiveness and user friendliness.

4. RESULTS AND DISCUSSION

This section elaborates the proof-of-the-concept prototype system designed using proposed home automation system (Cf. Section 3). In its simplest form, the prototype system has controls for the temperature, light bulbs, fans, door locks, and sprinkler for garden.

The Embedded Microcontroller Layer

We use Atmel AT89C51 microcontroller as a main control board, because of its high flexibility and cost effectiveness. We use LM35, a linear temperature sensor, for temperature measures, because it supports the functional range of temperature from -55°C to 150°C (National Semiconductor, 2000).

The other hardware components include ADC 0804 Analog to Digital Convertors, Potentiometers, Capacitors, Relays (12v), Zener Diodes, and DC Motors. We used C programming Language for the design of embedded microcontroller layer.

The Web Server Layer

The Web server layer requires a machine that can run a web server application, such as Microsoft's Internet Information Services (IIS), a database server application, such as Microsoft's SQL Server, and any dynamic web technology, such as Microsoft's ASP.NET. For the implementation of this appliaction, ASP.NET with C# (C Sharp) language is used to build web server application and deploy it on IIS. The screenshot showing status of all connected client modules is shown in **(Fig. 2).**

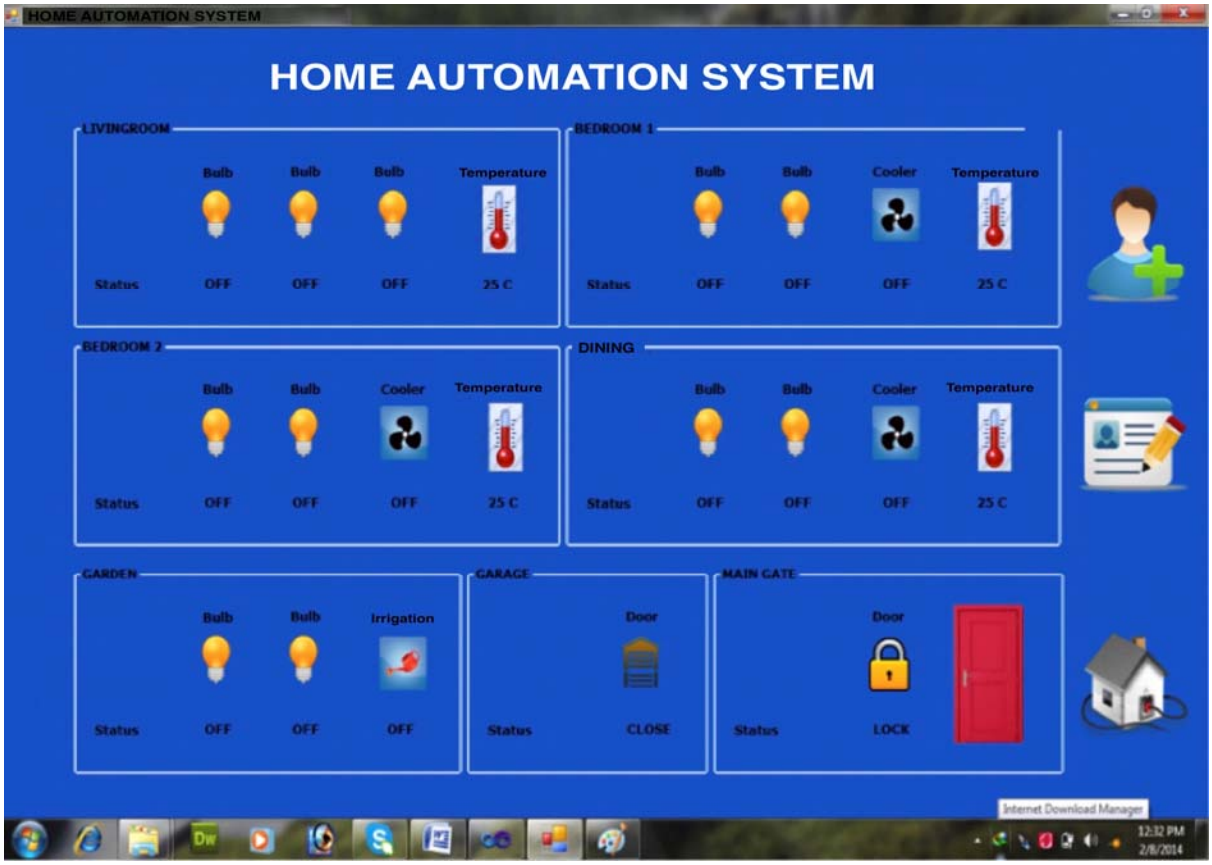


Fig.2. The screenshot showing status of all client modules



Fig. 3. The android app showing the status of Client Modules in garden

The Host Controller

The android based application is designed as a host controller to control the client modules. The application connects to the web server to send the command message. The web server, in turn, delegates the responsibility of transferring these messages to embedded controller. It is important to note that, before the users can send command through the application, they first need to register and log in to the system. The screenshot of android application showing the status of client modules in garden is shown in **(Fig. 3)**.

5. CONCLUSION

The advancment of technology has already improved the quality of human life in many dimensions. The technology introduced in a traditional home makes the home smart. Numerous researche efforts have appeared to transform a traditional home into smart home. Indeed, there are many issues and facets to address in the design of home automation system. Yet, the proposed systems have been merely attempting to improve one of the facet of overall system design.

In this paper, we propose and present multifacted framework that guides the design and implementation of home automation system. The framework consolidates the four key factors including scalability and flexibility, robustness to changes, cost effectiveness, and user-friendliness. We also present a flexible prototype design based on the proposed framework. The salient multilayred architecture of the design provides the flexibility, is robust to changes, and more importantly allows the use of heterogenous devices. The design, has been, eventually, validated by implementing a proof-of-the-concept system. The system is completely functional and can be implemented in any practical environment using low-cost hardware and commonly available computing equipment. Furthermore, this system can be enhanced using similar infrastructure technologies translating this system as a remote home monitoring or security system. The system can also be enhanced by providing the support of voice commands throuugh signal processing.

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