Low Cost Domotic System based on Open Hardware and Software

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***Abstract*—With the proliferation of wireless networks and their integration in electrical equipment, the possibilities for monitoring and control of electrical devices increased a lot expecting with this an increased usage of home automation systems. Nowadays, there are in the market several manufacturers that provide fairly comprehensive domotic solutions. However, these solutions are proprietary and have very high costs making it difficult to adopt. In this work, it is presented a low cost home automation system based on open hardware and software with support for a wide range of equipment. The system is based on a Raspberry Pi network and can be easily controlled via a mobile device. It is also possible to configure alerts that notify users when certain events occur and monitor the power consumption.**

Keywords-Domotic; home automation; smart home; mobile device; Raspberry Pi; low cost; open.

I. INTRODUCTION

The word domotic is frequently associated with the concept of smart home technology while allowing the management of electrical devices in a space in order to increase comfort, energy efficiency or safety. This word is the result of the junction of the word domus (house) with telematics (telecommunications and computing), assuming these concepts the existence of computer systems that monitor and control the set of existing electrical equipment. Despite home automation systems exist for more than 30 years, its adoption has been rather slow. Among the main barriers for this low adoption, stands out: (i) the high cost, (ii) the lack of flexibility to interconnect multi-vendor equipment, (iii) management skills and limited or difficult configuration, and (iv) the difficulty in ensuring security mechanisms [1].

Many of the facilities are made by users themselves [1] with DIY (Do It Yourself) equipment, and correspond in most cases to simple systems that enable remote control of equipment, task scheduling or security systems. Other equipment or systems imply the need for structural changes to be installed and its installation by skilled professionals increasing therefore costs.

There are plenty of cases of use of home automation systems. Lighting systems can be programmed to turn off under certain conditions or to automatically turn on when a person enters a dimly lit room. Shutters, HVAC (Heating, Ventilation, and Air Conditioning) equipment or central heating can be controlled according to information collected by various sensors that are monitoring parameters such as temperature, humidity, light or the presence of people in the room division. The use of sensors, such as smoke detectors, motion or breaking glass, allow to detect possible risk situations and initiate appropriate actions. Automated home entertainment systems allow users to predefine favorite settings, remove the need for multiple remote controls and listen to music, news or podcasts in any room of the house.

The home automation systems have a great application in the elderly population range in terms of comfort, convenience and safety. The increase in life expectancy has brought enormous challenges to many aspects of human life, especially in the welfare and health care of the elderly. Some problems associated with reduced mobility and dementia can be minimized through the use of remote control of a home automation system while the use of sensors can alert potential hazards.

Often, the concept of smart home is confused with home automation. The concept of smart home is usually used to define a housing which integrates technology and services in order to increase energy efficiency and improve the quality of life [3].

In this work, it is presented a low cost domotic system based on open hardware and software with support for a wide range of equipment. The system is based on a mini computer Raspberry Pi network that can scale according to the number of devices to be controlled. The system enables the control of these devices with a mobile device, and also allows the definition of `if-then` rules to automate certain types of tasks. It is even possible to configure alerts that warn users when certain events occur. The system also include a consumption register module that provides analysis mechanisms to allow a more rational use of energy.

In addition to this introductory section, this paper is organized as follows: Section 2 presents a summary of key technologies and projects in the field of home automation. Section 3 presents the proposed solution for a home automation system and Section 4 deals with the evaluation performed. Finally in Section 5 we present the conclusions and future work.

II. RELATED WORK

Communication protocols are the language that allows the sensors and actuators of a home automation system communicate with each other. Of all, the X10 protocol is the most popular. It was created in the mid-70s, and uses the electric network to send data between devices, which makes the installation of these devices easier without the need to

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pass any cables. There are a number of compatible devices with this protocol and its main drawback is the lack of robustness, because it is unidirectional and does not include a verification mechanism of sent commands. Nevertheless, its popularity led the adoption to work through radio frequency (X10 RF), and it is actually, the most widely used protocol in the world of home automation with numerous devices that support this protocol.

In recent years, there has been a proliferation of the use of wireless networks to control devices, which has facilitated the installation without much intervention on existing infrastructure. These systems, called Wireless Home Automation Networks (WHANs), include built-in sensors and wireless actuators that enable monitoring and control applications for home user comfort and efficient home management [2]. The main solutions of WHANs are based on X10 RF, ZigBee, Z-Wave, INSTEON and Wavenis networks. Those protocols differ in terms of the frequency used, range (indoors and outdoors), speed and costs. Gomez and Paradells [2], presents a survey of WHANs architectures and technologies detailing the main features of those protocols.

One of the most popular open source projects for general home automation is MisterHouse that is customizable, very flexible and fully compatible with most existing technologies [4]. A major problem of this system is it require good Perl programming skills to set it up and run it.

The Node-RED [5] project of IBM, allows to connect electrical devices, APIs and services online using a visual editor to build all logic and system behavior. Links are programmed as a flow chart in a very simple way, according to a targeted approach to the data flow. In fact, the Node-RED is more than a home automation system being considered by IBM a visual tool for wiring the Internet of Things (IoT).

`pilight` [6] is an open source domotic solution that runs on mini computers like the Raspberry Pi, the HummingBoard, the BananaPi, but also in various Linux distributions such as Arch, Ubuntu or Debian. The great advantage of `pilight` is the support for a wide variety of WHAN devices from different manufacturers, provided that they are compatible with the X10 protocol over RF (either 315 MHz or 433 MHz). `pilight` has a web interface that allows the control of the equipment through any browser and there are also several native applications for Android and iOS operating system. Since version 6 that `pilight` provides an `if-then` rule engine that allows the automation of tasks. All the configuration of `pilight` is made through a set of JSON files, which includes among others, the available devices, home divisions and rules.

Baraka et al. [7] present a solution similar to the solution presented in this paper but based on an Arduino and with fewer features or expansion possibilities.

In this work, we use open hardware and software with the module that allows the configuration and management of the system developed from scratch. We use `pilight` described above, and tested the system with the objectives of assessing system performance, test the system features in real situations and evaluate the system architecture.

III. PROPOSED SOLUTION

Fernandez and Losada [8] present a set of requirements quite common and discussed in the literature that aim to guide the design of home automation solutions. These requirements are summarized next, which were considered in the architecture solution proposed here and to which was added the low cost requirement.

1. **Low Cost.** The solution should have a low cost using inexpensive and modular equipment in order to grow with the user needs.
2. **Interoperability**. The central control system must be open and able to communicate with all sensors and actuators, in order to connect to various types of devices. Although some standards were adopted, there must be especially careful when purchasing new devices to ensure compatibility with the existing home automation system.
3. **Control and Remote Access**. The ability to control and communicate remotely with the system, is one of the most popular features. This feature allows users to monitor the home environment and also change the settings of lights, thermostats and other equipment, from a laptop, personal computer, smartphone or any mobile device.
4. **Scalability**. The system chance to expand its capacity according the needs and the evolution of technology itself.
5. **Flexibility**. The system must provide tools to customize the system to specific requirements.
6. **Robustness**. The system must be able to handle the most common problems, such as power failures, data persistence and adequate reporting mechanisms.
7. **Energy Saving**. The system should have the ability to help save energy by automatically turning off electrical devices, as well as providing the user with information that assists in decision-making for a more rational use of energy.

A. Solution Architecture

The proposed solution is based on the architecture illustrated in Figure 1, which consists of the modules described next: the Central Module, the Management Module, the Control Module, the X10 RF Devices and also the X10 RF Power Consumption Measuring Devices. The system enables the control of home automation devices compatible with the X10 RF protocol, thereby providing support for a large number of multi-vendor equipment.

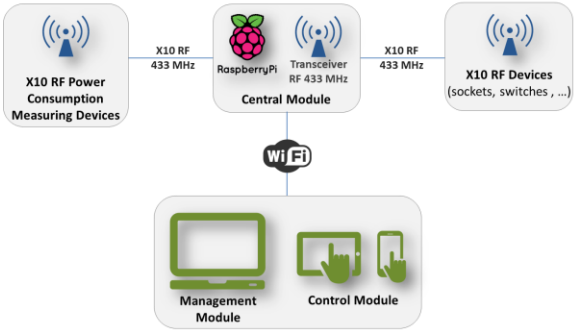


Figure 1. System architecture.

1) *Central Module*

The Central Module is responsible for maintaining the configuration and control of the home automation system. It is the component which communicates with home automation devices sending and receiving commands that allow a rational management of the system, such as turn on/off or adjust the lighting, opening or closing the shutters, turn on the washing machine at a desired time, among others. This module comprises a Raspberry Pi with a 433 MHz RF transceiver for a maximum range of 150 meters. The Raspberry Pi is a low-cost computer (from 20 €) with a size of a deck of cards. It runs Linux (Debian, Fedora or Arch) and has capabilities to interact with the outside world via programmable General Purpose Input / Output (GPIO) ports. The Raspberry Pi runs the `pilight` mentioned above and can be configured with the Management Module described next.

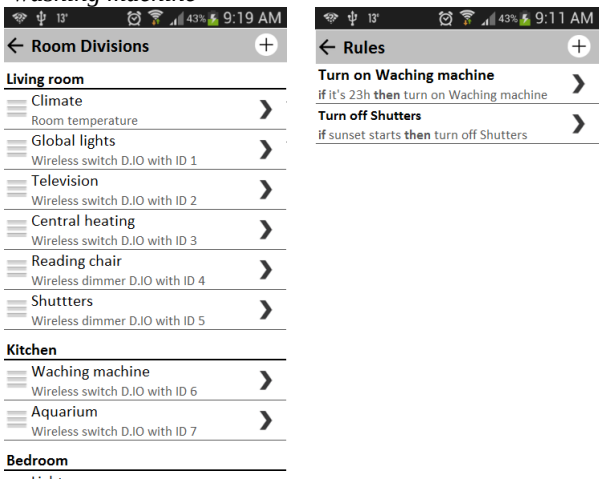
2) *Management Module*

The management module is a web application developed with jQuery Mobile that allows the management and the configuration of the entire system. `pilight` does not have this module, which was developed as part of the system here presented. This module is a web editor for the configuration files of `pilight` which maintains all the settings in JSON files. Figure 2 shows an example with the interface of the configured room devices with the corresponding devices (Figure 2a) and the created rules (Figure 2b).

A `pilight` rule is composed by a condition and an action. The condition defines the triggers that allow the execution of the action associated with the rule when the condition is verified.

The `pilight` rules module is very expressive and the management module allow the creation of conditions, like:

"*If it is 23h then turn on the washing machine*"
"*If it is time for sunset then close the shutters*"
"If the room temperature is greater than 25 degrees then turn on air conditioning"
"If it is 23h of Tuesday or Friday then turn on the washing machine"

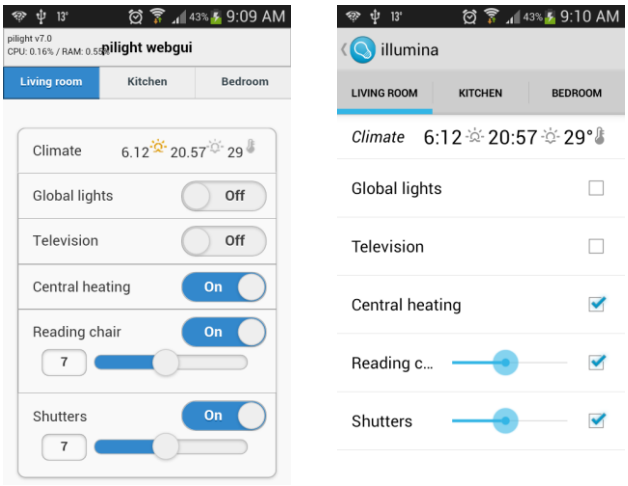


a) Room divisions b) Rules

Figure 2. Management module interface.

3) *Control Module*

`pilight` provides a web interface (Figure 3a) for the control through a mobile device. In addition to the web interface there are also available several native applications for Android (Figure 3b) and iOS that allow the same control. Those interfaces organizes information by the house division that are defined in the Management Module and within each division includes the devices to control. In addition to the domotic devices, it is possible to include information about the weather forecast gathered from available APIs like Weather Underground or Open Weather Map.



a) Web interface b) Android app (illumina)

Figure 3. Control module.

4) *X10 RF devices*

The solution is based on the use of X10 RF devices. We have used D.IO Chacon devices whose unit price starts at 7€. The D.IO product catalog includes sockets, switches, on/off modules, flood detectors, temperature sensors, humidity and motion, among many others.

5) *X10 RF Power Consumption Measuring Devices*

This is a functional module separated from the previous one, but which also use the X10 RF protocol to communicate with the Central Module. The use of power consumption measuring devices provides information that can be used for a more rational use of energy. This information includes current and historic consumption per equipment or room.

IV. EVALUATION

The system was tested in a house with about 150m^2 and domotic devices installed in three divisions of the house: the living room, the kitchen and one bedroom. Was used a total of 12 actuators from DI.O Chacon (9 switches and 3 dimmers) and 1 sensor (the AM2302/DHT22) which read the temperature and humidity of the living room.

For the Central Module was used one Raspberry Pi version B which has a 700 MHz ARM processor and 512MB of RAM. The DHT22 sensor and the RF 433 MHz transceiver was mounted on a breadboard according with the instructions available at the support site of `pilight`.

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The Management Module was used to configure all the system including the divisions of the house and the installed devices (Figure 2a), and also the rules used to perform automatically some predefined tasks (Figure 2b).

For the Control Module, was mainly used the Android app illumina (Figure 3b) and less frequently the `pilight` web interface (Figure 3a).

The tests were conducted for a month by the inhabitants of the house (one adult with 48 years old and two young people with 13 and 16 years old) on a regular daily basis with the objectives of (i) assessing the capacity and system performance, (ii) test the system features in real situations, and (iii) to evaluate the system architecture.

A. Results

With the test conditions described above the CPU usage is about 21-33% which is quite acceptable. This use corresponds mainly to decoding the RF signals and filtering and also the `pilight` rules engine that makes more use of CPU. As a result, system load largely depends on the rules and also the sensors used which broadcast RF signals from time to time forcing the use of CPU to decode these signals.

The distributed and scalable architecture of `pilight` allows easily add new Central Modules operating in a master-slave philosophy thus distributing the load of CPU and obtaining a higher range of the system than the 150 meters of the RF transceivers used.

During the tests, the system proved its reliability running without the need for intervention.

V. Conclusion and Future Work

This paper presents a low cost system based on open hardware and software that enables the remote control of devices compatible with the X10 RF protocol. The system can also automate tasks through an `if-then` rule engine and allow the measuring of power consumption.

Each Central Module in prototype version as the tested here, costs about 50 €.

The use of `pilight` as middleware platform for home automation devices, allow to address the interoperability for a wide range of equipment from various manufacturers.

The performed tests allowed to validate the system architecture and has proven to function well in a house of about 150 m^2. However, it is desirable to perform larger scale tests especially with the use of more home automation devices from various manufacturers and an enlarged Raspberry Pi network.

An important issue that will be considered in future, is the security of the system and also tests with the power consumption module.

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