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THE CONCEPT FOR THE "SMART HOME" CONTROLLED BY A SMARTWATCH

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Abstract. *In this paper a "Smart Home" solution is proposed in which power plugs in a remote room can be controlled by a smartwatch, an Android mobile device or a PHP web app. Communication between these devices takes place in real time via server using Node.js technology. An electrical circuit for determining current and voltage on the plugs via Arduino Wi-Fi module sends the measured values to the server, based on which the electrical energy consumption in each time interval can be determined. All the measured values are stored in MySQL database and used for creation of appropriate reports. Smartwatch app enables remote plugging and unplugging. In addition, the setting of limits for electrical energy consumption on each plug is enabled, as well as the power of the consumption device that can be plugged. Exceeding of the allowed values leads to the automatic unplugging.*

Key words: *IoT, Smart Home, Smart Watch, power consumption*

1. INTRODUCTION

In recent times, the world has seen an exponential rise in the number of devices connected to the Internet. In order to automatize business process, but also to improve life comfort, computers connected to the Internet became a part of our daily routine. A concept of connecting embedded computer devices within the existing Internet infrastructure is popularly called *Internet of Things* (*IoT*) [1]. That concept should enable connecting different devices, systems and services that exceed present communication of two machines. A task is put before the engineers to implement different protocols and applications for wide spectra of devices as air condition devices, washing machines, bio-chips or wireless sensors. This leads to development of different systems with wide application possibilities like context aware systems, ambient assisted living systems, smart homes, smart cities etc.

Considering the diversity of the devices, there are many challenges that an engineer needs to overcome when designing and implementing such a system. Main research

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directions and challenges are thoroughly described in [2]. Developing the architecture, designing or choosing hardware and sensors, deciding on the operating system or systems, choosing communication protocol, integrating "*things"* into the web by using web services are only some of the problems that we had in mind when we implemented IoT solution described in this paper.

One of the challenges is certainly the development of the architectural design that will enable scalability, interoperability and security. As trillions of things (objects) are connected to the Internet, it is necessary to have an adequate architecture that permits easy connectivity, control, communications, and useful applications. Several solutions are proposed like DIAT, MARM, MOSDEN, CloudThings and other [3]. In depth analysis of different context aware systems and smart home architectures and technologies can be found in [4] and [5].

Another challenge is a design of universal operating systems that would work on different hardware with a similar success. One of the most popular and most common operating systems is Android, as an open source operating system. In recent years, Tizen OS also gained popularity, due to its applicability on various devices, and support by Samsung Company.

Several communication protocols are used for communication between IoT devices. Most relevant is probably the SNMP protocol that forms the part of the IP stack and is universally supported. On the application level CoAP (Constrained Application Protocol) and MQTT (Message Queuing Telemetry Transport) are often used [6].

In the paper [7] Jabeur goes further by explaining that integration of real world things or RWTs into the web leads to more advanced perspective, where these things are abstracted into reusable web services, and not only viewed as simple web pages. These leads to the subset of IoT called Web of Things or WoT. RESTful Web services are based on Representational State Transfer (REST) [8] which is lightweight, simple, loosely coupled, flexible as well as easy to integrate into the Web using the HTTP application protocol. From a design perspective and compared to the traditional client-server architecture, the WoT has a flat architecture that should integrate the RWT into the web and make them mutually interoperate and fuse into complex web services. Jabeur further introduces artificial intelligence technics as well as the ideas of social networking into the IoT.

Smart home represents one context aware IoT system. It consists of home appliances, sensors, actuators and data processors and analyzers [9]. Home automation of appliances can be either wired or wireless. The idea of a *Smart Home* integrates many different aspects of IoT, energy efficiency and software engineering. For example, [10] describes connecting wireless sensors to internet, [11] describes platform for smart learning environment, which enables acquiring data from sensors distributed within the University building, and [12] smart home system based on sensor technology. Home devices control is usually performed from other smart devices, as tablets, mobile phones, smartwatches, smart wristbands, etc. There are several Smart Home systems that are proposed based on different architecture and different communication technologies like ZigBee [13], Bluetooth [14], GSM [15] and Wi-Fi[16].

As far as we know the first paper that mentions the possibility of using a smartwatch as a remote-control device in a smart home is [17]. However, this paper was written at the time when smartwatches were not yet widely available and were quite limited in comparison to nowadays smart devices. The paper [15] describes a system where Android smartphone is used for monitoring a home security system.

The power monitoring systems in home environments are described in [18] [19]. The first paper does not use smartwatch nor smartphone for monitoring, and does not implement real time communication as GUI needs to be refreshed so the data can be shown. The second paper does not use web and cannot be considered as scalable nor easy for integration.

In this paper, a Smart Home solution is described in which an Android mobile device, PHP server, and Tizen smartwatch app are used to monitor and control house power consumption. All three apps communicate over Wi-Fi, regardless the development technology, have identical functionalities, and communicate among themselves via common NodeJS server, via WebSocket and HTTP protocol. As a connection between hardware on one side and server app on another, an Arduino open source computer platform, based on a simple board with I/O pins and an ATMEL microcontroller, is used.

This solution represents the continuation of development of the remote control in Samsung Apps Lab and VTŠ Apps Team in the College of Applied Technical Sciences in Niš, and it is the expansion of the apps functionality for the lab access control system [20]. It also represents an addition to work already described in [12] by introducing the smart watch control and system for energy consumption monitoring and control.

Considering the growing popularity of smartwatches and their apps development specificity, the special focus is put on the control of the proposed Smart Home solution. In the section 2, the system architecture is presented, whereas in the subsequent chapters every part of the system is described. After the third and fourth section, in which the hardware for electrical energy and voltage measurement on the plugs are described, as well as the functioning of the Arduino module, in the fifth section a detailed description of server part of the system, the mobile device and the web app is given.

2. System Architecture Design

For setting up a system for energy consumption control in the home environment the following hardware components are needed:

- Microcomputer – An Arduino board with the Wi-Fi module, the SparkFun FTDI Basic Breakout Board and the LCD display
- Main server for sharing the data between clients. It can be a desktop computer or a service provided by the hosting provider
- Smartphone, smartwatch or PC device
- Wi-Fi network and Wireless router
- Customized power plug

The working principle of the whole system is shown graphically in Figure 1. All the Smart Home module users, regardless whether they want to have control via smartwatch or Android device, ought to be registered in the database of lab members. The application on the smartwatch enables us to remotely turn on and off the power plug, to set timer, and to set power limits for energy consumption, as well as the maximal consumption power that can be connected to any power plug. In this way, the watch on our wrist becomes a sort of personal home remote control device. Beside the smart watch app, the Android mobile application and PHP Web application were also developed with similar functionalities. Communication between all these applications happens in real time over the Node.js server. The connection between the power plug and electrical circuits for measuring current and voltage is implemented by using an Arduino microcontroller board. For testing the proposed solution two power plugs on one power strip were used. All measured values are saved in MySQL database and are used for energy consumption and cost calculations. All previously developed modules: Laboratory access control system, PHP Library of the VTŠ Apps Team and VTŠ Explorer App [2], use the same database which is stored on server. So, the first step for the administrator is to create a user account by filling out the appropriate web form in the PHP app. In that way, a universal username and password are given to all the members of the lab so that they can access all the above-mentioned apps (modules).

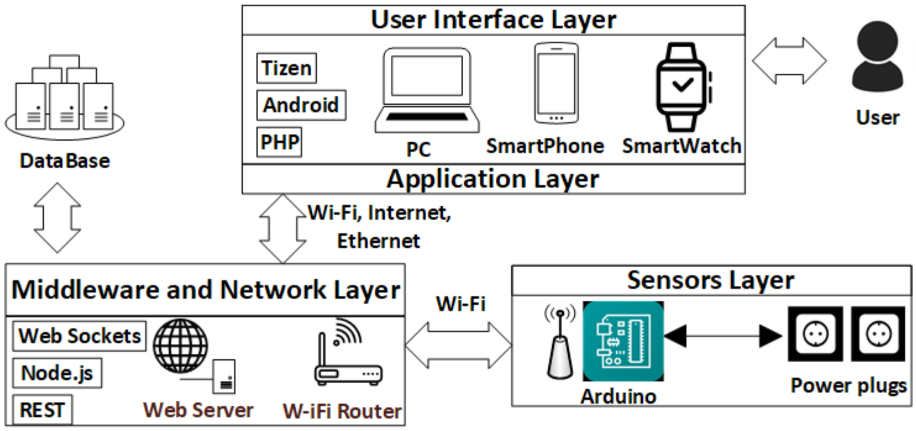

Fig. 1 The block diagram of the system software and hardware architecture

When creating an account, the PHP app checks whether entered username for newly created user is available. At the same time, a form validation is performed regarding the mandatory field checks and whether the data are entered in valid format. If created account meets all the requirements and security checks, the app stores it in database.

Two plugs are placed in the laboratory, and are connected with the Arduino microcontroller via the electrical circuit described in the following chapter. Arduino is used for voltage and electrical energy measuring, and it sends the measured values to the server app via appropriate Wi-Fi module.

The systems based on Wi-Fi have the advantage of using technology which is present or will be present in almost any modern electronic device. Its main feature is the existing wide support, alongside the fact that it is an upper layer protocol which allows communication over the Internet without needing a protocol translator [5]. Furthermore, Wi-Fi network today exists in almost every home with Internet access.

The app accepts the measured values on the server, and along with accepting date and time, stores them in the database. Based on measured and stored values, a current power chart on the plugs in real time is drawn. The server app sends these data to the smartwatch or Android device apps via appropriate service. Communication between server and above-mentioned devices is two-way, because the devices can send instructions for momentary unplugging, as well as the time when the plug should be switched on or off.

3. PLUG DESIGN

There are a lot of wireless power plugs available on the market with price ranging from 15 to 50 EUR per plug. To use the plug the costumer needs to install a proprietary mobile app. Integration with third-party apps is usually not possible, as well as getting the real-time power consumption data. The price, non-accessible API and unavailability of real time power consumption readings are the reasons why we decided to design and construct custom power plugs

The interior of the existing power strip is modified so the plugs could be physically divided. In Figure 2, a circuit implementation scheme for measuring electrical energy is shown. Calculated value represents the active power of the consumption device and is acquired as a product of the effective value of voltage and the power of the receiver. The active power is provided in technical specifications of home appliances, as well as their characteristics.

The information on electrical energy consumption is acquired using DL-CT1005A current sensor, through which a conductor is pulled, and the alternating current of the consumption device is transmitted through it. That alternating current is induced proportionally in current sensor’s coils. A 39Ω resistor, through which the alternating current flows causing alternating voltage drop (around 1V), is connected in parallel with the current sensor.

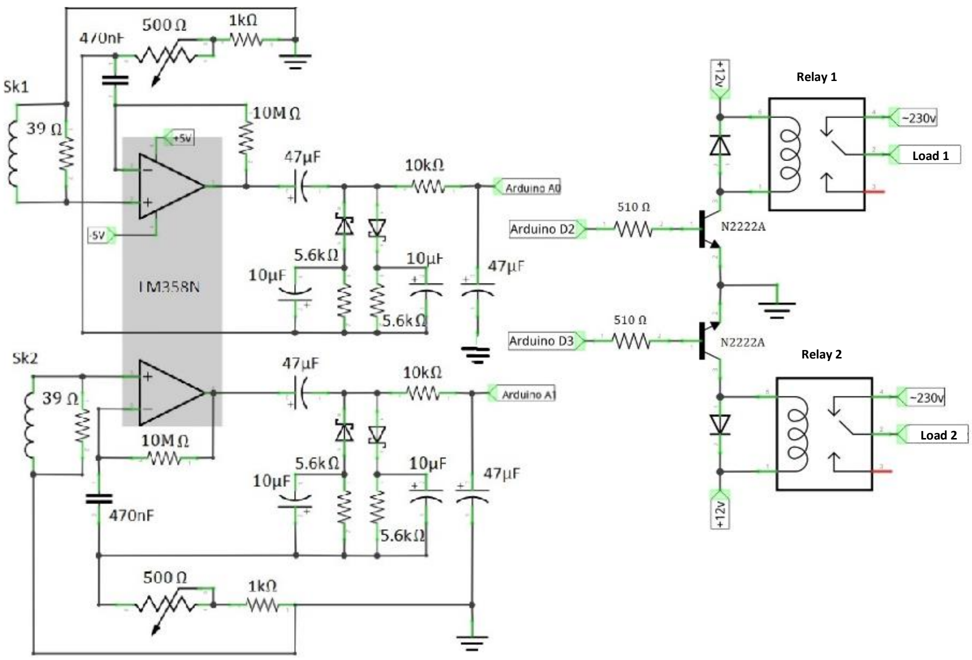

Fig. 2 A circuit implementation scheme for measuring electrical energy and circuit implementation scheme for relay control

The value of the gained voltage is amplified using LM358N operational amplifier to the point where it is applicable to transform it into direct voltage (Figure 2). The Schottky diodes are used for rectifying voltage because of their quality of having a lower voltage sag in comparison with silicon diodes. For comparing voltages at the input of A/D converter, the Arduino uses the internal reference voltage of 1.1V, so the maximum value of the voltage (for consumption device of 10A), received from the amplifying and rectifying circuit, is 1.1V. Considering that the display and Wi-Fi module are connected to 5V, the voltage varies in mV and is not even nearly precise as intern voltage generated as internal Arduino CPU.

Considering that the system monitors the power consumption of two independent devices, two current sensors are required (Sk1 and Sk2 in Figure 2), as well as the amplifiers and rectifiers for both current sources. At the output of the rectifying degree, the RC connection (between a 10kΩ resistor and a 47μF capacitor) serves as a low-pass filter, so more stable voltage is achieved at the input of the Arduino. The Arduino keeps filtering this signal further by repeating measurements for certain time interval and taking the mean.

Both consumption devices can be switched on and off remotely in a way that the instruction is sent from the mobile app, via server, to the Arduino device, ordering it to switch on/off the appropriate relay. A consumption device and a relay are connected in series to the mains voltage, and relay's coil is propelled by transistor's switch derived with PN2222A NPN transistor (Figure 2). From the Arduino's digital pin to the database, via 510Ω resistor, the transistor is saturated and the consumption device is switched on. Diodes neutralize counter electromagnetic force that occurs after the relay is switched off.

A circuit scheme for measuring voltage is shown in Figure 3. Mains voltage is the same on both consumption devices, so only one readout structure is necessary. The logic is galvanically separated from mains voltage with a transformation that shows 12V on its secondary. The Graetz Bridge, which is made with Schottky diodes because of the less attrition, generates the DC voltage. This voltage is too high to be led to an analogue Arduino input directly, so a voltage divider is created using 100kΩ and 1kΩ resistors. Using a 2.2kΩ potentiometer, which is connected in series to a 1kΩ resistor, output voltage is set in a fine way (around 800mV for mains voltage of 225V). At the output, the RC connection between a 10kΩ resistor and a 10μF capacitor serves as a low-pass filter.

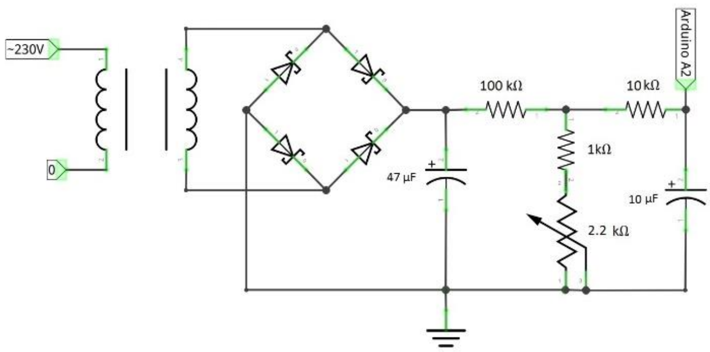

Fig. 3 A circuit implementation scheme for measuring voltage

4. ARDUINO AND SERVER COMMUNICATION MODULE

Arduino microcontroller board is an open source development platform based on 8-bit Atmel AVR or 32-bit Atmel ARM microcontroller. There are several models of Arduino boards that have different features, but all boards contain standard microcontroller components like oscillator, the crystal that regulates time periodic impulses of the processor clock, and 5V and 3.3V voltage regulators. For this project Arduino Pro Mini board was used, with ATmega 328 microprocessor and ESP8266 ESP-01 Wi-Fi module which are shown in Figure 4. The final look of the Arduino module and power plug is shown on Figure 5.

a) b) c) d) e)

Fig. 4 a) Arduino Pro Mini, b) Wi-Fi module ESP8266 ESP-01
c) FTDI cable, d) SparkFun FTDI Basic Breakout Board

Development environment needed for the board programming is completely free, open source, and can be downloaded for the Mac, Windows, or Linux operating systems. The processing power of the Arduino is not great, as it is built to be cheap and accessible, so the optimization of the code is important, so that the system would work without any latency. This is extremely important in a real-time system. In this project, the Arduino has several different responsibilities:

1. It measures the output of electrical current and voltage for each power plug that is described in section 3;
2. It writes measured values on the LCD display;
3. It communicates with the server by sending the measured values via Wi-Fi;
4. It receives from the server the power consumption limits for each power plug.

Communication between the Arduino and the PHP server is implemented by using the ESP8266 ESP-01 Wireless module (Figure 4b). The module uses 802.11 b/g/n standard and the TCP/IP protocol. The possibilities for the work mode are STATION, ACCESS POINT and BOTH. It is also possible to set a static IP address or port number, and to specify the explicit web address, as the module has the DNS capability to translate it to the IP address.

Arduino Pro Mini contains 14 digital input/output pins, from which six can be used as a PWM (Pulse width modulation) channels. Also, it has six analog entries and a reset button. This platform is categorized as an entry-level model and is designed for use where small board dimensions are required. Due to this, the board does not contain the USB connector. Therefore, connecting with a personal computer is not possible via USB cable, which leaves two other possibilities:

1. Direct connection via FTDI (*Future Technology Devices International*) cable (Figure 4c) which is used with the Arduino Pro Mini 16MHz module with 5V power source
2. Connection with additional SparkFun FTDI Basic Breakout Board (Figure 4d), which is used with the Arduino Pro Mini 8MHz module with 3.3V power source. We decided to use this solution.

Every pin on the Arduino board, from the 14 available pins, can be used as an input or output maximal current is limited to 40mA. Additionally, specialized pins are available for connecting the Bluetooth or Wireless module like RX (receive X) and TX (transmit X) pins, which can also be used for the UART TTL serial communication.

Fig. 5 The image of Arduino module and the custom power plug

5. Implementation of the Server, Web and Mobile Application

The server application is implemented in Node.js and PHP technologies. Node.js is a server-side JavaScript environment based on Google Chrome V8 engine, and is mainly used for the implementation of the fast simple scalable network applications. It is very efficient for development of the real-time applications, distributed applications, and applications that have the need for the large amount of data transactions or HTTP requests or full duplex communication via Web Socket protocol.

Communication between the Arduino module in the power plug, and the smartwatch or the Android device is done in real time by using the web sockets, which are implemented in Node.js and use socket.io library. Arduino monitors current and voltage on the consumption device, which is connected to the power plug, and forwards measured values to the Node.js server in real time. Node.js saves the measured values in the MySQL database, and forwards these values to the client applications, the smartwatch, and Android and web application. With any change in the state of the plug, the current or voltage values will be immediately synchronized on all the client applications.

All client apps communicate with the server via Wi-Fi. When any change occurs, on server or client side, data is sent to the server which forwards this information to all connected applications which immediately update the UI.

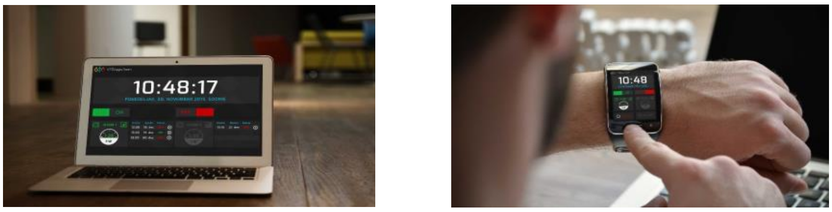

Fig. 6 Design and functionalities of the web application

Web application was developed in the PHP programming language with the MySQL database, and has the same functionalities as the Android and smartwatch app which is showed in Figure 6. The Android application was developed in Android Studio.

6. IMPLEMENTATION OF THE SMARTWATCH APPLICATION

Today’s mobile devices market has many different smartwatches manufactures, and many different operating systems that power them. The application for Smart Home control in this paper has been developed for Samsung smartwatch Gear S model, which works on Tizen operating system.

Tizen is an open and flexible operating system developed to run on different devices like mobile phones, cars, bracelets, watches, television sets, and other devices. It was made by open source software development community and is still open for anyone who wants to contribute to the project. There are different versions of the system, like Tizen Mobile, Tizen TV and Tizen wearable, and they are all compatible with the HTML5 standard.

Due to the small screen size and the small resolution of the watch (360x480), the design of the user interface (UI) turns out to be increasingly challenging. The UI of this type of app consists of several screens. Since the watch has only one physical button, it is only natural that different gestures must be used for navigation between screens. Swiping gesture from the top of the application to the bottom would signify closing the application. Swiping in the other direction, from the bottom to the top, would return you to the previous screen. By clicking the physical button, the app continues to run in the background, so when it is activated again, the user can continue where he left off.

Fig. 7 The smartwatch application screenshots annotated as 7a, 7b, 7c and 7d

The smartwatch can turn on and off the power plug autonomously by using timers. On the bottom of the screen, the next scheduled task with scheduled time is shown. To set the timer the user can click on the before mentioned task and the screen in Figure 7b will be shown. On this screen, the user can see all scheduled tasks for the future, sort them, delete them, and add the new ones. By clicking on the green button on the bottom, the new screen for button addition will be shown (Figure 7c).

To schedule a new task, the user needs to choose the power plug, type of action, time and date. By clicking in the middle of the application, on the part that shows current power of the consumption device, the screen with consumption date for that plug will be shown in Figure 7d. The data are sorted by the current tariff system in Serbia (blue, green, and red tariff). The user can also see the price in Serbian dinars.

In the Figure 8 we can see the results of the measured power consumption on the monthly scale for two power plugs used in the laboratory.

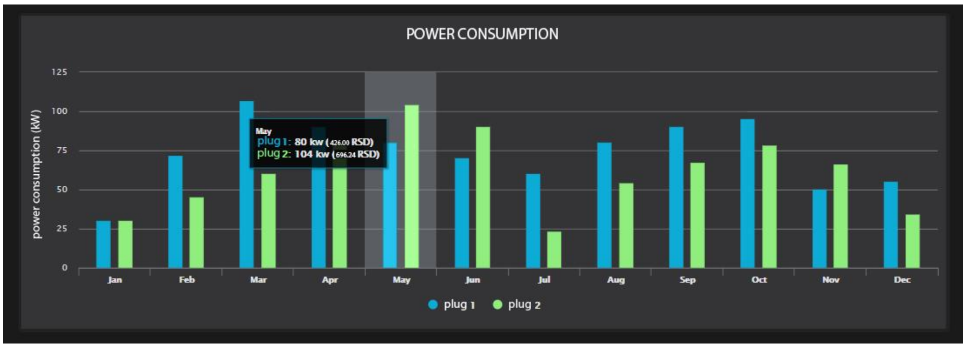

Fig. 8 Power consumption report

7. Conclusion

In this paper, we proposed and described the architecture model based on Wi-Fi protocol that controls and monitors power consumption by using different devices. There are multiple advantages of such a system comparing to standard home like better control of home appliances, convenience, better power consumption awareness, energy efficiency etc.

Considering other proposed solutions in scientific literature, our solution differs by implementing smartwatch application that can monitor and control power plugs in real time. All the controlling devices exchange data and synchronize in real time. The custom power plug was designed with Arduino board and Wi-Fi connectivity. The plugs can be controlled through the server as web services that can be accessed from any web capable device and are integrated into the "*web of things*". Finally, the rich and interactive Tizen, Android and PHP applications were developed which access these web services and are used to control devices and show the monitored data in a user-friendly way.

The system was constructed from widely available hardware components (Arduino, Wi-Fi module, smart watch) and from some that were custom-made (power plug). The total price for all the components is not more than 40 euros. The real-world application in home environment is possible for selected devices as it does not require changes in electric installations. However, it is not recommended for all wall power plugs, as better solutions exist. The electric installations can be changed, so all of them connect to one microcomputer, or power consumption measurement can be done on the main circuit breaker.

The attention when building the system was on accessibility, usability, openness, scalability, easy integration, and real-time data exchange, while other considerations like security, robustness and system optimization were also considered but were not in the prime focus of the research. Verbose data due to the protocol overheads increase the power consumed by the device and may make it less efficient. Emerging protocols such as CoAP can be considered to provide better performance.

The practical test of the Smart House system features easy control, good stability and scalability, and easy integration into larger systems so it can provide reference to the future design of the smart home hardware and architecture. Special attention in this paper has been given to the software development, especially to the smartwatch application due to the popularity and innovative concept that this technology represents. The integration of the other controlling devices as well as other sensors can be easily implemented and integrated in the proposed system, and is supported by the software architecture.

Additional work can be done to integrating smart TV as a sort of smart house hub that can monitor and control other house devices. Furthermore, the development of the intelligent systems that detect and learn about our behavior and help enrich and simplify our daily routines is more common. Artificial intelligence and machine learning techniques can be used to optimize and personalize energy consumption and personal preferences for optimal device usage. Proposed system can help and simplify the collection of the data needed for the training of such systems.

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