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Open Sensing Platform for HomeEnergy Monitoring in the Internet of Things

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Abstract

Currently our homes are equipped with many electronic devices and appliances that consume an important amount of electricity daily. The energy consumed by households could be decreased significantly by increasing consumers' awareness about their appliances energy usage. In this paper we present an energy monitoring system that offers consumers the possibility to monitor the energy utilization of their appliances. The proposed system is built over a wireless sensor network's open platform that provides the possibility to extend its functionality and offers compatibility with other solutions and applications.By designing the energy monitoring system using an open sensing platform, we aim at adhering to the vision of the Internet of Things where control devices and management systems share and combine that control data to improve their performances and increase users' awareness.

Keywords- *Internet of Things, Smart Grid, Wireless Sensor Networks*

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I. Introduction

The Internet of Things (IoT)[1]is a vision for a global network that connects physical world objects to the existing IT infrastructure. IoT has been inspired by on-going advances in emerging sensor technologies such as Radio-Frequency IDentification (RFID), wireless sensor networks, and mobile telephony that allows sensors to be deployed widely and cheaply on a massive scale. Ultimately, we expect the Internet of Things will have an incalculable impact on businesses, public services, and how we lead our daily lives[2, 3]. Ultimately, we expect the Internet of Things will have an incalculable impact on businesses, public services, and our daily lives.

One area that could benefit greatly from this vision is energy management in houses[4]. Currently, the largest building automation service is security, where CCTV cameras and intrusion detection sensors are being used. However, there is an increasing interest for more sophisticated management systems that could enable the management of energy consumption[5]. Many houses and building are equipped with many electrical devices and appliances that consume an important amount of electricity daily. A study conducted by the Energy Saving Trust shows that households in the UK waste an estimate of 8 per cent of their electricity bill on standby power [6]. This inefficient utilization of energy in homes and is generally due to the lack of awareness of consumers regarding the energy utilization of their appliances.The energy consumption of these appliances could be further reduced if consumers are informed about the energy consumption of their appliances and their operating environment. To provide an accurate control, the data generated by energy monitoring devices need to be combined with other types of information such as ambient conditions insides rooms, and offices, rooms' occupancy, energy utility pricing and saving policies, etc. Currently, most of home energy management solutions and tools use proprietary platforms making it impossible to share the obtained information with other devices, as promoted in the visions of the Internet of Things[7].

In this paper, we present the design of an energy monitoring system that uses an open wireless sensing platform, namely Berkeley's TelosB sensing mote. In this design we extend the capabilities of the wireless sensing platform to include the sensing of electricity current.

The remainder of this paper is organized as follows. Section 2 will review home energy monitoring solutions that exist currently in the market. Section 3 will present a description of the proposed energy monitoring systems and its components. Section 4 will discuss the evaluation of the energy management system through a test-bed. In section 5, we will draw our conclusions and present our future work.

II. Background

Over the last 30 years homes have increasingly become filled with a wide range of electronic devices and appliances that cumulatively consume significant amounts of electricity daily. Moreover, in many cases these devices are left switched on unnecessarily. By addressing the inefficient usage of appliances, the energy usage of these appliances could be significantly reduced improving energy efficiency and reducing costs. This objective could be achieved by equipping appliances with sensing devices that can measure their energy usage and report this to a monitoring service, commonly called a Smart Meter, appliances could make their energy consumption obvious to users which might raise energy awareness and prompt remedial actions.

There has been a number of real time energy monitoring solutions that have been designed with the purpose to provide consumers with feedbacks about their kilowatt-hour consumption and electricity costs[8, 9]. These real-time monitoring devices are able to read and record the amount of electricity usage in a house. Solutions such as Aztech[10], Cent-A-Meter[11], , and EML 2020H [12]record the electricity usage within a house and showthe current rate of consumption in statistical, graphical, and visual data formats.

In addition to real-time monitoring devices, utility companies are offering their customer online services that allow them to see their energy usage on the web along with their electricity bills[13-15]. For instance, British Gas offers it consumers an online energy tracking service, where a consumer can put his electricity meter's reading, and receives the cost of his current electricity consumption. Furthermore, the customer can set energy consumption goals and alerts in the context of reducing overall electricity usage.Although these devices and services offer the consumer a view of the electricity consumption in real time, they fall short from providing the accuracy required to implement an energy saving policy.

More recently, a number of tools have been proposed to monitor the energy usage of appliances [16]. Tools such as SmartPlug[17] are usually plugged into an electricity outlet to monitor the electricity usage of each appliance. However, most of these solutions use proprietary platforms; therefore it is impossible to share the obtained information with other control devices and services. The omnipresence of sensors in a home such as such as indoor ambient conditions, means that services could also monitor energy usage in relation to user behaviour and potentially make intelligent decisions over powering devices and appliances in real-time.

In this paper, we present the design of energy monitoring system using an open platform, composed of: TelosB a wireless sensing mote developed by the University of California, Berkeley, and Contiki, an open source operating for the Internet of Things devices. By building the energy monitoring system on this open platform, we aim at providing a solution that could be extended to include further monitoring capabilities and making it compatible with other solutions and applications.This system allows the user to monitor the energy usage at each appliance without any modification or physical contact with it or with its energy supply system. This energy monitoring system uses wireless communication to send the energy usage in real time to a client application located at the user computer, as illustrated in Figure 1.

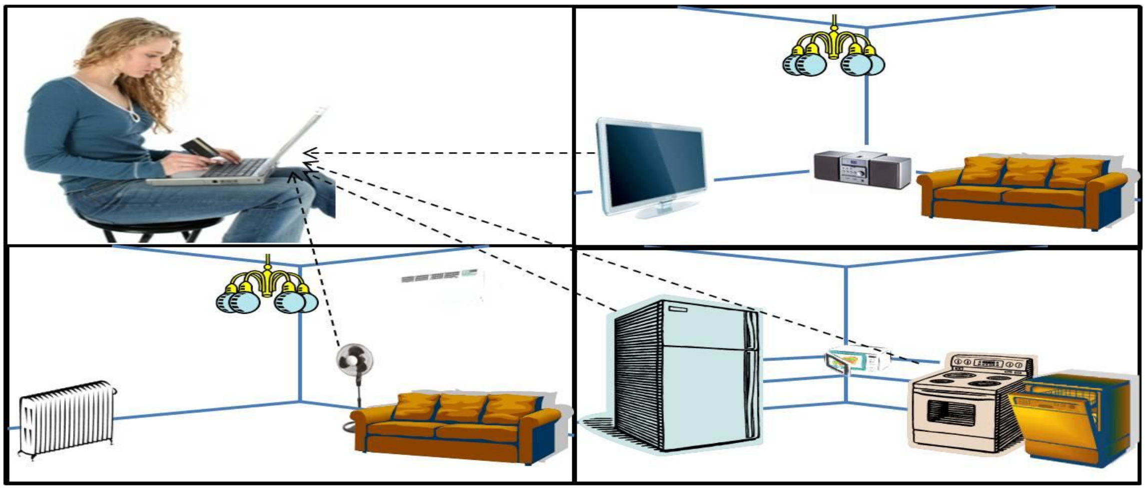

Figure 1 Wireless Home Energy Monitoring System

III. Design of an Energy Monitoring System for Home Appliances

In the proposed energy monitoring system we extend the capabilities of existing wireless sensing platform to include sensing of electricity current properties in an appliance. The proposed wireless electricity monitoring platform, illustrated in Figure 2, consists of a TelosB sensor mote, a *current clamp*sensor based on Hall Effect[18], and a signal amplifier.

The measured current is forwarded through the wireless communication medium to a computerin order to be processed by the energy monitoring client application before displaying it to the user in a readable format.

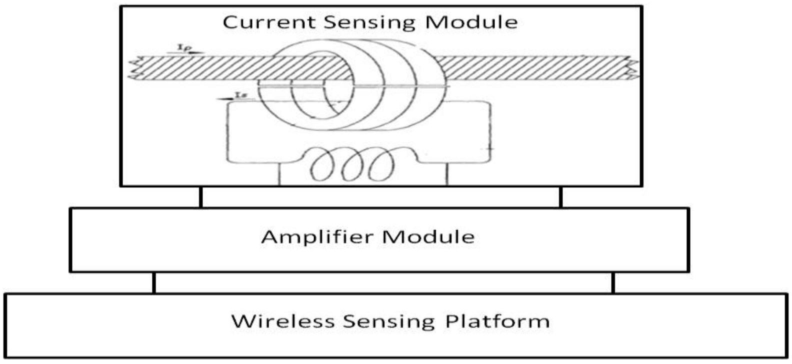

Figure 2 Wireless Energy Monitoring Platform

In this section we will explain in detail the design of the energy monitoring system, the functionality and characteristics of each of its components, and the design choices that we have made while designing this system.

3.1 WirelessSensing Platform

The main aim of this research work is to build an energy monitoring system for home appliances that uses an open platform in order to promote flexibility and compatibility with other monitoring system. To achieve this aim, we chose to use TelosB [19] an open sensing platform developed by the University of California, Berkeley. This wireless sensing platform, shown in Figure 3, has been designed with the purpose to enable cutting-edge experimentation for the research community. This sensing mote achievesminimal power consumption, while providing deployment flexibility and software and hardware robustness.

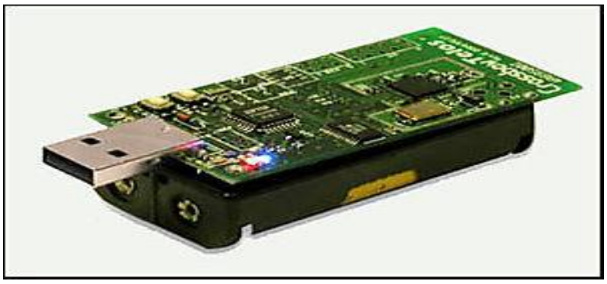

Figure 3 Crossbow TelosB Mote

As illustrated in Figure 4, typically wireless sensor mote consists of four basic components:

- **Sensing Unit**: This unit is composed of sensing components used to sense events, and Analog to Digital Converters (ADCs) which convert analog signals, produced by sensors based on the observed phenomenon, to digital signals. The TelosB mote used in this work is equipped with a temperature and acoustic sensors. However, in this work only the ADCs will be used to convert the analog signal produced by the current sensing module.

- **Processing Unit***:* The main task of this unit is the management of data processing procedures, such as processing sensing data, communication and data exchange procedures, etcTelosB mote is built over a MSP430F1611 processor that uses sleep mode while offering a fast wakeup. This feature ensures low power consumption and thus achieving longer battery life.

- **Transceiver Unit**: This unit connects the node to the network. As the sensor networks have low data rate, small data packets, and use short communication distances, the radio frequency (RF) communication is preferred in most sensor network research projects.The platform offers communication compatibility with IEEE 802.15.4/ZigBee [20] through its radio frequency (RF) transceiver.

- **Power Unit**:In a sensor node, power unit is one of the most important components because the lifetime of a sensor network depends on the lifetime of the sensor nodes battery

The TelosB sensing mote also offers an USB interface that allows plugging to a computer either for programming or communication purposes. Unlike other wireless sensing platforms that need a specific gateway to connect wireless sensing devices to the user, a TelosB mote could be connected to the user computer using its USB port, acting as the gateway between the user and the current sensing platform.

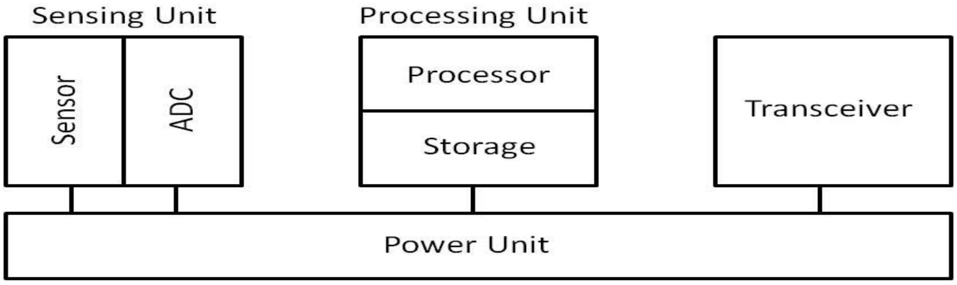

Figure 4 Architecture of a Wireless Sensor Mote

Finally, the TelosB platform provides expansion connectors and onboard jumpers that could be used to connect to other analog sensors and digital peripherals.

3.2 Electricity Current Sensing Module

The energy monitoring platform proposed in this workextends the TelosB sensing capabilities by adding a current sensor module to it, using the analogue expansion connectors for external sensors. This current sensor module is responsible for measuring the properties of the electric current that passes through the load feeding the monitored appliance.

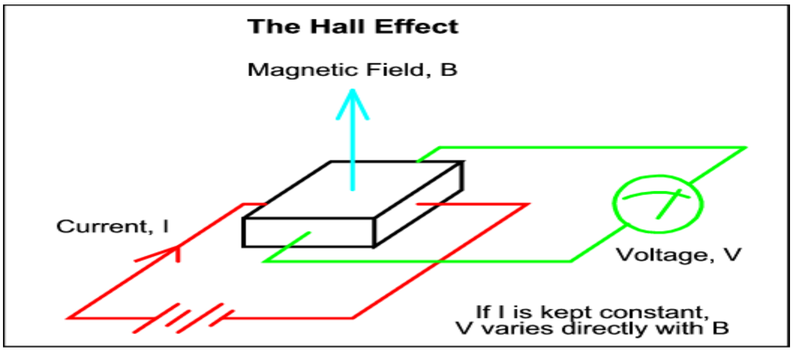

Figure 5 Hall Effect in Eletrcity Current

There are a number of current measurement methods that involve the design and integration of certain components and circuits. In addition to measuring the value of the electricity current, these techniques and components could be used to detect faults on the load.

These current measurement methods could be classified into two main categories:

- **Direct Measurement**: In this category of measurement techniques, a component is placed into the load to measure the electricity current. There isa number of direct measurement techniques such as: Current Sense Resistor, Inductor DC resistance, and Transistors [21].The resistor measurement is among the most common direct measurement methods. In this method, a resistor is placed in line with the current being measured and the value of the electricity current is measured using Ohm’s law [18].

- **Indirect Measurement**: This type of measurement methods exploits the magnetic field created by the passing current flow. There are many measurement techniques that exploit this property such as: Current Transformers, Rogowski Coil, and Hall Effect.The Hall Effect could be defined as the production of a voltage difference, called the *Hall Voltage*, across an electrical conductor, between the electric current in the conductor and the magnetic fieldperpendicular to the current, as illustrated in Figure 5. The Hall Effect sensing exploits this property by measuring the difference between the electricity current that flows through the wire and the resulting magnetic field. Figure 6 shows the current sensor that has been used in our energy monitoring system and the manner it is deployed to measure energy consumption in appliances.

Our aim in this work is to design an energy monitoring solution that does not require any modification of the electricity supply or deployment of the appliances. Therefore, we opted for a Hall Effect measurement technique due to it is a non-contracting approach and its accuracy even with low voltages as it the case with certain home appliances. In addition, this measurement technique is immune to external factors such as: dust, dirt, and water. Figure 6 shows the current sensor that has been used in our energy monitoring system and the manner it is deployed to measure energy consumption in appliances.

Figure 6 Current Sensor Based on Hall Effect

3.3 Signal Amplification Module

One of the main challenges in integrating the current sensor into the TelosB wireless sensingplatform is matching the output of the current sensor tothe wireless sensing platform reading input. The current sensor has very low output amplitude, and thus it needs to be amplified before it could be fed to the wireless sensing platform.In addition, the current sensor output value is formulated as an Alternative Current(AC), while the wireless sensing platform requires a Discrete Current(DC) as an input.

First, the AC signal generated by the current sensor is amplified using a non-inverting Operational Amplifier (Op Amp). The *Op-Amp*is a building block of electronic circuits that produce an outputvoltage larger than the voltage differencebetweenits input terminals (V_+, and V_-).As shown inFigure 7, the non-inverting *Op-Amp*output drives current into the resistor R1, and adds a negative feedback via voltage divider R_f. The voltage gain of the circuit G, is determined by the equation:$= 1 + {}^{R_f}\!/_{R_1}$, or by the equation: $G = \frac{V_{out}}{V_{in}}$.

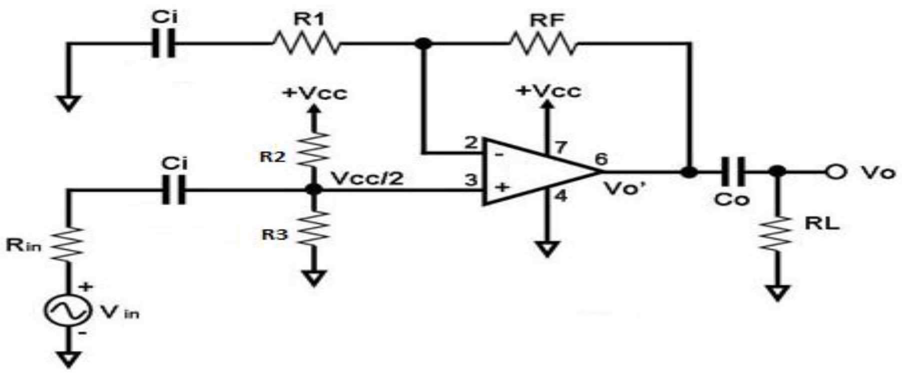

Figure 7 Signal Amplifier Model with Signal Rectifier

We assume that a home appliance energy consumption does not exceed 4000 watts, hence we set the voltage output that should go into the TelosB mote at: V_{out}= 2.5volts. Our measurements also showed that the measured voltage coming out of the current sensor is $V_{in} \cong$ 100mVolts. Therefore, the gain offered by the no-inverting *Op-Amp* should be:$G = \frac{2.5}{0.11} = 22.7$. By setting the value of R_1 to: $R_1 = 1k\Omega$, the value of the voltage divider $R_f$is: $R_f = 21.7k\Omega$.Finally, to change the signal from AC to DC we made few changes to the *Op-Amp*model shown previously, by adding a signal rectifier, as illustrated in Figure 7.

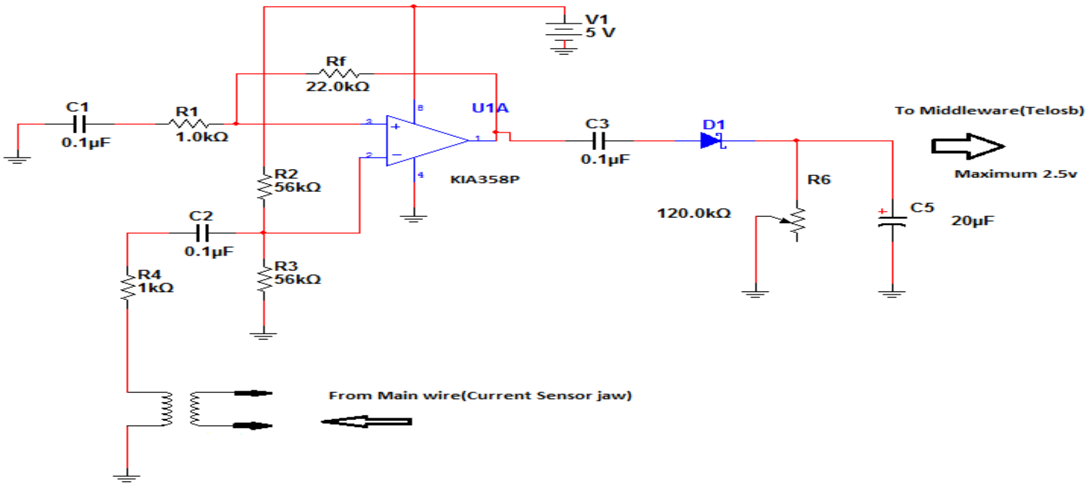

Figure 8 Signal Amplifier Model

We added a capacitor C3 that acts as an open circuit for DC voltage and a closed circuit for AC circuit, hence allowing AC voltage only. We connected the capacitor C3 to a *Schottky* diode (D1) which is used to drop the negative voltage. To remove ripple from the voltage, we used another capacitor C5 and a potentiometer R6, as shown in Figure 8 .

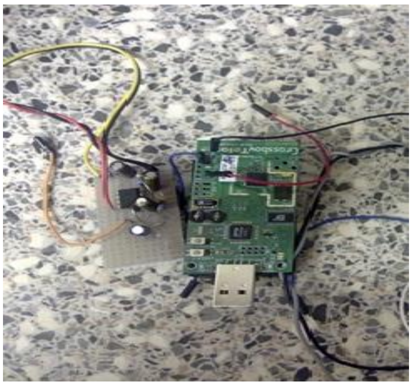

Figure 9 Energy Sensing Platform with Signal Amplifier

We added a capacitor C3 that acts as an open circuit for DC voltage and a closed circuit for AC circuit, hence allowing AC voltage only. We connected the capacitor C3 to a *Schottky* diode (D1) which is used to drop the negative voltage. To remove ripple from the voltage, we used another capacitor C5 and a potentiometer R6, as shown in Figure 8 .

3.4 Energy Monitoring Application

Deploying an accurate current sensor at the appliance and connecting it to the wireless sensing platform represents the first step into building the energy monitoring system. The measured data needs to be sent to the user using the wireless medium provided by the wireless sensing platform.

We designed an energy monitoring application that consists of two components: an energy monitoring agent that resides within the wireless sensing platform and an energy monitoring client that runs at the user-end.

A. Contiki Operating System:

We installed Contiki Operating System [22]on the TelosB sensing mote, a multi-taskingand open source operating system specially designed for low power embedded systems, such as wireless sensor mote.This operating system offers a light weight TCP/IP stack, called uIP that uses a very small code size, thus requiring low memory and computation resources. The uIP implementation is designed to have only the absolute minimal set of features needed for being TCP/IP compliant. The presence of this stack allows a full IP communication between the wireless sensor mote and the user through the Internet. Contiki operating system, offers an Application Programming Interface (API) that provides a number of functions to access, process, and transmit data collected by the wireless sensor mote.

B. Energy Monitoring Agent:

The energy monitoring agent has been developed using C programming language, and Contiki OS API, which offers a number of functions that allow accessing the data input received by the ADC module from the current sensor, and converting it from analogue to digital format. In addition to data conversion, the monitoring agent used the communication functions provided by Contiki API to send this data to the end-user.

C. Energy Monitoring Client

The energy monitoring client is a service that resides on the user computer and listens for data sent by the energy monitoring agent that resides on the wireless sensing mote deployed on the monitoring appliance. This client takes the data sent by the energy monitoring agent and displays it to the consumer using a graphic interface. We developed the energy monitoring client using C# programming language and we installed on a laptop computer connected with a TelosB mote connected to its USB port that acts a gateway between the user computer and the wireless sensing network.

IV. Test-bed and Evaluation

We set an experimentation test-bed with the aim to assess the performance of our energy monitoring system. We deployed two wireless current sensing platforms that have been designed according to the hardware architecture we proposed in this paper, as shown in Figure 10, and Figure 11.Our experiments focused on assessing the accuracy of energy measurement delivered by our energy monitoring system for different levels of power usage and voltages. We measured the energy usage of a number of appliances that have different energy usage levels (see Table 1) and compared them to the expected energy usage values.

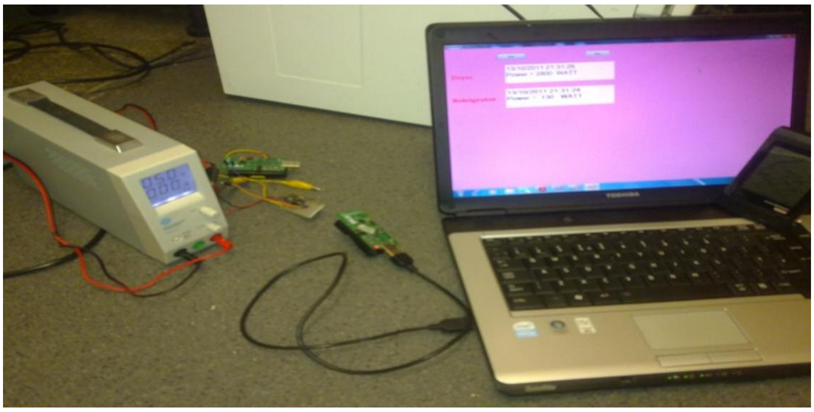

Figure 10 Open Energy Monitoring Platform

Category	Energy Usage	Appliance
Category 1	50 Watt to 400 Watt	lights, refrigerator and TV
Category 2	400 Watt to 1000 Watt	heater, iron and washing machine
Category 3	1000 Watt to 2000 Watt	microwave, Heater
Category 4	2000 Watt to 4000 Watt	Dryer, Electric cooker

Table 1 Energy Consumption Categories

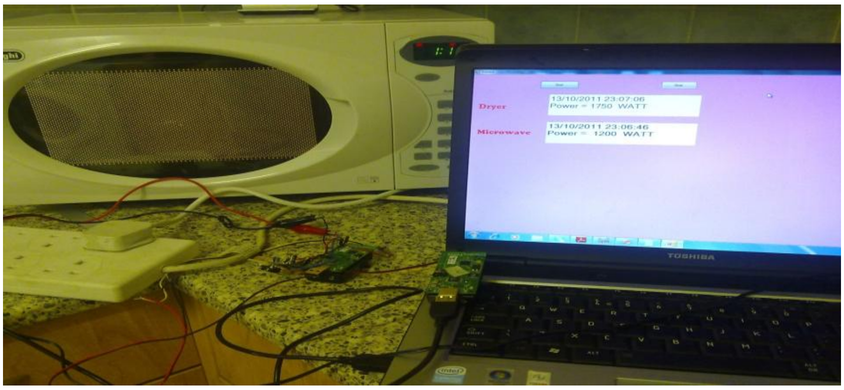

Figure 11 Energy Monitoring Testbed

Table 2 shows the energy usage results obtained using out energy monitoring system, and the energy result expected for each appliance. The expected results are taken from the technical information provided by the manufacturer of each appliance. Table 2 shows that there is a difference between the values measured using our energy monitoring system and the expected results. However, this difference is inversely proportional to the energy usage of the appliance. This results could be confirmed by the measurement accuracy presented in Figure 12.

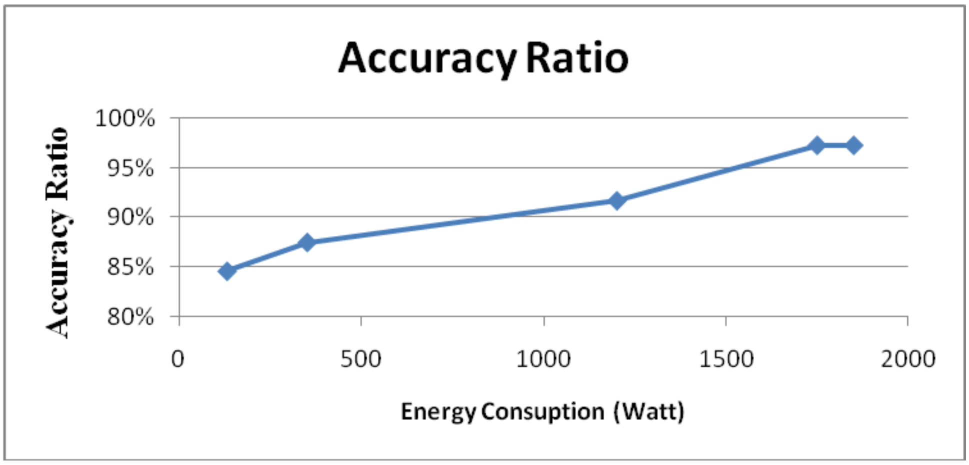

Figure 12 Energy Monitoring Accuracy

This figure shows that the measurement accuracy increases as the energy usage of the appliance increases. Thiswas expected as the measurement of low energy devices will produce a low signal which becomes hard to differentiate from noise signal even with the presence of a signal amplifier.

Appliance	Measured Value	Real Value
Refrigerator	110 Watt	130 Watt
TV (50inch)	400 Watt	350 Watt

Microwave Oven	1100 Watt	1200 Watt
Clothes Dryer	1800 Watt	1750 Watt
Heater	1800 Watt	1850 Watt

Table 2 Energy Consumption Measurements vs Real Values

V. Conclusion and Future Work

Appliances and electrical devices are important consumers of electricity in houses and commercial buildings. In order to achieve energy efficiency, it is important to increase consumers' awareness about their energy usage. In this paper, we presented an energy monitoring system that allows consumers to obtain information regarding the energy usage of their appliances. The proposed system offers an accurate view of appliances' electricity consumption in real time. This system adheres to the vision of the Internet of Things by offering opportunities to extend its functionality, and cooperation with other monitoring services through its open source platform. In future work, we will exploit these opportunities, by integrating this system which other types of home monitoring such as: temperature, occupancy, etc. We believe that this integration will allow appliances to adapt their energy usage according to their operating context, and to the consumer's energy saving policy.

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