# Cloud-based Low-cost Energy Monitoring System through Internet of Things

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***Abstract*—With the ever-increasing capacity of the Internet and demand for human lives, Internet of Things (IoT) applications is increasing like never before, primarily to facilitate smart homes and smart cities. However, consumers have become increasingly cognizant of the negative effects of energy consumption as well as the importance of footprint reduction. Despite the increased interest in energy reduction and consumption, the average consumer still feels intimidated and unsure of how to start. In this paper, we propose an energy monitoring system (*WattsOn*) to be used per room within a house that is efficient, intuitive, and economic (cost effective). The significant contribution of this paper is the design and development details of *WattsOn* prototype application. *WattsOn* is a low-cost IoT and cloud-based system that allows end-users to monitor, store and display energy usage data in an intuitive graphical user interface. As part of this system, we have also developed companion mobile applications in both platforms (Android and iOS), which allows the users to look at the real-time energy usage for the entire house or building to best pinpoint where excess energy is being used to understand better how to reduce consumption. The widespread use of our system will provide several benefits like saving on electricity bills by monitoring the usage and conserving the precious natural resources by reducing electrical energy consumption.**

***Index Terms*—IoT (Internet of Things); Cloud Computing; Energy Consumption; Smart Home; Security**

## I. INTRODUCTION

There is a massive development in new smart-houses. Smart-houses, which are houses equipped with highly advanced automatic lighting systems, temperature control system, security control mechanisms, and many other functions, can be seen everywhere in the world. Additionally, traditional buildings and smart facilities are increasingly expected to meet higher energy performance requirements [1]. Among these requirements, energy efficiency is recognized as an international goal to promote energy sustainability of the planet. Different approaches have been adopted to address this goal, the most recent relating the use of low cost small sensors, which are also known as Internet of Things (IoT).

IoT is one of the most recent revolutionary technologies, which consists of integration of sensing as well as communication capabilities to common things, in order to gather useful data. IoT enabled devices can be used to monitor various important physical, electrical or environmental parameters. This information is used to analyze, identify and solve different problems related to everyday life [2]. Power or energy management for efficient use of electricity is one such important problem, which can be addressed using IoT technology. IoT enabled energy monitoring devices can help solve this problem by providing granular information about electricity consumption. Up to present, many energy control methods have been proposed. By utilizing IoT, we developed a tablet-computer based Home Energy Management scheme to monitor the consumption of home energy [3]. With this scheme, users can set up management policies to control home energy consumption based on the time of a day. Researchers and applications developers proposed a smart technology, which provides real-time information about home energy consumption to users [4], [5], [6]. Other researchers allow the user to control the electric devices using a smartphone or a web-based interface [3], [7]. The main goal of all these technologies is raising consumers' energy consumption awareness, inspiring them to be more energy efficient.

However, to ensure widespread adoption of modern smart homes and ensure efficient energy usage in traditional homes, end users need a convenient and non intimidating approach to track energy consumption in a way that empowers them to pinpoint where they can cut back usage. Research shows that the most effective strategy users believe they could implement is to conserve energy (e.g., turning off lights, driving less) rather than efficiency improvements (e.g., installing more efficient light bulbs and appliances). This contrast affirms that end users have a skewed perception of energy consumption, which is also highlighted in [8]. The serious deficiencies highlighted by these results suggest that well-designed efforts to improve the public's understanding of energy use and savings could pay large dividends.

To address this problem, in this paper we present WattsOn, a low-cost IoT based system providing consumers with a home monitoring technology that tracks energy usage within each room. The data collected is averaged every thirty minutes and pushed to the secure cloud database. Finally, an Android or iOS device can display the energy consumption to the client in an easy to understand interface. Customers can view their data consumption within their house in a way that is broken down into each room. This feature allows the residents within a house to identify what rooms are using excessive energy at specific times in order to address wasteful habits or appliances. The goal of our system is to reduce society's overall energy consumption by providing an easy way to address where

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excess consumption is occurring. This holds each person accountable for doing their part to reduce unnecessary usage. As energy consumption goes down, the overall footprint of consumers will decrease, benefiting nature and the economy. The benefits of this system range from a micro-scale to a macro-scale seamlessly - from roommates splitting the electric bill to large-scale corporations reducing energy emissions.

Paper Organization: The rest of the paper is organized as follows: Section II describes relevant related works. Section III briefly presents the system architecture of WattsOn system. Section IV presents development details of our system. Section V presents the prototype implementation of the system. Section VI presents limitations and future research directions. Finally, Section VII concludes the paper.

## II. RELATED WORK

IoT and mobile technologies have opened the door for many solutions to conduct in-home energy monitoring. By utilizing IoT, researchers developed a mobile Home Energy Management scheme to monitor the consumption of home energy. Kopytoff and Kim developed a power meter, which provides real-time information about home energy consumption to users [4]. Aram et al. [9] contributed to the energy conservation approaches by reducing the amount of required communication. Lee et al. [10] designed an intelligent power management device, which adopts user's locations, motion detection, and living patterns as its parameters to reduce the energy consumed by some appliances, like lights and humidifier. As a sensor-based system, it could achieve 7.5% of power saving. Han and Lim introduced a home energy control system developed based on ZigBee and smart meters to provide users with intelligent services to enrich their lives [11]. Lien et al. [12] proposed a wireless power-controlled outlet module, which manages home power with a scalable mechanism using various sensors, such as temperature sensor, distance sensor, position finder, a passive infrared sensor, and ambient light sensor to sense the users' related data. Some other systems making use of additional microcontroller platforms like Arduino boards [13], [14], [15], and ATMEGA microcontroller board [16] have also been proposed for energy management. However, each of the technology has its pros and cons. Most of the technologies as mentioned earlier work when the devices and appliances are smart or equipped with smart meters. Additionally, the use of WiFi provides more extended range and higher data rate at the expense of more power consumption. ZigBee requires additional hardware deployment in the form of individual receivers and gateways. Bluetooth suffers from small range and low data rate. Our system is different from these technologies since our system is not dependent on any smart meters; instead, it is designed to work with traditional appliances in regular homes. It can monitor energy consumption in a house even if the appliances used are traditional and do not require any additional intelligent hacking.

## III. SYSTEM OVERVIEW OF WATTSON

The entire design of WattsOn system is divided into three significant subsystems - 1) Data Acquisition and Computing Module, 2) Remote Data Storage Module and, and 3) Mobile Application Module. The Data Acquisition and Computing Module primarily consist of various hardware and sensors that are necessary to collect data associated with each electrical device in each room within the house. The Remote Data Storage Module consists of database functionalities, which is in charge of creating and maintaining the cloud-based database. This database reflects the hardware and mobile applications' setup including security assurance. The third unit of our systems is the Mobile Application Module, which comprises two mobile applications (for Android and iOS users). Both Android or iOS users can access their data consumption via a user-friendly companion mobile application for WattsOn System.

### *A. System Architecture and Data Flow*

The WattsOn system is a fully integrated system with data flowing from hardware components, through a cloud database system, and eventually to our mobile applications (See Figure 1). On the hardware side, each Current Transformer (CT) clamp represents a circuit breaker to specific rooms or areas in a residence. CT clamps connect to an AC lead, which collects the energy usage simultaneously and is converted into digital signals through an Analog to Digital convertor. The data is sent to the Raspberry Pi Unit, which sends it to the database. Finally, the energy consumption data is pulled by our mobile application for each user account, which is displayed to the user in a user-friendly visual format.

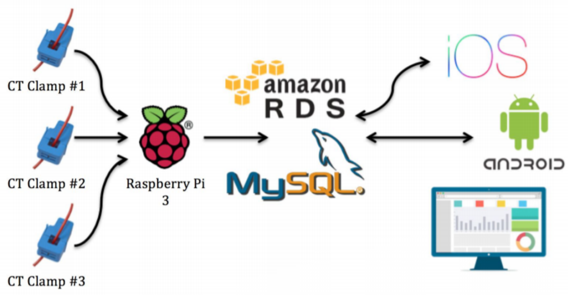


Fig. 1. Architecture diagram of WattsOn system

The data flow diagram is shown in Figure 2.

### *B. Hardware Sensing Devices*

We used a low-cost CT Clamps, to achieve our goal of creating a low-cost, effective, and simple data acquisition system. Our target is to collect the energy data from the AC feed behind the circuit box. It also creates an analog to digital converter with an ADC chip connected to a breadboard. This breadboard setup is fed the analog signal from the CT Clamp, and the digital output is sent to a Raspberry Pi 3. The Raspberry Pi 3 was chosen as an IoT device for two main reasons: it is wireless capabilities, and it is also a small,

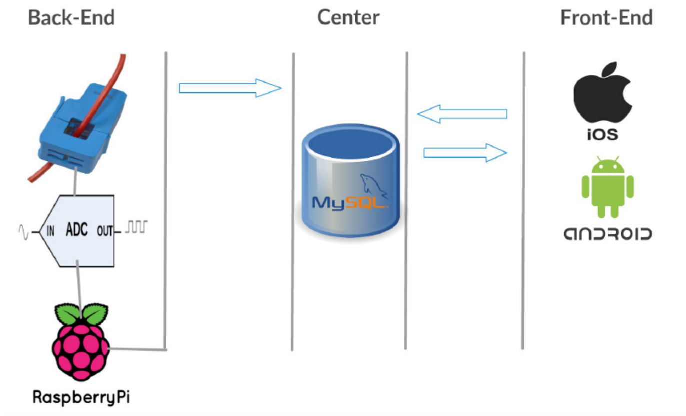


Fig. 2. Data flow diagram of WattsOn system

inexpensive, and powerful computing device. The Raspberry Pi's usability allows to process data and push it to the cloud-based database accurately and efficiently.

## IV. DEVELOPMENT: DATA SENSING, PROCESSING, AND STORING

In this section, we present the development details related to the various modules of our system.

### A. *Data Acquisition*

The energy consumption data is acquired using CT clamps attached to a single wire in a stripped extension cable which is plugged into a regular 120 Volt 60Hz power outlet. The leads of the clamps are connected to the breadboard where the analog to digital converter (ADC) converts the analog output of the clamps to a digital signal, which is interpreted by the Raspberry Pi 3, where it is processed and pushed to the database.

### B. *Data Processing*

Processing the data that is pulled from the clamps is controlled entirely from the IoT device (Raspberry Pi 3). A converter unit (consisting of python scripts) on the Raspberry Pi converts the received digital signal to a correct, readable value based on the CT clamp calibration (See Figure 3). The calibrated data are averaged every 30 min intervals and are finally sent to a cloud-based secure database (e.g., Amazon Relational Database Service) that runs a MySQL Server. Once a batch of data has been pushed to the database, the connection is closed. Since our system needs continuous monitoring, the system immediately returns to the pull function and starts to collect data for another 30 minutes to be pushed once again to the database. Multiple separate converter units run on the startup of the Raspberry Pi. Each unit is for a specific CT Clamp as to ensure that if a clamp fails, the other three will continue to run and collect data. The only way that the units should be shut down is if an admin stops all CT manually by connecting to the Raspberry Pi or if power is lost to the whole system. This module also has an email function that ideally would never actually be called but is there to catch any error that may occur within the system. This function uses the imported Simple Mail Transfer Protocol (SMTP) module to connect to an email server and send an email that states that a CT clamp has experienced an error and that the connection should be checked. The email also provides a customer service number to call if the error is not fixed by checking the CT clamp connection. This function is only executed if there is an error in the pull or push functions.

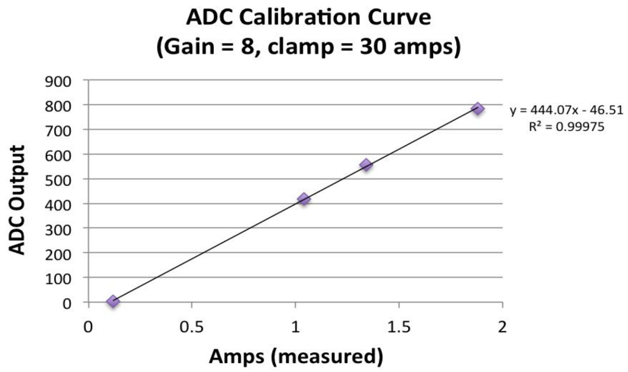


Fig. 3. Calibration on collected data from CT clamps

### C. *Database Specifications*

The database for WattsOn system is hosted in Amazon Web Services [17]. The database is also associated with a Virtual Private Cloud (VPC) to keep it publicly accessible. In order to store all the Restful application programming interface (API) somewhere that is easily accessible we used a virtual computing server. For this, a virtual machine (VM) on Elastic Compute Cloud (known as EC2) is used which allows the system create a virtual machine that can ran on Amazon's computing environment. The basic idea is to follow the LAMP platform in order to establish the VM. The LAMP procedure used Linux as the operating system, Apache as the web server, MySQL as the relational database and PHP as the scripting language. In order for the user to have the necessary interactions with the database, rather than obtaining the information directly from each of the applications, an Application Programming Interface (API) was created. In this case, the API is written in PHP, as PHP excels in connecting with MySQL type databases and password hashing functions. This API is hosted by Amazon Web Services, and is residing on an Apache Web Server to make it publicly accessible by all of the front-end applications.

## V. PROTOTYPE IMPLEMENTATION AND EVALUATION

To evaluate our proposed system, we implemented a prototype of WattsOn and also developed companion mobile applications in both Android and iOS. The performance of our system is analyzed on the basis of the accuracy of power data collection, conversion and finally displaying energy consumption in the mobile application [18]. We also analyze the performance of WattsOn based on the security, computation accuracy and cost.

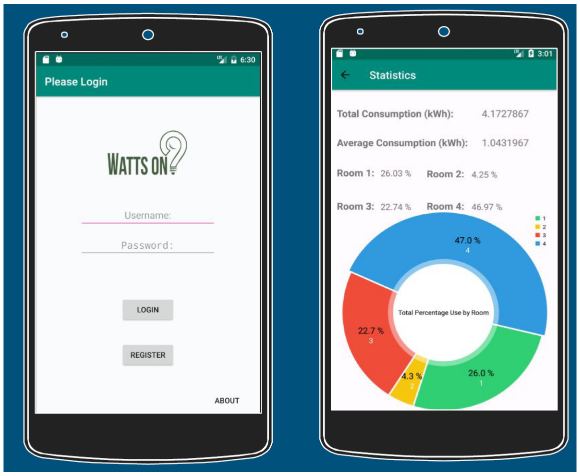
## *A. Android Mobile Application*

As a first step towards validating the project, we created a prototype application (user interface) that allows end-users to navigate through the various activities (See Figure 4). The prototype is an Android mobile application; the user opens that app, is presented with a splash screen that guides the user to the primary login page. This screen involves a flashing animated GIF file of the application's main logo. On this login page, there is an 'about' button on the bottom right of the screen. When clicked, this button shows a new page that briefly describes the main purpose of the application, while providing logo buttons that lead the user to the various social media pages. To create an account, the user needs to click the 'Register' button on the login page and enter their first name, last name, email, username, password, and phone number. All information is checked for validation. This information goes directly to the cloud-based database, while calling upon the respective application program interface (API) method to hash the password. Once the user is registered, the user is automatically sent to the login page, where they are now able to log in with their registered username and password. Once the user is logged in, they are presented with the Main Activity, which consists of three fragments in a tab view layout. These tabs are *Home*, *Monitor*, and *Settings*. To navigate between each fragment, the user needs to swipe between each tab merely.

The *Home* tab simply welcomes the user that is logged in. The *Monitor* tab includes a bar graph, created with the assistance of the open source library *MPAndroidChart* [19]. This bar graph directly represents the table shown in the bottom half of the tab. This table shows each of the four rooms corresponding the four clamps that are sending data to the database. Each room shows the latest updated energy consumption value from the database in kilowatt hour (kWh). The button *View Statistics* at the bottom of the activity takes the values seen in the table, and passes them to another activity called *Statistics*. This activity takes the passed values from the previous activity and calculates the total consumption, average consumption, and total percentage use by room. These percentages are parsed into an interactive pie chart to provide a clean graphical interface to see the exact percentage of each of the room's usage, to determine which room to should be using more or less energy. Navigating back to the tab layout, there is a *Settings* tab. This tab is a list of the user/home profile, about page, and logout page. The user profile shows the contents of the user logged in, and provides a space for the user to reset their password.

## *B. iOS Mobile Application*

In case of the iOS application (See Figure 5), when the user registers, the information that the user inputs goes directly to the database while calling upon the respective API method to hash the password - providing secure encryption for each account's password. However, before any of this data is sent to the database it is validated locally to ensure that valid, as well as matching, data is being entered. If there is an issue with the data being entered, then the user receives an alert detailing the problem. Once the user has successfully registered their account, the user is automatically re-directed to the Login page, where they are prompted to log in with the credentials that they just registered into the database. From the Home page, a user can see a *Logout* button that will safely end the current session within the application and sign user account out.



Total Consumption (kWh): 4.1727867
Average Consumption (kWh): 1.0431967
Room 1: 26.03 % Room 2: 4.25 %
Room 3: 22.74 % Room 4: 46.97 %

Fig. 4. Login and energy consumption statistics per room

Room Energy Breakdown
Room #1 1.09 kWh
Room #2 0.18 kWh
Room #3 0.95 kWh
Room #4 1.96 kWh

Fig. 5. iOS version of the Application

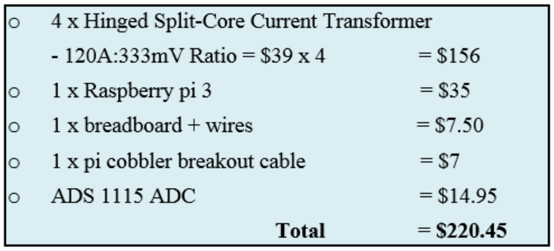
Additionally on the bottom of the navigation bar, there are two other pages: Data Display and Settings. The Data Display page has a pie chart and table view that will display the energy usage for the home of that user. The user can reset the data by clicking on the "reset data" button, as well as refresh the data with the “Update Data” button. The pie chart is interactive and can be rotated to allow the user to view the chart more easily. The Settings page allows the user to see two categories: Account Information, and Misc and Support. Under the Account Information Page header, there is a field that says “My Account” that gives the user the ability to edit their personal information.

### *C. Security Analysis*

Security and privacy are very essential in these types of application [20]. Developers and researchers tend to release these types of system without a sufficient study of the security measurement and privacy concerns [21], [22]. Users should be informed of any privacy or security concerns while using these systems [23]. The current security of the server is very strict and anyone without legitimate credentials cannot access both the cloud or the cloud-based database (e.g., Elastic Cloud Computing (EC2) and the Relational Database Service (RDS)). Currently, there are two types of security implementation in the servers. The first security is that the database requires a user to sign in with a username and password. The second security feature implemented into the system is the Virtual Private Cloud (VPC). Additionally, since the companion mobile applications for WattsOn deals with private information, secure transmission of all data is necessary. There should be sufficient security mechanism to provide authenticity of data and to prevent illegitimate users from accessing or modifying power data. Hence, to provide better security, the mobile application API does password hashing, which makes use of the *BCRYPT* function, based on the Blowfish cipher, a very strong algorithm that is resistant to traditional password cracking techniques [24]. We are aware of the existing of better security techniques. Hashing the user’s password ensures integrity, as the hash cannot be reversed, even if the hashed password is stolen from the database using an attack such as SQL injection.

### *D. Cost Analysis*

As summarized in Figure 6 , the cost of the system is moderate ( $220.45). There is no additional microcontroller board used in the power monitor sensor. Additionally, the hardware used is considerably low cost in comparison with commercially available monitoring devices. The companion mobile application can be downloaded and used for free.



| | | |
|---|---|---|
| o | 4 x Hinged Split-Core Current Transformer | |
| | - 120A:333mV Ratio = $39 x 4 | = $156 |
| o | 1 x Raspberry pi 3 | = $35 |
| o | 1 x breadboard + wires | = $7.50 |
| o | 1 x pi cobbler breakout cable | = $7 |
| o | ADS 1115 ADC | = $14.95 |
| | **Total** | **= $220.45** |

Fig. 6. Total cost breakdown for proposed system

## VI. DISCUSSION AND FUTURE WORK

There are several limitations of our current system. To start with, our system is merely a prototype and further research needs to be done to ensure that the system works accurately with as minimal false positives as possible. For example, we didn’t perform a rigorous testing of WattsOn in real environment, which we are planning to incorporate in our next version. Some of the other future works are very specific to the companion mobile applications while the rest are related to the overall research investigation. Next we summarize some of our future work and research directions:

- To solve the case of roommates or (housing sharing), individual registration page to register users to the system, which eventually will add user to the database. This would also allow multiple users to have multiple Raspberry Pi units assigned to a home, rather than using one unit that might not be suitable for a larger house. This would also require the addition of a home profile, and an option to edit the home profile (in the case that the user were to move).
- Adding a “History” page consisting of user’s energy consumption records. A similar page can also show how much money has been saved over a period of time, as well as making suggestions of how to decrease consumption.
- Currently, the database has three roles (Front, Center (Admin), Back) and all roles are allowed to have full access to the database. This can be seen as a major flaw because if a user, who is not an expert in a certain field, try and change rules to another part of the system, they may potentially bring down entire server unknowingly. The solution to this is to create IAM roles (securely control individual and group access) within the cloud-based server, that limits the privileges of the user working on the system. In addition, by creating IAM roles, it means that each and every individual user can have their own login identity, which also allows the manager to assign certain IP range to certain subgroup of the system.
- Another direction that needs further research is the design of the box containing the hardware. This will result in a box that is both more aesthetically pleasing and durable. It can be made out of a material that is light so that it can be mounted on a wall as well a water proof to protect the circuitry from water damage such as plastic or fiberglass. This material can also provide protection from any potential mild to moderate impacts.
- In order to provide better user experience and accuracy, we plan to investigate how to handle errors in data collected from the clamps.

## VII. CONCLUSIONS

People in this century have become increasingly aware of the negative effects of energy consumption as well as the importance of footprint reduction. To help people make informed decision about everyday energy consumption, in this paper, we presented the design and development details of a simple, secure and cloud-based system (WattsOn) to monitor every day energy consumption, which makes use of latest Internet of Things (IoT) technology. WattsOn provides an approachable, efficient, and easy to use service that can help end users to reduce energy consumption. It gives society the power to directly pinpoint what, where, and when energy is being consumed in order to address where excess occurs. Not only this will save consumers financial burden, but also it will reduce their overall footprint on the environment.

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## REFERENCES

[1] B. P. Jelle, "Traditional, state-of-the-art and future thermal building insulation materials and solutions–Properties, requirements and possibilities," *Energy and Buildings*, vol. 43, no. 10, pp. 2549–2563, 2011.

[2] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for smart cities," *IEEE Internet of Things journal*, vol. 1, no. 1, pp. 22–32, 2014.

[3] W. T. Hartman, A. Hansen, E. Vasquez, S. El-Tawab, and K. Altaii, "Energy monitoring and control using Internet of Things (IoT) system," in *Systems and Information Engineering Design Symposium (SIEDS), 2018*. IEEE, 2018, pp. 13–18.

[4] V. Kopytoff and R. Kim, "Google plans meter to detail home energy use," *San Francisco Chronicle*, 2009.

[5] A.-R. Al-Ali, I. A. Zualkernan, M. Rashid, R. Gupta, and M. Alikarar, "A smart home energy management system using iot and big data analytics approach," *IEEE Transactions on Consumer Electronics*, vol. 63, no. 4, pp. 426–434, 2017.

[6] K. Akkaya, I. Guvenc, R. Aygun, N. Pala, and A. Kadri, "Iot-based occupancy monitoring techniques for energy-efficient smart buildings," in *Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE*. IEEE, 2015, pp. 58–63.

[7] K.-L. Tsai, F.-Y. Leu, and I. You, "Residence energy control system based on wireless smart socket and iot," *IEEE Access*, vol. 4, pp. 2885–2894, 2016.

[8] S. Z. Attari, M. L. DeKay, C. I. Davidson, and W. B. De Bruin, "Public perceptions of energy consumption and savings," *Proceedings of the National Academy of sciences*, vol. 107, no. 37, pp. 16 054–16 059, 2010.

[9] S. Aram, I. Khosa, and E. Pasero, "Conserving energy through neural prediction of sensed data." *JoWUA*, vol. 6, no. 1, pp. 74–97, 2015.

[10] M. Lee, Y. Uhm, Y. Kim, G. Kim, and S. Park, "Intelligent power management device with middleware based living pattern learning for power reduction," *IEEE Transactions on Consumer Electronics*, vol. 55, no. 4, 2009.

[11] D.-M. Han and J.-H. Lim, "Design and implementation of smart home energy management systems based on zigbee," *IEEE Transactions on Consumer Electronics*, vol. 56, no. 3, 2010.

[12] C.-H. Lien, Y.-W. Bai, and M.-B. Lin, "Remote-controllable power outlet system for home power management," *IEEE Transactions on Consumer Electronics*, vol. 53, no. 4, 2007.

[13] A. Ellerbrock, A. Abdel-Majeed, and S. Tenbohlen, "Design and building of a cheap smart meter," *Institute of Power Transmission and High Voltage Technology, University of Stuttgart, Tech. Rep*, 2012.

[14] C. Gu, H. Zhang, and Q. Chen, "Design and implementation of energy data collection system using wireless fidelity (wifi) module and current transformer," in *System Science and Engineering (ICSSE), 2014 IEEE International Conference on*. IEEE, 2014, pp. 133–137.

[15] C. Klemenjak, D. Egarter, and W. Elmenreich, "Yomo: the arduino-based smart metering board," *Computer Science-Research and Development*, vol. 31, no. 1-2, pp. 97–103, 2016.

[16] Q. M. Ashraf, M. I. M. Yusoff, A. A. Azman, N. M. Nor, N. A. A. Fuzi, M. S. Saharedan, and N. A. Omar, "Energy monitoring prototype for internet of things: Preliminary results," in *Internet of Things (WF-IoT), 2015 IEEE 2nd World Forum on*. IEEE, 2015, pp. 1–5.

[17] E. Amazon, "Amazon web services," *Available in: http://aws. amazon. com/es/ec2/(November 2012)*, 2015.

[18] S. El-Tawab, S. Iskandarova, M. Almalag, and P. Ghazizadeh, "A methodology of teaching mobile development for undergraduate students in project-based classes," in *Proceedings of Society for Information Technology & Teacher Education International Conference 2018*, E. Langran and J. Borup, Eds. Washington, D.C., United States: Association for the Advancement of Computing in Education (AACE), March 2018, pp. 749–754. [Online]. Available: https://www.learntechlib.org/p/182606

[19] P. Jahoda, "A powerful & easy to use chart library for Android."

[20] C. Bradley, S. El-Tawab, and M. H. Heydari, "Security analysis of an iot system used for indoor localization in healthcare facilities," in *2018 Systems and Information Engineering Design Symposium (SIEDS)*, April 2018, pp. 147–152.

[21] K. Evers, R. Oram, S. El-Tawab, M. H. Heydari, and B. B. Park, "Security measurement on a cloud-based cyber-physical system used for intelligent transportation," in *2017 IEEE International Conference on Vehicular Electronics and Safety (ICVES)*, June 2017, pp. 97–102.

[22] M. U. Farooq, M. Waseem, A. Khairi, and S. Mazhar, "A critical analysis on the security concerns of internet of things (iot)," *International Journal of Computer Applications*, vol. 111, no. 7, 2015.

[23] E. Zeng, S. Mare, and F. Roesner, "End user security & privacy concerns with smart homes," in *Symposium on Usable Privacy and Security (SOUPS)*, 2017.

[24] N. Provos and D. Mazieres, "Bcrypt algorithm." USENIX, 1999.

[25] E. H. Salib, J. A. Erney, and M. E. Schumaker, "Designed-for-motivation based learning for large multidisciplinary team one semester hands-on network based course case study," in *Proceedings of the 2013 American Society for Engineering Education Annual Conference & Exposition*, 2013.