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Procedia Computer Science 160 (2019) 142–148

Procedia Computer Science

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The 10th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN 2019)
November 4-7, 2019, Coimbra, Portugal

IoT-Based Home and Community Energy Management System in Jordan

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Abstract

Due to the increasing demands on energy, energy savings have witnessed a great research community attention over the last decades. Currently, home electric-energy bill causes a headache for habitants in modern cities. Many home appliances are available and to some extent are necessary for moderate life. Some of appliances failure can go unnoticed. Careful monitoring and management of current drawn for every appliance in house can save user a great deal of money. In this paper, an IoT board is designed. This board consisted mainly from a microcontroller, Wi-Fi module and current sensor is manufactured as a small printed circuit board to be connected in series with each appliance in a house. Such integration provides a layer of monitoring for the overall energy consumption and ensures proper functioning of each appliance through monitoring its current range. Each outlet and switch in the house is monitored for power consumption around the clock. A smart collection and analysis of currents drawn by different loads results in a valuable feedback for the users and a way of curtailing peak consumption for the community.

Keywords: IoT-board; Home Energy Management; Current Sensing; Normative feedback; HEMS

1. Introduction and Background

Due to the increasing demands on energy, energy savings have witnessed a great research community attention over the last decades. Several solutions have been proposed to manage the energy consumption. One of the efficient methods in saving the energy consumption is the appliance load monitoring (ALM) methods for both residential and commercial use [1, 2, 3], in which ALM provides readings of the energy consumed. Generally, there are two broad approaches for ALM, which are intrusive load monitoring (ILM) and non-intrusive load monitoring (NILM). NILM needs a single sensing point on the main electrical panel of the energy service. Current drawn by all loads within a house is captured and then analyzed using neural network techniques [4, 5]. After that, based on the patterns of

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10.1016/j.procs.2019.09.454

currents drawn by the house, loads can be separated and their consumption are recorded. Recommendations or/and actions can be taken on specific loads to meet the user preferences of energy consumption.

Although NILM approach is a cost-effective approach, ILM is more accurate than NILM. ILM is based on using distributed sensing units attached to every appliance in the house or the commercial building. This paper focuses only on the ILM techniques; however, NILM is needed for general-purpose plug where loads are not known in advance. NILM investigation is out of the scope of this research.

IoT-based home energy management systems were heavily studied. Authors in [6, 7], utilized the IoT theme for remotely control devices. Applications of an IoT in controlling air conditioning devices and the like to optimize energy consumption has been studied in [8, 9, 10]. IoT system for DC-based homes were studied in [12]. Y. T. Lee et al. [11] proposed a cloud-based community hierarchy architecture for smart home energy management system. Users are informed by the total energy usage from several sensors connected to home devices. Community representative is connected to the system of all houses in the area via MQTT broker. They do not mention anything about health-monitoring capabilities for appliances inside houses. Energy management information were distributed via in-home displays in [13], further a discussion of automatic meter reading (AMR) was provided. Regarding the communications in home energy management systems (HEMS), authors of [14] addressed a power-line-communication scheme based on HTTP protocol. A residential gateway controller was proposed by authors in [15] to generate a plan for appliances usage in the connected houses considering weather conditions in Japan. M. Erol-Kantarci and H. T. Mouftah [16] proposed a WSN for optimization of energy consumption for consumers. They used several scenarios for optimization in community of consumers such as time of use tariffs, peak load hours, etc. Compared with no management systems their proposed system performance in terms of energy usage expenses is good. Energy management systems can achieve savings in electricity consumptions in range of 16-20% [17, 18]. In [19], authors proposed a system that enables users to watch their energy consumption by logging into a webpage. Their system aggregate power consumptions of home appliances and sends them to google documents where users can see their consumptions from time to time and tune usage accordingly.

In Jordan, there are seven tariff slices, in kilowatt-hour (KWH)/month, for houses ([0, 160], [161, 300], [301, 500], [501, 600], [601, 750], [751, 1000], above 1000). The slope increases when moving up through the slices and a jump in the total bill value occurs at 300 KWH/month because fuel-price differences is added as in Fig. 1. A careful monitoring of energy consumption during the month can save some amount of money.

This paper proposes an IoT solution for home energy monitoring and management in Jordan. The main aim of this solution is to reduce home-energy consumption cost and to keep the community consumption peak below a safe limit of the distribution network. This solution provides information about energy consumption and offers recommendations to the users based on their preferences and on the normal usage between community members. Normative feedback, [21, 22], proved to be effective in forming a good consumers' behavior in reducing energy consumption. In Jordan, many people ask their neighbors about their energy consumption to estimate normal usage of the energy. Based on the estimation one can see if her/his consumption is above or below the normal in his neighborhood to manage his own energy consumption. However, the proposed system in this paper collects data about energy consumption and recognizes similar consumption patterns to give a more precise and easy to access estimate of normal usage of energy. Moreover, appliances health in a house is observed and reported to the user for further actions based on currents drawn by the appliances.

The main component of this solution is an IoT board with Wi-Fi module, current sensor and a relay. This board has been designed and manufactured as a small printed circuit board to be connected in series with each appliance in a house. Thus, the system monitors the overall energy consumption and ensures proper functioning of each appliance through monitoring its current range.

The main contributions of this paper are:

1. Design and development of an inexpensive IoT board.
2. A simple framework for HEMS.
3. Employment of the proposed framework in Jordan to:
   (a) Keep community energy consumption peak below a safe limit.
   (b) Monitor appliances health through tracking electric current range.
   (c) Offer recommendations for users to optimize energy cost.

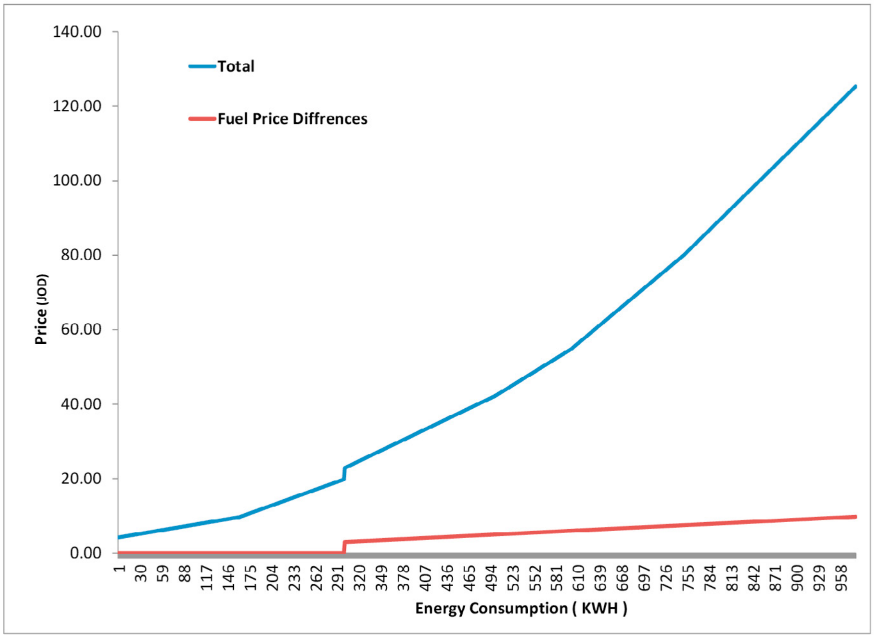

Fig. 1. Home energy tariff slices in Jordan.

The rest of this paper is organized as follows. Section 2 describes the architecture of the proposed system the encompass three levels. User level and its role in energy consumption reduction is discussed in Section 3. Administrator role is provided in Section 4. In Section 5 the developed board is shown. Paper is concluded in Section 6.

2. System Architecture

The proposed system architecture is shown in Fig. 2. The system consists of three main levels:

1. House level: where each appliance in the house is connected to power supply via IoT board (designed in this paper). Each house is connected to the upper level (IoT platform) via MQTT protocol [24].
2. IoT platform: There are many available commercial platforms such as AWS IoT Core from Amazon, Azure IoT Hub from Microsoft, and Google IoT Core from Google [23]. An IoT platform connects the lower level with the level of users. An MQTT protocol is used from/to house level and a HTTP protocol is used from/to users' level.
3. User/Admin level: Those are the consumers of the data aggregated by IoT boards in houses and the decision takers regarding the objectives of the system. For the user the objective is to control her/his appliances working time to lower his energy bill. While the admin objective is to maintain the consumption peak at any time below certain safe limit and to provide the users with recommendation (in the form of normative feedback) and diagnosis for their appliances.

For the aforementioned system, the problem at hand can be stated as follows: "Given n houses in a community with m appliances per each, where each appliance is equipped with an IoT board that monitors the current drawn by the appliance. It is required to minimize the energy consumption cost by each house as well as keep the total community consumption under certain safe limit. Further, it is required to monitor appliances for any possible failures that result in excess draw of current".
Based on this problem statement, the solution has two objectives:

- The objective for the house owner is to save money by prioritizing the usage of her/his appliances. Recommendation messages are sent on a predetermined times or upon request by the system to each user. A message has a

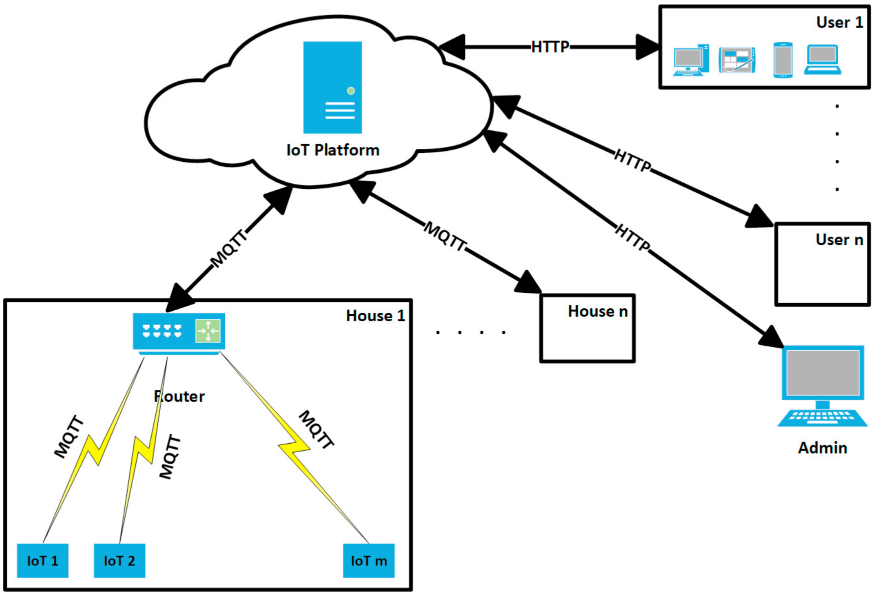

Fig. 2. System architecture showing the three structuring levels; houses, IoT platform and users/admin.

short-term usage history during billing period (one month in Jordan) and off-list suggestion based on long-term history (one year or more).

- For electric-energy provider (EEP) to keep overall energy consumption peak below certain limit that is set by the company policy or by load capabilities of the distribution network. A user is assumed to grant some control over house appliances to the EEP. An EEP, when needed, look at all houses in the community to decide which appliances to switch off to stay below peak energy consumption limit. To achieve this goal each user has a contract with the distribution company in which a user lists the appliances in a decreasing order of preferences. In this list, a user provides a value of preference to each item.

This system can be expanded to include the whole region (Jordan as a whole) by considering several communities and all other consumers such as hospitals, schools, factories, companies, etc. Further, all energy sources can be added to the system to fully control and mange energy consumption and eliminate blackouts or mitigate them. This system is beyond the scope of this paper.

3. House Energy-Consumption-Cost Saving

Electricity tariff slices in Jordan [20] are divided according to usage objective and quantity of consumption, in order to balance the various economic sectors. Table 3 summarizes the electricity tariff slices.

Table 1. Tariff Slices.

Slice Number	Household Tariff	Tariff (JOD)
1	From 1-160 KWH/Month	0.033
2	From 161-300 KWH/Month	0.072
3	From 301-500 KWH/Month	0.086
4	From 501-600 KWH/Month	0.114
5	From 601-750 KWH/Month	0.158
6	From 751-1000 KWH/Month	0.188
7	More than 1000 KWH/Month	0.265

Fig. 1 shows the energy price (JOD) versus energy consumption (KWH/month). The energy bill increases piecewise linearly as consumption increases. Fuel prices difference is added on the bill above 300 KWH and calculated from the first kilowatt. Customers are charged 0.010 JOD per KWH as the consumption exceeds 300 KWH. E.g., assume customer A consumed 290 KWH and customer B consumed 300 KWH, then customer A will not be charged for Fuel price difference and customer B will be charged 300 KWH *0.01 JOD/KWH=3.00 JOD above his bill. In other words, the fuel price difference added to the electricity bill makes a step, 3.00 JOD in our example. Therefore, customers need to keep their consumption below 300 KWH to avoid fuel prices difference increase as reflected in Fig. 1. IoT platform subsystem provides each user with a consumption report. The report provides the energy consumption details for every load in a house. It also gives a normative feedback based on one's consumption history and peer users energy consumption [21, 22]. Peer users are those who have similar appliances and house surface area. Normative feedback proved to be effective in forming a good consumers' behavior in reducing energy consumption. User can manage his appliances usage to avoid additional cost based on the report. Further, the system tracks the user's consumption and predict the bill value for the present consumption scenario. A recommendation can be in a form of usage management of some appliances, e.g., postponing the appliance usage to the next billing period to avoid additional cost incurred by moving to a higher tariff slice. For example, the increase in consumption from 299 to 300 KWH incurs an additional cost from fuel price difference, 3.00 JOD, and increase in tariff from 0.072 to 0.086 JOD per every additional KWH.

4. Community Administrator Role

The community admin (EEP) has an objective of maintaining the consumption within the community below a certain limit that is set by the distribution company policy. This goal can be achieved using the privileges granted to the admin by the users in a form of service contract. Further, the community admin provides the users with diagnosis reports about their appliances health. This is possible by monitoring currents drawn by each appliance for a long period. When there is a fluctuation in appliance energy consumption reflected by its current draw, an alarm is sent to the appliance user.

5. IoT Board

The proposed IoT board is an important part of home energy monitoring system. To keep this solution inexpensive, the following are the main parts selected for IoT board design:

- ESP8266: is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability produced by Shanghai-based Chinese manufacturer Espressif Systems. The chip first came to the attention of western makers in August 2014 with the ESP-12E module, made by a third-party manufacturer Ai-Thinker. ESP-12E is chosen. It works on 3.3V DC.
- 220V AC to 3.3V DC power supply: HLK-PM03 3W component is chosen. It is made by Hi-link company.
- 10A relay where its coil needs 3.3V DC to work: Since all components are working on 3.3V, this type of relays is chosen.
- Current sensor: ACS711 that works on 3.3V is chosen. It can measure currents up to 20A.

EasyEDA is used for circuit and PCB design, since it is free, easy to use and runs in web browser. The schematic diagram is shown in Fig. 3, and the PCB board in Fig. 4.

It is easy to program ESP-12E module in circuit by connecting JP1 to a USB port of a PC via a USB-to-UART adapter.

6. Conclusions and Future Work

This paper proposed a generic framework for home energy management system. The system is based on inexpensive IoT boards equipped with current sensor is designed and developed for HEMS. Where each appliance in a house

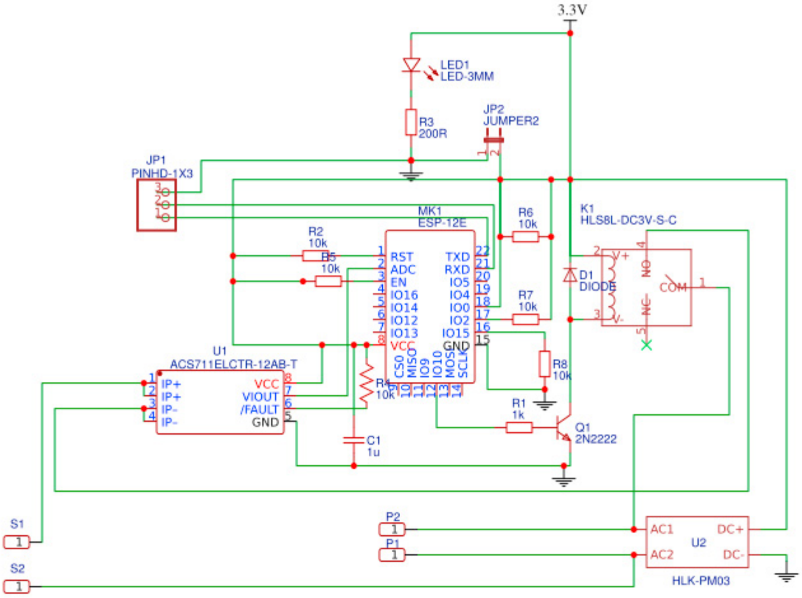

Fig. 3. Schematic diagram for the IoT board.

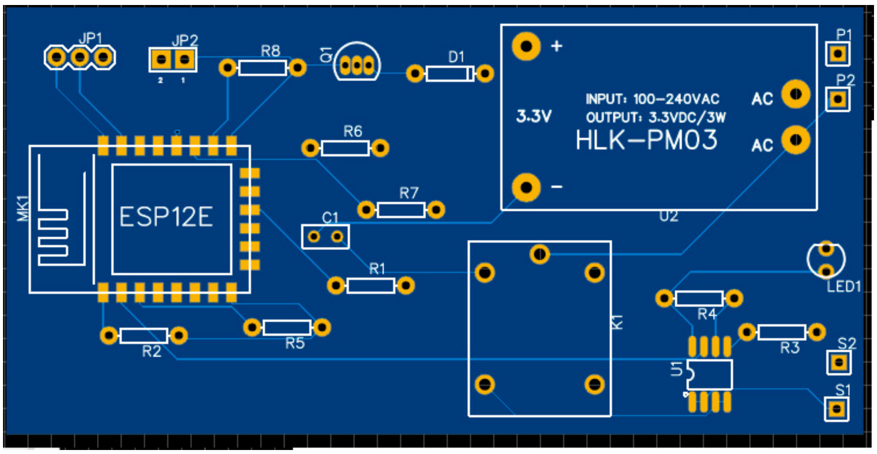

Fig. 4. Top view of the printed circuit board for the IoT design. This board can be resized to fit small size containers.

is connected to the power supply through this board. The proposed framework is projected on home energy management in Jordan. The system has three different levels; house level in which IoT boards are deployed, users/admin level where management of the appliances is done based on feedback from the third level which is the IoT platform. The IoT platform connects users and admin to appliances in subsequent houses. It also provides data analysis based on the rules set by power distribution company and preferences of the users. The designed IoT-board prototype cost is below \$5. IoT board cost can be less than \$3 for mass production. That is suitable for deployment by communities to curtail their energy consumption.

As a future work, we plan to deploy some IoT boards in a Jordanian community for a long period of time. Then, we will study the empirical results and compare it to what is expected and projected by this research.

References

[1] A. Zoha, A, Gluhak, et al, “Non-intrusive load monitoring approaches for disaggregated energy saving”,Sensors 12.12, pp. 16838-16866, 2012.
[2] K. He, L. Stankovic, J. Liao, V. Stankovic, Non-Intrusive Load Disaggregation using Graph Signal Processing, IEEE Transactions on Smart Grid, vol.PP, no.99, pp.1-1, 2016; doi: 10.1109/TSG.2016.2598872
[3] Cominola, A., et al. ”A Hybrid Signature-based Iterative Disaggregation algorithm for Non-Intrusive Load Monitoring.” Applied Energy 185 (2017): 331-344.
[4] M. S. Tsai and Y. H. Lin, Development of a non-intrusive monitoring technique for appliance’ identification in electricity energy management, 2011 International Conference on Advanced Power System Automation and Protection, Beijing, 2011, pp. 108-113.
[5] N. F Esa, M. P. Abudllah and M. Y. Hassan, A review disaggregation method in Non-intrusive Appliance Load Monitoring, Renewable and Sustainable Energy Reviews, vol.66, pp.163-173, 2016.
[6] J. Wang, J. Huang, W. Chen, J. Liu and D. Xu, “Design of IoT-based energy efficiency management system for building ceramics production line,” 2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA), Hefei, 2016, pp. 912-917.
[7] G. Mingming, S. Liangshan, H. Xiaowei and S. Qingwei, “The System of Wireless Smart House Based on GSM and ZigBee,” 2010 International Conference on Intelligent Computation Technology and Automation, Changsha, 2010, pp. 1017-1020.
[8] Serra, J., Pubill, D., Antonopoulos, A., & Verikoukis, C. “Smart HVAC control in IoT: Energy consumption minimization with user comfort constraints”, The Scientific World Journal, 2014, pp 1-11.
[9] Fong, K. F., Hanby, V. I., & Chow, T. T. “HVAC system optimization for energy management by evolutionary programming,” Energy and Buildings, 38(3), 2006, 220-231.
[10] Tacklim Lee, Seonki Jeon, Dongjun Kang, Lee Won Park and Sehyun Park, “Design and implementation of intelligent HVAC system based on IoT and Bigdata platform,” 2017 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, 2017, pp. 398-399.
[11] Y. T. Lee, W. H. Hsiao, C. M. Huang and S. C. T. Chou, “An integrated cloud-based smart home management system with community hierarchy,” IEEE Trans. Consumer Electron, vol. 62, no. 1, pp. 1-9, Feb. 2016.
[12] E. Rodriguez-Diaz, J. C. Vasquez and J. M. Guerrero, “Intelligent DC Homes in Future Sustainable Energy Systems: When efficiency and intelligence work together,” IEEE Consumer Electron. Magazine, vol. 5, no. 1, pp. 74-80, Jan. 2016.
[13] D. S. Kim, S. Y. Son and J. Lee, “Developments of the in-home display systems for residential energy monitoring,” IEEE Trans. Consumer Electron, vol. 59, no. 3, pp. 492-498, August 2013.
[14] Y. S. Son, T. Pulkkinen, K. D. Moon and C. Kim, “Home energy management system based on power line communication,” IEEE Trans. Consumer Electron, vol. 56, no. 3, pp. 1380-1386, Aug. 2010.
[15] N. Kushiro, S. Suzuki, M. Nakata, H. Takahara and M. Inoue, “Integrated residential gateway controller for home energy management system,” in IEEE Transactions on Consumer Electronics, vol. 49, no. 3, pp. 629-636, Aug. 2003.
[16] M. Erol-Kantarci and H. T. Mouftah, “Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid,” in IEEE Transactions on Smart Grid, vol. 2, no. 2, pp. 314-325, June 2011.
[17] T. Fiedler and P. M. Mircea, “Energy management systems according to the ISO 50001 standard — Challenges and benefits,” 2012 International Conference on Applied and Theoretical Electricity (ICATE), Craiova, 2012, pp. 1-4.
[18] K. Dittawit and F. A. Aagesen, “Home energy management system for electricity cost savings and comfort preservation,” 2014 IEEE Fourth International Conference on Consumer Electronics Berlin (ICCEBerlin), Berlin, 2014, pp. 309-313.
[19] Krishnan, V. Badri Rama, Keerthana Sandepudi, and Shaista Gazal. ”An optimised system for energy monitoring and data acquisition in substations/domestic applications using IoT.” E3S Web of Conferences. Vol. 87. EDP Sciences, 2019.
[20] Tariff structure, http://www.emrc.gov.jo.
[21] Schultz, P. Wesley, et al. ”Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms.” Energy 90 (2015): 351-358.
[22] De Dominicis, Stefano, et al. ”Making the smart meter social promotes long-term energy conservation.” Palgrave Communications 5.1 (2019): 51.
[23] Pflanzner, Tamas, and Attila Kertész. ”A survey of IoT cloud providers.” 2016 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO). IEEE, 2016.
[24] MQTT OASIS Standard, [online] Available: http://mqtt.org/.