Walls Have Ears: Using Conductive Surfaces of Furniture and Everyday Objects for Room-Wide Power Usage and Crowd Activity Sensing

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Abstract
We propose a design of self-powering room-wide power usage and crowd activity sensing that uses a single point of contact on a conductive surface of furniture or everyday objects such as metal frame of table or window, desktop PC case, rack, cabinet, and so on. We utilize these surfaces for energy scavenging from capacitive reactance and electromagnetic inductance, which are typically, occur in indoor house and office where there are many electrical appliances. We incorporate energy store and release strategy, and treat the charge accumulation time as a function of electrical appliance usage and human activity within a certain location. In this paper, we highlight principle of operation and prototype implementation result showing sensing log of an office room for 7 days timespan.

Author Keywords
Infrastructure-mediated sensing; localized crowd activity sensing; energy harvesting.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

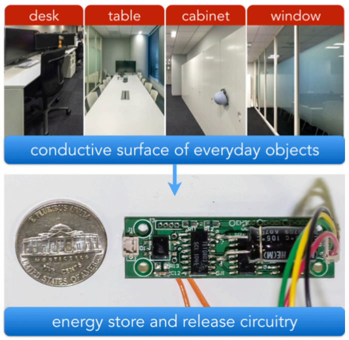

Figure 1: Scenario of our approach in leveraging the surface of everyday objects such as desk, table, cabinet, or window frame to perform room-wide power usage and activity sensing.

Introduction

Activity recognition is one of the main subjects in UbiComp and HCI field that can deliver great value and service for the users. Although personal activity recognition has been actively researched and commercially widespread (see [6] for a review), crowd activity recognition has been facing many challenges in providing effective and privacy aware solution. In separate work [6], we have shown that by measuring temporal characteristics of the ambient electric field we could infer a user's motion, gesture, and a short period of activity. However, we still need to source the power external from the sensor. Additionally, extended signal logging contains low signal-to-noise ratio (SNR).

In this paper, we present the design and feasibility evaluation of a self-powering room-wide power usage and crowd activity sensing that uses a single point of contact on a conductive surface of a furniture or everyday objects. We show that a table's metal frame paired with a reasonably good grounding from a desktop PC case can be utilized for energy scavenging, which leverages capacitive reactance and electromagnetic inductance typically occur in indoor house and office where there are many electrical appliances. We incorporate energy store and release energy scavenging strategy, and treat the capacitor's charge accumulation time as a function of electrical appliance usage and activity within a location. Figure 1 depicts overall scenario of our approach.

In contrast to other solutions such as utilizing optical sensors combined with computer vision techniques, or more conventional methods by analyzing data of an electricity meter; our approach offers the following advantages: 1) novel and effective utilization of a furniture's conductive surface towards infrastructure-mediated sensing; 2) completely self-powering, without any need for external power supply; 3) most houses and offices have sufficient amount of electrical appliances emitting considerable amount of electric fields for power scavenging; 4) preserves user privacy by not collecting camera frames or user specific inertial data; 5) low-cost both in bill-of-material and data storage/analysis; 6) completely localized single-point deployment. Therefore, directly wiring or clamping power line are unnecessary. Our contributions are therefore, summarized as follows:

- We propose a circuit model to explain the theory of operation, implemented our sensor design, and present details on its characteristics.
- We demonstrate power charge and delivery using our prototype hardware, and present a weeklong power usage and activity sensing experiment.

Related Work

Crowd activity sensing solutions often require massive deployment of sensors within an environment [4,9]. Add-on sensor installation cost for an existing office or house is not currently a feasible economy. Additionally, massive amount of sensors outputting large data will pose a challenge to process. Realizing this challenge, a hybrid approach that combines sensing from user individual smartphone and central computation server has been proposed [13]. In this scenario, user intention and a confirmation of participation are required.

Non-invasive sensing solutions to infer individual user's state have also been actively researched [1,6]. In this work, we aim to leverage similar non-invasive approach to infer activity within a certain location (e.g. room in typical house or office). Infrastructure-mediated

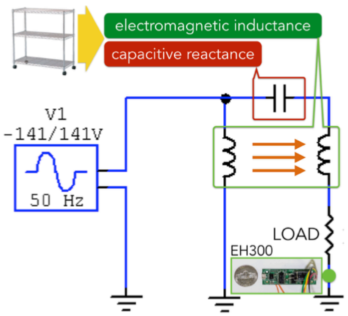

Figure 2: Circuit model and illustration of the hardware setup used for experiments to evaluate our proposed method.

sensing has been an active field of research due to its promising affordance in real-world deployment [2,3,11,12]. We share similar interest and aim to extend research in the domain of infrastructure mediated sensing. In this work, we extend [6,7] and propose self-powering solution that leverages readily available surfaces of the furniture and other surrounding everyday objects, which treats the charge accumulation time as a function of electrical appliance usage and human activity within a certain location.

Harvesting energy from an ambient wave, especially from radio waves have been actively researched. Previous research have proposed power harvesting from Radio Frequency (RF) [8,10,14], broadcasting TV towers [15], and from electromagnetic compatibility of leakage from a microwave oven's radio wave [5]. In this work, we explore the feasibility to use everyday objects, which are configured from conductive materials to harvest, store, and log charge accumulation to infer room-wide power usage and users activity.

Theory of Operation

Within our indoor living space, we often surrounded by various types of electrical appliances such as PCs, monitors, printers, HVAC system, and power lines that are continuously emitting electric fields. In this work, we use the resulting capacitive reactance and electromagnetic inductance (Figure 2) to provide electrical power to our sensing solution, and as a signal to infer the power usage and temporal activity.

In this work, we incorporate EH300[1] energy harvesting modules produced by Advanced Linear devices, which enable collection of energy from generators that produce low current. The charging input is specified above 4V at 200nA. Output of EH300 is enabled as soon as the capacitor reaches 3.5V and the output is kept active until the capacitor discharges to 1.9V.

Application: Activity Log in an Office Room

In this section, we explore the usability of our technique when deployed on a typical office work desk, located in an approximately 90m^2 wide non-partitioned office room. The room has many electrical appliances, such as PCs, LCD monitors, printers, etc. The actual setting of the study is depicted in Figure 3, which resembles the circuitry model depicted in Figure 2.

The desk we used was measured at 160×60cm. It had metal supporting frame that was exposed in the underside of the table's surface. The metal frame was coated by paint; therefore to ensure stable connection we located and connected the table's frame securing screw to EH300's J1+ terminal. In this experiment, we utilized an exposed screw of a PC's graphic card display connector as ground. The PC was always turned off during the entire period of this experiment.

Output Characteristics

Using the aforementioned setup, we took 10 measurement samples that were in average of 25 seconds. With this result we estimate the charging parameters. EH300 is equipped with 1000μF capacitor. The V_p terminal will be activated once the capacitor's charge achieved V_H=3.5V, and deactivated when discharged until V_L=1.9V. Therefore, electric charge for one charging period Q is:

[1] Advanced Linear Devices. Datashet - EH300/301: EPAD energy harvesting modules. http://www.aldinc.com/pdf/EH300.pdf

Figure 3: We deployed our approach on a work desk in an office room. The EH300's J1+ terminal was connected to the desk's metal frame, while the J1– terminal was connected to a display connector screw on a PC that was turned off during the experiments. We used a separate PC with a TWE-Lite USB-C receiver to log the capacitor charging time.

$$\begin{aligned} Q &= CV \\ Q &= 1000 \cdot 10^{-6} \cdot (3.5 - 1.9) \\ Q &= 1600\mu C \end{aligned} \tag{1}$$

Hence, the charging current I_C for the aforementioned experiment environment was:

$$\begin{aligned} I_C &= \frac{Q}{T} \\ I_C &= \frac{1600\times10^{-6}}{25} \\ I_C &= 57.16\mu A \end{aligned} \tag{2}$$

We estimate usable energy from EH300's capacitor:

$$\begin{aligned} E &= \frac{CV^2}{2} \\ E_{total} &= \frac{1000\times10^{-6}\times3.5^2}{2} = 6.125mJ \\ E_{remain} &= \frac{1000\times10^{-6}\times1.9^2}{2} = 1.805m \end{aligned} \tag{3}$$

$$E = E_{total} - E_{remain} = 4.32mJ$$

We conducted a weeklong experiment using our proposed strategy. Our experiment setup was configured as Figure 3. This experiment spanned from Monday February 23rd to Monday March 2nd, 2015.

Data Logging Configuration

We utilized a IEEE802.15.4 wireless module to send three consecutive packets to a receiver (TWE-Lite USB-C), which was located separately (d ≅ 5m). Within each packet, we send a sender device ID and a timestamp in milliseconds. Device ID was useful to avoid confusion between our experiment setup and other general communications. The timestamp was used to record the elapsed time between the beacon packets.

We designed our wireless module's firmware to send three consecutive packets when the module is powered using the accumulated energy from the environment. We verify the arrival of the three packets to filter bad transmission. We subtracted first packets of the consecutive period of operation to obtain capacitor's charging time.

Statistics of the Obtained Data

The statistics of the collected data are as follows:

- We collected 71,587 beacon packets during the one-week experiment.
- We filtered the collected data based on elapsed time, where we omit data with elapsed time less than 300 milliseconds, or greater than 60,000 milliseconds. This threshold values were decided by taking account of average elapsed time data (upper boundary), as well as to omit second and third beacon packets within the same period of operation (lower boundary).
- As the result of our filtering approach, we kept 24,654 data points.

Experiment Result

Our extended activity logging experiment results is shown in Figure 4. For easier interpretation, we show dateline, as well as both office working hours and non-working hours. We also show hourly moving average of the capacitor charging time by averaging consecutive 148 data points. This value was decided from the overall average charging time, which was 24.25 seconds. From the results, we can easily observe the temporal fluctuations, which are the capacitor charging time, ranged between 21 to 26 seconds. From the energy harvesting point-of-view, this result was encouraging when we consider the simplicity and affordability of our strategy.

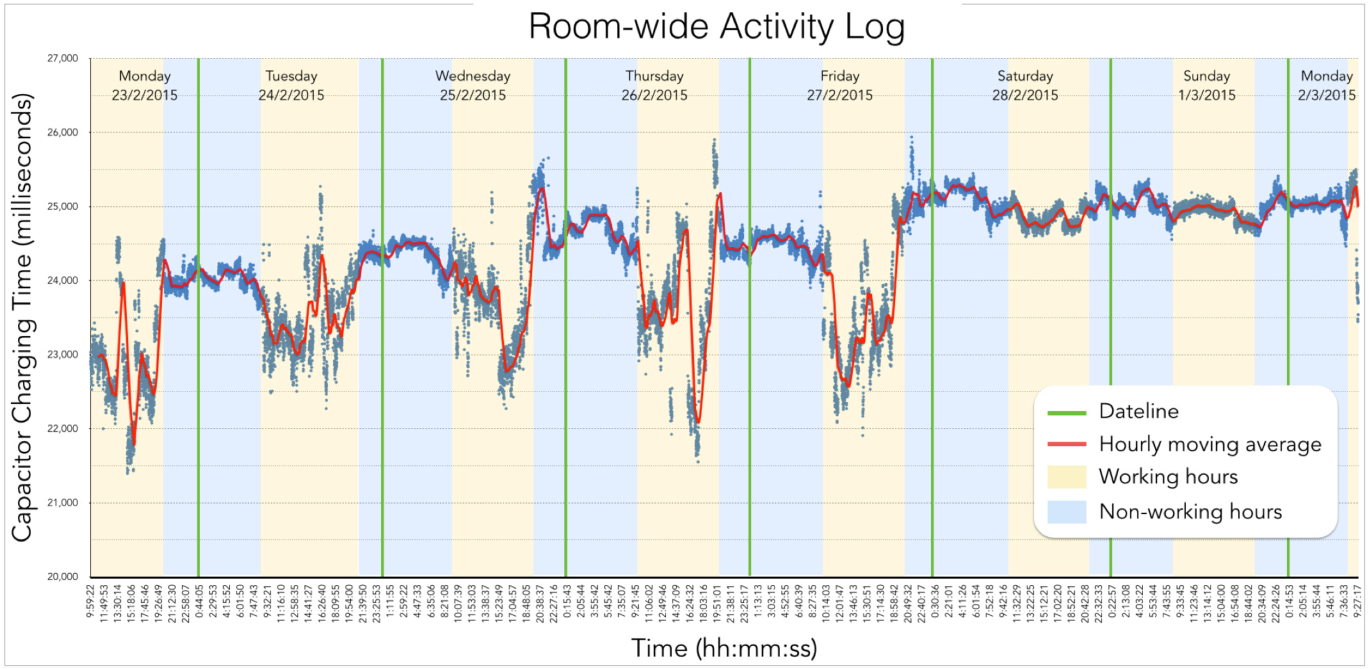

Figure 4: A weeklong room-wide activity log result using our proposed method.

Moreover, the temporal fluctuations in the capacitor charging time are intriguing. We highlighted office working hours and non-working hours in yellow and blue shade, accordingly. From Figure 4 we can easily observe that during the office working hours, the capacitor charging time were generally lower. Therefore we can conclude that there were larger magnitudes of ambient electric fields thus enable faster capacitor charging. This was mainly caused by the increasing amount of electric field emitted by electrical appliances such as PCs, monitors, etc., that were turned on during these hours. In contrast, non-working hours and weekends (Saturday and Sunday) depict less temporal fluctuations but longer capacitor charging time.

Conclusion and Future Work

We presented the design and feasibility evaluation of a self-powering room-wide power usage and crowd activity sensing that uses a single point of contact on a conductive surface of a furniture or everyday objects. We demonstrated that a table's metal frame paired with a reasonably good grounding from a desktop PC case can be utilized for energy scavenging from capacitive reactance and electromagnetic inductance, which are typically occur in indoor house and office where there are many electrical appliances emitting electrical field. We incorporated energy store and release energy scavenging strategy, and treated the capacitor's charge accumulation time as a function of electrical appliance usage and people's activity within a room. By conducting one weeklong office room logging experiment, we identified limitations to further refine our design and implementation.

References

1. Adib, F., Mao, H., Kabelac, Z., Katabi, D., Miller, R.C. Smart homes that monitor breathing and heart rate. In Proc. of CHI '15, pp. 837-846.
2. Cohn, G., Stuntebeck, E., Pandey, J., Otis, B., Abowd, G.D., Patel, S.N. SNUPI: sensor nodes utilizing powerline infrastructure. In Proc. of UbiComp '10, pp. 159-168.
3. Gupta, S., Reynolds, M.S., Patel, S.N. ElectriSense: single-point sensing using EMI for electrical event detection and classification in the home. In Proc. of UbiComp '10, pp. 139-148.
4. Intille, S.S., Larson, K., Tapia, E.M., Beaudin, J.S., Kaushik, P., Nawyn, J., Rockinson, R. Using a live-in laboratory for ubiquitous computing research, Proceedings of the 4th international conference on Pervasive Computing, pp. 349-365, 2006.
5. Kawahara, Y., Bian, X., Shigeta, R., Vyas, R., Tentzeris, M.M., Asami, T. Power harvesting from microwave oven electromagnetic leakage. In *Proc. of* UbiComp '13, pp. 373-382.
6. Mujibiya, A. and Rekimoto, J. Mirage: exploring interaction modalities using off-body static electric field sensing. In *Proc. of* UIST '13, pp. 211-220.
7. Mujibiya, A., and Torii, J. Demo: Energy Harvesting Using Everyday Objects. In *Proc. of* MobiSys '15, pp. 457-457.
8. Nishimoto, H., Kawahara, Y., Asami, T. Prototype implementation of ambient RF energy harvesting wireless sensor networks. In *Proceedings of the IEEE Sensors,* pp. 1282-1287, 2010.
9. Noguchi, H., Mori, T., Sato, T. Attentive information support with massive embedded sensors in room. In *Proc. of* HCI'07, pp. 883-892.
10. Parks, A.N., Sample, A.P., Zhao, Y., Smith, J.R. A wireless sensing platform utilizing ambient RF energy. In *Proceedings of the 2013 IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet)*, pp. 127-129, 2013.
11. Patel, S.N., Reynolds, M.S., Abowd, G.D. Detecting human movement by differential air pressure sensing in HVAC system ductwork: an exploration in infrastructure mediated sensing. In Proc. of Pervasive '08, pp. 1-18.
12. Patel, S.N., Robertson, T., Kientz, J.A., Reynolds, M.S., Abowd, G.D. At the flick of a switch: detecting and classifying unique electrical events on the residential power line. In Proc. of UbiComp '07, pp. 271-288.
13. Rachuri, K.K., Efstratiou, C., Leontiadis, I., Mascolo, C., Rentfrow, P.J. Smartphone sensing offloading for efficiently supporting social sensing applications. Pervasive Mob. Comput. 10 (February 2014), pp. 3-21, 2014.
14. Sample, A., Smith, J.R. Experimental results with two wireless power transfer systems. In *Proceedings of the IEEE Radio and Wireless Symposium, 2009 (RWS '09)*, pp. 6-18, 2009.
15. Vyas, R.J., Cook, B.B., Kawahara, Y., Tentzeris, M.M. E-WEHP: a batteryless embedded sensor-platform wirelessly powered from ambient digital-TV signals. In *Proceedings of the IEEE Transactions on Microwave Theory and Techniques*, vol.61, no.6, pp. 2491-2505, June 2013.