

Mashing up Multiple Logs in Home Network System for Promoting Energy-Saving Behavior

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Abstract—Recently, resource monitoring systems to visualize energy consumptions such as electricity and gas for home users, are developed. In the home, user's daily behavior affects total amount of consumption energy significantly. Such monitoring systems aim at making a user conscious of energy-saving behavior. Most of conventional systems provide summarized data on consumed energy to a user. From the data, a user can know result of excess consumption of the energy. In such visualization, however, it's difficult to investigate the reason by which energy consumption became excessive for users. In our research, we propose mashing up multiple home network system logs to improve use's daily behavior in the home. Especially, we illustrates mashing up data on energy consumption, appliance controller, and environmental sensor, which is usable for discovering the futility about user's behavior concretely.

I. INTRODUCTION

The energy consumption at home is dramatically increasing as houses are fully furnished with various kinds of electric appliances. In Japan, the energy consumption at home has increased by 30 percent in the last 15 years. The home network system is expected as a promising technology to promote energy saving behaviors of home users. In order to promote user's energy-saving behaviors, visualization on energy consumption are especially important. An empirical study shows that just visualizing in-home energy consumption was able to reduce energy use by 10-15 on average [1]. Recently, many appliance vendors are releasing various services and products that visualize energy consumption.

However, most conventional systems visualize the electric consumption only, with quite coarse granularity. Typically, an appliance shows the current electric consumption being used. Or, a system may describe a graph of the total amount of consumed electricity for a day. Such conventional systems allow users to know the effect of energy consumption. However, they are not enough to show the cause why and how such amount of energy has been consumed. For example, suppose that a user left a room with keeping lights on. A system is able to show how much electricity was used by the lights, but is unable to show that the lights were used wastefully. Without the cause, it would be difficult for users to improve their daily behaviors in the home.

In order to visualize the cause and effect of energy consumption, we propose to mash up various logs together with the consumption logs. Specifically, we introduce appliance control

logs and environment logs which can be collected via the home network system. The appliance control logs represent the date, the time, the user, and the appliance operation. So, they can be used as evidences of user's behaviors. On the other hand, the environment logs are the records of the environment sensor values such as temperature, humidity, brightness, etc. They represent contexts in which the user's behaviors are performed. The context can become criteria to check if each user's behavior is appropriate for energy savings. By mashing up the appliance control and the environment logs with the energy consumption data, a user can find and evaluate the relationships between the energy consumption and user's behaviors. For the above example, the system can visualize when the user turned on the lights, and when the user left the room. Therefore, the user can know wasteful usage of the lights afterwards. Thus, the cause and effect can be visualized.

We have implemented a prototype system within an actual home network system. The system consists of an appliance-wise power consumption logger, an appliance control logger, and an environment sensor logger. Using the system, we conducted a case study of visualizing daily behaviors of a subject.

II. PRELIMINARIES

A. Home Network System(HNS)

In the next-generation smart home, house-hold appliances and sensors get smarter and can be connected to networks. These devices are integrated via networks to provide value-added services. The system comprised of such smart appliances is called *Home Network System* (HNS)[2], [3].

The HNS makes it possible to remote-control and monitor home appliances. Also it can orchestrate multiple appliance together to provide value-added integrated services.

B. Energy Saving at Home

The energy consumption at home is growing significantly because home electrification and increase of home appliances. Improving energy-efficiency is significant.

Various energy-efficient appliances are sold by several vendors. BRAVIA[4] is a TV which has a human-detect sensor. The TV is automatically turned off if a user is absent in front of the TV. Many vendors and researchers try to improve energy-efficiency of such home appliances.

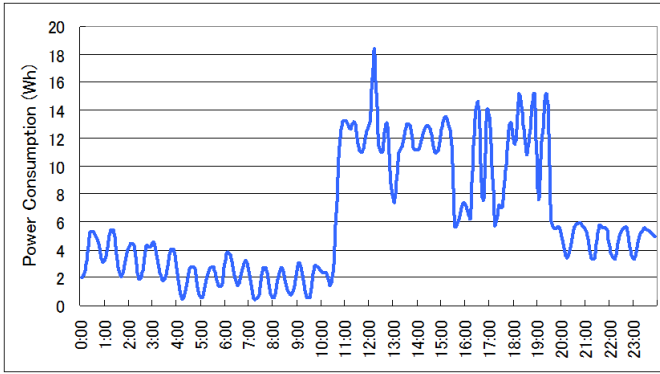


Fig. 1. Conventional Power Consumption Log

C. Feedback on Electricity Consumption

In order to promote energy efficient behaviors to users, *feedback* on electricity consumption is proposed by many researchers. Froehlich[5] says *differences in human behavior can significantly affect energy consumption and suggest that intervention strategies to promote sustainable behaviors could result in significant energy savings.*

Darby[6] reports adequate feedback may reduce user's energy consumption by up to 20 %. Actually, many feedback services corresponding with various granularity are proposed[1].

Google Power Meter[7] is a sensor which has a capability to acquire realtime power consumption data by attaching to the wattmeter. Users can look back consumed electricity with using the google power meter through the internet[7].

Most of such feedback services only shows power consumption logs per a room or per a house. Therefore, the following problems are considered in promoting more efficient energy consumption behavior to users.

P1: Though a user can know transition(*effect*) of energy consumption of the whole house, the user can't know the *cause* of the transition concretely. Here, the cause is concrete appliances and their functions which caused the power consumption.

Figure 1 shows the power consumption log in our experimental HNS for a day. This graph indicates transition of consumed electricity of the whole room. Generally, users can't identify which appliance or functions consumed such electricity only with using such graph.

P2: It is very difficult to identify that which power consumption behavior by users was *inefficient* only from the power consumption logs.

Users have to be able to recognize cause and effect concretely with using a feedback service from user's past power consumption behaviors to improve their behavior about using home appliances at home.

III. PROMOTING ENERGY-SAVING BEHAVIORS BY MASHING UP LOGS

In this paper, we propose new feedback service by mashing up multiple logs to improve problems P1 and P2. Our feedback

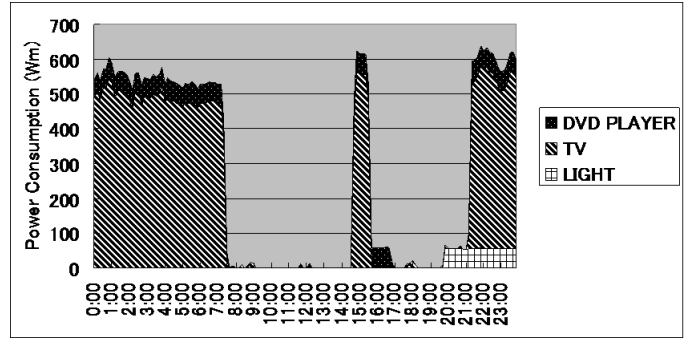


Fig. 2. Power Consumption Log by Stacking Line Chart

service contains three logs related to energy consumption at home. First one is *power consumption logs* per home appliance. Second is *appliance control logs* which indicate history of appliance control by users. Third log is *environmental sensor logs* which show transition of environment attribute value detected by various environment sensors. We integrate these three logs to promote user's energy efficient behaviors.

In this section, we denote detail of each log.

A. Power Consumption Log

The power consumption log is sequential data of consumed electricity per each appliance. In this research, the data is collected at a constant period(per 1 minute). The following log is actual power consumption logs about a light and a TV.

2009-09-26	21:20	light1	55.499
2009-09-26	21:20	TV1	476.085
2009-09-26	21:30	light1	56.657
2009-09-26	21:30	TV1	480.979
2009-09-26	21:40	light1	56.336
2009-09-26	21:40	TV1	496.325
2009-09-26	21:50	light1	57.017
2009-09-26	21:50	TV1	522.547

Each record consists of date, time, an appliance name and consumed electricity(Wmin) during the period respectively. In our feedback service, we used a stacking line chart to express transition of consumed electricity per appliance. Figure 2 shows visualized example of the power consumption log in our service. A user can know consumed electricity by each appliance.

B. Appliance Control Log

The appliance control log is history of invoked appliance functions by users. In this paper, we assume that there are some specific UIs which record who controlled which appliance functions.

The appliance control log shows the user's energy consumption behavior itself. Therefore, analysis about appliance control log is essential to improve user's behavior about energy consumption . Figure 3 shows an example of the appliance control log. In the log, date, a user name, an appliance

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[2009/09/26T11:22:46]:<UserA>:FAN,on
[2009/09/26T11:22:49]:<UserA>:LIGHT,on
[2009/09/26T11:29:07]:<UserA>:CURTAIN,open
[2009/09/26T11:29:14]:<UserA>:AIR_CONDITIONER,on
[2009/09/26T11:33:16]:<UserA>:FAN,off
[2009/09/26T11:47:40]:<UserA>:LIGHT,off
[2009/09/26T13:08:25]:<UserA>:TV,on
[2009/09/26T16:02:30]:<UserA>:AIR_CONDITIONER,off
[2009/09/26T16:31:27]:<UserA>:TV,off
[2009/09/26T17:02:41]:<UserA>:LIGHT,on
[2009/09/26T20:03:00]:<UserA>:TV,on
[2009/09/26T20:03:26]:<UserA>:AIR_CONDITIONER,on
[2009/09/26T23:29:27]:<UserA>:AIR_CONDITIONER,off
[2009/09/26T23:29:30]:<UserA>:LIGHT,setBrightness,8
[2009/09/26T23:29:33]:<UserA>:TV,ch,4
[2009/09/26T23:43:08]:<UserA>:TV,ch,8
[2009/09/26T23:43:10]:<UserA>:AIR_CONDITIONER,on
[2009/09/26T23:43:13]:<UserA>:CURTAIN,close
[2009/09/26T23:43:16]:<UserA>:LIGHT,off
[2009/09/26T23:44:03]:<UserA>:TV,off

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Fig. 3. Operation Log

name, an appliance function name and parameter values of the function are recorded when the appliance function is used.

C. Environmental Sensor Logs

The environmental sensor logs contain sequential data of various environmental attribute values such as temperature, humidity, brightness, etc. which is collected by corresponding environmental sensors. Environmental attribute values serve as a cause for users to control appliances in the room. In many cases, environmental attributes are used as context information which estimate contexts why the user controlled the appliance.

For example, in several situations such as "a heater was turned on because it became cold", and "a light was switched on since it became dark" etc., users can estimate whether their behaviours are inefficient or not with using environmental sensor logs.

The following sequential data shows examples of environmental attributes we collected in this research. Each record represents date, time, temperature(°C), humidity(%), brightness(lx), air volume(relative value between 0.0 and 99.9) and human-detect(true/false), respectively.

2009-09-26	11:22	31.5	41	65	1	false
2009-09-26	11:23	31	41	506	1	false
2009-09-26	11:24	30.75	41	513	1	true
2009-09-26	11:25	31	41	515	1.8	true
2009-09-26	11:26	31.5	41	509	1.6	true

Figure 4 shows examples of visualized environmental sensor logs.

D. Mashing-up Multiple Logs

So far we denoted three kinds of logs. It becomes possible to provide users with more concrete feedback which improves P1 and P2 by mashing up these three types of logs. The power

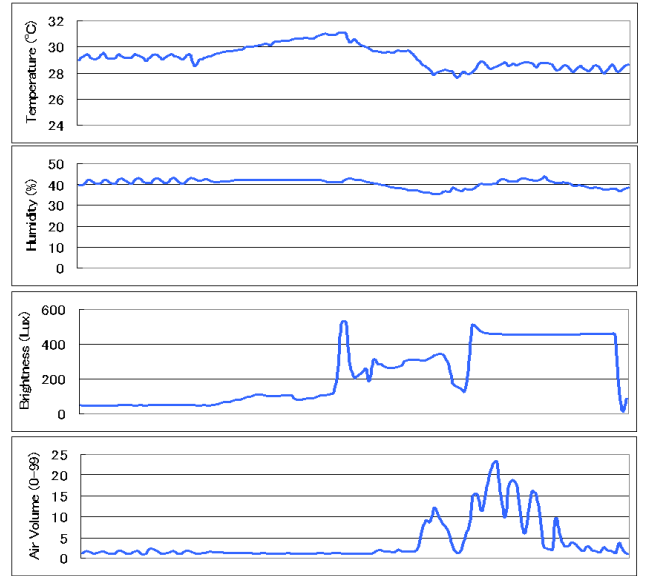


Fig. 4. Environmental Sensor Log

consumption logs represent transition of consumed electricity per appliance. With using only the power consumption log, although users can check the power consumption per appliance, they can't identify concrete appliance functions and which behaviors are inefficient.

By mashing up the power consumption logs and the appliance control logs, users can look back their behaviors about appliance control in the view point of power consumption. Furthermore, by mashing up the power consumption logs, the appliance control logs and the environmental sensor logs, users can identify past *energy inefficient behaviors* about appliance control.

Figure 5 shows visualized feedback screen by mashing up three types of logs in our system. The figure shows multiple logs for one day. In the upper side of the screen, the power consumption logs per an appliance in the form of the stacked line chart is presented. The user can select combination of appliances which display consumed electricity in the upper left side of the screen. In the upper right side of the screen, the appliance control logs are displayed for the day. The environmental sensor logs are expressed in the lower side of the screen. The user can choose an environmental attribute displayed in the screen. Only the value of human-detect sensor is always displayed in the lower right side of the screen because the value is most significant to estimate whether the behavior is inefficient or not.

With using our feedback service mashing up three types of logs, a user can identify energy inefficient behaviors easily.

IV. IMPLEMENTATION

Our feedback service consists of a *power consumption logger*, an *appliance control logger*, an *environmental sensor logger* and the *consumed electricity feedback screen*. In this section, we show details of each component of our service.

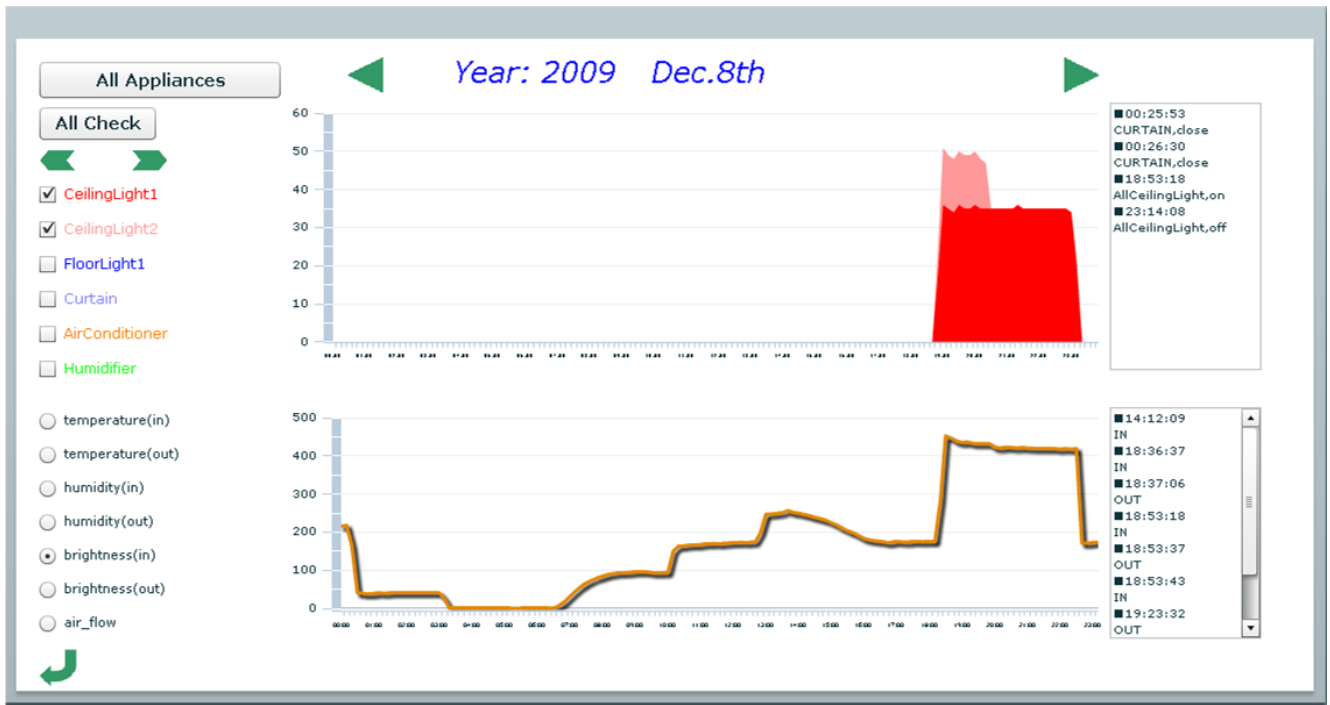


Fig. 5. Mashing Up Multiple Logs on the Feedback Screen

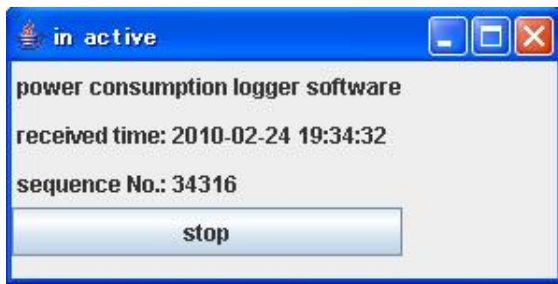


Fig. 6. Power Consumption Logger Software

Power Consumption Logger

The power consumption logger includes a home equipment network panel[8] and a power consumption logger software. The panel is connected to a power distribution unit(PDU), and collects consumed electricity per a circuit. In our HNS environment, one appliance is connected to one circuit. Therefore, consumed electricity for a circuit is consumed electricity by a certain appliance.

The collected electricity logs are sent to the logger software. Figure6 shows our logger software. The software receives the log information and adds to power consumption log DB.

The implementation environment of the software and DB is as follows:

- **Power Consumption Logger Software:** Java SDK 1.6 Update16. LOC is about 960.
- **Power Consumption Log DB:** My SQL 5.1.36.

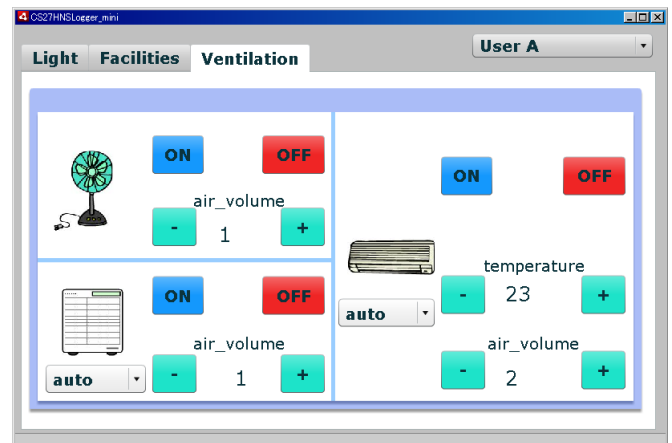


Fig. 7. Appliance Control Interface

Appliance Control Logger

We developed an appliance control interface to collect the appliance control log. Figure 7 is our appliance control interface. With using the interface, a user can control almost all functions of every appliance. The appliance control logs are automatically added to the appliance control log DB (MySQL 5.1.36). The interface is developed with Adobe Flex 3.4. LOC is about 1420.

Environmental Sensor Logger

The environmental sensor logger collects values of several kinds of environmental sensor. In this paper, we used the following sensors.



Fig. 9. Consumed Electricity Feedback for a Month



Fig. 8. Consumed Electricity Feedback for a Year

- Temperature Sensor(Phidgets Inc.[9])
- Light Sensor(Phidgets Inc.)
- Humidity Sensor(Phidgets Inc.)
- Human Detect Sensor with RFID Reader(Phidgets Inc.)
- Air Volume Sensor(ITWatchDogs)

The human-detect sensor using a RFID reader can detect who is in the room. Values of every environmental attribute are recorded for every minute by our environmental sensor logger software. The logger is developed with Perl(Active Perl 5.8.9.827). Its LOC is about 230.

Consumed Electricity Feedback Screen

Our feedback screen displays consumed electricity of several granularities. Figure 8 shows consumed electricity for every month. A user can select arbitrary month to get more detailed information about consumed electricity. Figure 9

shows transition of consumed electricity for a month. In the lower left side of the screen, the day at which consumed electricity was the lowest, and the day at which one was the highest are displayed. In this example, consumed electricity was the lowest at January 8th, and that was the highest at January 12th. In this screen, a user can select arbitrary day to detect past energy inefficient behaviours concretely.

Figure 5 shows most fine-grained consumed electricity and multiple logs such as the appliance control logs and the environmental sensor logs.

V. CASE STUDY

Before our case study, we collected actual logs of the consumed electricity, the appliance control and the transition of environmental attributes as the preliminary experiment. In the experiment, one subject lived in our CS27-HNS[3] for 5 month (from 2009/09/09 until 2010/01/31). He is 23-year-old. The HNS environment has the following 16 appliances.

- TV:Panasonic TH-58PZ800
- Air Conditioner:Corona CWH-187R
- Floor Light : Kishima Orbs
- Table Light : Kishima Orbs
- Motorized Curtain Rail:Navio Resite
- Air Cleaner and Humidifier:Hitachi EP-CV60
- Ceiling Light:National HK9392K
- Fan : Pieria
- HDD/DVD Recorder:TOSHIBA RD-S601
- TV Game Player:SONY PlayStation3 ECH-2000A and Nintendo Wii
- Component stereo:SONY Netjoke NAS-D500HD
- Speaker:Panasonic SC-HTR510-K

- Microwave:SHARP RE-SW10-B
- Refrigerator:SHARP SJ-23TM
- PC:CPU 2.19GHz,Memory 0.99GB, Win XP Professional

In our case study, we extracted some inefficient behaviours from the mash-up logs. Based on our following classification, we denote about extracted behaviours.

C1-1:Leaving Appliances ON(Type 1): This category C1-1 indicates the inefficient behaviours well known as one of the behaviours which should be improved. That is, the appliances are left on during the user's absence in the room. C1-1 was detected by the power consumption log and the environmental sensor log(especially, the human detect sensor's log) in our feedback service. In this case study, the TV and the Lights were left on during the user's absence.

C1-2:Leaving Appliances ON(Type 2): In this type of inefficient behaviours, appliances are left ON which can't provide its service. In this case study, the user watched a DVD movie with using the HDD/DVD player on the TV. The user finished watching its movie, and turned off only the TV. The HDD/DVD player was left ON though the player can't display any movies on the TV.

C2:Ignorance of Environmental Attribute: In this category of behaviours, a user which controls appliances is indifferent to the value of environmental attributes. In this case study, we detected that the user switched on the lights in spite of being bright enough in the room as a inefficient behaviour.

Figure 5 shows two ceiling lights are turned on. In this example, even if one ceiling light was switched off, brightness of the room didn't change. As a result, the user should have turned on only one ceiling light from a view point of energy saving.

C3:Combined use impossible: Inefficient behaviours in this category are detected when multiple appliances which can't be used together are used simultaneously.

In this case study, the user watched a TV program on the TV, and the HDD/DVD player was ON. As you see, the user can't watch a DVD movie by the HDD/DVD player simultaneously on the same TV.

C4:Combined use unnecessary: Multiple appliances which should not be used together are used simultaneously in the energy-savings point of view. In this case study, a user studies with the PC. If the TV was turned on during his/her study, its behaviour can be considered as a kind of useless one to perform energy-saving behaviour.

VI. CONCLUSION

In this paper, we propose the feedback service which shows the causal relation between user's behaviours and consumed electricity, in order to promote energy-saving behaviours. Our feedback service includes multiple logs. The power consumption logs, the appliance control logs, and environmental sensor logs are integrated and visualized on the service. As a result, our case study shows the inefficient energy behaviours which weren't be able to be detected by the conventional power

consumption log could be discovered with using our feedback service.

In our future research, we improve usability of our service and add more functions to look back more effectively, such as recommendation of behaviours.

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