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Intelligent context-aware energy management using the incremental simultaneous method in future wireless sensor networks and computing systems

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Abstract

In this article, we present an intelligent context-aware energy management for saving home energy consumption using activities of daily living. In order to extract energy-consuming patterns, we analyze daily activities, which are collected from location sensors and electronic appliances. In addition, we construct an energy management model using the incremental statistical method, which is improved by the ISM-based adaptive model using house construction and location of electronic devices. Furthermore, we provide a simulator that conducts the various functions using the energy-consuming patterns and present the simulation results for the verification and efficiency of our model.

Keywords: Energy consuming, Energy saving, Human activity pattern, Energy management

Introduction

Recently, numerous researchers and companies have much interest in the energy saving of home appliances automatically and efficiently [1-3]. The White House blog of President Obama's major announcement [2] on building efficiency represents that the "Better Buildings" initiative aims to achieve a 20% improvement in commercial energy efficiency by 2020, reduce companies' and business owners' energy bills by about 40 billion dollars per year, and save energy by reforming outdated incentives and challenging the private sector to act.

The first cross-European survey "the Habits of a Lifetime" reported how households use energy [4]. The habit of life is strongly related with the energy saving and wasting. In the survey, forgetting to switch the lights off when leaving a room is a massive energy waster. In the UK, lighting homes costs £1.9 billion a year, so switching off lights we do not need would slash CO2 emissions. In other words, behavior habits affect energy consumption. In [5], modification program has preliminary success in getting people to cut consumption. The website displayed real-time consumption data gives a positive effect for energy saving. A smart home has capability of energy saving by using the human activity patterns learning. Using heterogeneous sensors, the energy management system collects usage information of electric appliances about the activity patterns. Using these activity patterns, the system handles the energy consumption.

Traditional context-aware systems accomplish complicate sensing tasks and employ some complicate context interpretation. In general, a context-aware system for providing appropriate services should have four tasks involved in dealing with contexts: (1) context acquiring; (2) context interpreting; (3) disseminating context to interested parties; and (4) service modeling [6,7]. Furthermore, importance of saving the energy in a progress of the context computing system is being raised up recently.

In this article, we propose the energy management model using human activity patterns and Hierarchical Hidden Markov Model (HHMM) to minimize the wasting of energy. We describe a 3-level HHMM energy management model and adapted the incremental statistical method (ISM)-based energy management model using HHMM. In experiments, the results using ISM-based

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energy management model are presented. The proposed automatic system based on the energy management model using human activity patterns controls consumed energy efficiently and effectively. To save electrical power, the proposed energy management system accomplishes potential energy management by using control of devices from human activity patterns and real-time positioning data. Moreover, it is possible to infer electric appliances that a user wishes to use.

The remainder of this article is organized as follows. Section 2 describes related work. Section 3 introduces the outline of our system and the process of analyzing the activity patterns. Section 4 presents energy management model. Section 5 describes the experimental results. Section 6 gives the results of this article. Section 7 concludes this article.

Related work

EasyLiving and Independent LifeStyle Assistant (ILSA) are automation systems, which are focused on constructing automatic home environments based on the Internet infrastructure [8]. Medical Automation Research Center (MARC) at the University of Virginia has developed a communication module with a web-based data management server, which analyzes the meal preparation patterns of people including physiological signs such as heartbeat and body temperature [9]. MavHome at the University of Texas in Arlington is a home health monitoring system that assists in daily basic activities, which tracks vital signs, movement patterns, medicine taking schedules, and interaction with devices in the home [10]. The Center for Future Health at the University of Rochester provides an emergency response service [11]. Aware Home at the Georgia Institute of Technology has focused on the applications for supporting people with cognitive impairment in daily activities and communications [12]. Place Lab. of MIT has developed a portable kit that tracks movements of objects in the home, such as furniture and kitchen tool [13]. Adaptive House at the University of Colorado focuses on designing a self-programming home system, based on the lifestyle, needs, and preferences of the residents [14].

According the IEO2009 report, world marketed energy consumption is projected to grow by 44% over the 2006–2030 period, and total world energy use is projected to increase by 472 quadrillion British thermal units (Btu) in 2006 to 678 quadrillion Btu in 2030 [15]. Moreover, energy use in the residential sector accounted for about 15% of world delivered energy consumption in 2006 [15]. As energy consumption is constantly growing, energy management task of context-aware system should be taken seriously. Numerous researches have studied to save the energy using control of sensors [16-18]. However, the system is not applied with the human activity patterns. In order to control the power efficiently and effectively, energy saving method using human activity patterns should be considered.

To extract human activity patterns, various positioning systems have been presented to provide a real-time service based on the location of people. The positioning system is classified global positioning system and Real-Time Locating Systems (RTLS) by operation range. The global positioning system such as GPS is wide range tracking system; however, the system is not applied to indoor positioning system. RTLS is intended to locate people or things by small electronic devices carried on these items or persons. These systems determine the location carrying an RFID tag or Wi-Fi tag in real-time. Especially, most mobile devices used in wireless sensor network provide received signal strength indication and it can be used one of ranging sources without an additional hardware. The proposed system is applied as a potential energy saving method using human activity pattern and real-time positioning data. Using leaving and arriving activity patterns, the system manages automatically power mode and controls the heating and cooling system to save potential energy in a smart home and office.

System architecture

Background and application model

The common approach for minimizing the unnecessary energy wasting is to construct the energy management model by using the user position and devices position. In [19], an energy management model based on an HHMM was presented. The method tried to find an optimal way to handle on/off switching of device that can minimize the energy consumption while keeping the response time below the required level. The energy management model is pre-designed by using house construction and electronic devices' location. The pre-designed model is simple to construct. However, the limitation of pre-designed model does not manage the temporary use of devices. In addition, people may use two different devices that are placed at the separated room at the same time. If the system controls the device only by space divided by the house construction, this simultaneous use is ignored.

The proposed system is designed by two different models: the activity context model using the ISM [20] and the activity pattern-based energy management model. The activity context model shows the possible activities' sequence based on relative probabilities and temporal relations. The probability and temporal relation are saved and updated in an activity relation database. The energy management model utilizes the status of devices in use and out of use among working devices. Then, the devices out of use are changed to standby mode. Through control of only out of devices, the potential energy saving of an electronic device is possible in consideration of user convenience. In addition, the amount of consumed energy and saved energy by the energy management system are recorded periodically in the energy measurement database. Lastly, the total consumed energy and saved energy are provided user daily, weekly, monthly, and yearly for informing data and arousing user's attention about energy saving.

Figure 1 illustrates an application model that contains four different rooms where people generally use the devices in the same room at the same time. In the figure, Sets A, B, C, D, and E are formed in different rooms. If people use the devices that are placed Sets C and D at the same time, the system should consider Sets C and D in the same space. As a result, conceptual space should be constructed from activity patterns. In addition, people generally use the several devices simultaneously. For the group-based control of device for energy management, we divide the all appliances as several groups and construct as the set by the construction of house and human activity patterns.

Activity pattern extraction process based on incrementally simultaneous method

The aim of extracting the activity patterns is to organize the simultaneous activities in order to resolve conflicts, and to discover habits. The simultaneous activities occur at a certain place for a certain time period. First, many contexts are acquired from environmental sensors and electronic devices. Then, the activity patterns and the simultaneous activity patterns are analyzed using ISM which organizes the activities context model. In addition, temporal relations between the simultaneous activity patterns are represented using Allen's temporal relation logic after constructing the simultaneous activities as sets. Finally, an activity context model can be constructed, which has both the probability and the temporal relations. To extract the simultaneous activity patterns, the activity context model is constructed from the sets of simultaneous activities which determine the probability relations between the activities and determine a temporal relation within the sets. The simultaneous activity set is a set of activity contexts which have occurred at the same time. People can undertake a maximum of four activities at a time, because the limit of activities in each set is four.

In order to organize the set of simultaneous activities, activities are first divided into simultaneous activities and non-simultaneous activities. A non-simultaneous activity is a representative activity that does not occur simultaneously with other representative activities, but has sub-simultaneous activities. Whenever simultaneous activities occur, the statistical value is measured and updated on the previously recorded. This value is the probability that a user does one action while doing another action simultaneously in the same set. These probabilities are calculated incrementally by updating the previous data.

System architecture

The proposed energy management system controls the power mode of electronic devices by using the user's absence from the space where the device is placed. When a device that is placed in a certain room is used by a user, the system recognizes a user exists in the room. Whereas, the device mode is switched to standby mode when people leave the room that the device is placed. However, the user's convenience should not be interrupted in smart environments. To prevent inconvenience, we define temporal activity. In the case of temporal activity, the system

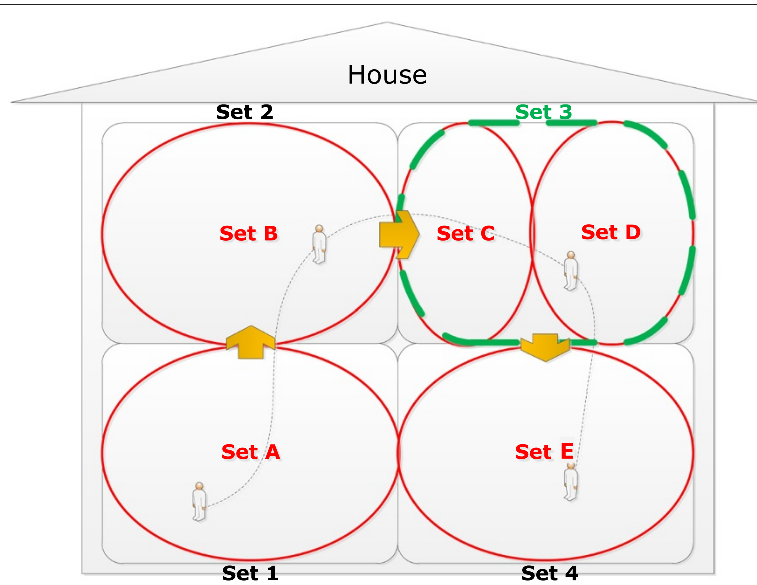

Figure 1 Illustration of an application model.

conserves the power mode of existing devices even though people leave the room where the devices are placed.

The process of potential energy management consists of three parts; data aggregator, observer, and manager including a simulator as shown in Figure 2. The data aggregator extracts relative probabilities and temporal relations which are related to the energy management from human activity patterns. The observer has two roles; real-time multi-user observation and real-time electronic devices monitor. The observer traces all users' position at the real-time and checks the status of all devices. The manager controls the power automatically by using the temporal relation of activity patterns, real-time user position data, and devices' status. Among working electronic devices, the manager detects a device that is out of use as power saving target. Then, the system controls the device power mode to switch to standby mode.

In addition, the amount of the calculated energy is periodically displayed with the consumed energy of the maximum consumed device. The proposed energy management system provides an automatic energy managing service as well as a guide to power consumption using the display service of amount of consumed energy and an amount of saved energy. The proposed context-aware system measures distance between a user and a device as well as users' position. When a user moves to other position, the system calculates the distance between the base position and the user's current position. The energy management system sets up the standby mode or sleep mode after checking the in short range or out of range.

Energy management model

The ISM considers the management of temporary service. In addition to the temporary service, the energy management model using ISM could manage the user-oriented service seamlessly and efficiently. Furthermore, the ISM based on the incremental probability presents optimal learning results. However, ISM permits an activity to be included in multiple sets in the process of constructing the simultaneous activity patterns set, that is, confusion of service control can occur by service activity duplication.

The ISM is an effective approach to extract the user activity patterns and predict the next activity. However, the ISM is required the additional function for development in efficiency using removal of the overlapping service for supporting the predicted service and power saving service. In the process of switching the simultaneous activity patterns set, the native ISM-based system commands all existing services to stop and then services in the next set

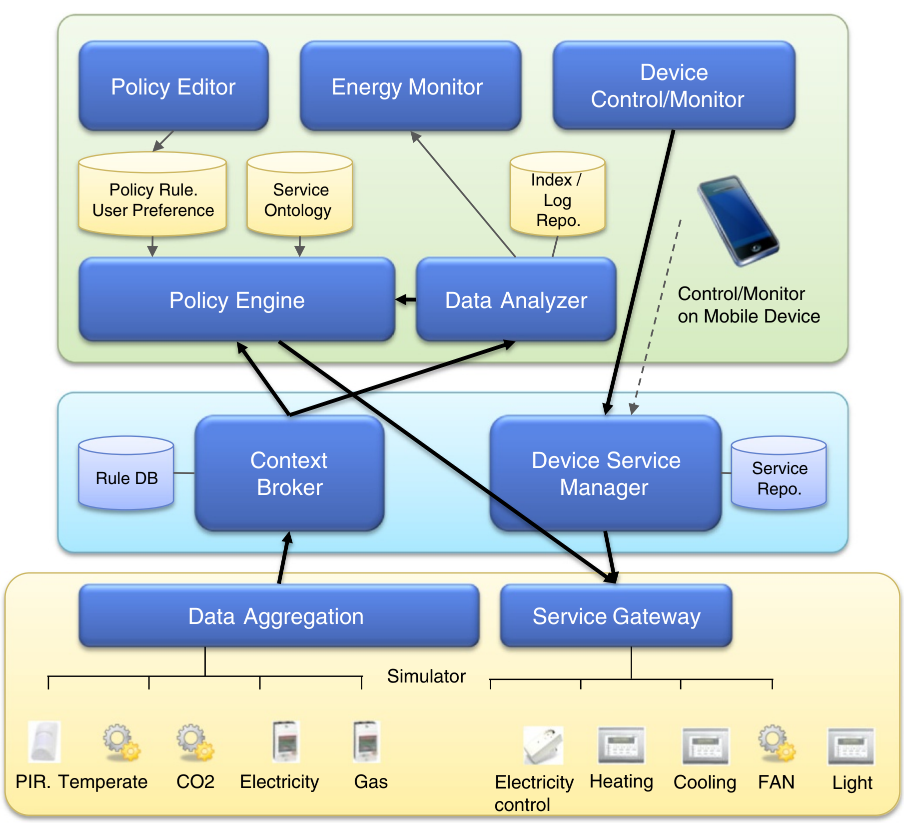

Figure 2 System architecture.

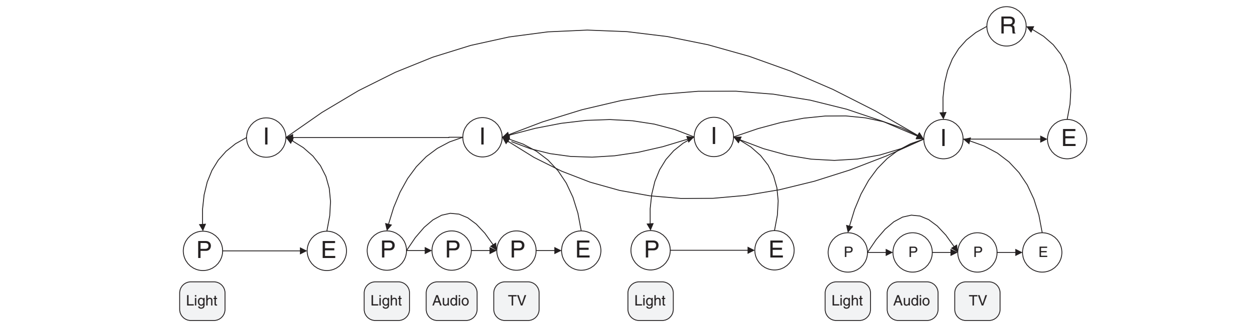

Figure 3 3-level HHMM-based energy management model.

to start although some service devices should keep the previous status.

In addition, service time is delayed to keep the previous power status of electronic devices because the native ISM-based system should control device's status after checking whether the device is the same one. The energy management model should solve the problem of the duplicated service to reduce the delay time and to prevent unnecessary on/off wasting. To remove duplicated service, the energy management model using ISM is applied by the HHMM. The duplication is removed by knowing house construction and location of existing electronic devices. To minimize the wasting of energy, we propose the energy management model using user activity patterns and HHMM. First, we describe a 3-level HHMM energy management model. Next, we present an adapted ISM-based energy management model using HHMM. Lastly, the proposed simulator using ISM-based energy management model is presented.

3-Level HHMM-based energy management system

The 3-level HHMM system [19] models the electronic device usage of a user as shown in Figure 3. The component of the energy management model is a device that is used by a user. The 3-level HHMM is organized based on the position of electronic devices. One node at the root level represents the state of a user when a user is at home. Two nodes at the second level represent the states that a user is in a room such as a living room, a bedroom, a kitchen, and a bathroom. Three nodes at the third level represent the states of electronic devices such as a TV, a computer, an audio, and a light of each room. The key parameter between nodes is calculated probability from accumulated incremental data.

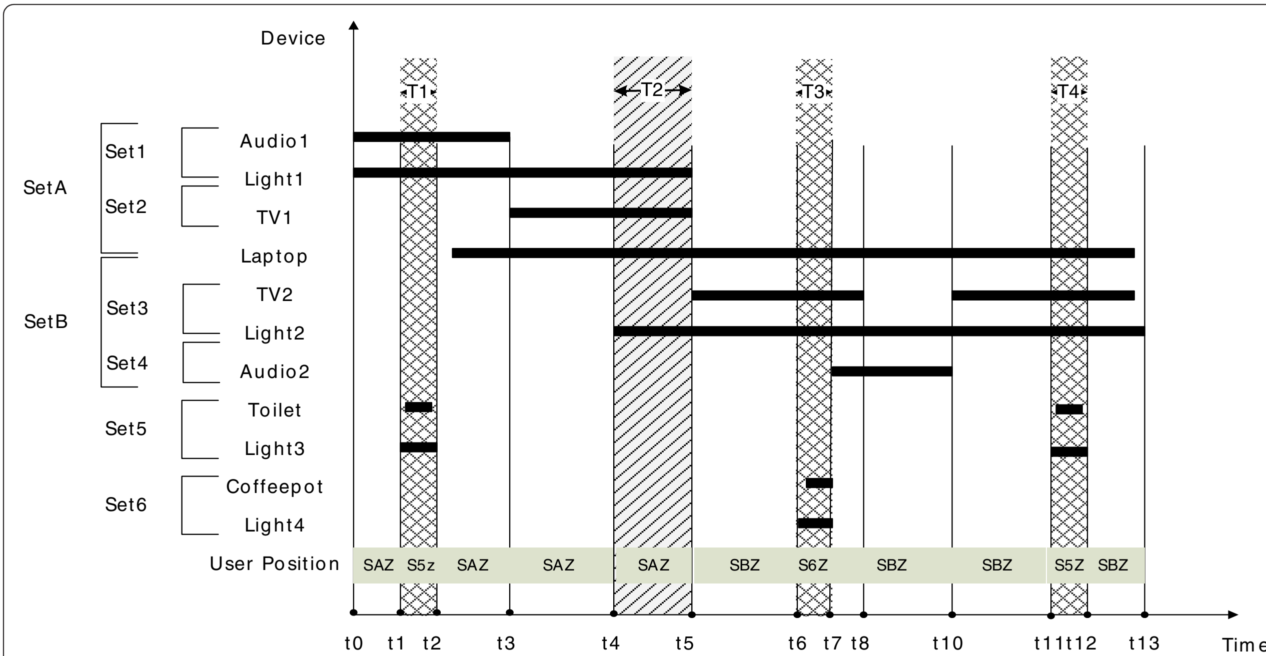

Figure 4 Example of devices of simultaneous activity patterns set.

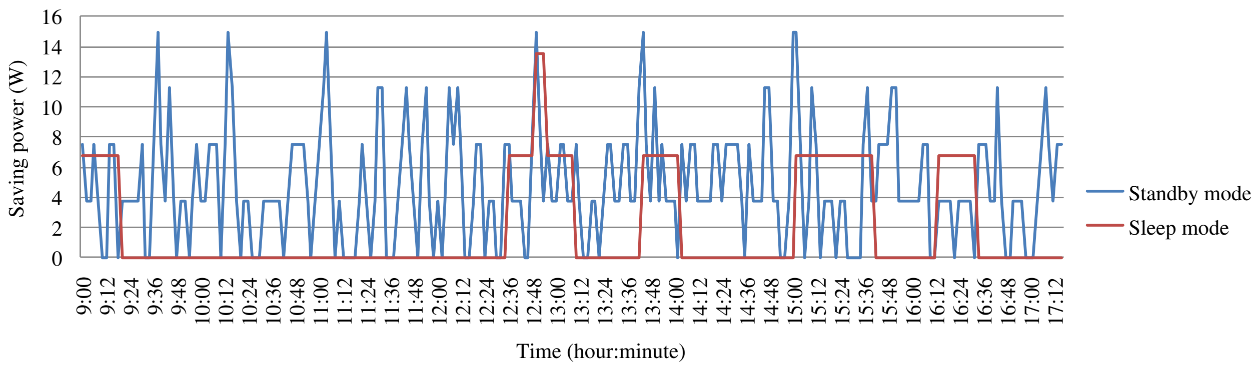

Figure 5 Occurrence of each mode for a period in a workday.

ISM-based energy management system

The adapted ISM-based energy management model is to control unnecessary electronic devices without the interruption of temporary activity as well as to remove delay by the duplicated service devices. First, data aggregator acquires a lot of contexts from sensors and electronic appliances. After acquiring context, the activity patterns and simultaneous activities patterns are extracted by analyzing the collected contexts. The simultaneous activity patterns are constructed as the simultaneous activity patterns set [20]. According to the University of Oregon [21], the maximum activity number which a person can do simultaneously is four. Therefore, the number of sub-activity is limited as four. Next, temporal relation of the simultaneous activity patterns set is determined between the sets by using the Allen's temporal relation. In the simultaneous activity pattern set, the activity has the probability relationship with another activity, and the simultaneous activity pattern set has the probability relationship with another set. The probability is incrementally updated daily using the aggregator.

In addition, separated sets, which contain electronic devices in the same place, are merged, and then the duplicated service devices are removed. For example, electronic devices of the Audio1 set and electronic devices of the TV1 set are in the same space, the lights of two sets are same one. Two sets are merged and the duplicated light is removed. Finally, the energy management model using ISM is reconstructed without duplication service.

The goal of manager is to find only one activity set which should be kept on working using the power use pattern, real-time user position, and device status form data aggregator and to stop services in unnecessary sets. Figure 4 shows an example of devices of simultaneous activity patterns set. First, Sets 1 and 2 are merged to become a Set A

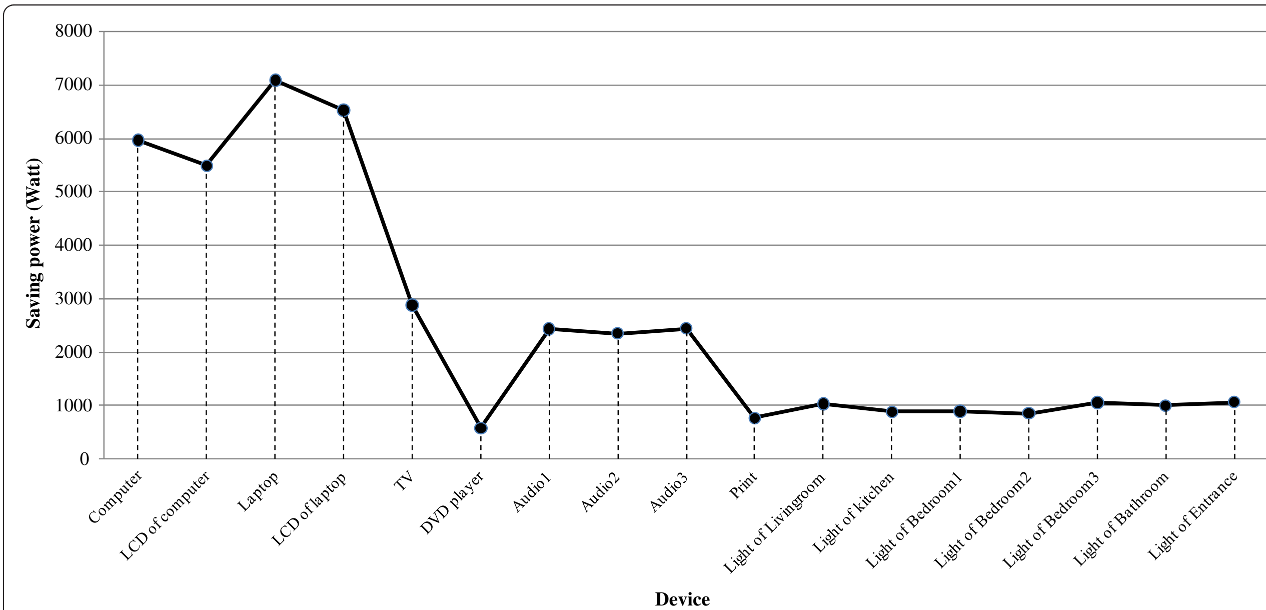

Figure 6 Average of daily saving power (W).

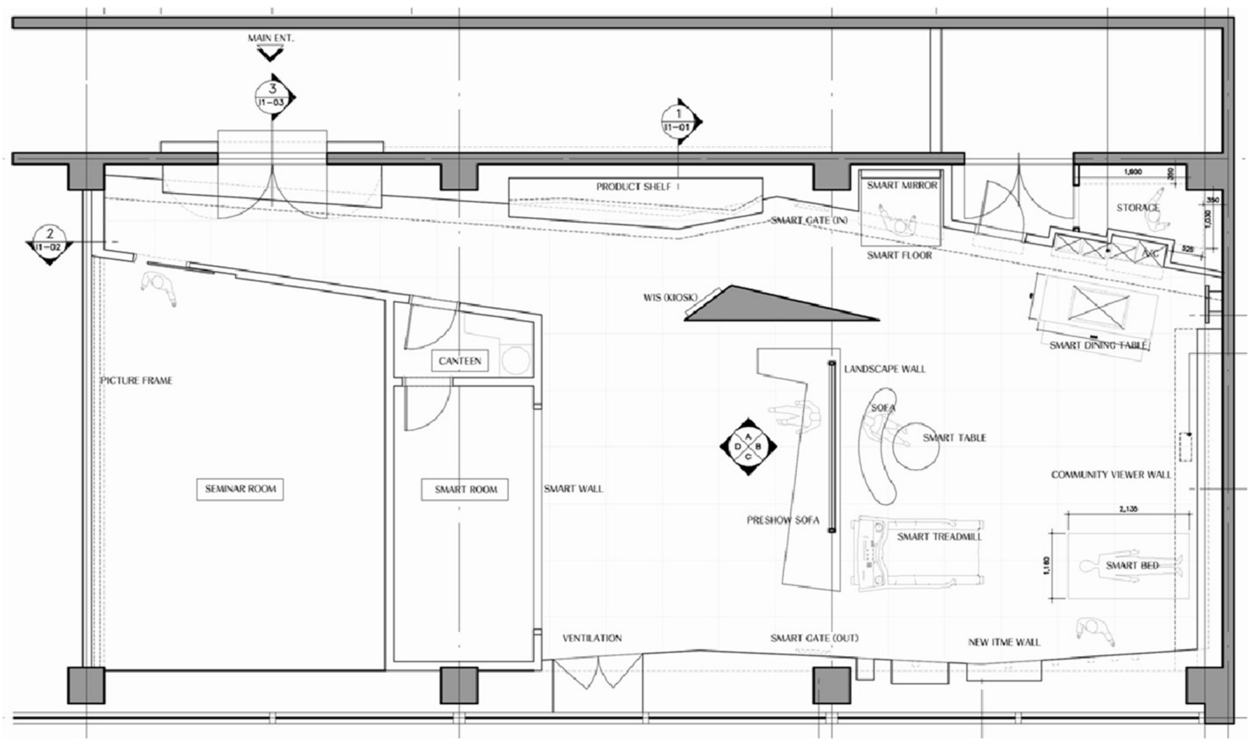

Figure 7 Construction of a test-bed.

and duplicated services are removed to prevent unnecessary on/off.

After merging without the duplicated service, the energy management system recognizes unnecessary services to stop at the real time. In the figure, the system finds that Sets A and B exist simultaneously in T2. Then, the system requests the observer real-time user position. In this case, the user is in Set A Zone (SAZ), that is, all service devices of Set B are stopped by the system. In addition, temporary services as the components of the simultaneous activity patterns are possible to control electronic devices effectively and it leads to power saving.

Unless the system distinguishes the temporary service among the set, it causes potential danger that is continuous service device is stopped by control based on only user's position without user's intention. Unless the system includes a device of temporary use, the system cannot control even the use of the device for a longer period. Therefore, temporary set should be distinguished among the sets. In Figure 4, temporary use of Set 5 has no effect on the control of existing set such as Set A in T1 and Set B in T4. The standard duration of temporary set is based on the average of duration by learning.

Heating and cooling system management

The energy management of heater/air conditioner is achieved by controlling running time using the human activity pattern. The office is warm by heat transfer or heat conduction. Heat transfer or heat conduction is the transition of thermal energy from a hotter object to a cooler object. To quantify the quantity of heat, Q is defined as thermal conductivity k, transmitted in time t through a thickness L, in a direction normal to a surface of area A, due to a temperature difference $\triangle T$.

We assume that the heater without pre-heating and heater including pre-heating have the following conditions: outside temperature, t_o; setting temperature, t_s; conduction coefficient $k = k'$, $A{:}A'$. According the formula, heat is based on transmitted time and temperature difference. Therefore, the quantity of heat between when heater uses for 1 h without pre-heating ($K'\ x(t_s - t_o)xA'\ x1$) and when heater uses for 1 h after pre-heating (=$0.5xt_s$) for 1 h is as follows:

$$\Big(k'x(0.5xt_s - t_o)xA'x1 + k'x(ts - 0.5xts)xA'x1 = k'Ax(t_{s-}t_o)\Big). \tag{1}$$

Heater wastes same energy to rise up the temperature slowly for longer time than rise up the same temperature quickly for a short time, but it is more effective for a user.

Human activity patterns are applied to save energy by remaining heat. The proposed context-aware system can predict the time when a user is leaving the office using

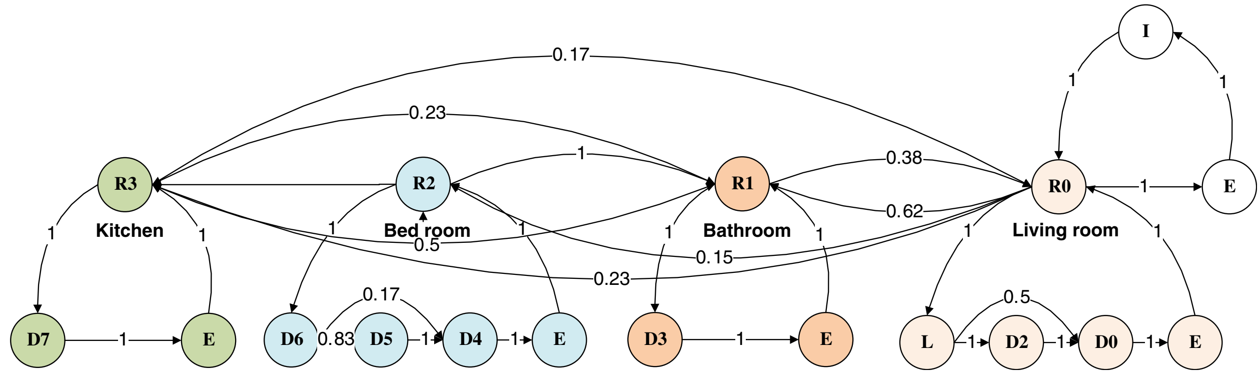

Figure 8 Results of 3-level HHMM model.

the human activity pattern. In regarding to remaining heat, the heater can be stopped before some period from the user leaves. If the heater which works for 10 h shortens by 9 h, 10% of energy is improved.

Experiments

Simulator

Using the ISM-based energy management model, the simulator has been developed to show consumed and saving energy of all electronic devices and to encourage energy saving as detecting electronic devices that consumes maximum energy. The result of the consumed and saving energy is displayed as daily, weekly, monthly, and yearly.

First, the simulator is set up using the number of rooms, electronic devices, each device's position, and people in the building. Next, the simulator calculates the consumed and saved energy of the device using ISM-based energy management system and shows the result of calculated energy. The electronic device that has maximum consumed energy amount is announced periodically (weekly, monthly, and yearly).

Results

We assume that a person works from 9 a.m. to 5 p.m. The mode of appliances is automatically set up by using the distance from the user's appliances and the duration of work. The appliance is waked up before the user comes back to the appliance for continuous work. Figure 5 shows occurrence of each mode for a period in a workday. The mode of an appliance turns to standby mode immediately when a user is in short range, and the mode turns to sleep mode when a user is out of range. The appliance consumed 101.58 W on idle mode, 75.35 W on standby mode, 54.22 W on sleep mode. Figure 6 shows the average of daily energy saving of each device.

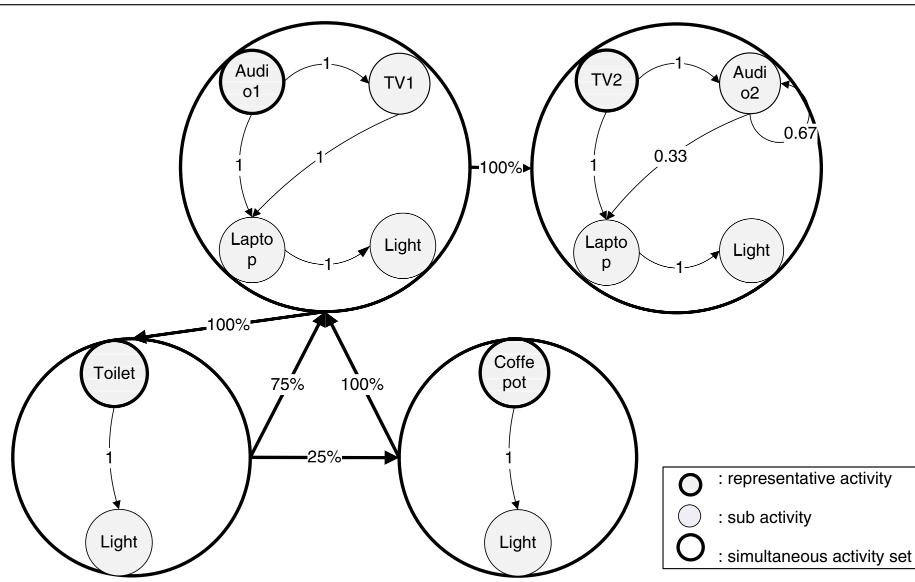

Figure 9 Result of ISM-based energy management model.

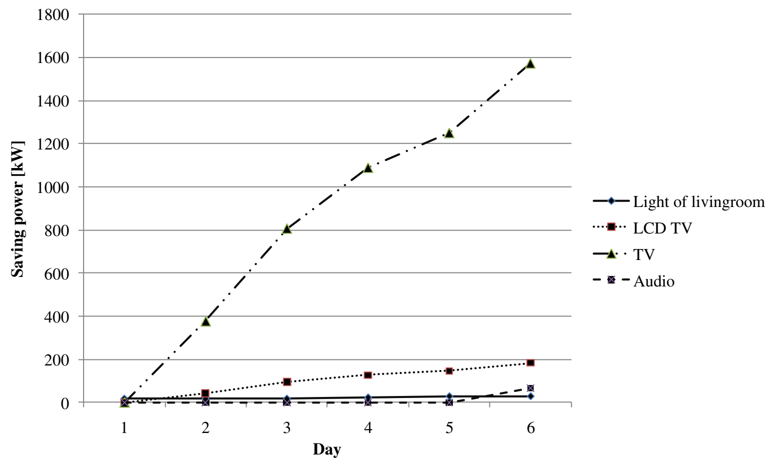

Figure 10 Saving energy of devices in the test-house for applying the ISM-based energy management system.

The heater without pre-heating and heater including pre-heating have the same condition: outside temperature, 0; setting temperature, 20; conduction coefficient $k = 0.02$, A: 20 m^2. According the formula, heat is based on transmitted time and temperature difference. Therefore, the quantity of heat between when heater uses for 1 h without pre-heating ($0.02 \cdot (20 - 0) \cdot 20.1 = 8.28$ kcal) and when heater uses for 1 h after pre-heating for 1 h ($0.02 \cdot (10 - 0) \cdot 20.1 + 0.02 \cdot (20 - 10) \cdot 20.1 = 8.28$ kcal) is same. Heater wastes same energy to rise up the temperature slowly for longer time than rise up the same temperature quickly for a short time, but it is more effective for a user.

We analyzed the activity patterns of a single after arriving home, and before going to bed to corroborate efficiency of the ISM-based energy management model. The power modes of electronic devices are automatically set up by using the ISM-based energy management model for energy saving in a device. The mode of electronic device turns to standby mode immediately when the ISM-based energy management system recognizes that the user is out of access range from the device. In addition, the device is waked up before the user comes back to the room where the device is placed. Figure 7 shows a test-bed composed of a living room, a bedroom, a kitchen, and a bathroom with sensors and devices.

Figure 8 shows the results of 3-level HHMM model. One node at the root level represents the state of user when a user is home; I (Indoor). Two nodes at the second level represent the states that a user is in a room such as R1 (Living room), R2 (Bathroom), R3 (Bedroom), and R4 (Kitchen). Three nodes at the third level represent the states of devices such as D1 to D7 of each room. The key parameter between nodes is calculated probability from accumulated history data. For example, the probability form R1 to R0 is 0.38.

Figure 9 shows the result of ISM-based energy management model. Four simultaneous activity pattern sets are constructed with probability relation between the sets. For

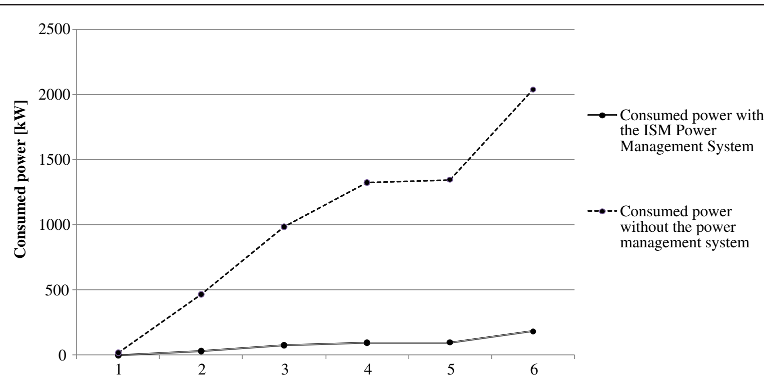

Figure 11 Total consumed energy of the test-house for applying the proposed energy management.

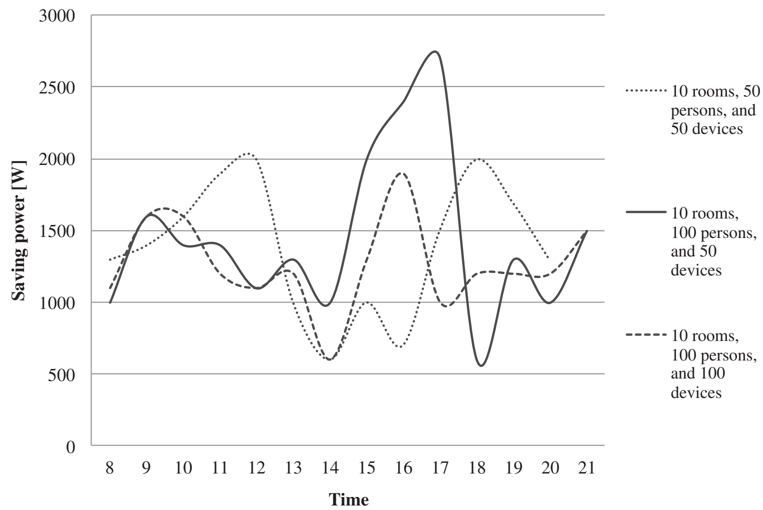

Figure 12 Daily total saving energy.

example, one set has Audio, TV1, Laptop, and Light as simultaneous activities. The set has 100% relationship with the next set which is placed on the right side.

The simulator has significantly showed the energy efficiency of the ISM-based energy management system. Using the simulator for applying the ISM-based energy management system, saving rate is estimated daily, weekly, monthly, and yearly. Figure 10 shows the saving energy of each electronic device in the test-house that the ISM-based energy management system is applied. Figure 11 shows the result of wasted energy in case of ISM-based energy management system and in case of the normal system without ISM. The wasted energy without the energy management system is average 2.64 times higher than wasted energy using the ISM-based system daily. As estimated electronic energy saving efficiency, 60.13%, monthly saving cost is 19.80 dollars and when we assume that the user maintains the same patterns.

The simulator presents the saving and consumed energy, and the overall mount of calculated energy daily, weekly, monthly, and yearly from accumulated data. To cover the overall data in the proposed energy management system, we assume an enormous amount of random activities. The duration of electronic device is applied using standard Gaussian random value. The hourly saved energy pattern is shown in Figure 12. During work time, more people use device, save-efficiency increases. As the number of persons is double, minimum 3% to maximum 33% is saved. Figure 13 shows the weekly consumed energy of living TV during 47 weeks. Weekly saving energy average

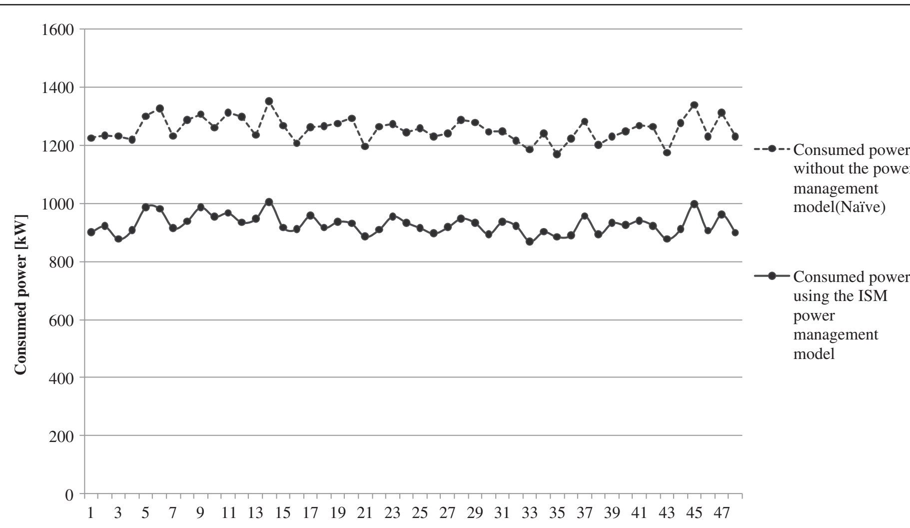

Figure 13 Weekly consumed energy of living TV during 47 weeks (1 year).

using the ISM-based energy management system is 327.69 kW and weekly average of saving rate is 26%.

Conclusion

We have developed the ISM-based energy management model including a 3-level HHMM model to manage the energy of electronic devices based on the analyzed activity patterns and real-time observed data. The activity contexts are collected from the environmental sensors and electronic appliances. Our proposed management system could control the unnecessary wasting energy of electronic devices by using observing position data and device status. In addition, we presented the simulation results to verify energy saving efficiency of the proposed energy management model. In the future, we will improve our method for multiple users and include all the current sensors into the proposed system. In addition, we plan to extend our method to three-dimensional topology of the building to achieve more energy saving.

Competing interests

The authors declare that they have no competing interests.

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