Predicting Collective User Preference for Optimal Comfort Level in Smart Buildings

Syafril Bandara[1], Takeshi Yashiro[2], M. Fahim Ferdous Khan[1], Noboru Koshizuka[1,2], and Ken Sakamura[1,2]
[1]Interfaculty Initiative in Information Studies, The University of Tokyo, Tokyo, Japan
[2]YRP Ubiquitous Networking Laboratory, Tokyo, Japan
Email: {syafril, khan, koshizuka, ken}@sakamura-lab.org, takeshi.yashiro@ubin.jp

***Abstract*—The idea of smart building has become closer to reality due to the recent advances in ubiquitous computing technologies. However, it still remains an open question how a computational system can optimize user comfort levels in buildings, which is crucial because it affects the quality of life and work of all occupants. Since multiple users share building spaces and they have hierarchical relationship to each other, it is not ideal to decide controllable comfort parameters based on a single users' preferences, and so collective users' preferences have to be considered. In this paper, we propose an algorithm to predict users' preferences based on the organizational hierarchy of the occupants, which can be used as a decision mechanism in smart building environments. To evaluate the proposed algorithm, we conducted experiment in real smart building environment, and recorded the number of manual interventions to control device settings before and after the deployment of the proposed algorithm. Our algorithm could successfully decrease the number of manual interventions by 64.2%.**

Keywords*—*smart buildings, smart buildings API, context-awareness, directed graph, organizational hierarchy

I. Introduction

The recent advances in ubiquitous computing technologies provide great benefits to access and control the physical world through a network. The development of these technologies in a building becomes a solution to realize smart building. One of the purposes of smart building is to provide a comfortable space for occupants. Since people spend more than 80% of their lives in buildings, the environmental comfort is strongly related to the occupant's productivity and quality of life and work [1]. The occupants of smart building have their own comfort conditions. When their own comfort conditions are not satisfied, they may take an action to change current conditions in order to satisfy their own comfort conditions. To optimize user comfort level, it is important to learn the occupants' comfort conditions from user activities.

Many solutions [2] [3] [4] [5] [6] [7] have been proposed for predicting user preference in smart environment. However, our review indicates that previous researches mainly focus on predicting single user preference and do not address the relationship between occupants. In [5] [6] [7] the prediction for users with various preferences have been proposed. Since they do not consider the relationship between occupants, as a result, these approach may not be practical in situations where the hierarchy relationship is exists between the occupants. Since multiple users share building spaces and they may not have identical comfort conditions, it is necessary to consider collective user preference. The goal of our work is to provide an optimal comfort level to the occupants by predicting collective user preference based on real life relationship between the occupants in smart buildings.

In this paper, we propose an algorithm for automatically predicting collective user preference in smart buildings. The building spaces are occupied by a group of occupants who belong to an organization. In an organization, usually some kind of hierarchy exists between the occupants. We observe how this organizational hierarchy influences a decision of comfort conditions for multiple users. When a group of occupants with different authority gather in one place, the occupant who has the greater authority tends to decide the comfort conditions. From this observation, we design an algorithm to predict user preference for a group of occupants. We define a model for a group of occupants who share a building spaces. A relationship between the occupants can be defined by investigating in the group who has changed the current conditions in order to satisfy his own comfort conditions. The comfort conditions for the group can be obtained from the last applied conditions. The relationship of the occupants and the comfort conditions are generated by monitoring the interaction between the occupants and the environment. The collective user preference can be predicted from the relationship of the occupants that have been defined and the comfort conditions that have been obtained. Based on the prediction, the system is able to provide optimal comfort level for the occupants in smart buildings.

To evaluate the proposed algorithm, we conducted experiment in real smart building environment. We measured the number of manual interventions which were done by occupants when they applied their comfort condition to the system. Since the number of manual interventions indicate the comfort level of the occupants, we compared the number of manual interventions before and after the deployment of the proposed algorithm. As a result, the total of number of manual interventions after the deployment of the proposed algorithm, decreased by 64.2%. The result shows that the proposed algorithm is feasible to optimize comfort level in smart buildings.

The rest of the paper is organized as follows. Section II discusses the related work. Section III presents the basic idea of algorithm for predicting collective user preferences, and how to resolve conflict of user relationship between the occupants. Section IV presents design of our smart building architecture. Our experimental results are shown in section V. Finally, we conclude the paper in section VI.

978-1-4799-8751-1/15/$31.00 ©2015 IEEE

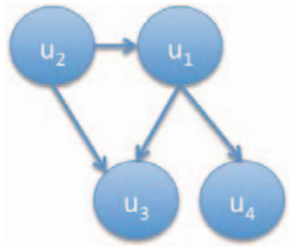


Fig. 1. Hierarchical Relationship of Occupants

II. Related Work

Up to the present, much work has targeted prediction of user preference in smart environment. Chen [2] designed a context-aware recommendation system that predicts a user preference using past experiences of like-minded users. They used collaborative filtering to automatically predict the influence of a context on an activity. Moreno et al. [3] proposed an energy-efficient management system based on Internet of Things (IoT) approach. They also presented Smart Comfort Prediction Module, which is responsible for providing comfort preferences to the occupants. In this framework, user comfort preferences are acquired and learned by the system once the user has interacted directly with the system. The system is able to provide users with their comfort preferences after detecting each user presence and estimating their location. Schumann et al. [4] presented algorithm for predicting the comfort preferences of users solely based on the temperature readings and their previous comfort votes. Yu et al. [5] proposed credit system for generating policies form multiple user preference. Each user is given 100 credits, which they may spend on various preferences. A preference item's final setting is chosen to be that of the user who spends the most credit. Yamamoto et al. [6] proposed a context-aware device control method for general users with different preferences on controllable targets in public smartspaces. In order to maximize the comfort levels of all users, they summed up comfort level functions of all users and select the maximum value and applied the value to a device. Lin et al. [7] proposed a three-layer system for learning inhabitants' behaviors based on the observations from sensors in order to provide suitable service to the users.

However, most of the previous works focused on single user preference. In [5], credit system has been presented to solve the difference of user preference. Since multiple users in building have hierarchical relationship to each other, this approach may not be practical in various situations. In [6], summation of comfort level functions of all users has been presented. Such approach may not feasible for optimizing comfort level in smart building since the summation of comfort level of all users not always be a collective user preference of the occupants. In [7], Multi-user Interaction Model that used Bayesian Networks is presented. The goal of the model is to infer the appropriate a *group service* for inhabitants. Their works focused on inhabitants in smart home. Therefore, it only discussed inference a *group service* without addressing the relationship between occupants. Since the relationship among inhabitants in smart home is different to the relationship among occupants in smart building, their approach may not be suitable for smart building environment. How to predict collective user preferences in smart building is the emphasis of this paper. To the best of our knowledge, no work has focused on how to predict collective user preference based on the organizational hierarchy of the occupants in smart building.

III. Algorithm for Predicting Collective User Preference

In this section, we propose an algorithm for predicting collective user preference. First, we explain the basic idea on how we extract a relationship of the occupants from the interaction between the occupants and the system and used it for predicting collective user preference. Second, we describe how to resolve the conflict of relationship between the occupants.

A. Basic Idea

We started by investigating how the occupants do an action in order to satisfy their own comfort conditions. When an occupant enters a room in smart building for the first time, our algorithm provides default conditions. If default conditions do not satisfy the occupant, he would take an action to manually change the current conditions. We assume that there is a smart building system which the occupant is able to control the devices in building space through the system. Smart building system records every access from the occupant in the access log, from which our algorithm learns collective user preference that can be used to provide an optimal comfort level to the occupants in smart building.

Formally we define U as a set of all occupants:

$$U = \{u_1, u_2, ..., u_n\} \tag{1}$$

We define comfort condition of all occupants C as:

$$C = \{c_1, c_2, ..., c_n\} \tag{2}$$

where c_i is a comfort condition of u_i. Comfort condition may be room temperature, illumination, or humidity. At first, all c_i is initialized as undefined, which indicates that the comfort condition of u_i is unknown.

When the set of users G_L are sharing space in the room, and an occupant u_L who is a member of G_L changed the room condition manually, the new condition c_L is recorded as new log entry L in access log,

$$L = \{G_L, u_L, c_L\} \tag{3}$$

From this log entry, we can make the following assumptions:

- Compared to the others occupants in G_L, u_L has greater authority. For example, if $G_L = \{u_1, u_2, u_3\}$ and $u_L = u_1$, the system learns that $u_1 > u_2$, $u_1 > u_3$. The notation $a > b$ means that a has greater authority than b.
- The preference of u_L is c_L, and the system updates $c[u_L] := c_L$

For example, if we have two logs $L_1 = \{G_x, u_1, c_x\}$ and $L_2 = \{G_y, u_2, c_y\}$, where $G_x = \{u_1, u_3, u_4\}$, $G_y = \{u_1, u_2, u_3\}$, c_x = 22°C, and c_y = 26°C. From G_x and u_1 we get:

$$u_1 > u_3, u_1 > u_4 \tag{4}$$

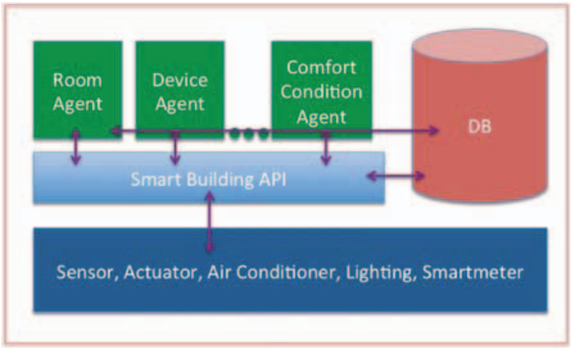


Fig. 2. Smart Building System Architecture

and from G_y and u_2 we get:

$$u_2 > u_1, u_2 > u_3 \tag{5}$$

We want to use the two logs above for optimizing the room temperature for new a user group $G_z = \{u_1, u_2, u_4\}$, who are sharing space in the room. We decide who has the greatest authority in G_z by using the previous logs. Considering that $>$ is a partial order relationship, we obtain the following equation from (4) and (5),

$$u_2 > u_1, u_2 > u_4 \tag{6}$$

which means that u_2 has the greatest authority in G_z. According to (6), we can choose c_2 as the comfort temperature for G_z.

From the observation above, we can express the hierarchical relationship of $U = \{u_1, u_2, u_3, u_4\}$ as directed graph in Fig. 1.

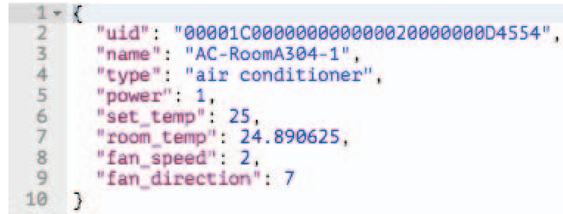
We use topological sorting [8] top-to-bottom for choosing which user's comfort preference to be adopted for all users. If the system does not know the hierarchical relationship between members of collective users, system provides a default comfort preference, and waits until an occupant who has greater authority changes the condition.

The algorithm predicts the collective user preference based on the interaction between the occupants and the system. Therefore, the algorithm can be used even in a group of occupants which do not have a hierarchical relationship. The occupants may decide the comfort conditions by voting. After they decide the comfort conditions, one of the occupants will apply it to the system. As we explain before, system will record this condition as comfort condition for them and it can be used for predicting a comfort conditions of the same group of occupants in the future.

In order to keep user preference and user relationship information up to date, we update user preference when the occupant directly access and change the current conditions. We also update the occupants relationship when the room state changes, the occupant enter or leave a room, and the occupant make a change to the current conditions.

B. Resolving Conflicts

In real world, the hierarchy may not exist between the occupants who share the building spaces. In this condition,



```
{
  "uid": "00001C00000000000000020000000D4554",
  "name": "AC-RoomA304-1",
  "type": "air conditioner",
  "power": 1,
  "set_temp": 25,
  "room_temp": 24.890625,
  "fan_speed": 2,
  "fan_direction": 7
}
```

Fig. 3. JSON Representation of Air Conditioner State

each user may tends to decide the comfort conditions and do arbitrary action in order to apply their own comfort conditions. If the edge is added to the occupants relationship graph for every action to the environment, the loop may be created. The loop will cause inconsistence of relationship between the occupants.

In order to avoid inconsistence of relationship of occupants, we break loops by removing the older relation that caused the loop. In the previous example, the directed graph can be denoted as below.

$$\begin{aligned} G &= \{V, A\} \\ V &= \{u_1, u_2, u_3, u_4\} \\ A &= \{(u_2, u_1), (u_2, u_3), (u_1, u_3), (u_1, u_4)\} \end{aligned} \tag{7}$$

If users u_1, u_2, u_3, u_4 are in the room, and u_1 change the room condition manually, we destroy edge (u_2, u_1), so that u_1 and u_2 would not have the loop, which can be considered a conflict in hierarchy.

There are some possible solutions to prevent the loop of relationship. The first solution is to keep the current relationship and ignore the new one or remove the current relationship and apply the new one. We can interpret the loop as the occupants having the same authority. If we keep one relationship and ignore the other one, the same authority can not be defined. The second solution is to keep the relationship which has the bigger count of access, and remove the relationship when the occupants have the same count of access. With this solution, an occupant is able to plan to get priority from the system by increasing the number of access. As a result, the system will prioritize an occupant who may not be the user with the greatest. For this reason, we prevent the loop relationship by only removing the old one. Therefore, the same authority of occupants can be defined and no one will get the priority.

IV. System Design and Implementation

The system configuration shown in Fig. 2 depicts the smart building system in our architecture. We developed Smart Building Application Program Interface (API) which can be used to access devices such as sensors, actuators, air conditioner, lighting, and smart meter. We use Representational State Transfer (REST) API and choose JavaScript Object Notation (JSON) as the data format in our Smart Building API. Fig. 3 shows the JSON representation of air conditioner state. The occupants of the building can easily develop an application using Smart Building API. We use Ubiquitous ID (uID) [9]

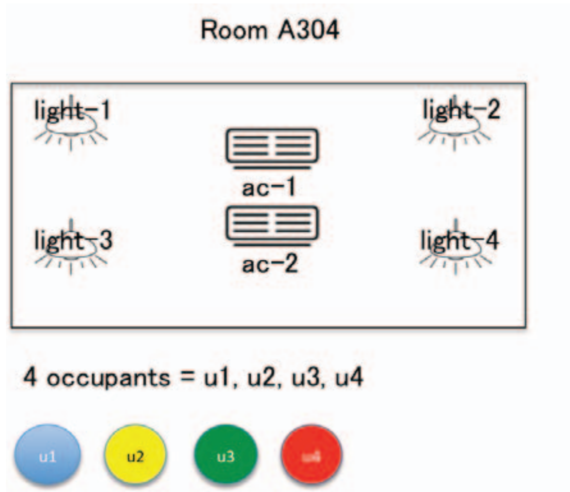


Fig. 4. Room A304 of Daiwa Ubiquitous Computing Research Building

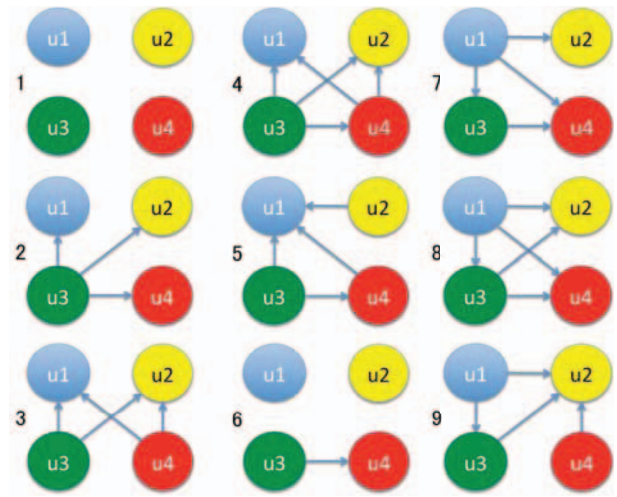


Fig. 5. Transition of Relationship of Occupants

architecture, and assign a 128bit unique id to devices in the building.

We developed several agents for providing services to the occupants. *Room Agent* is responsible for providing service to the occupants in the room. When the occupant enter or leave the room, *Room Agent* will update the current occupant on the system and ask *Comfort Condition Agent* to provide an appropriate condition for the remaining occupants. *Device Agent* manages the device when an occupant manually change device settings. *Comfort Condition Agent* is responsible for providing comfort condition to the occupants in the room based on proposed algorithm. When the occupants change device settings, *Device Agent* will notice *Comfort Condition Agent* to update user preference of the related users. The occupants interact with the system through room control application which is explained in the next section. The access log includes user id, device id, device settings and timestamp is recorded in data base.

V. Evaluation

In order to evaluate the proposed algorithm, we have developed a room control application in which the proposed algorithm is implemented. We evaluated the algorithm in the smart building named "Daiwa Ubiquitous Computing Research Building"[10] located in Hongo campus of the University of Tokyo. We measured the number of manual interventions before and after the deployment of the proposed algorithm to the system. The manual intervention is done by an occupant when the current conditions of the room do not satisfy his comfort conditions. Therefore we are able to know comfort level of the occupant from the number of manual interventions.

A. Room Control Application

In order to let occupants interact with the smart building system, we have developed room control application. The room control application is web-based, the occupants interact and control a device in the room from the browser. Room control application also shows the current settings of the devices in the room. Therefore, the occupants are able to know the current settings before changing it.

B. Experiment Scenario

We evaluate the proposed algorithm in room A304 of Daiwa Ubiquitous Computing Research Building. The room is alloted to 4 occupants: one female and three males. We asked them to use the room control application when they want to change device settings. We used the lights and air conditioner as the devices in our experiment. We conducted the experiment into two phases.

1) First Phase, before deploying the algorithm: We recorded when and who enter and leave the room. We also recorded when and who access the device through room application and change the device settings. We conducted the first phase of experiment for a period of one week. From the data of the first phase of experiment, we obtained the user preference of all occupants. As shown in in Fig. 4, room A304 has four lights and two air conditioners.The user preference that we obtained include the temperature settings of air conditioner 1, and air conditioner 2, and which light that occupant usually use.

2) Second Phase, after deploying the algorithm: We use record of room state and access log that we obtained in the first phase of experiment as the input of the proposed algorithm. As the output we obtain the hierarchy of the occupants in room A304. We also predict the collective user preference of the occupants in room A304. We deploy the prediction to the system, so that the system will automatically change the room conditions when the room state is changed. If the condition which is provided by the system do not satisfy the occupants, they can manually change the condition through room control application. We recorded the manual interventions in the second phase of experiment for a period of one week.

C. Experimental Results

From the first phase of experiment, we obtained the relationship of occupants in room A304. Fig. 5 presents the transition of the relationship of the occupants. In initial stage, there are no edges in the graph. When one occupant accesses and changes the device settings, edges are created from the current occupant to all other occupants. In order to avoid inconsistency in directed graph, we do not create the opposite direction of edge. As shown in Fig. 5, after the occupants u3 changes the temperature of air conditioner, the relationship changes from 1 to 2. Then the occupants u4 changes the temperature of air conditioner, the relationship changes from 2 to 3. From this figure it can be seen that proposed algorithm destroy the edge from u3 to u4 in order to avoid the inconsistency in directed graph.

We show the comparison of the number of manual interventions in first phase and second phase of experiment in Fig. 6. In first phase of experiment we obtained 67 manual interventions from all occupants, which decreased to 24 manual interventions in second phase of experiment. The total number of manual interventions decreased by 64.2%. For each occupant, the number of manual interventions decreased as follows :

- for occupant u1, 80% (from 25 to 5)
- for occupant u2, 70% (from 10 to 3)
- for occupant u3, 60% (from 10 to 4)
- and for occupant u4, 45.5% (from 22 to 12)

The occupant u4 showed the least reduction of manual interventions. From the record of room state, we obtain that the occupant u4 was the first one enter room A304 most of the time. Since we did the experiment during the summer season, the first occupant who enter a room may set the temperature low than their comfort temperature in order to cool the room faster. Therefore, when the occupant u4 enter room A304, he is not satisfied with the conditions provided by the system, and change the temperature lower than his comfort temperature. After the room become cool, he changes the temperature to his comfort temperature. Since the system record the last applied condition as the user preference, this case may occur for the user who enter the room for the first time.

This result shows that our proposed algorithm can automatically predict collective user preference from the user preference and the relationship of occupants. Since the total of number of manual intervention decreased by 64.2% after the deployment of the proposed algorithm, our algorithm is feasible to optimize comfort level in smart buildings.

VI. Conclusion

In this study, we have observed how the characteristic of organizational hierarchy of occupants in smart building influences a decision of comfort conditions for a group of occupants. In order to provide an optimal comfort level to the occupants, we have proposed an algorithm to predict collective user preference unlike most other work which focuses on single-user situation. The proposed algorithm is intuitive, because it predicts collective user preference based on real life relationship of the occupants in smart buildings. We evaluated the proposed algorithm by measuring the number of manual intervention before and after deployment of the algorithm. The results show that the proposed algorithm reduces the number of manual intervention for all occupants. We believe that our proposed algorithm is feasible to optimize comfort level in smart buildings by predicting collective user preference.

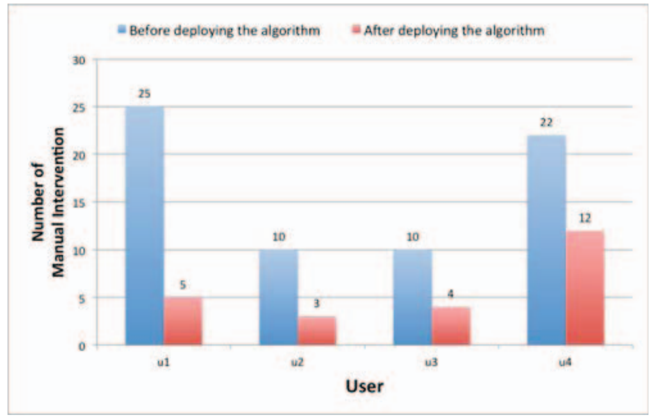


Fig. 6. Number of manual intervention before and after deploying the algorithm

Acknowledgment

This work is partially supported under the Strategic Information and Communications R&D Promotion Programme (SCOPE), the Ministry of Internal Affairs and Communications, Japan.

References

[1] Dounis, Anastasios I., and Christos Caraiscos. "Advanced control systems engineering for energy and comfort management in a building environment—A review." Renewable and Sustainable Energy Reviews 13.6 (2009): 1246-1261.

[2] Chen, Annie. "Context-aware collaborative filtering system: Predicting the user's preference in the ubiquitous computing environment." Location-and Context-Awareness. Springer Berlin Heidelberg, 2005. 244-253.

[3] Moreno, Maria V., Miguel A. Zamora, and Antonio F. Skarmeta. "User-centric smart buildings for energy sustainable smart cities." Transactions on Emerging Telecommunications Technologies 25.1 (2014): 41-55.

[4] Schumann, Anika, Nic Wilson, and Mateo Burillo. "Learning user preferences to maximise occupant comfort in office buildings." Trends in Applied Intelligent Systems. Springer Berlin Heidelberg, 2010. 681-690.

[5] Yu, Der-Yeuan, Ettore Ferranti, and Hadeli Hadeli. "An intelligent building that listens to your needs." Proceedings of the 28th Annual ACM Symposium on Applied Computing. ACM, 2013.

[6] Yamamoto, Shinya, Naoya Kouyama, Keiichi Yasumoto, and Minoru Ito. "Maximizing users comfort levels through user preference estimation in public smartspaces." In Pervasive Computing and Communications Workshops (PERCOM Workshops), 2011 IEEE International Conference on, pp. 572-577. IEEE, 2011.

[7] Lin, Zhi-Hao, and Li-Chen Fu. "Multi-user preference model and service provision in a smart home environment." Automation Science and Engineering, 2007. CASE 2007. IEEE International Conference on. IEEE, 2007.

[8] Kalvin, Alan D., and Yaakov L. Varol. "On the generation of all topological sortings." Journal of Algorithms 4.2 (1983): 150-162.

[9] Koshizuka, Noboru, and Ken Sakamura. "Ubiquitous ID: standards for ubiquitous computing and the Internet of Things." IEEE Pervasive Computing 4 (2010): 98-101.

[10] Sakamura, Ken. "Programable Architecture : A smart control system in Daiwa Ubiquitous Computing Research Building." TRONWARE vol.148, 2014. (in Japanese)