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EVALUATION OF BEHAVIOR ESTIMATION USING WARD'S METHOD IN MULTIFUNCTION OUTLET SYSTEM

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Abstract- Home Energy Management System (HEMS) is standard as a system for reducing power consumption in ordinary homes. The system prevents the users from forgetting to turn off home appliances. However the system is too simple to more reduce power consumption. Therefore we aim to reduce power consumption by figuring out a user's behavior to control home appliances. However to estimate user's behavior is difficult for the system. So we develop Multifunction Outlet System into a function to control home appliances. The function uses Ward's method which is an unsupervised learning for estimation of a user's behavior. In this paper, we evaluated a result of estimate of a user's behavior from sensor data by Ward's method.

Index terms*:* Ward's method, Sensor Networks, HEMS.

I. INTRODUCTION

According as people are raising environmental awareness, reducing power conservation has been required in ordinary homes. A power consumption of latest home appliances decreases year by year. These appliances have some sensors of infrared, temperature and so on. For example, an air conditioner with an infrared sensor has a function of detecting a person in a room. If there is no person in the room, then the air conditioner turns itself off. However a detection range per sensor is so narrow that it gives a false result. So the function needs to use multiple sensors. This method has been realized by Home Energy Management System (HEMS). HEMS connect each home appliance with a network. Therefore HEMS can use multiple sensors to detect a person. Therefore construction of a long-term care system for the elderly and research on stabilization of sensor networks on the premise of HEMS are being conducted [1][2][3][4][5]. On the other hand, HEMS has two problems. One of the problems is that a method of controlling home appliances is too simple. For example, a user can set home appliances to turn off when a person is not detected in a room. However, the way does not consider the user's behaviors like "reading a book" or "watching television" and so on. It can reduce power consumption as well as hindering a user's life in some cases. The other problem is the high cost for users because they must repurchase any home appliances only for HEMS. Accordingly, an energy conservation system for ordinary home needs "a user's behavior can be evaluated" and "low cost".

Some research [6][7][8] have elements for estimation of a user's behavior. This research [9] uses consumption patterns and usage time of home appliances to evaluate a user's behavior. On the other hand, the other research [10] evaluates a user's behavior using some infrared sensors attached in a room. According to the research, the method using only infrared sensors gives accuracy rate over 80\%. Based on these studies, we attempt to evaluate a user's behavior by merging the two methods. We develop Multifunction Outlet System [11][12][13]. The system uses attached Adapter unit to all of home appliances in a house. Adapter unit has various sensors to estimate a user's behavior. A tap type system connected to home appliances has been developed some laboratories [14][15][16][17][18]. In these researches [19][20][21], in addition to the sensors installed in the room, the resident has an acceleration sensor to improve the accuracy of behavior estimation. In this research [22], we define that behavior of residents is over 10 minutes and estimate behavior. Our system uses Ward's method to the sensor data of these sensors for behavior classification. In this paper, we evaluate Ward's method estimation of a user's behavior.

II. MULTIFUNCTION OUTLET SYSTEM

Multifunction Outlet System is a system to support saving energy targeting an ordinary home. This system is composed of three units: Adapter unit, Communication Control unit and Server unit. This system needs various type of sensors for classifications. Adapter unit is equipped with multiple sensors to measure air temperature, infrared and light. In addition, this unit measures a power consumption value of a connected appliance using an electric current sensor.

Communication Control unit controls sending information between Adapter unit and Server unit. Communication between Communication Control unit and Adapter unit uses ZigBee protocol. These two units are equipped with XBee to use this protocol. XBee is a wireless module of low power consumption [23]. Communication between Communication Control unit and Server unit uses HTTP protocol. Therefore sensor data of Adapter units are stored Server unit via Communication Control unit. It is common to use ZigBee protocol to construct a sensor network. Therefore, a research [24] on the stability of the network is being conducted.

Server unit has two functions. One is to let a user's access by using a browser and figure out sensor data of each Adapter unit. The other is to run an instruction control of home appliances.

The instruction control is created by a user or a system. In case of the user, he registers the action with a time schedule to control home appliances in a room. According to the schedule, the action controls home appliances to connect Adapter unit. In case of the system, Server unit analyzes sensor data for the estimate of the user's behaviors. According to the result of the estimate, the action selects home appliances to control. If this system has a problem like making a wrong estimate, the user can re-control a home appliance by accessing Web server of this Server unit.

Figure1 shows a simple example of using Multifunction Outlet System. A user registers his behaviors as actions to the systems. The user programs his actions to Server unit of the system. In this figure, the program is composed of three patterns: "Action 1: Watching Television", "Action 2: Reading a Book" and "Action 3: Not at Home". Table 1 shows actions and controls of home appliances. In this system, according to a use's action pattern, home appliances are turned off when they are not used. As a result, an ordinary home can realize saving energy. In the next section, we evaluate the estimate when we use sensor data of Multifunction Outlet System.

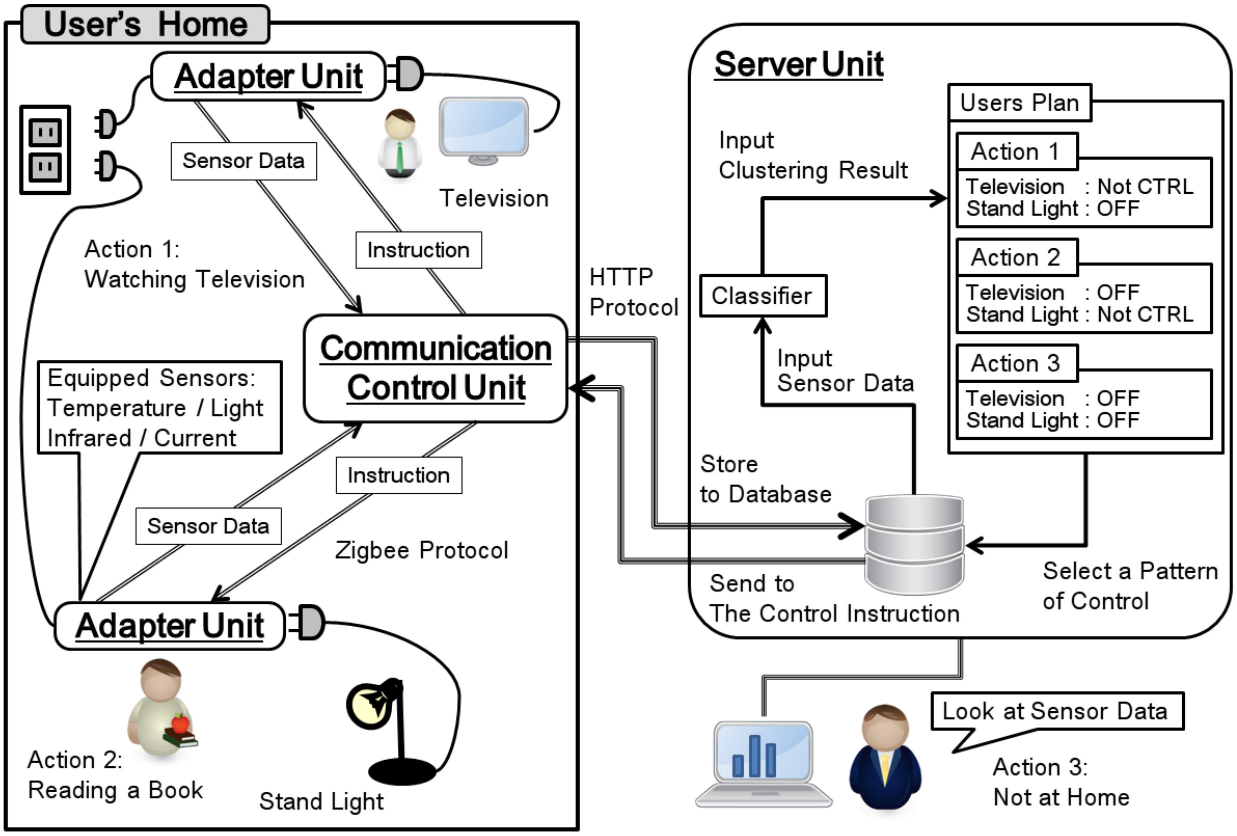

Figure 1. Multifunction Outlet System

Table 1: Action Pattern and a Control of Home Appliances

Pattern	Television	Stand Light
Action 1: Watching Television	* not control	* turn off
Action 2: Reading a Book	* turn off	* not control
Action 3: Not at Home	* turn off	* turn off

III. EXPERIMENTAL PREPARATION

We used two datasets for evaluation. The datasets are sensor data stored in Multifunction Outlet System. The datasets inserted a partition between each action because we use the partition to evaluate the clustering result. The partition means start and end time of a user's action. These two datasets selected from 55 days log of a person living alone using Multifunction Outlet System.

He was twenty and had recorded his own actions and time of data beforehand. In the experiment, we used sensor data of seven Adapter units with four types sensors: air temperature, infrared, light and electric current. These sensor data were sent to Server unit from Adapter units at intervals of ten seconds. The system calculates a mean value for one minute of the data and use the median filter to remove noise from sensor data. Besides, Adapter unit was equipped with various sensors which were different in the range of output. Therefore, this system processed a scaling of sensors' data. As for the scaling we used maximum value and minimum value of each sensor. We defined a dataset of one day as "sample", and we used "sample" as an estimate base of the user's actions. The user's actions are defined in Table 2. We defined the dataset of another day as "test", and we used "test" to evaluate the result of estimate by "sample". The user's actions of "test" are defined in Table 3. These tables show user's actions of one day and each action’s times. "Action ID" in these tables shows to assign ID.

In the next section, we show the evaluation of a user's action using Ward's method to "sample" dataset.

Table 2 : Action Log of a Day(Sample Dataset)

Start Time	End Time	User’s Action	Action ID
00:00	00:07	cooking	1
00:07	00:52	in the living room	3
00:52	01:02	in the toilet	2
01:02	04:03	in the living room	3
04:03	13:07	sleeping	5
13:07	13:55	in the living room	3
13:55	14:10	in the washroom	6
14:10	14:33	cooking	1
14:33	14:43	in the toilet	2
14:43	15:11	in the living room	3
15:11	17:21	being out	4
17:21	17:33	cooking	1
17:33	18:34	in the living room	3

18:34	18:54	in the washroom	6
18:54	21:38	in the living room	3
21:38	22:00	cooking	1
22:00	22:45	in the living room	3
22:45	22:50	in the washroom	6
22:50	23:03	in the bath room	7
23:03	24:00	in the living room	3

Table 3 : Action Log of a Day(Test Dataset)

Start Time	**End Time**	**User's Action**	**Action ID**
00:00	00:13	in the living room	3
00:13	00:20	in the toilet	2
00:20	03:38	in the living room	3
03:38	10:10	sleeping	5
10:10	10:22	in the living room	3
10:22	10:34	in the toilet	2
10:34	10:43	in the washroom	6
10:43	10:51	in the living room	3
10:51	10:57	in the washroom	6
10:57	11:10	in the living room	3
11:10	20:00	being out	4
20:00	21:58	in the living room	3
21:58	22:04	in the washroom	6
22:04	22:18	in the bath room	7
22:18	22:22	in the washroom	6
22:22	24:00	in the living room	3

IV. EXPERIMENT 1: CLUSTERING BY WARD'S METHOD

a. Ward's Method

Ward's method is one of a hierarchical clustering technique. At the initial state, all clusters are singletons. When using Multifunction Outlet System, sensor data corresponding to a minute becomes each cluster. Next, the method creates a new cluster from two clusters which are a combination like minimum of variance at clusters. The method repeats this process until creating a single cluster all data included.

Figure 2 shows clustering an example of "sample" dataset. We figured the data of the period from 13:10 to 14:30 in the dataset. A sensor data in the example was averaged every ten minutes not per minute. The vertical axis in the figure shows "Level", a variance value which merges any two clusters. The horizontal axis in the figure shows "Cluster" at the initial state.

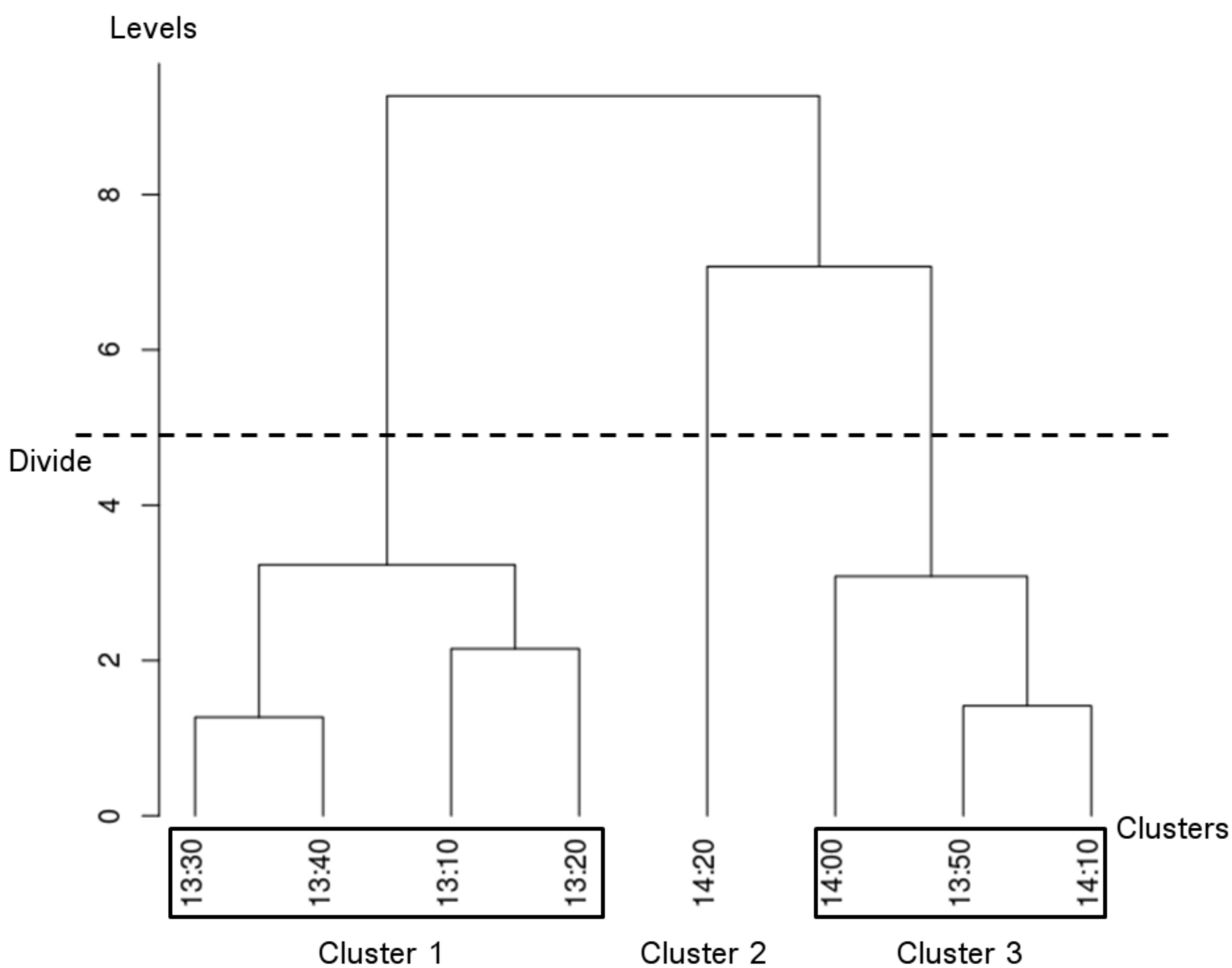

Figure 2. Clustring of Sensor Data by Ward's Method

Table 4 shows a user's actions and the time range. "Divide" in the figure is a location to divide dataset. A location was decided to create three clusters because the user's actions are divided into three patterns. Table 5 shows a result of mapping each cluster to actions. The result of clustering was accurate except for the data of ten minutes from 14:10. A possible cause of this except data is that to include a user action moving from a toilet to a kitchen. We evaluate a result of clustering all "sample" dataset in the next section.

Table 4 : User's Action Log

Time range	Action
13:10 – 13:55	Action 3
13:55 – 14:10	Action 6
14:10 – 14:30	Action 1

Table 5 : Result of Clustering

Cluster ID	Time Range
Cluster 1	13:10 – 13:50
Cluster 2	14:20 – 14:30
Cluster 3	13:50 – 14:20

b. Evaluation of Clustering by Ward's Method

In this section, we changed a time range from ten minutes to per minute for estimation of short time actions. In this case, we divided the dataset into seven because a user creates seven actions of home appliances controls. Table 6 shows a result of clustering. These percentages mean how much proportions of "Action ID" are included in each cluster. 1 to 7 of "Action ID" corresponds to those of Table 2 and 3. In addition, we assigned "ID" from "a" to "g" to the clusters taken from Ward's method. A boldface number appears most frequently in each cluster. In this table, "e" and "f" were exactly classified in each cluster. However "a" and "c" included various actions. Classification of "Action 4" and "Action 5" was difficult for the method because "d" of clustering results was actually a mix of multiple actions.

Table 6 : Result of Clustering by Ward's Method (Number of Clusters are 7)

ID	Action ID						
	1	**2**	**3**	**4**	**5**	**6**	**7**
a	22.1%	6.5%	**70.1%**	0.0%	0.6%	0.6%	0.0%
b	0.5%	0.0%	**98.6%**	0.0%	0.0%	0.9%	0.0%
c	9.8%	0.0%	**72.2%**	1.0%	0.0%	17.0%	0.0%
d	0.0%	0.0%	0.0%	28.2%	**71.2%**	0.0%	0.0%
e	0.0%	0.0%	0.0%	0.0%	**100.0%**	0.0%	0.0%
f	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%
g	7.2%	7.2%	**82.6%**	0.0%	0.0%	2.9%	9.4%

The experiment was decided a number of control plans by user. However the number is different by user. Therefore other way is simpler pattern of user's actions than Table 2 and 3. This time we defined three actions: "Active", "Non-Active" and "Not in the room". Table 7 shows a simple pattern of user's actions. "Simple Action ID" in this table is used to assign ID. "Status" in this table shows a user's actions.

Table 7 : Simple Action Patterns

Simple Action ID	Status	Actions(Action ID)
I	Active	cooking(1), in the toilet(2), in the living room(3), in the washroom(6), in the bath room(7)
II	Non-Active	sleeping(5)
III	Not in the Room	being out(4)

"Actions" in this table are used to classify actions of these tables 2 and 3. Table 8 shows the clustering result of this dataset. This result is more accurately clustered than the result of table 6. However, "Action III" does not identify from the result. "Action II" and "Action III" included less active of user in sensor data of "sample" dataset.

Table 8 : Result of Clustering by Ward's Method (Number of Clusters are 3)

ID	Action ID		
	I	II	III
a	0.0%	80.9%	19.1%
b	99.7%	0.0%	0.3%
c	99.4%	0.0%	0.0%

We compared the result of Ward's method with some other results. Figure 3 shows levels when a total of clusters are different. A level is a minimum distance among each cluster. A change amount of levels are smaller than between "2" and "3" for between "3" and "4" in a number of clusters. Therefore we attempted to divide a clustering "sample" dataset into four clusters; the result is shown in Table 9. In the table, "a" was included in "Action III", the result was more accurate than Table 8.

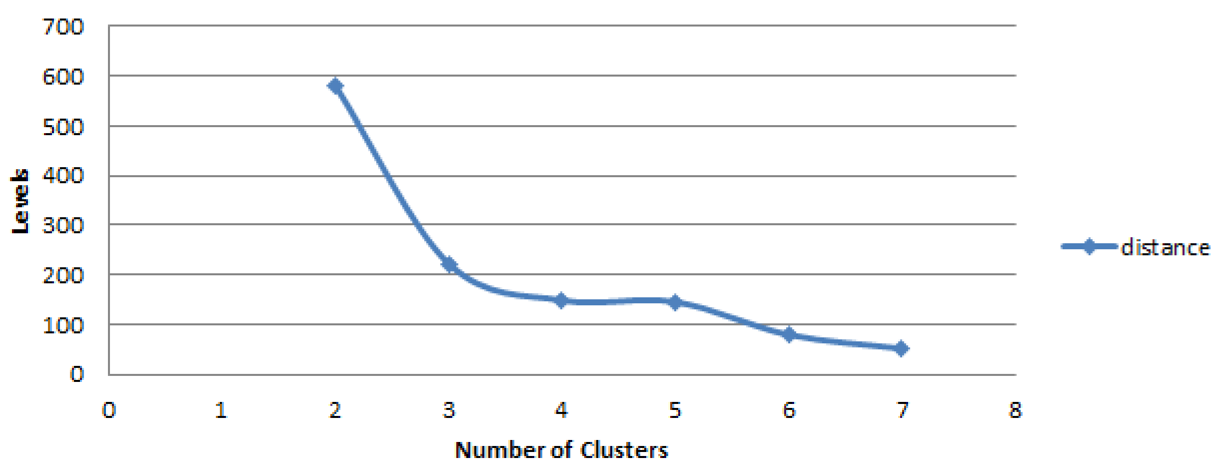

Figure 3. The Minimum of Distance of Each Cluster

Table 9 : Result of Clustering by Ward's Method (Number of Clusters are 4)

ID	Action ID		
	I	**II**	**III**
a	0.0%	71.2%	28.8%
b	99.7%	0.0%	0.3%
c	99.4%	0.0%	0.0%
d	0.0%	100.0%	0.0%

V. EXPERIMENT 2: ACTION IDENTIFICATION BY WARD’S METHOD

a. Method of Action Identification Using Ward's Method

This identification of the method uses a result of clustering "sample" dataset by Ward's method. This input data is one minute of "test" dataset. The method measures a distance between each cluster and the input data. The input data is identified to a cluster which is the nearest at all clusters. In this case, the method defined a total number of clusters so that a cluster and an action are homologized. This classifier uses the result of Section IV-B.

b. Result of Action Identification Using Ward's Method

Table 10 shows the result evaluated from a user's behavior estimation using "sample" data. "Action ID" in this table are the same us those of Tables 2, 3. "Result of The Test Dataset by Classifier" in this table shows output results of a cluster labeled from "A" to "G". These labels are the same as "Action ID" from "1" to "7". The right answers of each cluster are in boldface. "Rate" in this table shows the accuracy rate of clustering results that includes number of correctly classified in each clusters.

Some actions were correctly classified like "Action ID" 1 and 4. A correct answer of the Action 1 was number zero because it did not include "cooking" in the "test" dataset. However, other clusters included margins of error from correct answers.

Table 10 : Classification of Sensor data by Ward's Method

Action ID	**Result of The Test Dataset by Classifier**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
1	**0**	0	0	0	0	0	0
2	0	**0**	189	0	0	0	0
3	0	9	**40**	0	0	19	14
4	0	0	5	**530**	196	0	0
5	0	0	12	0	**196**	0	0
6	0	0	49	0	0	**0**	0
7	0	10	165	0	0	6	**0**
Rate	100.0%	0.0%	8.69%	100.0%	50.0%	0.0%	0.0%

VI. CONCLUSIONS

In this paper, we evaluated a method to estimate a user's behavior from adapted sensors of many home appliances. In this method, the control pattern of home appliances was defined by a user, and then we clustered sensor data by Ward's method using the number of the pattern as a division number. Some behaviors can be clustered to 100% in one cluster but a few behaviors were mixed multi behaviors in one cluster. Therefore according to the difference of division numbers, the evaluated results gave different clustering accuracy. In the next step, we plan to use the method of machine learning overlaid with this paper's result to improve accuracy.

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