Resource-efficient Management Scheme of Sensor Data

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***Abstract*- In this paper, we propose a resource-efficient management scheme of sensor data for building energy saving. To manage buildings, we collect data from the variety of sensors in buildings able to recognize illumination, motion, temperature, humidity and so on. We analyze this data and derive energy saving measures from it. In case there is a large amount of data from the sensors, most of it is redundant if the data period is shorter than needed for services. We need a method to manage the data and to save the data in a resource-efficient manner, in terms of energy, time and space to save the data. Therefore, we propose a method to select the adequate period of sensor data to manage and use some meaningful data for the energy saving service. Using this method, we can save the resources for sensor data and derive the energy saving measures more quickly and efficiently without all sensor data.**

Keywords-Resource; Sensor Data; Compression; Energy.

I. INTRODUCTION

These days, environment pollution and climate changes have become world-wide issues [1], and international community has made progress towards the reduction of carbon emissions. To support these efforts, many kinds of green technologies are studied in many areas including buildings. Since residential and commercial buildings consume over 21% of total energy use in South Korea, many energy management solutions in buildings are studied and developed such as Building Automation System (BAS) and Building Energy Management System (BEMS) [2]. BEMS manages and saves energy consumption in buildings by collecting many kinds of data from building automation system and sensors in buildings. Some BEMS technologies have more than 8,000 sensors, so the volume of sensor data is too large to save and manage. Many works have studied the compressing of data in order to save resources [3][4], such as energy, time, storage and so on. Shannon-Nyquist sampling theorem has been widely used as a base theory for digital systems [5][6]. But, the theorem is assessed again in academia by Compressed Sensing (CS) theory [7][8]. Donoho et al. introduce CS and show that fewer number of samples are required than the conventional approach. They consider that raw samples are redundant and can be compressed before being transmitted.

In this paper, we propose a method of efficient management of sensor data in terms of energy, time and space saving. We collect data from sensors and save it into the database according to the service interval. Using our scheme, we can save energy, time and space for the sensor data for building energy saving.

The rest of this paper is organized as follows: We introduce background and related works in Section II. We propose resource-efficient management scheme of sensor data in Section III. Finally, we draw conclusions in Section IV.

II. RELATED WORKS

A. Conventional Compression and Compressive Sensing Mechanism

In a conventional sensor system, each sensor node performs Analog-to-Digital Conversion (ADC) at the Nyquist rate that should be set at least twice the maximum frequency of the measured signal [9]. Uniformly spaced samples are obtained during a fixed time period. These raw samples are redundant and they can be compressed before being transferred. Because sending the redundant data is inefficient, compression can be done in order to reduce the number of bits transmitted and save transmittal power. However, two things are considered for this approach. First, is that all the sensed samples are required to be gathered and stored at a collaboration location, and thus inter sensor correlation cannot be performed unless all the sensed samples are at a single location. Second, compression operations can be performed at the central location.

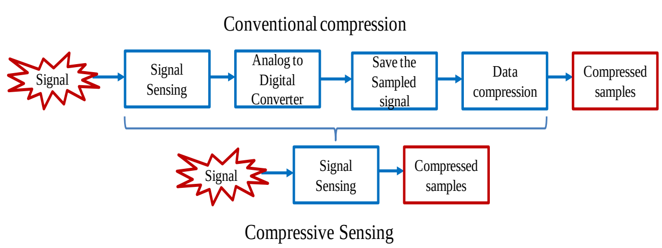

Figure 1. Conventional Compression and Compressive sensing

Compressive sensing is a sampling method that converts high dimension input signal into another signal that lies in a space of smaller dimension [10][11]. As described in Figure 1, Donoho et al. suggested the compressive sensing theory, which obtains compressed signal from complex signal processing using simple matrix operations, under the assumption that the observed signal is sparse [7][9]. Using

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CS, obtaining signal from sensors can be very simple and efficient without complex computation [6].

B. *Building Energy Management Technology*

As time goes on, the performance of various equipments in buildings is degraded, and energy usage increases because of faults and errors of the old equipments. So, building energy management is essential for maintaining initial performance [2]. However, equipments in most buildings are not managed systematically and professionally, because monitoring and inspection of the facilities are mostly based on the facility managers' experience. To solve these problems, many technologies, such as Energy Management Systems (EMS), Facility Management Systems (FMS) and BEMS, have been developed and used for building management. For these technologies, the main mechanism for efficient management of building is BEMS. The technology includes the software, hardware, and services associated with the Information and Communication Technology (ICT)-based monitoring, management, and control of energy. The main function of BEMS is to reduce the whole energy cost by decreasing energy consumption. The BEMS is similar to a traditional BMS, but it differs in that it places more emphasis on energy [3]. The BEMS has many functions for building energy management, and its main features are as follows:

- Monitor, track, control, and manage buildings to reduce energy use and maintain comfort of residents
- Provide optimized energy control measures by reducing unnecessary energy use
- Monitor, track, and manage equipment and energy usage via sensors, meters and systems

These days, most of BAS vendors have their own building management solutions. As shown in Figure 2, the Enterprise Buildings Integrator (EBI) system of Honeywell is for integrated facility management, application areas in buildings to provide control and manage functions [12]. The Architecture of Honeywell EBI system consists of various databases and application programs, which enable building managers to monitor, control and display the equipments in buildings. Siemens has building automation software, named APOGEE [13], which offers many functions for building management. First, it integrates multiple building systems no matter the manufacturer or installer achieving greater flexibility through open protocol interoperability. Also, it expands, upgrades, and optimizes facility systems in buildings.

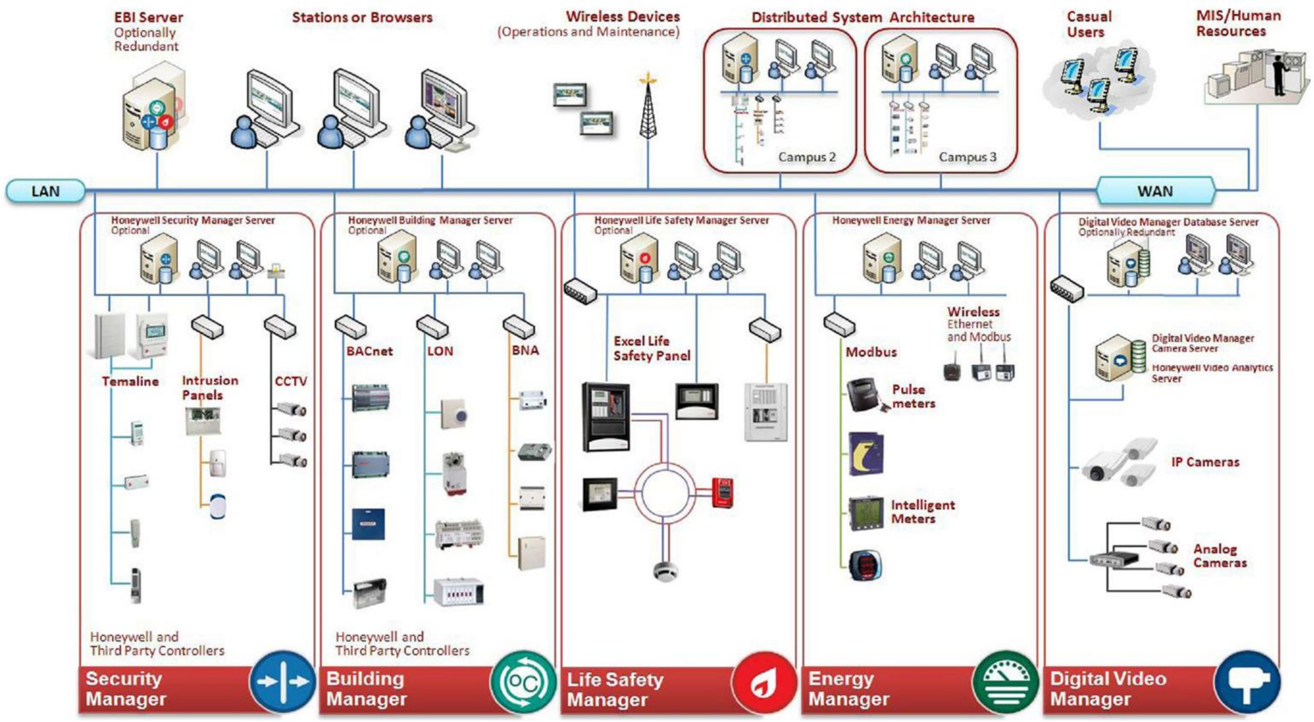

Figure 2. An Architecture of Honeywell EBI system [12]

III. RESOURCE-EFFICIENT MANAGEMENT SCHEME OF SENSOR DATA

We implemented a resource-efficient management scheme of sensor data for building energy saving. There is a lot of data from various sensors in buildings that can be used for energy saving. From all this data, we periodically select only some data to use and manage, considering the service interval. For example, if the service interval is 15 minutes, then we choose 1 piece of data per 1 minute. This way, the amount of data is smaller than that of original data. Also, data processing time can be reduced. As illustrated in Figure

3, the Remote Building Management Center (RBMC) manages a lot of building energy. Each building has many sensors and meters to collect data such as temperature, humidity, illumination, motion, power and gas, and so on. For meaningful data, the number of sensors in a large building is over 8,000, and the interval of some sensor data is very short, such as 1 second or less. When data is collected from sensors in the unit time of 1 second, some data has different values at the same time due to the sensing range and the collecting time interval. Then, the data processing time, the size of the database and data consistency can be the problem in the RBCC.

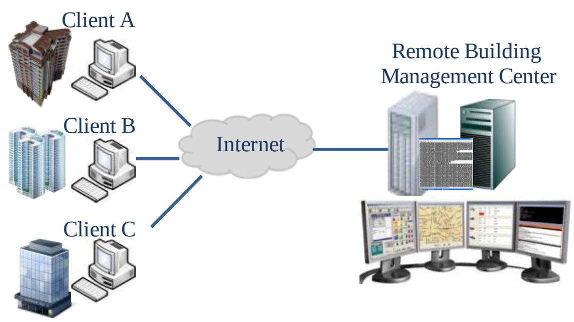

Figure 3. Configurations of the buildings and remote building control center

We installed four kinds of sensors, such as illumination, temperature, humidity and motion, in our office as shown in Table I, where the temperature and humidity sensors exist in one module. We collected sensor data for 192 days in our office. Although the data is for only part of the building, the total amount of data is huge.

TABLE I. DESCRIPTION OF FOUR KINDS OF SENSORS

Category	Number of Sensors	Total Number of Data	Number of Data for one day
Illumination	13	22,279,198	116,011
Motion	4	8,836,260	26,159
Temperature & Humidity	9	19,058,079	97,453

The interval of each sensor data and the number of data per minute is as illustrated in Table II. The data was collected and saved every 6-9 or 20 seconds, but energy saving services in buildings can be performed every 10 and 15 minutes. The energy saving service for lamps in restrooms of our building is performed every 10 minutes, and the duration of 15 minutes is frequently used as time interval for delivering power meter information [12]. Although the duration is shorter, the amount of energy saving may be similar because of the cost of the power on and off. Furthermore, the comfort of the residences in a building can be reduced. If the duration is longer, then the amount of energy saving may be reduced. In case that the time interval is 15 minutes, the saving scenario is as follows: if there is no-one in a zone for 15 minutes, then the lights in the zone are automatically turned off. So, the number of data per minute is unnecessarily frequent for our service.

TABLE II. INTERVAL OF EACH SENSOR DATA AND THE NUMBER OF DATA PER MINUTE

Category	Sensor ID	Duration (second)	Number of data per one Minute	Average Number of Data per one Minute
Illumination	130f	20	3	7.3
	1310	20	3	
	1312	6~8	8.57	
	1313	6~8	8.57	
	1314	6~8	8.57	
	1315	6~8	8.57	
	1316	6~8	8.57	
	1317	6~8	8.57	
	1318	6~8	8.57	
	1319	20	3	
	131a	6~8	8.57	
	131b	6~8	8.57	
	131c	6~8	8.57	
Motion	1405	6~8	8.57	7.2
	1406	6~8	8.57	
	1407	20	3	
	1408	6~8	8.57	
Temperature & Humidity	120a	6~8	8.57	7.3
	120b	6~8	8.57	
	120c	20	3	
	120d	20	3	
	120e	6~9	8.57	
	120f	6~9	8.57	
	1210	6~8	8.57	
	1211	6~9	8.57	
	1212	6~8	8.57	

We propose a method to save and manage the sensor data considering the service interval. We supposed that the interval of data from illumination, temperature and humidity is every 1, 2, 5, 10 and 15 minutes. The duration of 15 minute is the unit of metering system for power usage statistics used in Korea [14]. Also, it is used for demand controller because the sensor values of temperature and humidity do not change much, and the value of illumination is needed only when the service is performed. However, the values of motion sensor are needed every minute to detect the duration of absence. So, we use the sensor data every minute among the collected data.

Table III shows the result of the number of data for one day to be saved in the database. The volume of data is very small and the time to save is shorter compared with the original data.

TABLE III. THE NUMBER OF DATA BY THE PROPOSED MECHANISM

Category	Number of data (per minutes)				
	1	2	5	10	15
Illumination	15,819	7,916	3,167	1,584	1,056
Temperature & Humidity	5,760	2,880	1,152	576	384
Motion	12,951	6,479	2,592	1,296	864

As illustrated in Figure 4, we get the pattern of one illumination sensor data for 1 hour from 7 to 8 AM in the morning to view detailed data. As seen in the graph, if the interval is over 10-minutes, then the effect of the energy

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saving service can be reduced. In these cases, we have to pick the reasonable duration for the service.

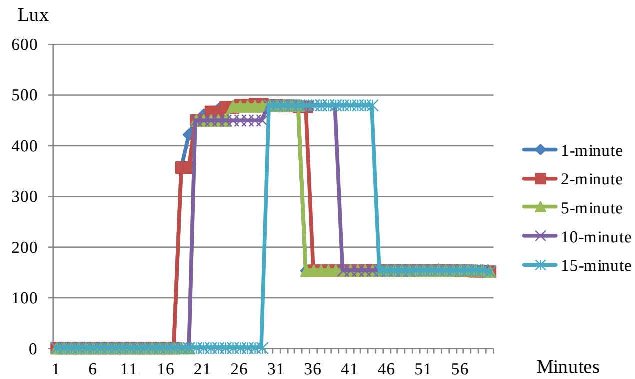

Figure 4. Data of Illumination Sensor for 1 hour

When the lux (lx) value for illumination is over 300, we know that the lamp is on. So, we can get the accuracy rate for the energy saving service using the following model:

$$Accuracy^{s,i} = D_{300}/D_{Total} \quad (1)$$

s: service, i: interval
D_{300} : Number of lux data over 300
D_{Total}: Number of total data

In the 2-minute interval, the accuracy rate is 98.3 because the number of accurate data is 59 out of the total of 60. The number of accurate data for the durations of 5, 10, 15 minutes are 58, 53 and 38, respectively. If the building policy of energy saving needs the accuracy rate of 90%, then the interval 10 and 15 have to be discarded. Table IV shows the comparison of the accuracy between the original data and the proposed mechanism for the data of 1 hour. In the table, we show the number of original data and the revised number of accurate data. Here, we assume that the data value is same as the previous data for the duration in the revised number of accurate data.

TABLE IV. COMPARISON OF THE ACCURACY BETWEEN THE ORIGINAL DATA AND THE PROPOSED MECHANISM FOR THE DATA OF 1 HOUR

Category	Accuracy rate (%)					
	Original Data	Period (minute)				
		1	2	5	10	15
Original No. of Data	543	60	30	12	6	4
Revised No. of Accurate Data	543	60	59	58	53	38
Accuracy rate (per 1 minute)	100	100	98.3	96.7	88.3	63.3

We get the illumination pattern for 1 day with the same sensor above as described in Figure 5. The patterns are almost the same even if the duration is longer. But, if we select sensor data for long duration, then the energy saving service also can't be provided in time and the amount of saving energy is reduced. For example, if we have data for each 5 minutes, then the light may be turned on for 4 minutes and 59 seconds after users' absence. So, we have to select the adequate period considering the energy saving rate and data management time and storage space as following:

$$Period^{s,i} = \alpha \times Saving^{energy} + \beta \times Saving^{db,\ time} - \gamma \times Error^{probability} \quad (2)$$

s: service, i: interval
α : The weight of the energy model
β : The weight of the database and processing time
γ : The weight of the error probability

In (2), the weight for the period of data selection is determined by the building energy manager. The error probability is calculated as:

$$Error^{probability} = Interval^{data} / Interval^{service} \quad (3)$$

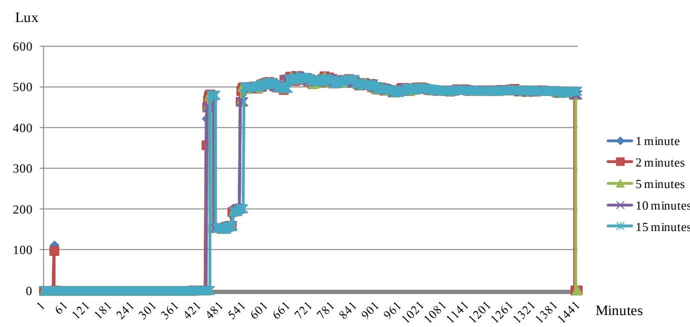

Figure 5. Data of Illumination Sensor for 1day

TABLE V. RESULT OF THE PROPOSED MECHANISM FOR THE DATA OF 1 DAY

Category	Accuracy rate (%)					
	Origin-al Data	Period (minute)				
		1	2	5	10	15
Original No. of Data	12,989	1,440	720	288	144	96
No. of Accurate Data	12,989	1,440	1,439	1,435	1,430	1,400
Accuracy rate (per 1 minute)	100	100	99.9	99.6	99.3	97.2
Reduction rate of No. of Data	0	88.9	94.5	97.8	98.9	99.3
Probability of Error (per 1 minute for 15-minute interval)	0	0	13.3	33.3	66.7	100
Result (α = β = γ =1)	100	188.9	181.1	164.1	131.5	96.5

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Table V shows the result when we assume that all values of α, β, and γ are 1. We consider the accuracy rate for energy saving, then we select the data period as 1 minute. We can select best period as 1 minute. Also, 2 or 5 minutes of intervals can be chosen according to the building's energy policy. 10 or 15-minute interval is difficult to be selected because the probability of service error is high and the amount of energy saving is reduced.

IV. CONCLUSION

Because the environment pollution and climate changes have become world-wide concerns, energy saving is essential in all industrial areas. For this reason, several technologies are explored for saving energy in buildings. Among these technologies, BEMS manages and saves energy consumption in buildings by collecting several kinds of data. A challenge is that the large volume of sensor data constitutes a problem to save and manage.

Many works have studied data compressing in order to save resources, such as energy, time, storage, and so on. These works consider that redundant raw samples can be compressed before being transmitted.

In this paper, we proposed an efficient management of sensor data in terms of energy, space and time saving. Using our proposed mechanism, the time and space to save the sensor data was reduced compared to the case that did not use our mechanism. We plan to measure and analyze the amount of the energy saving and its effects as further study. We are also planning to apply the compressive sensing regarding the relations among sensors.

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