Estimation for Spatial Distribution of Temperature and Humidity by Using Sensor Networks

Katsuhiro Igarashi, Dai Hanawa, and Kimio Oguchi

***Abstract*—Authors propose a method to estimate the spatial distribution of temperature and humidity from data acquired from sensor networks in a university library. Preliminary experiments show that our proposed method can estimate temperature and humidity.**

***Keywords*—Sensor Networks, University Library, Temperature and Humidity Distribution, Spatial Interpolation.**

I. INTRODUCTION

RECENTLY, people enjoy life by using a variety of home appliances. Among them, personal comfort systems such as an air conditioner are well adopted. Air-conditioning management systems have been introduced to all places such as relatively small family homes and large facilities. The air-conditioner is an example of the life home appliance that is triggering the release of carbon dioxide and thus global warming. Carbon dioxide levels increased by 35 % from 280 ppm in 1750 to 379 ppm in 2005. It is predicted that if the increase trend continues, it will increase to 540-970 ppm (more than twice or three times) by 2100. Global warming has recently become a significant problem all over the world. It is predicted that if global warming continues, the world's average temperature will rise by 1.1-6.4 degree Celsius, and the average world sea level will rise by 18-59 cm by 2100 [1]. Therefore, an air-conditioning management system that can save energy is desirable for individual houses, schools, companies, and public institutes. According to the previous investigation by the authors [2][3], the typical university library must maintain a suitable temperature and humidity level to prevent damage to major quantity of books and ensure the comfort of about one hundred readers by finely controlling air conditioning equipment. However, most users and managers of Japanese libraries are dissatisfied with their current air-conditioning systems. Therefore, urgent development of air-conditioning system to create a comfortable environment for users and books in the library is necessary.

The authors have presented a new air conditioning management approach for spaces like university libraries to provide comfortable environment for both users and books [4]. It confirmed the need to accurately determine the spatial distribution of temperature and humidity in a library, a state of users and books, and a single air conditioning management system which appropriately correspond these time variations. Here, a single air conditioning system means that a group of several zones or rooms each of which has different attributes, e.g. temperature and humidity is supported by one system.

In order to capture the spatial distribution of temperature and humidity, it is straightforward that use of a lot of sensors will function this purpose. However, it requires a plenty of sensors for large space and it may not apply in the air of large atrium. Therefore, estimation is needed to estimate the local condition and to create a suitable temperature and humidity in a place where humans or books coexist. Then, a comfortable environment will be able to be created for humans and books in the university library. And the energy could be saved.

This paper starts by describing a technique to estimate the temperature and humidity at arbitrary points in the library from acquired temperature and humidity information from sensor network nodes distributed throughout a library. Next, the results of a preliminary experiment are presented and discussed.

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II. METHOD FOR ESTIMATING TEMPERATURE-HUMIDITY DISTRIBUTION FROM SENSOR NETWORK DATA

When acquiring the temperature and humidity distribution in a university library, a relatively simple measurement technique that does not negatively impact the users and is not an eyesore is desirable. Several researches such as estimating the temperature of the place where the sensors cannot install, the flow of the walker, and environmental information by sensor networks were reported so far [5][6]. And their usefulness was confirmed. Therefore, in this paper, a technique to estimate the temperature-humidity at arbitrary points by interpolating data provided by a sensor network is introduced.

In particular, first, data is acquired from the temperature-humidity sensors (measurement sensors) installed in the library. Next, the temperature and humidity data is interpolated at arbitrary points in the library.

This paper uses the IDW (Inverse Distance Weighted) method, one of the basic interpolation techniques. Estimated value $\hat{z}$ of the temperature (or the humidity) at an arbitrary point is derived from the following expressions where n is the number of the measurement sensor nodes, z_i is output of sensor i (i = 1, 2, … , n), and w_i is the weight coefficient of sensor i.

$$\hat{z} = \sum_{i=1}^{n} w_i z_i \qquad (1)$$

Where, weight coefficient w_i is given by equation (2) that uses distance d_j (j = 1, 2, … , n) between the estimation point and the measurement sensor and a positive real number r.

$$w_i = d_i^{-r} \Big/ \sum_{j=1}^{n} d_j^{-r} \qquad (2)$$

III. REQUIREMENT

Requirements of temperature and humidity were 23 ± 2 degree Celsius and 55 ± 10 %, respectively. The reason why these requirements were adopted was as follows.

A Japanese research paper suggested that most people (90 %) feel comfortable in the temperature range of 21-25 degrees Celsius and humidity range of 0-65 % [7]. For conservation of books, a suitable temperature is about 22 degree Celsius and a suitable humidity is about 55 % [8].

Based on the results of these investigations, we consider that temperature and humidity in library should be kept from 21 to 25 degree Celsius and around 55 % respectively, to offer suitable environment for humans and books. We employed half of these ranges as the applicable limitations in the error.

We consider the error of interpolation for temperature estimation should hold less than ± 2 degree Celsius. Difference between upper limit and lower limit is 4 degree Celsius. We also consider the error of interpolation for humidity estimation should hold less than ±10 %. Difference between suitable humidity for books and upper limit in humidity for humans is 10 %. We employed this value as the applicable limitations in the error.

IV. PRELIMINARY EXPERIMENTS

A. *The purpose of the experiments, and the method*

The experiments were performed to evaluate the temperature and humidity estimation accuracy of the proposed technique. In the experiments, the error is calculated as the difference between the measured temperature-humidity values and the corresponding interpolated values.

In this paper, the experiments were performed to estimate temperature-humidity distribution in a cuboid space. First, measurement sensors were placed at all eight corners of the cuboid. Next, temperature and humidity sensors (which differ from measurement sensors) were placed at multiple estimation points within the cuboid to acquire actual temperature-humidity data. In addition, the value of r in an expression (2) is set 1 or 2 to compare the better accuracy.

These experiments were conducted in two environments shown below.

1) *Experiment 1 –Seikei University Building No.11 second floor meeting room*

The steady environment which does not almost change in temperature and humidity was better to assess basic performance of the proposed method under the simple situation. The inside of the meeting room in this experiment was closed chamber which contained an unused air-conditioner, no humans, and closed windows and doors. Three cuboids with lengths of 1, 1.5 and 2 m were used. Estimation points were set at the intersections of a 0.5 m grid. Figure 1 shows an example of sensor placement. In the cuboid lengths of 1, 1.5, and 2 m, the total number of estimation points was 19, 56, and 117, respectively. Temperature and humidity were measured for 30 minutes in total (ten minutes * three times) for each cuboid and data was acquired and logged at five seconds intervals.

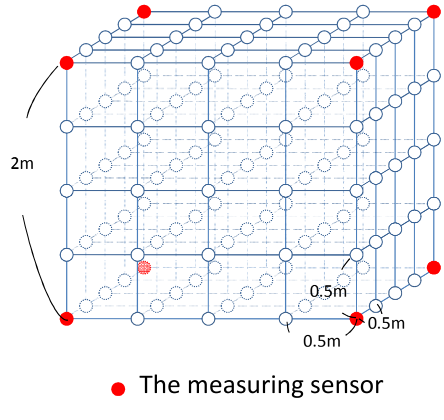

Fig. 1. Sensor location of the experiment 1(Example: One side is 2 m.)

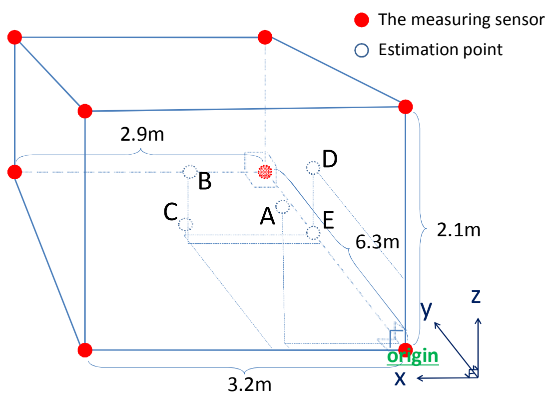

Fig. 2. Sensor of the experiment 2.

TABLE I
LOCATION OF ESTIMATION POINT

	Coordinate [m]		
	x	y	z
A	1.41	0.21	1.10
B	1.60	3.00	0.72
C	1.60	3.40	0.10
D	0.00	3.00	0.72
E	0.00	3.00	0.00

2) *Experiment 2 –Seikei University Library third floor north*

Figure 2 shows the location of the eight measurement sensors and five estimation points (A-E) whose coordinates are listed in TABLE I. Temperature and humidity sensors were measured for 3 hours at five second intervals.

B. Results

Figures 3-10 show the mean errors of temperature and humidity in experiments 1 and 2. First, the modulus average of the error per each interpolation was calculated for each estimation point. Next, the distance from the nearest measurement sensor was determined for each estimation point. Finally, estimation points were grouped according to distance, and the average per estimation point (mean error) was determined.

The mean error of the estimation using proposed method was calculated by

$$\text{mean error} = \frac{1}{m}\sum_{k=1}^{m}\left|t_k - \hat{z}_k\right| \quad (3)$$

Here, m and t_k (k = 1, 2, … , m) are the number of the data and the true value of temperature (or humidity), respectively.

C. Discussion

The proposed method can estimate accurately actual temperature and humidity.

The mean error in temperature estimation and that in humidity estimation were less than 1 degree Celsius and less than 1 % respectively, regardless of the experimental space, the shortest distance from nearest measuring sensor, the value of r and the length of the edge of cuboid. On the basis of these results, the validity of the proposed method was confirmed in the mean error.

Comparing the results between the experimental spaces, the mean error in meeting room was larger than that in university library. These results show that the change of temperature (or humidity) between measurement sensors in university library seems to be more moderate than that in meeting room.

Next, after comparing the mean error in the proposed methods between different value of r, better results were obtained for r = 2 than r = 1. Temperature in nearer point from estimation point is considered to have greater contribution to the actual temperature.

In Figures 3-6, the mean error decreased in inverse proportion to the shortest distance from measurement sensors. Currently, we analyze the relationship between the mean error and the distance.

In Figures 9-10, the mean error of points C and D were larger than the other points. The reason of these results was that, during the measurement, the temperature and humidity around points C and D have changed more rapidly several times in comparison with the other points.

V. CONCLUSION

This paper has proposed a technique to estimate the spatial distribution of temperature and humidity in a cuboid space.

Preliminary experiments showed the technique can

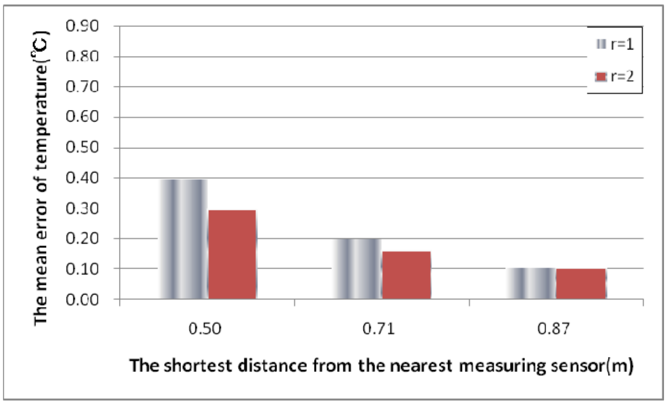

Fig. 3. The mean error of temperature in meeting room(1 m cuboid).

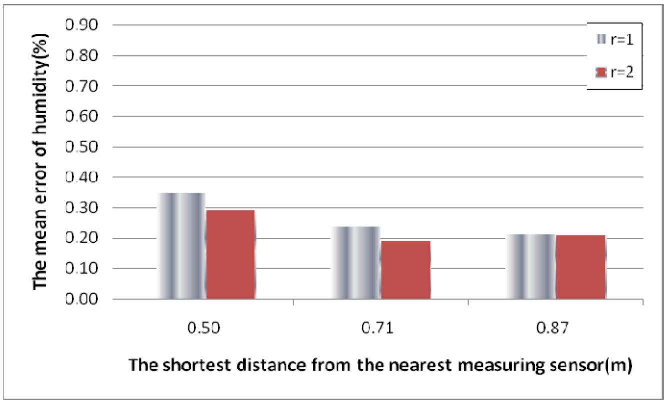

Fig. 4. The mean error of humidity in meeting room(1 m cuboid).

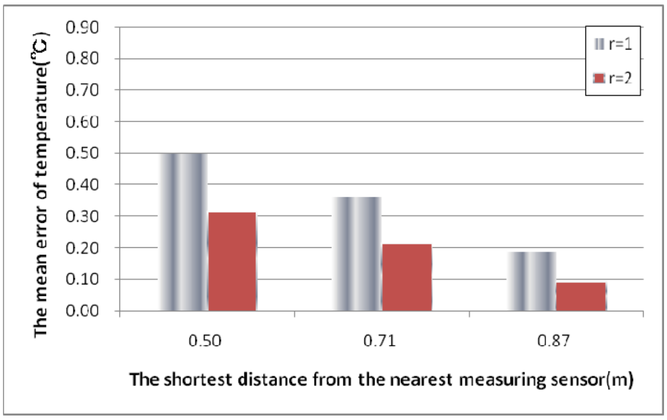

Fig. 5. The mean error of temperature in meeting room(1.5 m cuboid).

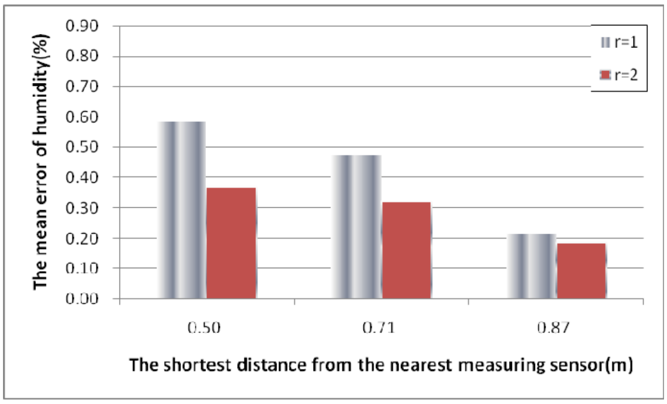

Fig. 6. The mean error of humidity in meeting room(1.5 m cuboid).

estimate temperature and humidity inside of a measurement sensor cube with 2 m sides in simple situation(the closed chamber which contained an unused air-conditioner, no humans, and closed windows and doors not to be almost changed in temperature and humidity.) with accuracies of less than 1 degree Celsius and less than 1 %, respectively. Furthermore, in the experiment within a library of Seikei University for estimating temperature and humidity of the cuboid (approximately 2.9 x 6.3 x 2.1 m), estimate accuracy were also less than 1 degree Celsius and less than 1 %. Therefore, the proposed method performs well. In addition, r = 2 yields slightly higher accuracy than r = 1.

The experiments performed here to validate the proposed technique are quite preliminary in nature. Future tasks are to perform experiments that estimate the temperature and humidity inside bigger cubes and to study air-conditioning control methods that take into consideration the behavior of humans and the movement of books. Moreover, new ways to interpolate spatial distribution of temperature and humidity and control a single air conditioning management system are necessary when there is a thermal source between two measurement points.

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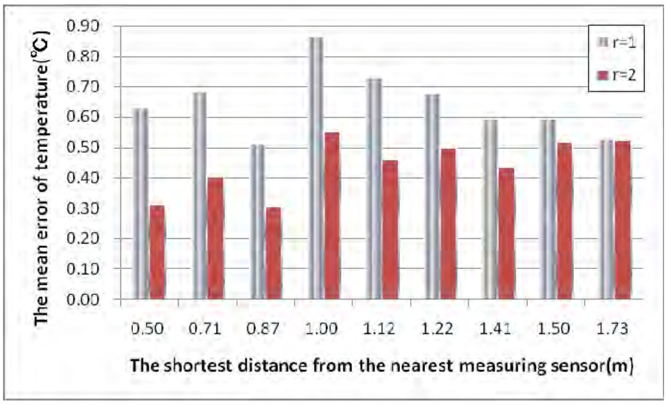

Fig. 7. The mean error of temperature in meeting room(2 m cuboid).

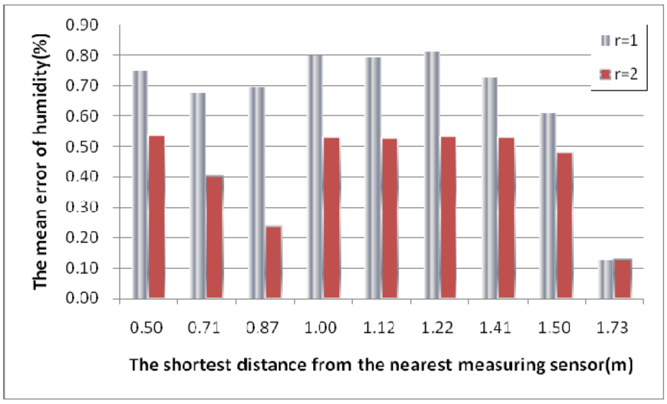

Fig. 8. The mean error of humidity in meeting room(2 m cuboid).

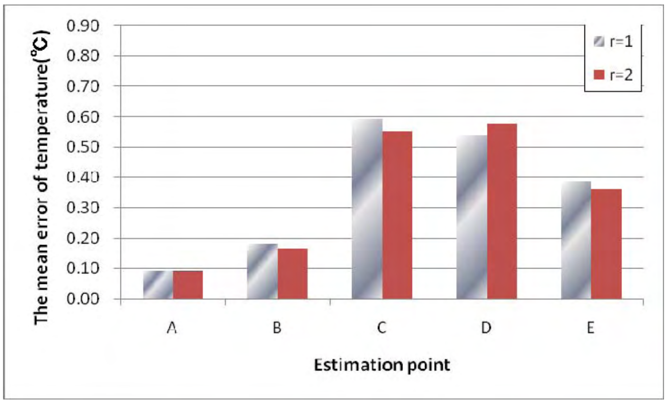

Fig. 9. The mean error of temperature in university library.

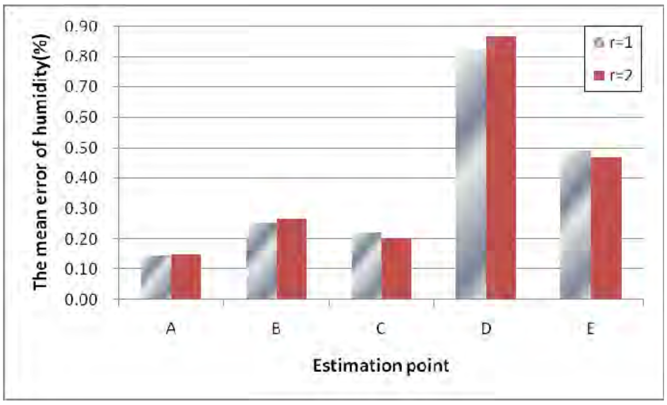

Fig. 10. The mean error of humidity in university library.