# Multiple Use of the Information Captured by Cost-effective Sensor Networks in University Libraries

Kimio Oguchi[1,2], Takaaki Tomono[2]
[1]Graduate School of Science and Technology
[2]Faculty of Science and Technology
Seikei University
Musashino, Tokyo, Japan
oguchi@st.seikei.ac.jp

Dai Hanawa[2,3]
[3]present affiliation: School of Design and Architecture
Nagoya City University
Nagoya, Aichi, Japan

***Abstract***— To create smart / intelligent environments for libraries with ICTs, we must gather as much information as possible; the conventional approach is to use many dedicated sensors. This will increase the system cost, sensor data traffic loads, and difficulties in installing the equipment. Therefore, finding some redundancy in the captured information or interpreting the semantics captured by non-dedicated sensors could reduce the number of sensors, sensor network traffic loads and system cost. In this paper, two methods are proposed and their ability to discern the presence of humans. The results show the feasibility of the proposals.

***Keywords*— Sensor network, Environmental manage, Human recognition, $CO_2$, RSSI.**

## I. Introduction

Sensor networks (SNs) have been advancing with the recent rapid progress in smart/intelligent sensor devices, broadband / ubiquitous network technologies, and Internet extension to everything (IoT). SN applications have been adopted and indispensable for daily human life in such areas as security, efficiency, safety, comfort, and ecology. Therefore, research into devices, systems, and applications is active everywhere.

Our laboratory has been researching several content transfer related applications by using wireless sensors and sensor networks that mainly focus on the vital human information captured by wearable sensor(s) [1, 2] and environmental information capture [3, 4]. In our studies, wearable acceleration, angular velocity, foot pressure, and heart rate sensors, and FIR (Far InfraRed) image capturing cameras [5] are used for the former application, and temperature, humidity, and lighting illumination sensors, FIR cameras, and tree-worn acceleration sensors for the latter application. Regardless of the type of sensor used, the basic information transfer process is virtually the same for all applications. In sensor-based applications, the sensors/sensor network captures environmental information, which is then processed to reduce its volume or to indicate status. Event (alert)/raw data is then transferred via broadband / ubiquitous networks to a node / station which extracts context or interprets the meaning (semantic computing), and takes the appropriate feedback/action [1].

In our research on environmental information capture, we noted that human presence recognition is one of the key pieces of information in managing the environment, and checking the security.

For this purpose, use of still / motion cameras and captured image processing is a straight-forward, and simple approach. FIR cameras are also used with extended functionality to cover low light occasions e.g. at night. Cameras offer high performance in finding humans, or to recognize specific individuals. However, this clearly raises privacy concerns, system cost for higher resolution, and the difficulty of implementing (installing) the system.

Other sensors such as ultrasonic, pressure, and laser range sensors are attractive in terms of performance, but they bring higher costs and installation difficulties.

In general, if we want some information on, for example environment status, dedicated sensors are needed. This will increase the number of sensors and thus system cost, sensor data traffic loads, and installation difficulty. Therefore, finding some redundancy in the captured information, or interpreting the semantics captured by non-dedicated sensors will reduce SN overheads.

This paper clarifies the feasibility of recognizing human presence in a space by processing information captured without dedicated sensors. It introduces and verifies two methods as implemented in a cost-effective prototype sensor network for the university library. This methods process $CO_2$ concentration, intended to check environment status and the received signal strength indication (RSSI) between wireless transmitters (Tx) and receivers (Rx).

Section II overviews library requirements in terms of environmental management. It also describes technical study items to create smart/intelligent environments for the library with Information and Communication Technologies (ICTs). Section III proposes two methods that can recognize human presence without any additional sensors, together with the experiments conducted. Section IV discusses the results and a conclusion and future works are given in Section V.

Part of the RSSI method and experiment described in Sections III. C. and IV. B., have already been presented [6].

## II. Requirements and Technical Study Items

### A. Requirements

Generally speaking, libraries are heterogeneous spaces where human(s), books and other materials for storage co-exist. Their environmental requirements differ greatly from those for the office / home.

Our survey of the current situation with regard to the building structures and air conditioning systems of 28 large Japanese libraries identified the following further important issues as regards their environmental systems [7];

- Most libraries have a large atrium with at least one glass wall and a high roof,

- In most libraries, the managers must manually fine-tune the air conditioning system,

- Most libraries do not have a well-developed information network infrastructure,

- The air conditioning system must be able to create a comfortable environment for both users and books, and

- Most users and managers are dissatisfied with their current air-conditioning systems.

To resolve these issues and to create smart/intelligent library environments, the use of ICTs, especially SNs is essential.

### B. Key technical study items

In order to create smart / intelligent environments for libraries with ICTs, several key technical study items have to be resolved;

- SN configuration,
- Types of sensors and their attributes,
- Information transfer method among sensors and aggregate node,
- Feedback to manage the environment including air-conditioning, and
- System cost.

As expected, the number and type of sensors directly influences system cost. Installing many dedicated sensors will yield high accuracy but the attendant overheads will be excessive.

Therefore, finding some redundancy in captured information, or interpreting the semantics captured by non-dedicated sensors will reduce SN loads and system cost.

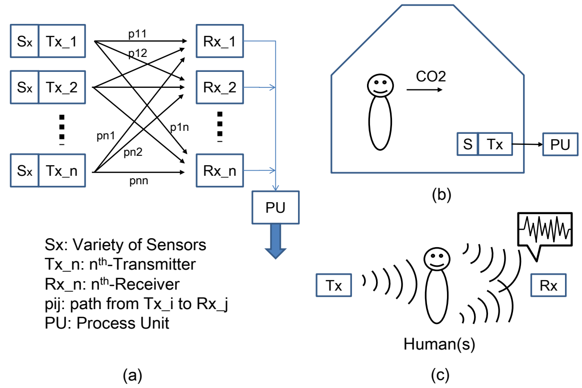


Figure 1. (a) Basic configuration of the proposed sensor network (SN) system image. (b) $CO_2$ method; human presence raises $CO_2$. (c) RSSI method; RF signal is influenced by human presence.

## III. Experimental Methods

The two proposed methods are tested to verify that human presence can be ascertained from data collected by other sensors.

### A. General System Configuration

Figure 1 (a) depicts the basic system configuration; a variety of sensors with low power wireless Txs are supported by multiple Rxs. Each Tx has one or more sensors that capture environmental information. The processing unit (PU) gathers the signals from sensors, and transfers them to the next node.

Sensors used in the experiments are for temperature, humidity, lighting illumination, noise, and $CO_2$.

### B. $CO_2$ Method

#### 1) General principle:

Due to the global warming, $CO_2$ is being created in large quantities and its concentration is continuously increasing [8]. Current value is about 400 ppm (this is called the baseline hereafter).

The increase in $CO_2$ concentration by human respiration in a closed space ($IC_{CO2}$) is given by;

$$IC_{CO2} = V_{exhaled} \text{ x } C_{CO2} \text{ x } n_{breath} / V_{space}. \quad (1)$$

where $V_{exhaled}$ is the volume of each exhaled breath, $C_{CO2}$ the $CO_2$ concentration in an exhaled breath, $n_{breath}$ the respiratory rate per minute, $V_{space}$ the volume of the closed space. Given the typical values for adults, ($V_{exhaled}$) = 0.5 L, ($C_{CO2}$) = 4 %, ($n_{breath}$) = 15, (1) is given again as;

$$IC_{CO2} = 0.3 \;/\; V_{space} \text{ [ min}^{-1}\text{]}. \quad (1)’$$

As the volume of the closed space used in the experiment was 4,440 L (details below in III. B. 3)), (1)’ gives the $IC_{CO2}$ value of 67.6 ppm/min. This means that if a person is present in the space, $CO_2$ concentration will increase at the rate of 67.6 ppm per minute from the baseline.

*2) Judgement method:*

The proposed $CO_2$ method is as follows;

1. Calculate the change in value of captured $CO_2$ concentration ($DC_{CO2}$) e.g.,

   $DC_{CO2}(t_0) = (C_{CO2}(t_0) - C_{CO2}(t_{-1})) / (t_0 - t_{-1})$ (2)

   where $t_0$ is the current time and $t_{-1}$ the previous time span,
2. Eliminate noise if needed in the obtained value,
3. Compare the obtained value and the given threshold value ($C_{th\_CO2}$), and
4. If the value exceeds the threshold, it is judged that someone is present, otherwise none.

*3) $CO_2$ sensor configuration:*

Figure 1 (b) shows basic configuration of the experiment on the $CO_2$ method. Sensor module used here is a prototype consisting of an S8 sensor chip (SenseAir, DC 5 V driven, 400 – 20,000 ppm measurement range [9]; less than US$ 100) and a signal transmitter (Tx) for a USB connection. The PU is a Laptop PC (Lenovo G580; Win8; Celeron1000M 1.8 GHz; 4 GB).

Closed space used is a walk-in greenhouse with durable clear plastic cover and roll up door whose size is about 1.2 x 1.9 x 1.9 m (W x L x H). This was placed in the laboratory for this test.

Subjects were young males with ages of 22 or 23y.

*C. RSSI Method*

*1) General principle:*

The RF signal on the related path (pij: the path between Tx_i and Rx_j) (Figure 1 (a)) is basically stable if nothing disturbs the link. However, the presence of object(s) on the path i.e. between a Tx and an Rx, disturbs the RF signal so the signal strength varies over time as illustrated in Fig. 1(c). The system recognizes human presence on the path if the signal variation exceeds some threshold. The process unit (PU) in Fig. 1(a) realizes not only captured signal processing, but also RSSI processing.

*2) Judgement method:*

The proposed method recognizes human presence if the signal variation differs from that when nothing is present. Its detailed procedures are as follows:

1. Acquire baseline data in advance.

- Measure RSSI values on each path (pij) for a given time period, and
- Calculate standard deviation (SD) of each.

2. Estimate whether object(s) (human or other) is present or not.

- Measure RSSI values on the paths in the region of interest (ROI), or specific area,

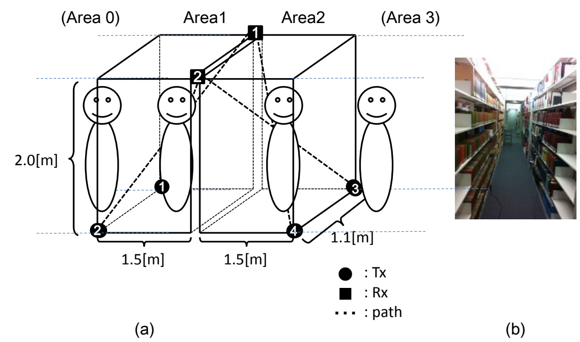


Figure 2. (a) Locations of Txs and Rxs between book shelves. (b) Photo of the book shelves. Both are in the university library.

- Calculate SD of the paths,
- Calculate the sum of squared error (SSE) according to equation (3) given below, and
- Judge, for the area, whether object exists or not by comparing the SSE output by the equation for the two conditions.

$$SSE_i = \sum_{x=1}^{n} (\sigma_{i,x}^{l} - \sigma_{i,\min(1 \le x \le n)}^{m})^2 \qquad (3)$$

where $i$ corresponds to the condition (present or not present) of the area, $\sigma^l$ to the standard deviation (SD) of the baseline data for path $x$, and $\sigma^m$ to the SD of the measured data for path $x$ under condition $i$. It is noted that *min* in the equation means to choose the minimum value among those for different paths.

*3) Sensors and experimental environments:*

After a preliminary experiment, field experiments were conducted in the university library in order verify the proposed RSSI method in the field.

Sensor terminals used were ZigBee types operating at 2.4 GHz frequency range (MOTE SN21140J and BU2110J, Crossbow [10]). RSSI values are obtained by using the pre-installed function.

Figure 2 (a) shows locations of Txs and Rxs between book shelves in the field experiment. Photo of bookshelves in the university library is also shown in Figure 2 (b). The preliminary experiment used the same configuration.

## IV. RESULTS AND DISCUSSIONS

Results of the two independently conducted experiments are described below: $CO_2$ method and RSSI method.

### A. $CO_2$ Method

*1) Experiment to set parameters in judgement process:*
Figure 3 shows $CO_2$ concentration variation results for 10 second periods with a human present or not. Ground truth of human presence is depicted by the rectangular waveform at the bottom of the figure. In this experiment, a human entered 3 times and stayed for about 15 min. The space is closed, but there some gaps between the floor and the house.

As clearly indicated;

- $CO_2$ concentration increases just after the human entered and monotonically increased thereafter,
- Rate of the increase, several tens ppm / min, basically equals the calculated value described in Section III.B.,
- The increase for the 15 min period was 1,000 ppm,
- The value decreases just after the human left, and
- The decrease was sharp just after the human left but softened thereafter. The baseline was not recovered.

Therefore, considering this result and (1)', several values are set.

*2) Performance of the proposed method:*
The $CO_2$ method detects human presence if, at the given time, the moving average value exceeds the threshold (i.e. 5).

TABLE I summarizes the results of the experiment conducted in the closed space in the laboratory. Numbers described in each cell correspond to the detection rate. Numerator corresponds to the total number of judged results at the sampling time, and denominator all sampling periods. G expresses "Good result". Case I corresponds to "no one present" in the space. Case II to "someone present".

TABLE I shows the concordance between actual human status and judged one. If only human exist case (Case II) is considered, the performance is only 0.63 as the proposed method is not able to detect human presence ($CO_2$ increase) just after he/she enters in the space. However, for both cases, corrected detection rate is high, 0.86 (= 640 / 748).

TABLE I. RESULTS OF $CO_2$ METHOD IN THE LABORATORY.

| Case | Human status | In the space | |
|---|---|---|---|
| | | Not exist | Exist |
| I | No one | 465/468 = 0.99 (G) | 3/468 = 0.01 |
| II | Exist | 105/280 = 0.37 | 175/280 = 0.63 (G) |

a. G: Good result

### B. RSSI Method

*1) Experiment to set parameters in judgement process:*

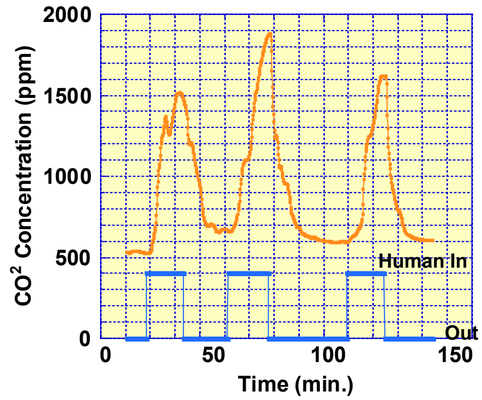


Figure 3. $CO_2$ concentration variation example in terms of human in/out in the closed space.

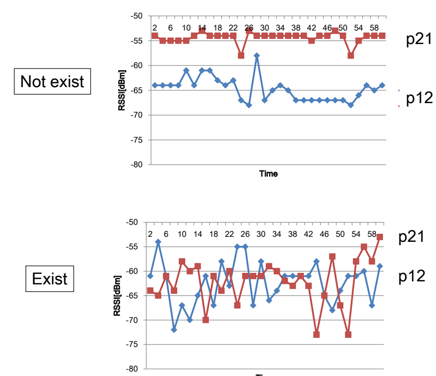


Figure 4. Measured RSSI value examples where (a) no one is present on paths $p1_2$ and $p_21$, and (b) a human is present.

Figure 4 shows examples of measured RSSI values in area 1 when (a) no one present, and (b) one human present. Two paths, p12 and p21 that cross each other were used as depicted in Figure 2 (a). As shown, the received signal is basically stable with no one present, but it varies a lot when someone is present. SDs of these measured values were used as the baseline data as indicated in III. C. 2).

*2) Performance of the proposed method:*
TABLE II summarizes the results of the field experiment. Numbers described in each cell correspond to the calculated SSE. Case I corresponds to "no one present" in area 1 or area 2. Case II to "someone present in area 1" while case III to "present only in area 2". Not exist/ exist in area 1 or 2 described in the first row means that SSE was derived from the baseline data in area 1 or 2, respectively. Case IV corresponds to "human present in both area 1 and area 2." Case V and IV correspond to someone exists in just outside area 1 (area 0) or 2 (area 3), respectively. This experiment considered only possible cases.

In the TABLE, S after the number shows the obtained value was smaller than the other one. G or NG under the number expresses a good or a not good match, respectively, i.e. the estimated status and the actual status agree, or not. As seen in the TABLE for area 1, some cases yield poor results while area 2 always achieves 100 % agreement. However, combining the areas yields 75% accuracy (9/12). The reason for the fall in accuracy was that the location examined was complex with a lot of shelves and books mixed together.

TABLE II. FIELD EXPERIMENT RESULTS IN THE UNIVERSITY LIBRARY. VALUES SHOW CALCULATED SSE.

| Case | Human status | Area 1 | | Area 2 | |
|---|---|---|---|---|---|
| | | Not exist | Exist | Not exist | Exist |
| I | No one | 0.358 **(S)** **(G)** | 23.5 | 2.01 **(S)** **(G)** | 32.5 |
| II | Area 1 | 1.27 **(S)** **(NG)** | 10.3 | 3.46 **(S)** **(G)** | 37.8 |
| III | Area 2 | 0.729 **(S)** **(G)** | 26.6 | 7.99 | 2.21 **(S)** **(G)** |
| IV | Area 1 & 2 | 4.53 **(S)** **(NG)** | 4.80 | 7.46 | 2.51 **(S)** **(G)** |
| V | Area 0 | 8.71 | 1.86 **(S)** **(NG)** | 0.428 **(S)** **(G)** | 24.1 |
| VI | Area 3 | 0.139 **(S)** **(G)** | 16.3 | 2.53 **(S)** **(G)** | 7.49 |

b. **S: Smaller than the other**

c. **G: Good result.**

d. **NG: Not good result.**

## V. CONCLUSION AND FUTURE WORK

Libraries are heterogeneous spaces for humans and books. In order to create smart/intelligent environments for libraries with ICTs, the convention approach, installing many dedicated sensors, increases the number of sensors, system cost, sensor data traffic loads, and installation difficulty. Therefore, finding some redundancy in the captured information, or interpreting the semantics captured by non-dedicated sensors can reduce the number of sensors, sensor network loads and system cost.

This paper proposed two methods to recognize human presence in spaces by analyzing $CO_2$ and RSSI data, and experimentally verified their feasibility. Experiments showed that human presence can be recognized with accuracy from 63 % and 75 %, respectively, without any dedicated sensors.

Future work include integrating the two methods, and verifying the performance of human recognition and original environmental information capture as well. Continuous information capture in the field is also planned.


## ACKNOWLEDGMENT

The authors thank S. Maruta for his assistance in the RSSI experiment.


## REFERENCES


[1] K. Oguchi, “Content Transfer and Supporting Technologies in a Home Environment over Next Generation Convergence Home Network - From Vital Information Transfer to Broadband Content Transfer”, International Journal of Digital Content Technology and its application (IDCTA), vol.3, no.3, pp.124-135, Sept. 2009.

[2] K. Oguchi, Y. Enomoto, S. Terada, D. Hanawa, “Sensor-based e-Healthcare in a next generation convergence home network”, Proc. ISABEL2011, Paper.1., Oct. 2011.

[3] D. Hanawa, H. Yamamoto, T. Koide, T. Shoji, K. Suzuki, S. Yamakawa, I. Watanabe, K. Oguchi, “Sensor networks for creating comfortable environments in university libraries. J. of CIE., vol. 33, no. 5, pp.645-652, July 2010.

[4] K. Igarashi, D. Hanawa, K. Oguchi, “Estimation for spatial distribution of temperature and humidity by using sensor networks”, Proc. of TSP2011, pp. 227-230, Aug. 2011.

[5] NIPPON AVIONICS CO., LTD., http://www.infrared.avio.co.jp/en/

[6] K. Oguchi, S. Maruta, and D. Hanawa, “Human positioning estimation method using received signal sterength inndicator (RSSI) in a wireless sensor network”, Proc. of FNC2014, Paper FNC S2-4, Aug., 2014.

[7] H. Yamamoto, K. Suzuki, T. Koide, S. Yamakawa, D. Hanawa, I. Watanabe, and K. Oguchi, “Investigation on and air-conditioning system of the library in Japan”, Proc. of ICCCS2009, pp.112-115, Nov. 2009.

[8] IPCC (International Panel on Climate Change), “Fouth assesment report: Climate change”, http://www.ipcc.ch/

[9] SensAir, “SenseAir S8”, http://www.senseair.se/products/oem-modules/senseair-s8/

[10] Crossbow Home Page, http://www.xbow.jp/motemica1.html#kit