Automatic Estimation of the Number of People Remaining in a Room by using a Micro Computer and Environmental Sensors

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Abstract

Purpose / Context - It is important to estimate the number of people remaining in a room to allow for modification of the room environment and effective energy use.

Methodology / Approach - A prototype of an automatic estimation system consisting of a general-purpose microcomputer and environmental sensors (e.g., a thermometer, hygrometer, and CO_2 concentration sensor) was fabricated. We applied "Arduino 2009" as a root device and "XBee" as an extension.

Results – According to experiments performed with this system, correct estimation was obtained once per eight tests.

Key Findings / Implications – Although sufficient precision has not yet been demonstrated, our preliminary experiments led us to recognize that the system would be capable of error-free operation. We aim to achieve usable precision results by discarding the factors leading to incorrect estimations.

Originality - This paper proposes a method to estimate the number of people remaining in a room of a house based on both CO_2 concentration and humidity changes.

Keywords - Remaining, Expiration, Arduino, XBee

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1. Introduction

The outdoor climate, especially the sun, wind, and air temperature, affects the indoor climate in low-energy houses. Further, it is important to estimate the number of people remaining in a room to enable appropriate modification of the room environment and to ensure effective energy use. In the past, the manual maintenance of a daily logbook by inhabitants was an orthodox measurement method to track the daily number of people remaining in a room. However, this type of measurement has externalization defects and places a mental load on inhabitants. In the future, a simple measurement technique is needed that would not constitute a breach in privacy. This paper proposes a method to estimate the number of people in a room of a house based on both CO_2 concentration and humidity changes. Application of this method led to the fabrication of a prototype of an automatic estimation system consisting of a general-purpose microcomputer and environmental sensors.

2. Proposed Estimation Method

The number of people remaining in a room is estimated based on measurements recorded by the sensors (e.g., a thermometer, hygrometer, and CO_2 concentration sensor) located indoors/outdoors and using the following equations:

$$C(t) = C_o + \frac{k}{Q} + \left(C(0) - C_o - \frac{k}{Q} \right) e^{-\frac{Q}{V}t} \quad (1)$$

$$k = mk' = mMP \quad (2)$$

$$\sigma(t) = \sigma_o + \frac{h}{Q} + \left(\sigma(0) - \sigma_o - \frac{h}{Q} \right) e^{-\frac{Q}{V}t} \quad (3)$$

$$h = mh' + h'' = mh' + \beta \frac{\varphi(t) - \varphi(0)}{100} \quad (4)$$

$$h' = L + B = L + \gamma(h''' - L) \quad (5)$$

$$L = (2.1613 \times 10^{-9} M^2 + 9.6943 \times 10^{-7} M)\left(\sigma_L - \frac{\sigma(0)+\sigma(t)}{2}\right) \quad (6)$$

$$h''' = -1.3697 \times 10^{-8} (\theta - 0.18181)(M - 58.939)(M - 1444.9) \quad (7)$$

The coefficients of eq. 6 & 7 were calculated from values indicated by Shiotsu et al. (1998) and Carrier Air-Con. Comp. (1966). The metabolic rate per person (M) is assumed to be 87.3 W as a module (1 met), as the surface area of the human body is 1.5 m^2, and the range is set between a minimum value of 61.1 W (0.7 met) and a maximum value of 305.6 W (3.5 met). It is important, but difficult, to measure room ventilation as a definite quantity, as this would require the room to be airtight and ventilated only by mechanical fans, as a precondition.

3. Automatic Estimation System

The system consists of "Arduino" as the root device and "XBee" as an extension. The functions of the root device are measuring the room environment, performing calculations for estimation, and wireless connection with the extension device that measures the outdoor environment. We used a unit of code that is uploaded to and run on an "Arduino" board (i.e., a sketch) as a program for the estimation process (see Figure 1). "Arduino" possesses both multiplicity of functions in an easy-to-use design and performes economically in electric power consumption, while there are limits of procedures (e.g., in case of Arduino2009, seven significant digits, clock speed of 16 MHz, and memory of 30,720 bytes). "XBee" is a radio communication module with an available distance of 40 m.

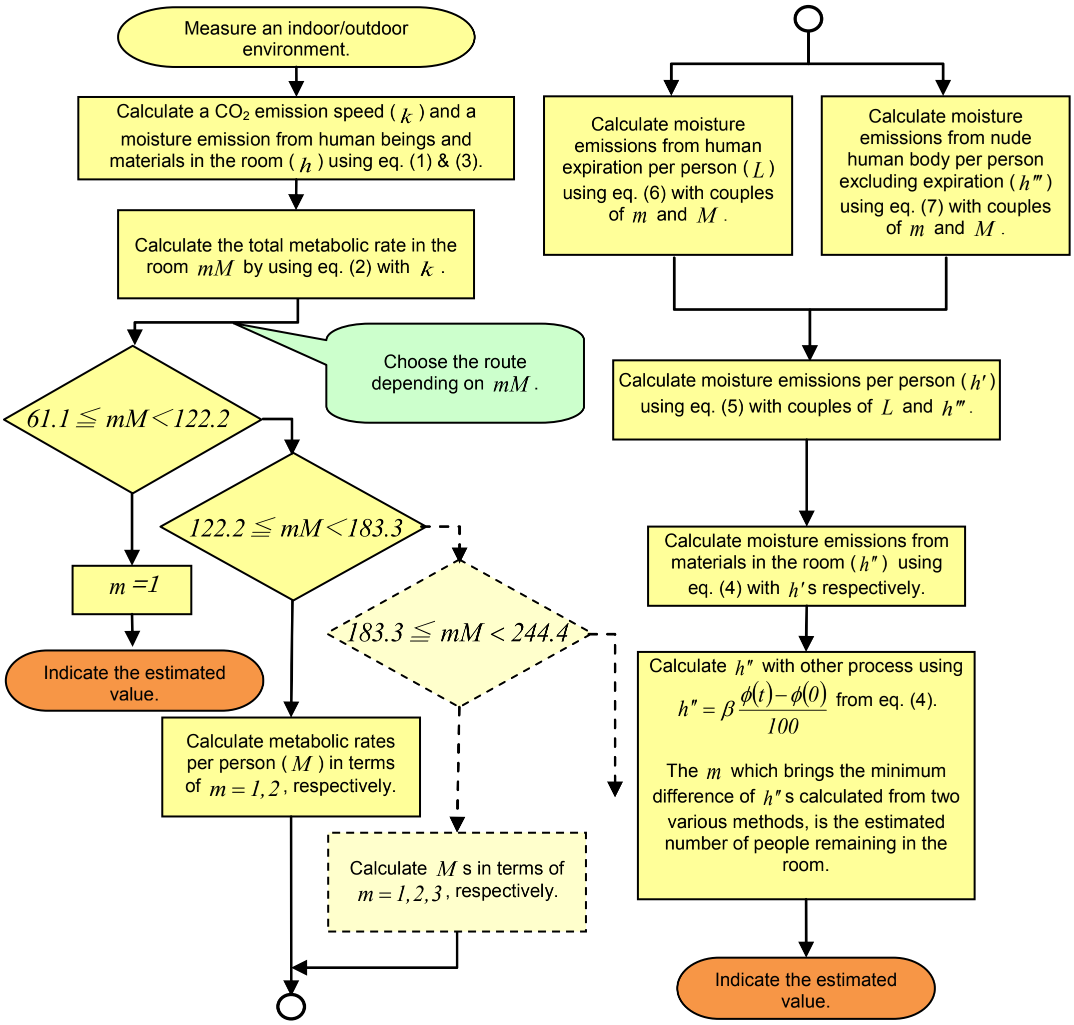

Figure 1 Flow chart of the estimation process

4. Results from Experimentation with the System and Discussion

The actuation of the system as well as the precision of estimation were determined by performing an experiment in a room (6.0 m depth × 3.3 m width × 2.4 m height, 2 people inside) on the fourth floor of a building on Feb. 6, 2015. Q was controlled at a constant value of 0.105 m^3/s by an annexed ventilation fan. $C(t)$ was increased to more than twice the outdoor concentration prior to the examination and was uniformly distributed by blowing the room air. β and γ were set to 0.68 g/s and 0.35339, respectively, from legitimate data (Sugawara, 2009). According to the results listed in

Table 1, correct estimation was obtained once per eight tests. Although sufficient precision has not yet been demonstrated, it is recognized that the system could run without error.

Table 1: Measured value and estimated number of people

Time [min]	5 min before (Indoor Temperature, Relative Humidity, CO_2 Concentration)	Present (Indoor Temperature, Relative Humidity, CO_2 Concentration)	Present (Outdoor Temperature, Relative Humidity, CO_2 Concentration)	k [mg/s]	mM [W]	h [mg/s]	Estimated m [people]
0	32.8 °C, 25.5 %, 1726 ppm	25.9 °C, 25.8 %, 1091 ppm	18.7 °C, 22.0 %, 513 ppm	-7.97	-93.7	-0.0043	Failure
1	26.4 °C, 26.0 %, 1418 ppm	25.4 °C, 25.4 %, 1044 ppm	18.4 °C, 22.4 %, 513 ppm	27.46	323.0	0.2124	2
2	26.4 °C, 25.0 %, 1301 ppm	24.9 °C, 31.0 %, 971 ppm	29.7 °C, 31.0 %, 736 ppm	-16.11	-189.6	-0.1307	Failure
3	25.9 °C, 25.2 %, 1225 ppm	24.9 °C, 25.7 %, 932 ppm	19.4 °C, 22.6 %, 523 ppm	20.44	240.4	0.2082	1
4	25.9 °C, 25.4 %, 1157 ppm	24.9 °C, 26.1 %, 891 ppm	18.7 °C, 22.0 %, 509 ppm	20.41	240.1	0.2436	1
5	25.9 °C, 25.8 %, 1091 ppm	24.9 °C, 26.4 %, 866 ppm	18.7 °C, 21.9 %, 509 ppm	24.22	284.9	0.2539	1
6	25.4 °C, 25.4 %, 1044 ppm	24.4 °C, 25.9 %, 834 ppm	18.7 °C, 21.9 %, 509 ppm	21.07	247.9	0.2208	1
7	24.9 °C, 31.0 %, 971 ppm	24.4 °C, 25.9 %, 810 ppm	19.4 °C, 22.5 %, 528 ppm	22.04	259.3	0.2040	1

5. Conclusion

In this study, we proposed a method to estimate the number of people remaining in a room of a house based on both CO_2 concentration and humidity changes. We applied the system consisting of "Arduino 2009" as the root device and "XBee" as an extension. Although sufficient precision has not yet been demonstrated, it is recognized that the system could run without error. We aim to achieve usable precision results for the system by discarding factors leading to incorrect estimations.

6. References

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7. Nomenclatures

B	Moisture emission from human beings per person excluding expiration [g/s]
$C(t)$	CO_2 concentration at t [mg/m^3]
C_o	Outdoor CO_2 concentration [mg/m^3]
h	Moisture emission from human beings and materials in the room [g/s]
h'	Moisture emission per person [g/s]
h''	Moisture emission from materials in the room [g/s]
h'''	Moisture emission from nude human body per person excluding expiration [g/s]
k	CO_2 emission speed [mg/s]
k'	CO_2 emission speed per person [mg/s]
L	Moisture emission from human expiration per person [g/s]
m	Number of people in the room [person]
P	CO_2 emission quantity for metabolic energy consumption (=0.085) [mg/J]
Q	Ventilation quantity of the room [m^3/s]
t	Time after the experiment starts [s]
V	Volume of the room [m^3]
M	Metabolic rate per person [W]
β	Proportional coefficient [g/s]
γ	Proportional coefficient [n.d.]
$\varphi(t)$	Relative humidity at t [%]
θ	Air temperature [°C]
$\sigma(t)$	Absolute humidity at t [g/m^3]
σ_o	Outdoor absolute humidity [g/m^3]
σ_L	Absolute humidity inside human body (= 43.774) [g/m^3]