Sensor Nodes Localization for Temperature Distribution Measurement System

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Abstract: In sensor network systems, all the nodes are interconnected and the positional information of each sensor is essential. To measure the temperature, position detection and communication functions are required. Many sensor nodes are distributed to a measurement field, and these sensors have three main functions: they measure the distance to the other nodes, the data of which are used to determine the position of each node; they communicate with other nodes; and they measure the temperature of each node. A novel range measurement method using the difference between light and sound propagation speed is proposed. The experimental results show the temperature distribution as measured with the aid of the determined positions. The positions of every node were calculated with a PC program. Eight nodes were manufactured and their fundamental functions were tested. The results of the range measurement method, which takes relatively accurate measurements, contribute significantly to the accuracy of the position determination. Future studies will focus on 3-D position determination and on the architecture of appropriate sensors and actuators.

Keywords: Sensor network, Position determination, Temperature distribution measurement, Localization

1. INTRODUCTION

Recently, there has been increasing concern about sensor network systems. Sensors for temperature, moisture and object detection are desired everywhere. In a sensor network system, sensors are interconnected and the positional information of each sensor is essential. Acquiring positional information facilitates advanced analysis. Temperature monitoring in the control room of a data center is one of such example. However, for stable maintenance, many measurement points are required to monitor the temperature. To integrate such a system of temperature measurement, position detection and communication functions are needed. In this research, we realized a prototype of this kind of system. There are many studies that determine 2-D or 3-D positions with the aid of RF devices in sensor network systems[1][2][3]. Because RF signals are avoided in data centers, we now propose infrared light and ultrasonic for communication and range measurement.

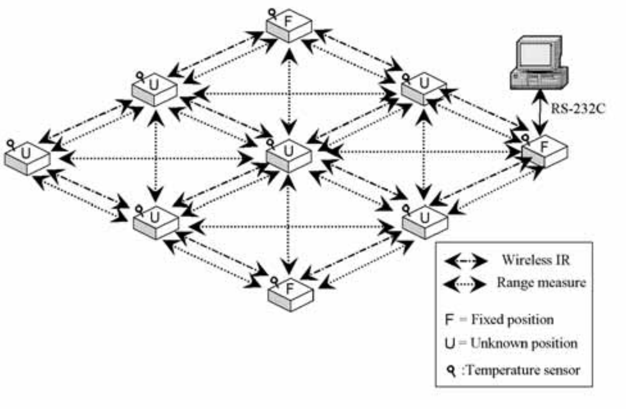


Fig. 1 Schematic of measurement system.

Figure 1 shows a schematic view of our system. Many sensor nodes are distributed to the measurement field, and eight boxes represent these nodes. The nodes are all interconnected; every node has a temperature sensor; and all the temperature data are collected with the aid of mutual communication. In Fig.1, each node appears to be arranged on a grid point but is actually placed in an arbitrary position. However, because all the nodes are placed arbitrarily, the positions must be measured after the placement. We therefore propose a novel method of measuring the distance between pairs of nodes, and present a method of calculating the coordinates of the 2-D positions. Only eight prototype nodes were fabricated and we confirmed all the functions, including the temperature measurement. If we had fabricated more nodes, the temperature distribution could have been measured more closely.

2. METHOD OF POSITION DETERMINATION

Our method of position determination requires several functions. For example, data communication with an optical signal, range finding with two nodes, data acquisition with optical communication, and position determination with the gathered data. A position determination method using a novel range measurement is described in this section.

2.1 Range measurement using speed difference between light and supersonic

In our measurement, the RF signal is avoided because of the supposition that the data center (server room) is being used. For the range measurement, we propose a novel method based on the difference in speed between light and supersonic sound. Figure 2 shows the principle of range measurement.

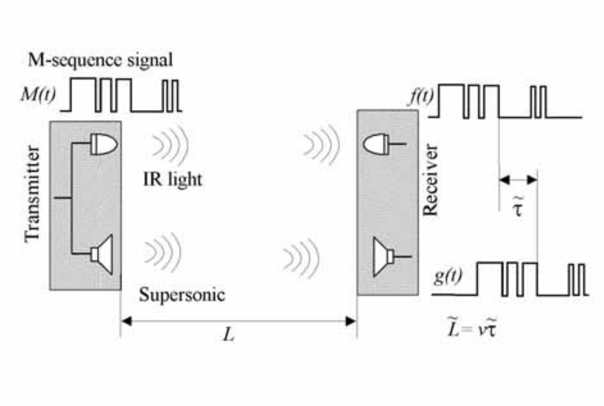


Fig. 2 Schematic of measurement system.

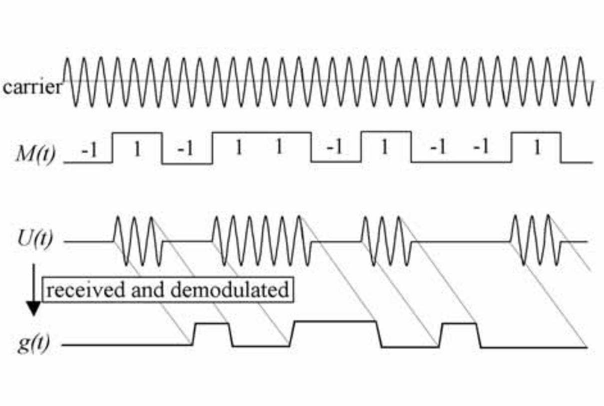


Fig. 3 Waveform of supersonic signal.

An M-sequence infrared (IR) and supersonic signal are both emitted at the same time. Whenever these propagated signals are detected at the same distance (L) there is a difference of $\tilde{\tau}$ for the detected time if the IR and supersonic propagation time are t_{ir}, t_{su} respectively. Therefore, $\tilde{\tau}$ is denoted by

$$\tilde{\tau} = t_{su} - t_{ir} \, . \tag{1}$$

With the use of τ, the estimated range L is determined by the following equation:

$$L = \frac{t_{su} - t_{ir}}{\frac{1}{v} - \frac{1}{c}} = \frac{v\tilde{\tau}}{1 - \frac{v}{c}} \approx v\tilde{\tau} \, , \tag{2}$$

where v and c are the propagation speed of supersonic, IR, respectively. The speed of the IR signal is significantly faster than that of the supersonic wave, and the term $v/(1-v/c)$ is nearly equal to v. To determine the difference in the propagation time τ, we used a cross-correlation function. If the functions $M(t)$, $f(t)$ and $g(t)$ denote the detected light wave and the supersonic wave, then τ is calculated with the following cross-correlation functions:

$$C_f(\tau) = \frac{1}{T}\int_0^T f(t) \cdot M(t+\tau)dt \, , \tag{3}$$

$$C_g(\tau) = \frac{1}{T}\int_0^T g(t) \cdot M(t+\tau)dt \, . \tag{4}$$

If the τ denotes the peak of the correlation function, and τ_{f} and τ_{g} correspond to $C_f(\tau)$ and $C_g(\tau)$, respectively, then $\tilde{\tau}$ is determined as follows:

$$\tilde{\tau} = \tau_g - \tau_f \, . \tag{5}$$

Many kinds of signals can be used for $M(t)$, such as an impulse wave or sinusoidal wave but, from the view point of the properties that can be distinguished from the noise and the signal, we selected the M-sequence. The main property of the M-sequence is that it has an autocorrelation of only one peak for each cycle.

Figure 3 shows schematic waveforms of the supersonic signal used in this measurement. For the supersonic transducers, we used the following: a 40 kHz carrier; an M-sequence signal, $M(t)$, with a positive and negative value; and a modulated signal, $U(t)$, which was applied to the supersonic transmitter. The detected signal had a time delay, but the waveform itself was similar to $U(t)$ except for some kind of deformation. The received signal was demodulated, and we then obtained the waveform $g(t)$. In contrast, the optical modulated signal was almost the same as $M(t)$, as shown in Fig.3, but the value +1 corresponds to "ON" and the value -1 corresponds to “OFF”. The optically detected signal $f(t)$ is almost the same as $M(t)$.

In this measurement, the length and order of the M-sequence must be determined carefully. We tried the fifth, sixth and seventh order of the M-sequence in terms of the length of the signal. The calculation time of the cross-correlation and the polynomial of the M-sequence were determined as follows[4]:

$$m(x) = x^5 + x^4 + x^3 + x^2 + 1 \, . \tag{6}$$

2.2. Position determination by range data

Figure 4 shows a flowchart of the method of determining the positions of the sensor nodes. It shows how we measured the range of possible combinational pairs of nodes and used optical communication to gather all the data. As described in Fig.1, the positions of three nodes must be known if we are to determine the 2-D coordinates before measuring the ranges. We collected all the data for the range measurement on a PC, used the least square error method to determine the 2-D positions. The variable ℓ_{ij} denotes the range data between node i and j. When the position of the i-th node is denoted by (x_i, y_i), and the set of initial positions for the calculation are set properly, we conducted iteration to minimize S.

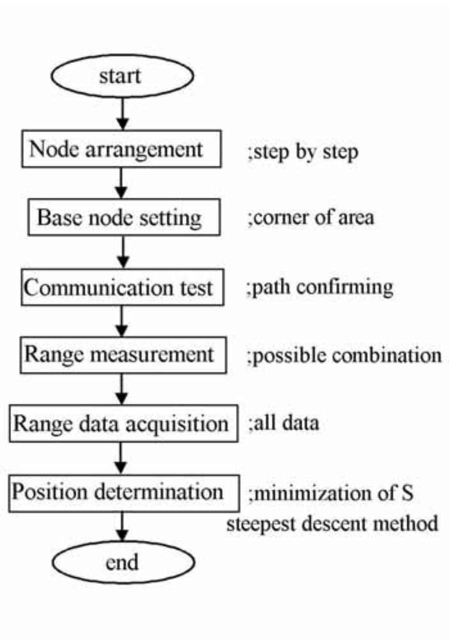


Fig. 4 Flowchart to determine sensor node position.

$$S = \sum_{ij} \left(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} - \ell_{ij} \right)^2 . \qquad (7)$$

Because we can partially differentiate the function *S*, we used the next partial differentiations for the steepest decent method[5]. In this case, we set the iteration learning coefficient, α, to 0.2.

Given the brevity of this paper, it is difficult to accurately describe the effect of the initial position and the local minimum problem. We therefore avoided these problems in order to approximate the initial positions. Equations (8) and (9) were iterated until the *S* value was close to zero; for instance, 0.001.

$$x_{i,j}^{(k+1)} = x_{i,j}^{(k)} - \alpha \left. \frac{\partial S}{\partial x_{i,j}} \right|_{x_{i,j} = x_{i,j}^{(k)}} , \qquad (8)$$

$$y_{i,j}^{(k+1)} = y_{i,j}^{(k)} - \alpha \left. \frac{\partial S}{\partial y_{i,j}} \right|_{y_{i,j} = y_{i,j}^{(k)}} . \qquad (9)$$

3. DESIGN AND FABRICATION OF THE SYSTEM

3.1 System configuration

Figure 5 shows the configuration of the proposed system. Each node structure uses a microprocessor as well as several sensors and actuators. All the functions except for the position determination were implemented in a H8/3048F microprocessor and its program. We expanded the memory for data restoration, and used a clock frequency of 10 MHz. In determining the 2-D position, we used supersonic transmitters, receivers, IR LEDs and IR photo sensors, though the sensitivity characteristics of these devises was limited. As a result, it was difficult to cover by one device. As discussed in the next section, we used a rectangular electric board for the circuit and microprocessor, and we placed supersonic transmitters, LEDs and photo sensors on four lattices of the electric board.

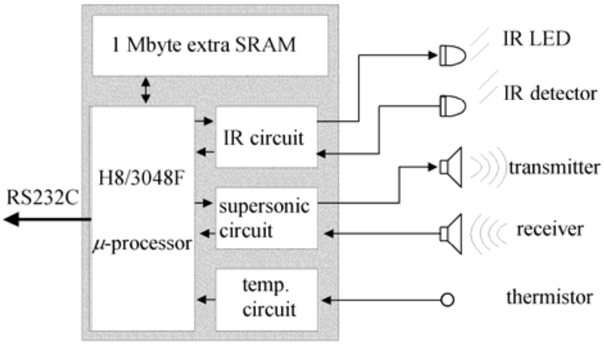


Fig. 5 System configuration of sensor node.

The same construction and software was used for all nodes, and only one node was connected to the PC to gather range and temperature data. We used a dry cell battery for the power source, which consumed 20 mW for normal communication and 300 mW for the range measurement. Although the power consumption seems too high for the range measurement, the period for determining the position is brief. Consequently, most of the time is used for normal communication.

3.2 Optical Communication

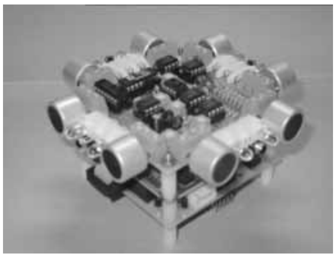
Although several protocols can be used, the purpose of this experimental system is to confirm that all functions work properly. We therefore adopted the simple RS-232C protocol and applied an IR signal instead of an electrical signal. The baud rate for the optical communication was set to 2,400 bps and the electrical RS-232 rate to 57,600 bps.

3.3 Acquisition of the temperature data

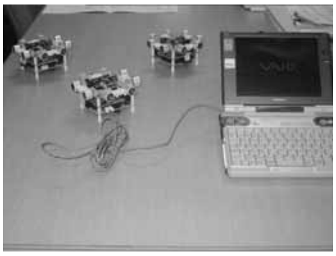
To measure the temperature, we used a thermister in each node. We then used IR light communication to acquire all the temperature data. After attaching a thermister to each electric circuit board, we observed a difference between the atmospheric temperature and the on-board temperature. As a result, more ingenuity is required for the actual usage. We also used the temperature data to compensate for the velocity of the sound.

3.4 Fabrication of nodes and data gathering system

Figure 6(a) shows a photograph of the fabricated nodes, and Fig.6(b) shows a photograph of the PC that was used for position determination. The program for the H8 was developed with the C language and a specific programming environment. We also developed a position determination program for the PC. Every node is independently operated by a dry battery and a unique program. After fabricating the eight nodes, we installed the same program in all the nodes. The fundamental functions of all the nodes were tested and confirmed. Only one node was connected to the PC (as shown in Fig.6 (b)), and the necessary data was gathered for the PC.



(a) Fabricated sensor node including range measurement and optical communication devices.



(b) Experimental scene.

Fig. 6 Photograph of experimental setup.

4. EXPERIMENTAL

4.1 Experimental setup and procedure

Figure 6(b) shows an example of the experimental scene. We fabricated eight nodes to measure the temperature distribution. Two kinds of experiments were conducted: in one we used a pair of nodes for the range measurement; in the other we used eight nodes to the position determination and range measurement.

4.2 Results and discussion

Figure 7 shows the results of a range measurement taken with a pair of nodes. The setting range was from 0.25 m to 3.5 m, while the measured range depended on the order of the M-sequence. The fifth, sixth and seventh order of the M-sequence were measured. However, although the margin of error in the results is almost the same, there are many differences in the calculating time for the correlation. After considering the measurement range and calculation time, we selected the polynomial of eq.(6), an AD sampling rate of 10 kHz, and an M-sequence modulation frequency of 1 kbps. In this measurement, we used two nodes, and the temperature was used to compensate for the range data. From these results, the margin of error in the range measurement was less than 3 percent for the 0.25 m to 3.5 m range.

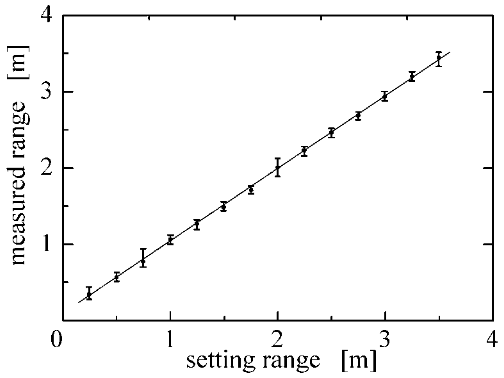


Fig.7 Experimental results of range measurement.

Figure 8 shows the layout and arrangement of the eight nodes for the position determination experiment. The positions of node 2, node 6, and node 8 are known, and node 1 is connected to the PC.

The placement of the eight nodes at the positions shown in Fig. 8 was based on the number of each node. Each pair of nodes was then tested for communication with the optical medium. For the wiring between the PC and node 1, we used RS-232. Figure 9 shows the connections between node 2 and node 3, between node 3 and node 4 ... and between node 7 and node 8. This procedure means that all the nodes are connected by a single route. Although many communication procedures were considered for data acquisition, we sought only to confirm the possibility of position determination.

Next, a command for range measurement was sent from the PC to the all nodes, and range measurements were taken for all possible pairs. Table 1 shows the experimental results of the range measurements.

Using all the data from Table 1, we used the steepest decent method described in sec.2.2 to calculate the positions of all the nodes. The initial positions of all nodes except node 2, node 6, and node 8 were set to (2.0, 2.0). Table 2 shows the results of the calculations, along with the temperature of each node. The errors of the calculated position are within a range of ±4 cm. After trying several arrangements of the sensor nodes, the margin of error for most of the range measurements was less than 6 cm for the 0 m to 3 m range, and the position errors were within 10 cm.

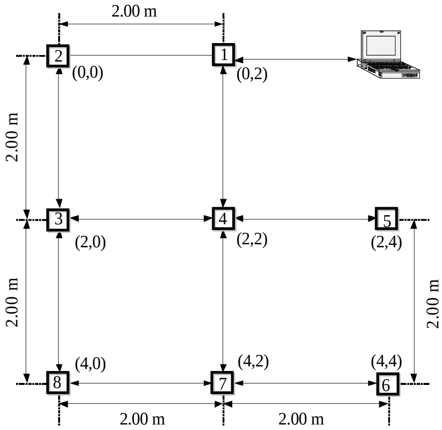


Fig.8 Layout of node arrangement.

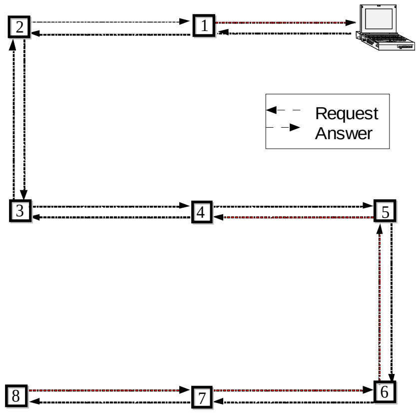


Fig.9 Communication procedure for 8 nodes.

Table 2 also shows the results of the temperature distribution measurement. Because a thermister was attached to the electrical board for these measurements, the heat generated from the MPU produced temperatures that were higher than room temperature. To measure the temperature distribution, more nodes are needed though the procedure for acquiring the data is the same as discussed in this paper. In our prototype system, the communication method is poor and it is impossible to communicate freely. However, to send messages or information, there are many schemes such as the “flooding technique” or other multihop schemes. Nonetheless, our aim was simply to check the possibility of position determination and temperature distribution measurement. In the first trial, we confirmed the validity of our system. In the future, we hope to improve the free communication, including multihopping, and to refine the measurement of 3-D positions.

Table.1 Experimental results of range measurement for Fig.8.

pair node #	range[m]	pair node #	range[m]
1-2	1.99	4-5	2.03
1-3	2.91	4-6	2.88
1-4	1.98	4-7	1.99
1-5	2.90	4-8	2.96
2-3	1.93	5-6	2.08
2-4	2.97	5-7	2.68
3-4	1.94	6-7	1.99
3-7	2.82	7-8	2.02
3-8	1.99	—	—

Table.2 Example of experimental results of temperature measurement.

Node #	X[m]	Y[m]	Temp.[deg.]
1	-0.05	1.96	36.5
2	0.00	0.00	36.9
3	1.97	-0.07	35.6
4	1.97	1.97	34.3
5	1.96	4.01	36.1
6	4.00	4.00	35.0
7	4.01	1.97	36.3
8	4.00	0.00	33.8

5. CONCLUSION

We have discussed a method for determining the position of sensor network nodes. By fabricating more nodes and using a more sophisticated program for communication, we can obtain more precise measurements of the temperature distribution. In the future, we hope to study 3-D position determination along with the architecture of appropriate sensors and actuators.

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