High-Accuracy Localization via Measurements of RSSIs and LED Light Angles for Low-Cost WMSNs

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***Abstract*—Wireless multimedia sensor networks (WMSNs), constructed from multiple sensor nodes with cameras, are expected to collect visual data over wide ranges. Existing studies have attempted to estimate the positions of nodes using received signal strength indicators (RSSIs). To improve the accuracy of the estimations of node positions, we propose a new localization method using both RSSI and images sensed by camera sensor nodes for WMSNs. Camera sensor nodes, with positions that are unknown measure the angles of LED light signals emitted by anchor nodes and their RSSI values, Using the RSSI values, nodes can calculate the distances from the anchor nodes. In addition, using the plural angle values, nodes can calculate their own position with high accuracy. We built a small WMSN test bed and measured the average estimation errors. We confirmed that the average estimation errors of a method using only the RSSI values and our proposed method are 1.07 m and 0.29 m, respectively. Therefore, the proposed method could reduce the estimation error by approximately 73%.**

***Index Terms*—Wireless sensor networks, Cameras, Localization**

I. Introduction

Wireless sensor networks (WSNs) are network systems that comprise multiple sensor nodes with radio communication equipment and are currently of interest as a method to extensively gather data. WSNs are used to collect environmental data such as temperature, precipitation, and illuminance. In addition, WSNs are expected to be used for various systems such as landslide detection [1] and human tracking [2]. Of the WSNs, significant attention has been paid to wireless multimedia sensor networks (WMSNs) that are constructed using multiple sensor nodes with cameras. WMSNs can collect visual information for detection and tracking systems. Typical WMSN applications track harmful animals and provide traffic avoidance and person locator services [3].

When applications collect sensing data via WSNs, the locations where the data are sensed are necessary. Therefore, all the nodes need to know their own coordinates. However, it is not always easy to identify the positions of all the nodes. There are two ways to deploy nodes in the field: (1) deploy each node individually at a position that has been determined in advance or (2) scatter the nodes over a wide area (e.g., sprayed from the air). In the former case, each of the node positions must be measured precisely. This requires additional time and effort. In the latter case, the deployment costs can be kept lower. However, it is necessary to estimate the positions of all the nodes prior to running the WSNs. To introduce the WSNs easily, it is desirable to autonomously estimate where the nodes are deployed. Therefore, we focus on the autonomous position estimation problem for nodes (called **localization**). Localization is a common problem for WSNs, and there are many existing studies. Many localization studies calculate the inter-node distance via the received signal strength indicator (RSSI). Nodes can measure the RSSI with low cost and power consumption. However, the RSSI value is unstable owing to radio attenuation. Therefore, there are accuracy problems with a localization that depends only on the RSSI value.

In this study, we propose a method to estimate the position of nodes using the RSSIs and video in WMSNs. Nodes in WMSNs have radio communication and camera devices. Our approach requires that both WMSN node devices be used for localization. The radio communication device can measure distances from anchor nodes by measuring the RSSI value. In addition, the camera can measure the angles to anchor nodes via videos. Therefore, we added an inexpensive LED light to each node. The anchor nodes, whose positions are known, blink and emit radio waves during the position estimation. A node whose position is not specified measures the direction to the anchor nodes optically by recording the flashes from the anchor nodes. Our method estimates the node position from the RSSI values and the directions of the anchor nodes using the law of cosines. The results experiments show that the average estimation errors for a method using only the RSSI values and the proposed method are 1.07 m and 0.29 m, respectively. The proposed method was able to improve the estimated error by approximately 73%.

II. Related Work

For WSNs, various localization techniques have been proposed. These techniques can be roughly classified into two types: range-free and range-based methods.

Range-free methods estimate the node positions without measuring the distance to the nodes. The advantage is that those methods are low cost in terms of price and power consumption. However, the accuracy of the estimated position is worse than if it is calculated using a the range-based method.

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Taking the Centroid method as an example, a node calculates the center of the anchor nodes that can communicate directly with it and regards this position as its self-position [4]. With the DV-HOP method, the nodes count the number of hops from the anchor nodes to themselves and calculate their own coordinates using the number of hops as the distance from the anchor nodes [5]. Both methods reduce the cost of calculation and communication, and are suitable for applications that require only a rough position of the nodes.

Range-based methods estimate the node positions based on the measurement data, such as the distance or the angle between the nodes. In some cases, range-based methods use not only the distance or the angle, but also satellites or WiFi spots. While the cost of the equipment and the power consumption are larger, range-based methods can estimate the node positions with high accuracy. For example, there are localization methods that use laser or ultrasound to measure the distance between nodes [6], [7]. Even though these methods cannot be used when there is a large distance between the nodes, the position of the nodes can be estimated with very high accuracy. In another example, a localization method using AOA estimates the position based on triangulation [8], [9]. These methods have the advantage of requiring only a few anchor nodes to perform estimates. However, the accuracy deteriorates significantly when an obstacle exists in the path of the radio waves. Furthermore, other localization methods that use TOA let the nodes estimate their own positions based on the difference in the arrival time of the radio waves of plural anchor nodes. Using radio waves from satellites or a WiFi station, the nodes can directly compute the absolute position. However, this method is not suitable in some cases, because it could amplify the error resultimg from the variation in the surrounding environment or it may not be available in basements, which are out of reach of radio waves. Finally, there are localization methods using the RSSI value [10]–[14]. Here, the nodes measure the signal strength of the radio wave from the anchor nodes and estimate the distances. Because every node in the WSNs has a radio communication device, no additional equipment is required for localization. However, the estimation error may become large due to the instability of the RSSI. Even though the estimation accuracy is poorer than for other range-based methods, this method, which requires less cost and power consumption, is more suitable for WSNs [15]. Therefore, the accuracy of localization methods using RSSI needs to be improved.

In this paper, we propose a high-accuracy localization method based on RSSI that adds only an inexpensive LED light to each node in the WMSN. We describe the details of the RSSI localization in Section III.

III. Localization via Measurements of the RSSI

A. *Mechanism of Localization via Measurements of the RSSI*

In WMSNs, nodes are equipped with wireless communication devices for transmitting and receiving data. In general, wireless communication devices have a function to output the RSSI value. When a radio wave is transmitted from one node to another, the RSSI expresses the electrical power of the radio wave logarithmically based on 1 mW. The units of the RSSI values are dBm. RSSI often becomes negative because the received power is less than 1 mW. Even though localization methods based on RSSI require no dedicated equipment to measure the distance between nodes, this method permits position estimation with better accuracy compared to range-free localizations.

1) Technique to Measure the Distance Between Nodes: Assuming that the radio wave from the antenna of the wireless device is evenly discharged in all directions, it is known that the power density of a radio wave at a point D m from the emitter is inversely proportional to the surface area of a sphere whose radius is D. Therefore, when the transmission power of the radio waves is P mW, the radio wave strength P_D mW/m^2 can be expressed by Eq. (1) using the distance D m:

$$P_D = \frac{P}{4\pi D^2} \tag{1}$$

RSSI expresses the received power of the radio wave P_D logarithmically based on the 1 mW. The received power can be re-expressed based on the RSSI expression as Eq. (2):

$$\begin{aligned} RSSI &= 10\log_{10}(\frac{P}{4\pi D^2}) \\ &= 10\log_{10}(\frac{P}{4\pi}) - 10\log_{10}(D^2) \end{aligned} \tag{2}$$

Defining $RSSI_0$ as the RSSI value at a distance of 1 m and setting $D = 1$, Eq. (3) can be derived from Eq. (2):

$$\begin{aligned} RSSI &= RSSI_0 - 10\log_{10}(D^2) \\ &= RSSI_0 - 20\log_{10}(D) \end{aligned} \tag{3}$$

Radio waves attenuate according to their distance from the emitter, and the RSSI values and the distances are negatively correlated as shown in Eq. (3). Therefore, it is possible to estimate distances using the measured RSSI values. The constant, 20, present on the right-hand side of Eq. (3) is a theoretical value and will have various values depending on the location. Setting this constant to be the RSSI attenuation constant N, Eq. (4) can be derived from Eq. (3):

$$D = 10^{-\frac{RSSI - RSSI_0}{N}} \tag{4}$$

When calculating the distance using the RSSI, the calculation is performed according to Eq. (4). Note that it is necessary to use a value of the RSSI attenuation constant, N, that is appropriate for each location.

If a node can receive radio waves from three or more anchor nodes, it is possible to estimate its position by calculating a plurality of distances using each value of the RSSI based on Eq. (3). When a node receives radio waves from three anchor nodes, a_1, a_2, and a_3, the node calculates the distances r_1, r_2, and r_3 and estimates its own coordinates s as the minimized square sum of the distance errors $a_1s - r_1$, $a_2s - r_2$, and $a_3s - r_3$. Fig. 1 shows a conceptual diagram of the localization calculated using the RSSI values of the radio waves of three anchor nodes: a_1, a_2, and a_3. However, because the RSSI

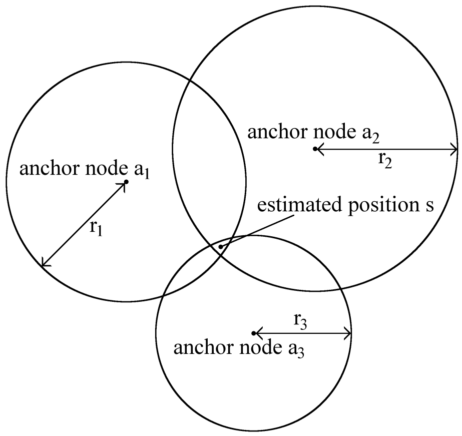

Fig. 1. A conceptual diagram of the localization

value is easily influenced by noise, the distances r_1, r_2, and r_3 include errors, and these errors also occur in the estimated coordinate s. In Section IV, we propose a localization method to reduce the estimation error using the direction to each anchor node.

IV. Localization via Measurements of the RSSI and the LED Light Angles

In this paper, we propose a method of localization via measurements of the RSSI values and the video shots that is suitable for WMSNs. While the distance between nodes is calculated using the RSSI in conventional methods, our proposed method uses not only the RSSI, but also the angle information measured by recording the anchor nodes with a camera to improve the accuracy. This proposed method is similar to localization techniques based on AOA in that it uses angle information. However, it does not require further equipment for the AOA measurement, such as high-directional antennas or an array of antennas; instead, it uses a camera for the measurement. Because the nodes in WMSNs are often equipped with cameras, we have only to add an inexpensive light to the nodes to optically measure the direction to the other nodes. In addition, the measurement accuracy is better because light has stronger linearity than radio waves.

A. Target Environment

The localization method proposed in this paper is appropriate for a WMSN satisfying the following conditions:

- The WMSN is outdoors;
- The nodes are fixed after deployment;
- Each node is equipped with an LED light and a 360-degree camera;
- There are two types of nodes: nodes whose coordinates are unknown (**estimation nodes**), and anchor nodes whose coordinates are known;
- Three or more anchor nodes exist; and
- Each node has a unique ID.

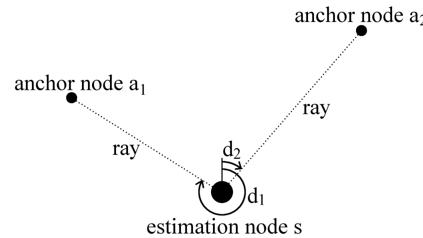

Fig. 2. The optical angle measurement (a bird's-eye view).

B. Formulation of the Problem

When an estimation node s computes its coordinates, the following information is used:

- The coordinates of the anchor nodes that s can communicate directly with (a_1, a_2, $\cdots$, a_i);
- The RSSI value of the anchor node's radio wave at a distance of 1 m (previously measured);
- The direction of each anchor node measured by s;
- The RSSI attenuation constant; and
- The Value of the RSSI for each anchor node measured by s.

Of the above items, the coordinates of each anchor node and the RSSI values at a distance of 1 m are assumed to be known in the initial state. The direction information for each anchor node will be measured by the camera, and the RSSI attenuation constant will be estimated using the proposed method described in Section IV-C. The elements to be solved for this problem are the two-dimensional coordinates (x_s, y_s) of estimation node s.

C. The Proposed Method

In this section, we describe a method to solve the problems described in Sections IV-A and IV-B. The position estimation operation for the proposed method consists of three phases: position estimation with the camera , attenuation constant estimation, and composite position estimation.

1) The Position Estimation with the Camera Phase: When estimating the position with the camera, the estimation nodes perform optical measurements and position estimations. For the optical measurement, all anchor nodes turn on their mounted LED light units with a unique flashing pattern corresponding to their anchor node number. The estimation nodes detect the flashes of the anchor nodes using their cameras and measure the horizontal angles and anchor node numbers. The horizontal angles d_1 and d_2 of the anchor nodes a_1 and a_2 are determined as in Fig. 2. The estimation nodes that can detect the flashes of two anchor nodes, a_1 and a_2, using their mounted cameras, calculate the interior angle $\angle a_1 s a_2$ as the difference between the measured horizontal angles of a_1 and a_2. This angle, $\angle a_1 s a_2$, is calculated using Eq. (5):

$$\angle a_1 s a_2 = min(|d_1 - d_2|, 2\pi - |d_1 - d_2|) \qquad (5)$$

Based on the law of cosines, using the coordinates of the two anchor nodes, (x_{a_1}, y_{a_1}) and (x_{a_2}, y_{a_2}), the estimation node s

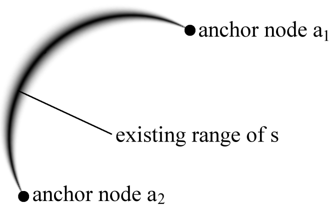

Fig. 3. The narrowed range of coordinates using the horizontal angle information

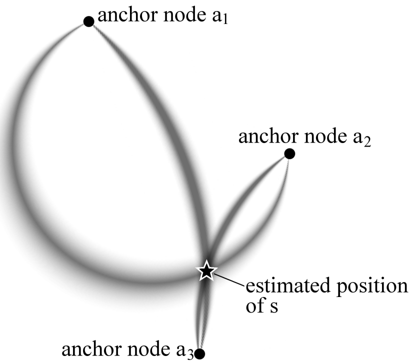

Fig. 4. The estimated position calculated from three directions

can narrow the range of its own position to set of coordinates $(x_s,\, y_s)$ satisfying Eq. (6):

$$\begin{aligned}&(\ x_{a_1}-x_{a_2})^2+\ (y_{a_1}-y_{a_2})^2\\&=(x_{a_1}-x_s)^2+(y_{a_1}-y_s)^2+(x_{a_2}-x_s)^2+(y_{a_2}-y_s)^2\\&-2\sqrt{(x_{a_1}-x_s)^2+(y_{a_1}-y_s)^2}\,\cdot\\&\quad\sqrt{(x_{a_2}-x_s)^2+(y_{a_2}-y_s)^2}\cos\angle a_1sa_2\end{aligned}\tag{6}$$

By performing calculations on the triangle formed by the two anchor nodes, a_1 and a_2, and the estimation node s, the existence range of s can be narrowed to an arcuate shape, as shown in Fig. 3, according to the theorem of circumferential angles.

If the node can detect the flashes of three or more anchor nodes, the node calculates its own coordinate ranges for all combinations of the triangle and determines its coordinates by integrating the range derived from each triangle using the least squares method. If an estimation node can measure the three horizontal angles of the anchor nodes, the estimated position is determined to be at the point shown in Fig. 4. An estimation node that can detect more than three anchor nodes can determine its own position to a single location.

2) The Attenuation Constant Estimation Phase: When calculating the positions of the nodes using RSSI data, it is necessary to know the RSSI attenuation coefficient. Therefore, in the attenuation constant estimation phase, the nodes measure the RSSI and estimate the RSSI attenuation constant. First, all of the estimation nodes measure the RSSI of each anchor node and record it. Then, the RSSI attenuation constant is derived

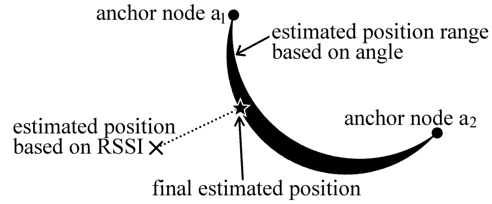

Fig. 5. Position estimation using both RSSI and the camera

from the value of the measured RSSI and the coordinates of the nodes calculated in the position estimation phase by the camera. Given that the estimation nodes that can detect the flashes of three or more anchor nodes in the position estimation with the camera phase are localized with very high accuracy, we assume that these nodes are quasi-anchor nodes. The quasi-anchor nodes calculate the distance to the anchor nodes using the coordinates estimated by the camera. Taking the RSSI damping constant as a parameter, the quasi-anchor nodes also calculate the distance by substituting the measured RSSI into Eq. (4) and deriving the constant satisfying the equations of the two distances computed in different ways. Repeating this operation for all the anchor nodes that the quasi-anchor nodes can communicate directly with and averaging these values yields the RSSI attenuation constant.

3) The Composite Position Estimation Phase: In the composite position estimation phase, the coordinates of all the nodes are determined. The nodes that detected the flashes of three or more anchor nodes in the position estimation with the camera phase determine their own coordinates using the estimated result based on the camera. The nodes that detected the flashes of one or zero anchor nodes in the position estimation with the camera phase determine their own coordinates using the estimated result based on the RSSI. The nodes that detected the flashes of only two anchor nodes narrow the range of their own coordinates using the angle information. When a node can measure the horizontal angle of two anchor nodesm a_1 and a_2, it calculates the range of its own coordinates by substituting the interior angle $\angle a_1sa_2$ into Eq. (6) with an allowable error of the interior angle $\angle a_1sa_2$ of 10 degrees. In the narrowed range of coordinates, it determines its own coordinates as a point that is at the shortest Euclidean distance from the position estimated based on the RSSI (Fig. 5).

V. Experiments

We conducted experiments to assess the accuracy of the estimated position using the proposed method. We constructed a small-scale WMSN and then measured the RSSI and took videos using the cameras. In this experiment, we estimated the positions of the nodes with a position-estimating method using only RSSI (**the conventional method**) and the proposed method under the same conditions and evaluated their estimation accuracies.

TABLE I
CONFIGURATION OF THE WMSN

The number of anchor nodes	4
The number of estimation nodes	5
The distance between the nodes	2.5-8.6 m
Field size	6 m $\times$ 8 m

TABLE II
THE ANCHOR NODES (4 PLACES): a_1, a_2, a_3, AND a_4

Beacon signal transmission unit	
Hardware	HTC Nexus 9
Wireless communication standard	Bluetooth 4.1 Class1
Beacon signal protocol	iBeacon
Transmission frequency	10Hz
Application	Locate Beacon v2.6.1
RSSI value at the distance 1 m	-62.4 (Measured)
Flash light emitting unit	
Light source	white LED $\times$ 1
Power consumption(when lighting)	265 mW (Measured)
Interval of blinking	about 3Hz
Irradiation angle (Horizontal)	360

TABLE III
THE ESTIMATION NODES (5 PLACES): s_1, s_2, s_3, s_4, AND s_5

Beacon signal Receiving unit	
Hardware	SONY Xperia Z2
Wireless communication standard	Bluetooth 4.0 Class1
RSSI measurement frequency	1Hz
Application	Locate Beacon v2.6.1
Pulse detecting unit	
Shooting device	Logicool C525
Optical device	mirror dome
Recording resolution	1280 x 720 px
Angle of view (Horizontal)	360

A. Experiment Configuration

The parameters of the WMSN built for the experiments are shown in Table I. The specifications of the anchor nodes and the position measurement nodes are shown in Table II and III, respectively. The WiFi communication function and the LTE communication function were turned off to avoid radio interference. Because the amount of equipment was insufficient, we produced only one position measurement node. A measurement was made at one point, and then a measurement was made at subsequent points. In this way, we obtained the data for five points.   In the experiment, we focused on fabricating nodes using only inexpensive components. Therefore, we did not use 360-degree cameras for the position measurement nodes; instead, we used a typical Web camera and a mirror made by removing the handle of a ladle. Fig. 6 shows a schematic diagram of the Web camera that was used in the position measurement nodes. The locations of the nodes are shown in Fig. 7.

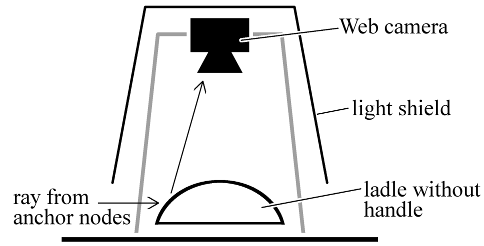

Fig. 6. Schematic diagram of the Web camera.

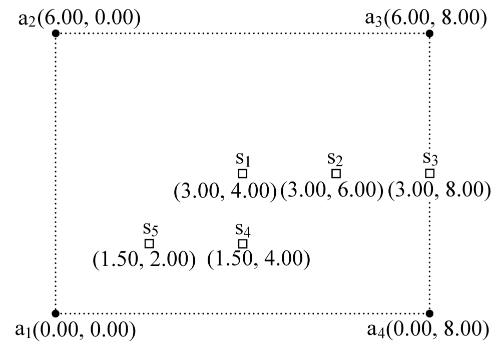

Fig. 7. Configuration for the experiments (units: m).

B. Experimental Setup

The WMSN described in the previous section was installed in an open flat outdoor area with no obstacles within 10 m. The anchor nodes were installed at four locations at the points a_1-a_4 so that the upper sides of the tablets faced the center. After installation, the anchor nodes continuously blinked and sent the beacon signal. Because the cameras have a poor response when performing optical communication, the blinking frequency was set to approximately 300 ms. The estimation node recorded the video from the Web camera and the RSSI of the beacon signal of each anchor node at the point s_1-s_5. To counteract the wave reception directivity of the node, the smartphone at the estimation node was fixed so as to face the direction of the anchor node when measuring the RSSI, the RSSI was measured 10 times per measurement, and the data were aggregated based on the average value from the first to fourth quintiles. The horizontal angle was measured by plotting only the light spots of the anchor nodes that were visible in the video and had identifiable IDs. As shown in Fig. 8, the top of the image was set to a reference angle (0°). After collecting all the data, we estimated the position of the node using the conventional method and the proposed method. Note that the RSSI value at a distance of 1 m was -62.4, which is the value determined from preliminary experiments. Then, we repeated the localization of five locations with the conventional method by changing the RSSI damping constant to determine the attenuation constant in this field. The attenuation constant was calculated using the least squares error method. When calculating the RSSI attenuation constant with the proposed

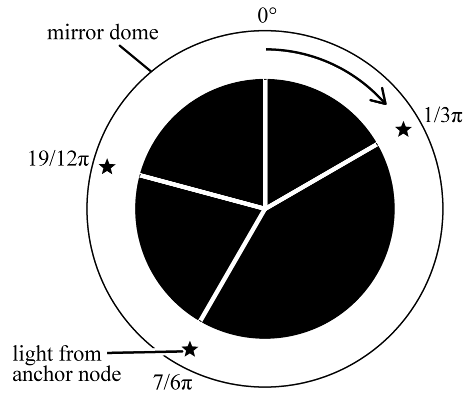

Fig. 8. Angle measurement in the captured image

TABLE IV
THE MEASURED RSSI

	a_1	a_2	a_3	a_4
s_1	-73.7	-89.5	-76.0	-77.0
s_2	-76.5	-83.7	-75.7	-81.0
s_3	-88.5	-84.8	-74.3	-72.0
s_4	-75.2	-77.5	-73.5	-73.0
s_5	-71.2	-77.0	-88.0	-78.2

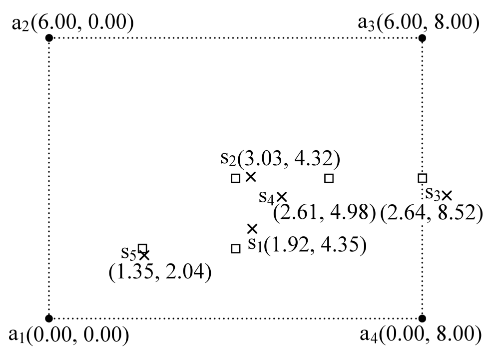

Fig. 9. The positions calculated using the conventional method (units: m).

method, we estimated it using the method described in Section IV-C.

C. Experimental Results

Table IV shows the value of the measured RSSI at the five point locations in this experiment. The estimated coordinates calculated using the conventional method are shown in Fig. 9 and Table V. We calculated the RSSI attenuation constant using the methods described in Section V-B and got a value of 23.76. Subsequently, in calculations with the conventional method, we use this attenuation constant. The average value of the estimation error in the five locations was 1.017 m.

Next, we describe the experiment using the proposed method. Table VI lists the horizontal angles of the anchor nodes measured at the five points, s_1-s_5. The entries described as N̈/Aäre anchor nodes from which light could not be detected

TABLE V
THE COORDINATES CALCULATED USING THE CONVENTIONAL METHOD

	Estimated coords.[m]	Actual coords.[m]	Error[m]
s_1	(1.92, 4.35)	(3.00, 4.00)	1.135
s_2	(3.03, 4.32)	(3.00, 6.00)	1.680
s_3	(2.64, 8.52)	(3.00, 8.00)	0.632
s_4	(2.61, 4.98)	(1.50, 4.00)	1.481
s_5	(1.35, 2.04)	(1.50, 2.00)	0.155
		Average error	1.017

TABLE VI
MEASURED HORIZONTAL ANGLE

	a_1	a_2	a_3	a_4
s_1	N/A	152.5	259.0	336.0
s_2	N/A	77.0	171.5	287.5
s_3	N/A	N/A	90.5	271.5
s_4	N/A	38.0	123.0	197.5
s_5	289.0	26.5	106.0	162.0

TABLE VII
THE COORDINATES CALCULATED IN THE POSITION ESTIMATION WITH THE CAMERA PHASE

	Estimated coords.[m]	Actual coords.[m]	Error[m]
s_1	(2.91, 4.08)	(3.00, 4.00)	0.120
s_2	(2.85, 6.06)	(3.00, 6.00)	0.162
s_3	Not estimated	(3.00, 8.00)	]
s_4	(1.62, 4.29)	(1.50, 4.00)	0.314
s_5	(1.68, 2.34)	(1.50, 2.00)	0.385

from by the camera. At many of the measurement points, the estimation node was not able to detect the horizontal angle of the anchor node a_1. This is because a_1 was reflecting the sunlight and seemed to be lit at all times in the video. The estimated positions determined in the position estimation phase by the camera are shown in Table VII. Because the anchor nodes could not be detected, the position of s_3 was not estimated. We estimated the RSSI attenuation constant using the estimated coordinates of s_1, s_2, s_4, and s_5, and we obtained a value of 23.72. Because the estimation error of the camera was small, this value is essentially the same as the RSSI damping constant calculated in the conventional method. Using this RSSI damping constant, the position of s_3 was estimated from the RSSI and integrated with the results in Table VII. The final results of the estimated position are shown in Fig. 10 and Table VIII. The average error of the five estimated coordinates calculated using the proposed method was 0.263 m. Compared to the conventional method, the average error was reduced by 74%. For node s_5, the result of the conventional method indicates a better value than that of the proposed method. Because the proposed method is based on the assumption that the 360-degree camera is perfectly horizontal, the error became larger when the 360-degree camera was mounted at a tilt due to miscellaneous

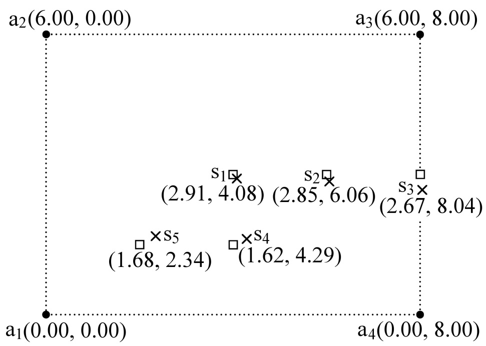

Fig. 10. The positions calculated using the proposed method (units: m).

TABLE VIII
THE COORDINATES CALCULATED USING THE PROPOSED METHOD

	Estimated coords.[m]	Actual coords.[m]	Error[m]
s_1	(2.91, 4.08)	(3.00, 4.00)	0.120
s_2	(2.85, 6.06)	(3.00, 6.00)	0.162
s_3	(2.67, 8.04)	(3.00, 8.00)	0.332
s_4	(1.62, 4.29)	(1.50, 4.00)	0.314
s_5	(1.68, 2.34)	(1.50, 2.00)	0.385
		Average error	0.263

installation. The conventional method makes estimates with unreliable accuracy, but may estimate with high accuracy; therefore, the estimation accuracy of s_5 using the conventional method was better than the proposed method in this case.

D. Evaluation of the Experimental Results

When compared to the conventional technique, the proposed method was able to reduce the average error by 73%. Even without measuring the RSSI attenuation constant in advance in the field, it is possible to make accurate estimations. It was found that the optical measurement of the angle with visible light, which has a strong directionality unlike radio waves, is useful for improving the accuracy of the position estimate. Furthermore, because the outdoor setting was exposed to direct sunlight, the measurement of some angles may become impossible.

VI. Conclusion

For a WMSN whose nodes have 360-degree cameras, we proposed a method to improve the accuracy of the position estimation by adding an inexpensive light to the nodes. We built a small WMSN using only inexpensive equipment, which was evaluated via experiments. The average estimation error using the proposed method was approximately 0.3 m, this error was approximately 73% less than when using the conventional method in the same environment. Without the pre-measured RSSI attenuation constant, it was possible to perform high-precision position estimations. In the future, we aim to create a larger WMSN, such as one in a forest, in which there are estimation nodes that cannot see even a single anchor node.

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