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3D Localisation in Ad Hoc Sensor Network with Embedded Camera and LEDs†

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In sensor networks, the location measure is one of the most important information. The simplest way to know the location of sensor nodes is to put a GPS receiver to each node. But this way is not suitable to indoor sensor networks. There are many researches of the location information. In this paper, we propose a new model for localizing in sensor networks with image sensing. We assume that the proposed models may be suitable to indoor sensor networks. Each sensor node, which mounts a camera and infrared LEDs, detects its 3D location by taking a set of images from the embedded camera. The 3D location information will be informed to other nodes via wireless communication. From simulations and experiments of a prototype sensor network with tiny CMOS embedded camera, we confirmed that it is able to detect 3D location information based on the proposed 3D localizing models in a real scene.

Key Words: vision based positioning, 3D localization, embedded camrea, LED marker

1. Introduction

In ad hoc sensor networks, the exact location information of nodes is very important for most of all applications. If sensor nodes are fixed in some well-organized way, there is no need to detect the location information. But if sensor nodes are located arbitrarily or movable, the location information of each node has to be detected. Sensor information without location description are not able to satisfy most of all applications. However, in the conventional sensor networks, it is difficult to acquire the location information of nodes.

The simplest way to know the location of sensor nodes is to put a GPS receiver to each node. But this way has many serious problems. First, GPS cannot work indoors or in an area where nodes cannot receive radio waves from GPS satellites. Second, the power consumption of GPS receiver is relatively high, so that to attach GPS function is not suitable to sensor nodes with poor batteries. In sensor networks, the power consumption has to be reduced to survive the sensor nodes as long as possible. The size of GPS receiver and its antenna expands the form factor of sensor nodes. Sensor nodes are should be expected to be small.

There are many researches about detecting location information in the area of sensor network. GOMASHIO is a system that location information is obtained from hop counts from nodes whose locations are known [1]. AHLoS is a system using ultrasonic sensors based on sound wave propagating time [2]. A gradient sensor of radio wave with orthogonal antenna is one of the promising methods for estimating 3D location, because sensor network originally owns radio wave transmitter and receiver [4),5)].

The goal of this paper is to detect the exact 3D location information by image sensing technology [6]. In this paper, we propose three types of image-based localizing models, point marker node type, local marker node type and area marker node type. It is assumed that the proposed models will be used indoor and sensor nodes are located arbitrarily or movable without the reference nodes.

2. SYSTEM CONFIGURATION

2.1 Point Marker Node Type

We presume that many sensor nodes make up wireless multi-hop network autonomously, and all nodes can execute bi-directional communication with information packets. As shown in **Fig. 1**, each sensor node has an infrared LED and a tiny camera, whose intrinsic camera parameters are known, ex. focal length. The camera takes an image of other nodes' emitting LED through an infrared lens filter. By using infrared ray, the nodes can detect flashing of the LEDs without being affected by the environmental light.

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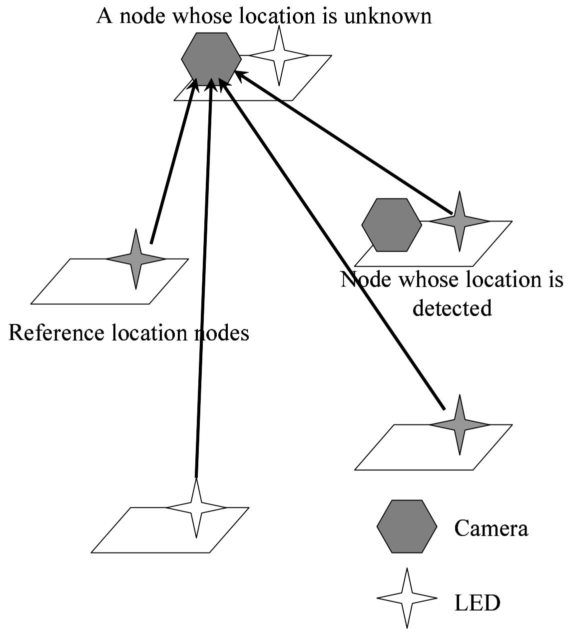

Fig. 1 System Configuration

There are two types of nodes: reference location node and other regular nodes whose locations are not determined and should be measured. The reference location nodes are ones whose location are known previously, and these nodes are used as the three-dimensional reference points like a lighthouse for detecting the location of a node whose location is unknown.

And each reference location node or each node whose location is currently known turns on their embedded infrared LED sequentially one by one in the whole network. When only one LED of some node is turned on, all other nodes whose locations are unknown take images. After taking the image, node dose image processing to compute X-Y coordinates information of a bright spot. If the node can obtain at least four X-Y coordinates information of bright spots in sequential image capturing, the node can calculate 3D location information itself. Once the node whose location is detected, it plays a roll as a reference node used for detecting the location of the rest unknown nodes. All nodes used for detecting are expected to be stationary during the measuring. If the condition is not assured, each node involves motion detection like an acceleration sensor and then activates an exception procedure.

2. 2 Local Marker Node Type

Here, we explain local marker node type model as **Fig. 2**. In this model, a reference location node has four embedded controllable LEDs. The four LEDs are geometrically co-planar. In the point marker node type model, the its reference location node has only one reference LED,

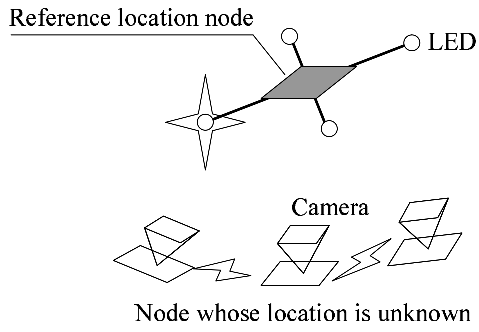

Fig. 2 Local Marker Node Type

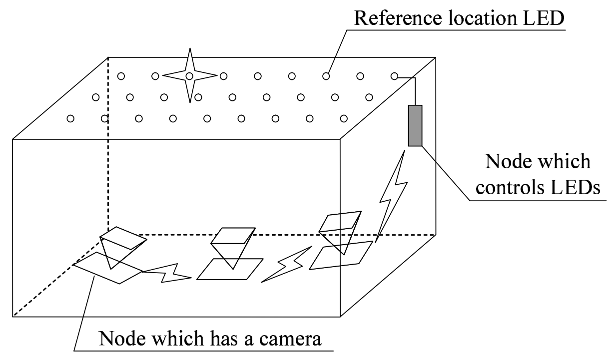

Fig. 3 Area Marker Node Type

so it needs at least four reference location nodes for detecting 3D locations of nodes whose locations are unknown. But in this model, if there is only one reference location node, each node is able to detect its 3D location independently. In practical way, the reference nodes are attached onto the ceiling or wall.

2. 3 Area Marker Node Type

In area marker node type, plural reference location LEDs are attached onto the ceiling, and the special node controls these LED array as in **Fig. 3**. Unlike point marker node type which assumes many reference location nodes spread widely, this type is unified to the room ceiling. As for measurement accuracy, this type may archive good accuracy due to many well-organized reference points denoted LED array.

3. METHOD OF CALCULATION OF LOCATION

The pin-hole camera model is shown in **Fig. 4**. Here, I is the image plane, F is the focal plane, f is the focal distance, C is the pinhole. Light goes through point C, and focuses I.

We place x-axis and y-axis and others as shown in Fig. 4. In this coordinates system, a point $m(x, y, z)$ in the image and a point $M(X, Y, Z)$ in a free space are shown in Eq.

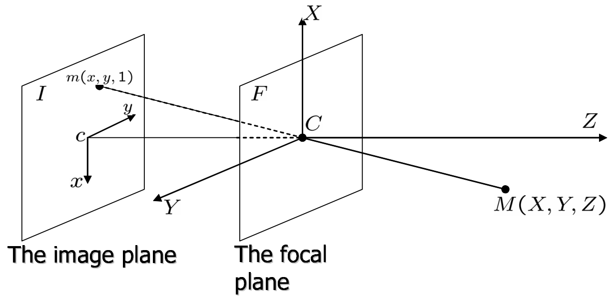

Fig. 4 Pin-hole Camera Model

(1).

$$x = f\frac{X}{Z}, y = f\frac{Y}{Z} \tag{1}$$

Rewriting Eq. (1) in matrix, we obtain

$$s\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{2}$$

Here, s is scalar, Next, we denote relations between the camera coordinate system and the world coordinate system. If we rotate and translate the world coordinate system, we can obtain the camera coordinate system. This homogeneous expression is given by

$$\boldsymbol{M_C} = \boldsymbol{R}\boldsymbol{M_W} + \boldsymbol{t} \tag{3}$$

Here, $\boldsymbol{M_C}$ is the camera coordinate system, $\boldsymbol{M_W}$ is the world coordinate system, $\boldsymbol{R}$ is the rotation matrix, $\boldsymbol{t}$ is the translation matrix. We define the rotation matrix $\boldsymbol{R}$ as first rotation α on Z-axis, second rotation β on Y-axis, last rotation γ on new Z-axis.

$\boldsymbol{R^{-1}}$ times Eq. (3), we obtain

$$\boldsymbol{R^{-1}M_C} = \boldsymbol{M_W} + \boldsymbol{R^{-1}t} \tag{4}$$

The origin of the camera coordinate system is described $\boldsymbol{R^{-1}t}$. Rewriting equation (2), on the world coordinate system, we obtain

$$s\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \boldsymbol{A}\begin{bmatrix} & \boldsymbol{R} & & \boldsymbol{t} \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{5}$$

Here, $\boldsymbol{A}$ is the camera intrinsic parameters which include focal distance, $\boldsymbol{t} = [t_x, t_y, t_z]^T$. We assume that the camera intrinsic parameters and the location of nodes in the image, the coordinates of the node are known. Unknowns are the angle of rotation α, β, γ, and t_x, t_y, t_z, and scalar s. s differs in each pixel. If we get three X-Y coordinates of nodes whose locations are known in one image, there are nine unknowns and nine equations. But unique solution is not solved. If we acquire at least four X-Y coordinates, we can determine the exact 3D location.

Table 1 Specifications of sensor node "MICA"

Frequency	4MHz
Flash ROM	128K bytes
SRAM	4K bytes
Radio frequency	916MHz
Power source	2 AA (3V)

Fig. 5 Sensor node "MICA"

Table 2 Specifications of CMOS camera "Treva"

Size	30 × 32 × 16 mm
Weight	10g
Resolution	96 × 72 pixels
Lens	Fixed focus
Power source	DC 3V
Actuating current	20mA
Image format	16bit YUV

4. IMPLEMENTATION OF SENSOR NODE

We have constructed a set of prototype sensor node connecting an embedded camera on MOT-KIT311 sensor network developing kit produced by ""Smart Dust"" project of UC Berkeley [7]. The kit includes four "MICA" processor/radio boards, and three MTS310 sensor boards, one MIS510 programming and serial interface board. Specifications of "MICA", regular sensor nodes, are shown in **Table 1**.

We implant a tiny CMOS camera onto "MICA" sensor node. It is a small consumer CMOS camera; "Treva" (Kyocera Corporation) used for Personal Handy Phone (PHS) accessory. "Treva" is fairly low power consumption at lower frequency clock (near DC) with the advantage of CMOS technology. Its image resolution is 96 by 72 pixels. There is another advantage for sensor nodes that "Treva" needs only two digital I/O lines: clock input and data output. The specifications of "Treva" are shown in **Table 2**, and its overview and a sample image are shown in **Fig. 6**.

The prototype sensor node we developed is shown in **Fig. 7**. In the current implementation, the sensor node

Fig. 6 CMOS camera "Treva" and its sample image

Fig. 7 Prototype sensor node with embedded camera

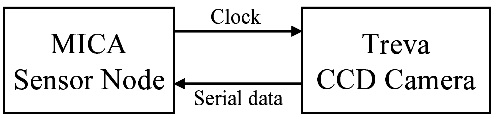

Fig. 8 The connection between "MICA" and "Treva"

supplies 1 kHz clock to the camera (**Fig. 8**). In this case, it takes about 3 minutes to capture an entire image data, and the current consumption is about 50 mA.

5. CONTROL OF LEDs BY PACKET COMMUNICATION

In this chapter, we explain about control method of LED illumination in our prototype system. In our sensor network, each sensor node has a function of packet data communication and is assigned with an unique ID number.

For example, we consider the situation that the node of ID 3 turns on its LED and the node of ID 5 takes picture. First, a command packet is transmitted to the node of ID 3 from the base station. The packet involves the command "Turn on the LED" and the ID of the target node and the target LED. If the node of ID 3 gets the packet, the node turns on its target LED and rewrites the packet to a new command packet which involves "Take Picture" and new target ID. Next, the command packet is transmitted to the node of ID 5 from the node of ID 3. If, the node of ID 5 gets the packet, the node will capture an image and obtains the coordinate information of blight spot in the image. As the node usually has little memory, the node will transmit not the raw image data but only the coordinate information.

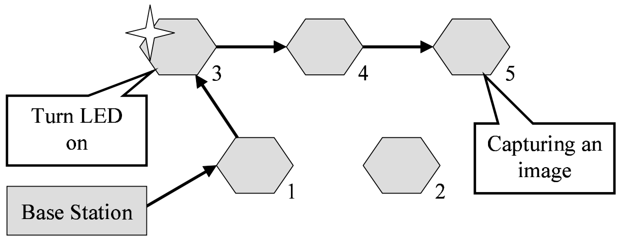

Fig. 9 Control of turning LED on and capturing an image

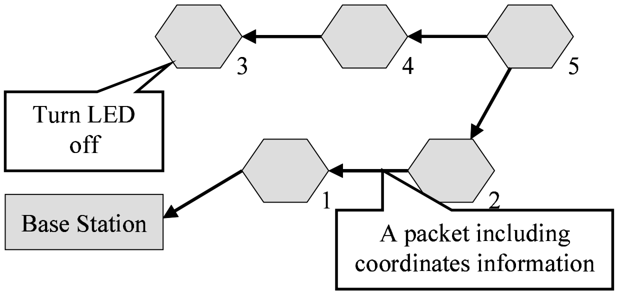

Fig. 10 Control of turning LED off and transmission the packet

If the node starts to capture an image, the node transmits a packet to the node of ID 3. The packet involves a command "Turn off the LED" and target ID. In this way, we can minimize the time of illuminating of the LED, and reduce the consumption of LED power current.

If the node can get the coordinate information of blight spot, the packet which involves the coordinate information is transmitted to the base station. When the node of ID 3 acquires the packet, it turns off its LED.

In the same way, the base station collects the coordinate information of other reference nodes distributed to the measurement space. Once the base station is able to collects necessary number of coordinate information, location information is calculated, and the information is transmitted to the interested node.

6. EXPERIMENTS

6.1 Prototype Experiment(Point Marker Node Type)

In order to confirm the 3D positioning function of the proposed sensor network based on point marker node type, we have experimented with the prototype sensor nodes in Fig. 7. The reference LED markers are located at (0, 0, 0), (100, 0, 0), (0, 100, 0) and (0, 0, 100)[mm]. A sensor node to be measured are located at random. Experimental results on the positioning accuracy are shown in **Table 3**.

6.2 Simulation Experiment

We have done a computer simulation with a dis-

Table 3 Experimental 3D positioning (Point marker node type)

	Axis	Detected location	Original location
Experiment 1	X	90mm	70mm
	Y	60mm	20mm
	Z	290mm	300mm
Experiment 2	X	80mm	70mm
	Y	200mm	220mm
	Z	250mm	270mm
Experiment 3	X	290mm	120mm
	Y	220mm	290mm
	Z	530mm	710mm

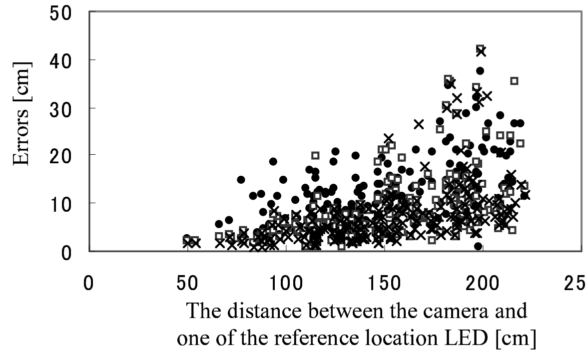

Fig. 11 Error distribution of simulation experiment of point marker node type

crete camera model having the image resolution same as "Treva" to estimate the amount of positioning errors. In order to confirm its error distribution, an imaginary target node is located at random for thousand times. The errors versus the distance between the camera and the reference node are shown in **Fig. 11**. Dots(●) show the errors detected by four reference LEDs, dots(□) are that detected by five reference LEDs, dots(×) are that detected by six reference LEDs. We can confirm that when there are much number of reference LEDs, the errors can be reduced.

6. 3 Prototype Experiment(Local Marker Node Type)

We constructed a prototype local marker node in local marker node type in Fig. **Fig. 12**. The four reference location LEDs mounted on the node are located at (500, 500, 0), (700, 500, 0), (500, 700, 0), (700, 700, 0)[mm]. Experimental results on positioning accuracy are shown in **Table 4**. The error of the Exp. 1, 2 is about 30mm, 250mm, respectively.

6. 4 Simulation Experiment

Computer simulation of local marker node type, was done in the same way as simulation experiment of point marker node type system. The difference is that the four reference LEDs are located on co-planer. The results are shown in **Fig. 13**. The errors of local marker node type are larger than that of point marker node type. We suppose that the co-planar reference LEDs degrades the accuracy of depth measurement rather than three-dimensionally spread LEDs.

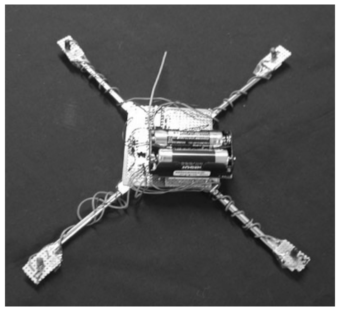

Fig. 12 Prototype of local maker node

Table 4 Experimental 3D positioning (Local marker node type)

	Axis	Detected location	Original location
Experiment 1	X	280mm	300mm
	Y	630mm	600mm
	Z	530mm	600mm
Experiment 2	X	780mm	700mm
	Y	380mm	450mm
	Z	770mm	750mm

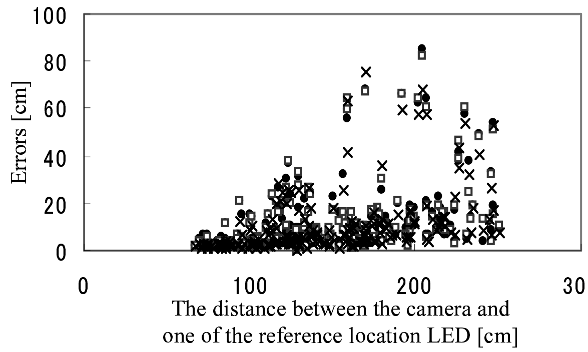

Fig. 13 Error distribution of simulation experiment of local marker node type

7. CONCLUSION

In this paper, we have proposed three types of model for 3D localization in sensor networks with image sensing. We have confirmed that the proposed 3D locating methods are able to measure the sensor nodes satisfyingly by experimenting with the prototype system. The experiments denote the expected characteristic of positioning errors; when the node was far from the reference location nodes, the error increases in poor image resolution. Our next argument in this research is how to compensate this kind of error characteristics. For reducing errors, we have to consider not only increase of a number of reference nodes but also some compensation mechanism between sensor nodes.

On the other hand, we will consider to reduce the actuating current of each node with a camera and LEDs. The actuating current of the experimental node is about 50 mA when activating the embedded CMOS camera. Also, we would shorten the detecting time. In the current implementation, it takes no less than 3 minutes to capture an image. Thus, the total detecting time is currently no less than about 15 minutes.

Authors believe that this kind of image sensing function on a tiny sensor node may become the next important key issue of sensor network.

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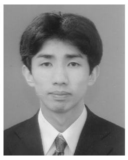

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