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Position Estimation of Mobile Robots Based on Coded Infrared Signal Transmission

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***Abstract*—A system based on coded infrared signal transmission for the estimation of position of mobile robots in a structured environment is reported. Particular emphasis is placed on the polar coordinate arrangement in which signals are sent from the transmitters situated at the corners of the boundaries of operation. A multisensor system, strategically situated onboard the robot, has been found to improve the accuracy of the position estimation substantially. The information detected by the sensors is suitably processed to calculate the central position of the robot geometrically. The algorithms for the position calculations and the operational strategy are presented. This system forms the basis for the coordination and cooperation philosophy of multiple mobile robots sharing the same environment and performing cooperative or competitive tasks.**

***Index Terms*—Autonomous operations, coordinate systems, infrared, mobile robots, position estimation, signal transmission.**

I. INTRODUCTION

RECENT progress in computers, communications, and control technologies are enabling mobile robots to become truly autonomous. In addition, multiple autonomous mobile robots (MAMR's) are maturing from research stages to a new realm of applications in both research laboratories and industry. One of the essential components for the satisfactory performance of mobile robots is the availability of accurate and reliable sensory systems. Depending on the requirements of applications, many different position sensing mechanisms based on different physical principles have been developed by various researchers [1]–[4]. Accurate prediction of the locations of MAMR's are important mainly for efficient task division, navigation, and collision avoidance. Inevitably, robots must know their own positions and the position of others at all times. Therefore, a regular update of locations needs to be implemented and the information must be effective and meaningful to all robots sharing the same environment [5].

A shortfall in the application of MAMR's is that they require some form of central coordinator which ensures effective coordination of movements and efficient load sharing. However, as illustrated in the literature, the central coordinator does not have to be a separate off-board device but can be distributed among the robots through an effective inter-robot communication system operating under suitable software [5].

At present, two classes of MAMR systems may be distinguished. The first class is formed by those that accomplish tasks by being directly guided by a central coordinator. This central coordinator is assumed to be in possession of information about the environment and the tasks to be performed which are known *a priori*. The second class of robots are those that gather information about their environment and act accordingly in an overall system coordinated manner [6]–[8]. This paper discusses the second class of robots, where the environment is identified by a coded infrared grid vision system. The vision refers to the ability of mobile robots to understand their environment in a similar way that vision allows humans to understand their surroundings.

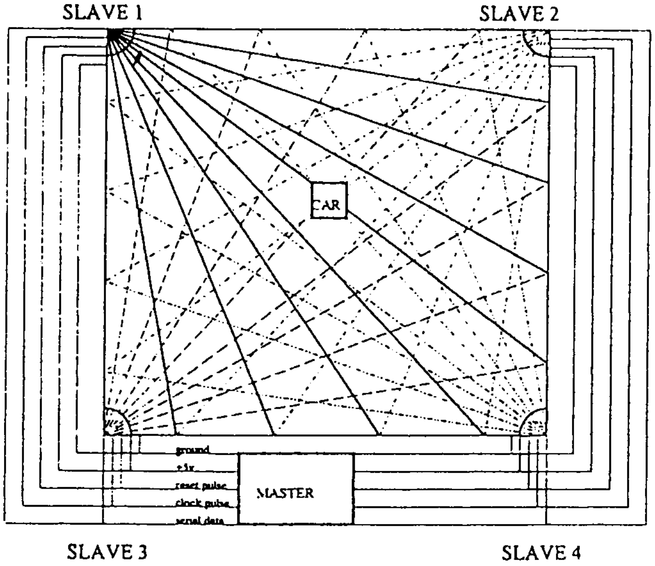

Fig. 1. Basic system layout.

II. MATHEMATICAL APPROACH TO POSITION ESTIMATION

The basic arrangement of the position sensing system that utilizes infrared technology arranged in polar configuration is shown in Fig. 1.

This system is comprised of groups of infrared transmitters located within four transmission beacons situated at each corner of the operating environment. Each transmitter is arranged in such a manner that an infrared receiver located anywhere within the field will always receive the emitted radiation from at least four transmitters with a minimum of one transmitter per beacon.

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TABLE I
ARRANGEMENTS OF CODES

STATION 1	ANGLE	STATION 2	ANGLE	STATION 3	ANGLE	STATION 4	ANGLE
< = 11100	80°	> = 11110	80°	= = 11101	80°	? = 11111	80°
space = 00000	10°	“ = 00010	10°	! = 00001	10°	# = 00011	10°
$ = 00100	20°	& = 00110	20°	% = 00101	20°	‘ = 00111	20°
(= 01000	30°	* = 01010	30°	) = 01001	30°	+ = 01011	30°
, = 01100	40°	. = 01110	40°	- = 01101	40°	/ = 01111	40°
0 = 10000	50°	2 = 10010	50°	1 = 10001	50°	3 = 10011	50°
4 = 10100	60°	6 = 10110	60°	5 = 10101	60°	7 = 10111	60°
8 = 11000	70°	: = 11010	70°	9 = 11001	70°	; = 11011	70°

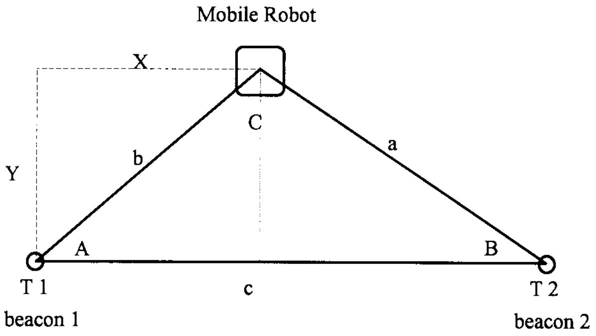

Fig. 2. Position estimation of robot.

The underlying principle of this position sensing technique is that a receiver located on the mobile robot is capable of determining the direction from which the received infrared radiation has originated. This is achieved by having each infrared LED periodically transmit a unique data character into the operation field to be detected by the infrared sensor located on the robot. Then, the triangulation calculations can be performed on this data in order to determine the relative position of the receiver with respect to the location of the transmitters.

An example is given below to illustrate the mathematics involved in the implementation of this technique. Fig. 2 is used for the estimation of the location of a robot.

Using the characters received by the sensors on the robot from transmitters T1 and T2 and based on the sine rule

$$a/\sin A = b/\sin B = c/\sin C.$$

With a known distance between transmitters T1 and T2, and the angles A and B are known, the X and Y coordinates can then be calculated.

Although, it is sufficient to receive information from only two beacons for position estimation, similar sets of calculations can be done using the data characters from the other beacons. A total of eight possible combinations of calculations can be performed. The statistical techniques can then be applied (such as removing extremes, averaging, etc.) on the resulting set of multiple coordinates in order to yield final X and Y coordinates and the direction of the movement of the robot.

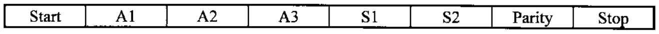

Fig. 3. Coding of infrared signals.

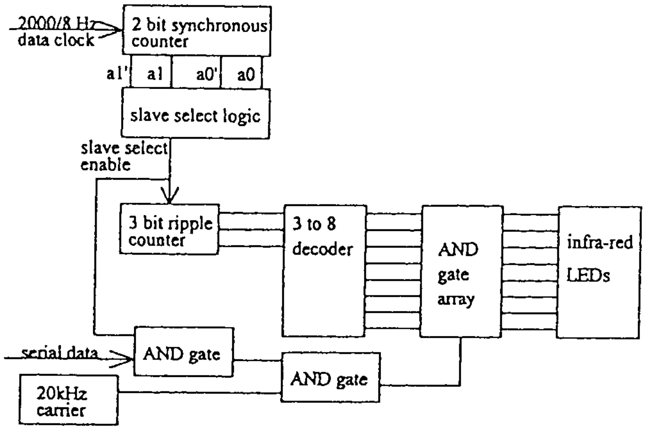

Fig. 4. Basic block diagram of beacon and transmitter control unit.

III. TRANSMITTER CODES

The transmitter codes are used to identify the beacon, the individual transmitter and the region of the field. Fig. 3 shows the format of information transmitted from each transmitter.

The arrangement of the codes is depicted in Table I. It can be seen from the table that two bits are used to identify each station, 00 being the least significant bits for station 0; 01 for station one; 10 for station two; and 11 for station three. The remaining three most significant bits determine the information to be transmitted. For example, 000 represents an angle of 10° and 111 an angle of 80°.

The codes are distributed between the beacons and infrared transmitters by the circuit shown in Fig. 4. The output from the synchronous 2-bit counter driven by the data clock is used by the beacon select logic to determine to which beacon the incoming data was intended. The three ripple counter and 3 to 8 decoder are used to cycle through the infrared transmitters in order to ensure that each one transmits the same data character in an orderly sequence. The carrier frequency of 40 kHz is logically ANDed with the serial data and the transmitter enable signals in order to reduce the power consumption of the infrared LED’s.

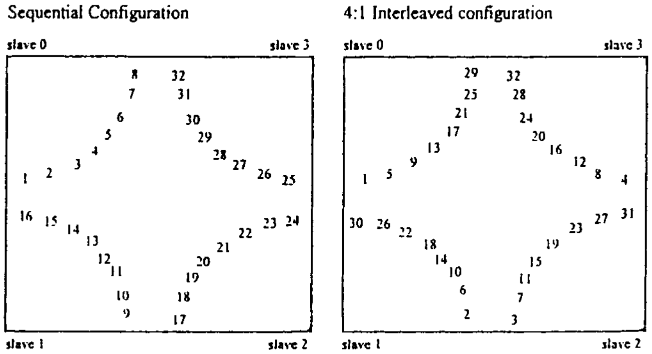

Fig. 5. Sequential and 4 : 1 interleaved infrared polar configuration.

Fig. 5 shows two of the possible configurations of transmission order for the signals. Present arrangements are the sequential and interleaved modes. Comparison of these configurations resulted in significant speed advantages for the latter method. This was primarily due to the fact that an object within the sequential system does not receive the fourth data character from beacon 3 until all characters from the previous beacons have been transmitted. Performance of the system have shown that the 4 : 1 interleaved system has an 81% faster response time than the sequential method.

IV. COMPLETE DESIGN AND RESULTS

The software for position determination was done in a modular form as follows:

1) obtaining the transmitted data;
2) deciphering the codes into angles;
3) calculating the coordinates for each transmitter;
4) formatting the results for position estimation and subsequent tasks.

The flow diagram of the main program is given in Fig. 6. The program acquires the transmitted codes in an asynchronous form and extracts information from these codes. The X and Y coordinates of all transmitter sets are calculated and accurate results are extracted from the data.

The program was repeated three times for the three infrared receivers located on the robots to enhance accuracy. An example of the results for the position estimation is given in Table II.

The integrity and consistency of the system have been tested with measurements by moving the receivers at every one meter point on a 10 m × 10 m grid. The readings were compared with measurements taken by measuring tapes. The results are shown in Fig. 7.

Fig. 7 shows the three recorded accuracy ratings:

1) @ is for very good, which has an error less than 5 cm (0.5%);
2) X is for good, which has an error between 5 cm and 10 cm (0.5% to 1.0%);
3) O has an error of greater than 10 cm (>1.0%).

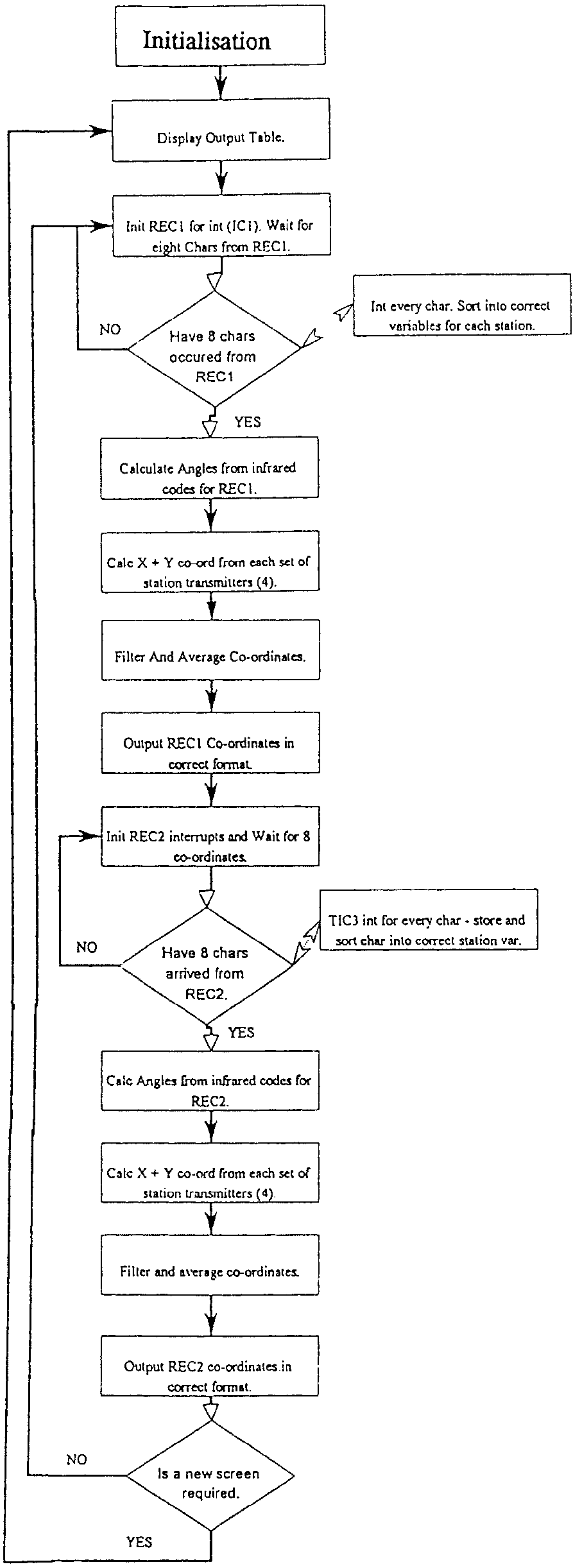

Fig. 6. Flowchart of the main position estimation program.

V. SYSTEM APPLICATIONS

A number of possible applications of this system are currently being studied. These are: multirobot game operations,

TABLE II
RESULTS FOR POSITION ESTIMATION

Transmitter	X Program	X Measured	Y Program	Y Measured
T1 T2	7.50 m	7.54 m	4.80 m	4.72 m
T2 T3	7.10 m	7.14 m	4.95 m	5.00 m
T3 T4	7.50 m	7.54 m	5.20 m	5.28 m
T1 T4	7.50 m	7.47 m	5.35 m	5.42 m

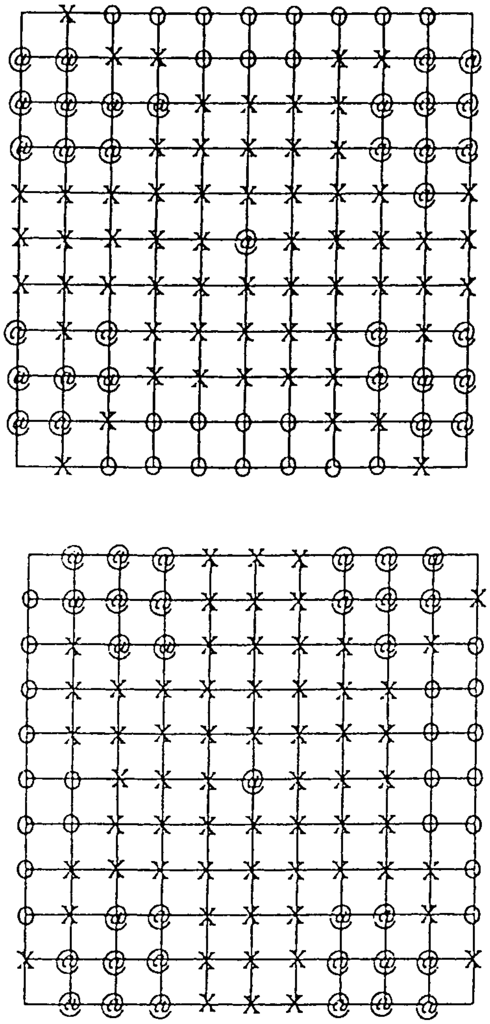

Fig. 7. Accuracy of position estimation.

single robot path finding and goal seeking, warehouse applications, and mining applications.

VI. CONCLUSIONS

A position sensing system based on an infrared coded signal transmission method has been discussed. Associated software and hardware for signal extraction has been introduced. The sensing-system accuracy has been detailed and the improvement of the accuracy with multiple sensing mechanism has been demonstrated. Some possible applications are suggested.

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