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Operation of mobile robots in a structured infrared environment

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Abstract: ***A micro robot has been built and integrated into a structured infra red positioning sensing system. In the position sensing system the operation area is divided into sectors to allow multiple robots to operate simultaneously. The robot monitors its position whilst in motion and makes its own logical decisions. It can autonomously decide for the next action to execute. It is also able to avoid both dynamic or static obstacles by either sensing a possible collision or by anticipating obstacles from its position and position of others by means of acting on a set of given prioritised instructions. Errors in the system have been discussed and recommendations are made.***

1. INTRODUCTION

There are many benefits associated with 'intelligent' autonomous robots and vehicles which are capable of inferring information from their surroundings [1], [2], [3]. However, so far, the progress of this field has been limited due to technological restrictions in the form of accurate robotics vision and sensors, processing power and memory [4], [5]. However, automatic guided vehicles (AGV) exist in a variety of applications from the manufacturing industry to military surveillance [4], [5], [6]. The main benefits of such vehicles being the ability to report information from places unreachable or uninhabitable by humans. In addition the tireless dedicated task of a robot can provide much greater production efficiency in industry. In most applications robots can sense their position in a limited way and act either by an externally controlled set of instructions or in a preprogrammed manner. Many researchers are concentrating on developing 'intelligent' or 'self aware' robots where they know their position at all times [1], [2], [3].

If a robot can locate its position within a global referencing system at any instant of time, then a database of instructions or events probable within that environment can be programmed into the robot, creating true autonomy within that environment. Furthermore, by constructing multiple robots and enabling a communication system between them, the team of robots can be programmed to cooperate together to achieve a given task. This will obviously be a very desirable objective as it has the potential to increase the efficiency in completing the given tasks.

Eren and Fung [7], [8] have reported an infrared position sensing mechanism based on coded infrared signal transmission which has the potential to give autonomy. In this paper an improved version of the position sensing mechanism has been presented and the operation of a mobile robot has been evaluated. The positioning system comprises of four transmitting beacons, one situated at each corner of a square operational area. Each beacon has 16 infrared transmitters dividing a 90° angle into equal zones. The transmitters are separated from one another by a black blanking panel and each transmitter sends a unique 6 bit identification character.

In this way, any robot in the field equipped with appropriate infrared sensors is able to capture the identification characters sent from the beacons. By performing trigonometric triangulation calculations the position is determined in the form of Cartesian coordinates. In order for the robot to successfully locate it's global position it requires at least two control bytes from two different beacons. The polar grid used to determine the reception of control bytes is given in Figure 1. The numbers 0 - 3 represent the four transmitting beacons, where each of the circles are the scaled representation of the robot in a 3 by 3 meter operation area.

2. THE MOBILE ROBOT

A robot (the Rug Warrior) has been developed at MIT for the purpose of investigating path planning intelligence and self learning algorithms. The kit was purchased from Joker Robotics [9]. It is an MC68HC11A1 controlled micro robot, with 32K

SRAM and numerous sensors on board. The main control PCB is mounted on a circular steel base and two DC motors control the motion of the robot. In this application, a number of sensors and modules were interfaced to the main PCB. These were: SN754410E H-Bridge DC motor controller, two LTE-4206 IR transmitters, GPIU52X IR receiver, two P5587 IR transceivers, three momentary SS5GL13T switches, and 8 BPW50 infra-red photodiodes. Two field IR receivers are placed on probes on the perimeter of the robot chassis so an approximate orientation can be geometrically calculated, based on the information received from the beacons. The field IR receivers utilise four BPW50 infra-red photodiodes on each of the probes. They are positioned facing outward in a north, south, east and west configuration. Parallel connection allowed these diodes to cover a full 360° angle on each probe. The receivers are operational within an initial 3x3 meter field and they are capable of recovering signal accurately in the presence of noise They provide a serial TTL signal level output which can be applied to the SCI on the 68HC11. The signal capture procedure is illustrated in Figure 2.

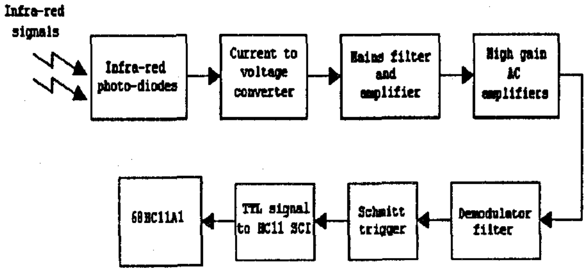

Figure 2: Field IR signal recovery

The GPIU52X IR receiver is mounted on the front of the robot to receive any reflected infra red radiation from the local IR transmitters such that robot can detect obstacles both on the right or on the left side. Three momentary SS5GL13T switches are placed on the perimeter of the robot chassis. One at the rear and two on the front right and left sides. When the skirting hits an obstacle in any combination of switches is supplied to the 68HC11 to provide a bump detection system around the robot perimeter.

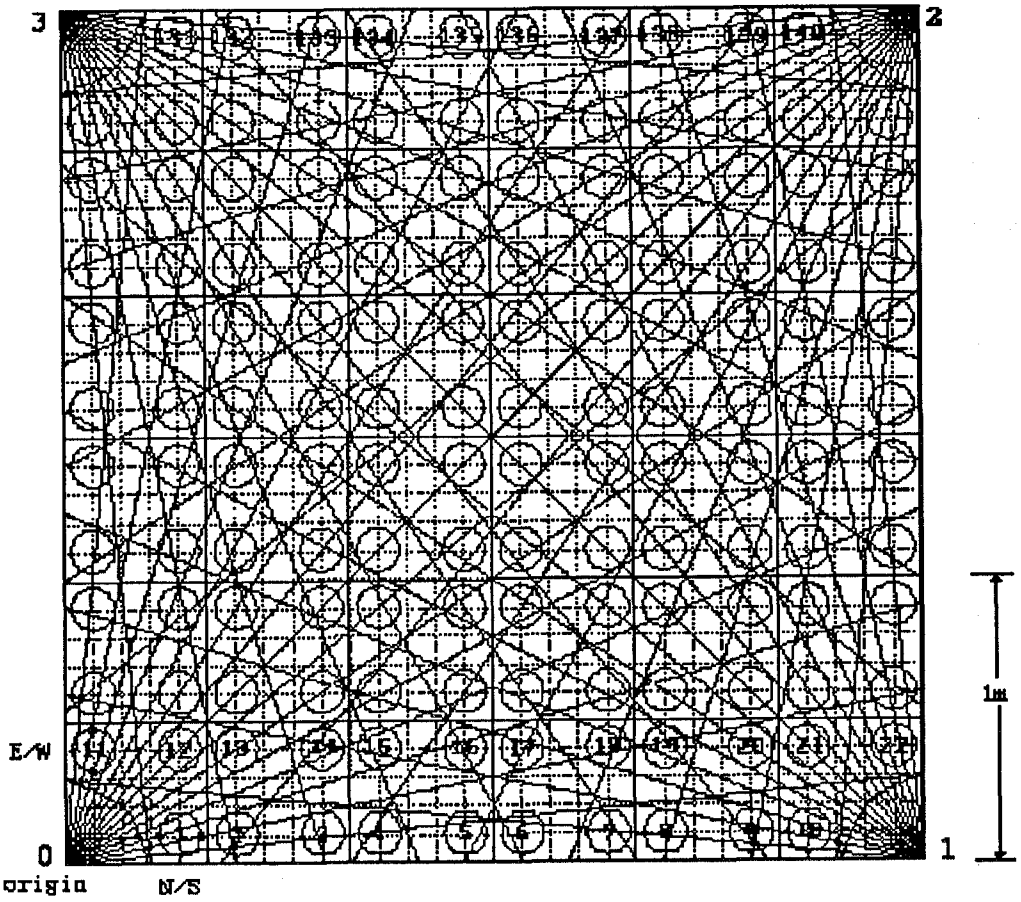

Figure 1: Robot testing locations

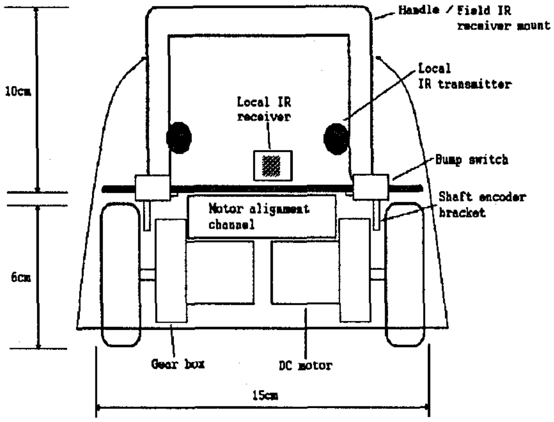

Figure 3: Micro robot construction

A shaft encoder system provides an accurate means of obtaining DC motor feedback. Two P5587 IR transceivers were mounted underneath the chassis close to each wheel. These IC's emit an IR beam and detect any reflected IR radiation. Two circular disks with black and white stripes at regular intervals were glued to the inside of the wheels. There are 32 stripes in all which implies 16 distinct transitions. The IR radiation is reflected on the white surface back to the IC at regular intervals, providing a count proportional to angular rotation. The location of all the sensors are illustrated in Figure 3.

3. SOFTWARE CONTROLLER

For this work, a software controller has been developed which has two major parts. The first part is the software necessary to acquire the IR data transmitted from each beacons for calculations of the position in real-time operating situation. The second part is the robot controller, which services the robot sensors and provides facilities to avoid obstacles enabling the robot to navigate autonomously.

The Interactive C language v1.1 and p-code v2.82 were used for all the code development. The interactive command line environment compiles into pseudo-code for a custom stack machine rather than native code for a particular processor. The run-time machine language module resident on the slave processor interprets the pseudo-code commands and returns results to the host machine [10]. A benefit of this system architecture is the multitasking facility. The processors state is fully defined by the system stack and program counters which means tasks can easily be switched by loading the new stack pointer and program counter values. After creating functions to service particular sensors or actuators, it is possible to make the function a process which will run indefinitely, until it is halted or reset. That is processes can be created or destroyed dynamically during run-time. Any number of separate C processes may be spawned and executed with their own local variables where interprocess communication in achieved through global variables. This system has provided a basis for the main software controller.

Position Sensing: The asynchronous communication, data sorting, position and orientation calculations are the major stages involved in the procedure of position sensing. It is necessary to maximise the time efficiency of the system employed in order to obtain real-time operational positioning.

The receiver module attached to the robot provides a constant 2400 baud data stream at the SPI which is being time division multiplexed between the right and left receiver channels. After each character has been sampled it is necessary to filter the data and store the correct characters as variables. The most efficient way to do this with a real-time operation in mind, is to develop a linear bitwise comparison filter.

As indicated before, it is only necessary to obtain an angle address from two transmitting stations in order to calculate the Cartesian coordinates. Having obtained two correct angles it is possible to convert the existing polar representation into a Cartesian representation. Since there are 16 divisions of each transmitting station, it follows that the 90° corner is divided into angles of 5.625°. In addition, as can be seen in Figure 1, each angle address received is referenced to one corner. Figure 4 illustrates the calculation procedure.

It is evident that redundancies will exist in the calculations if all angles are received correctly. In a single grid refresh it is possible to obtain 4 sets of coordinates. Simple application of the sine rule gives the following relationships for the triangle in Figure 4.

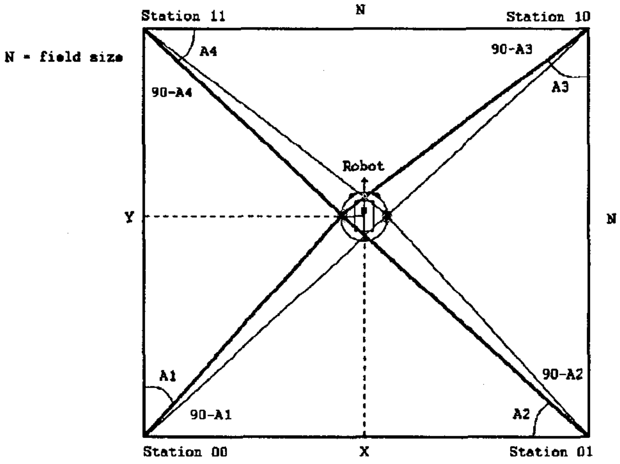

Figure 4: Position Calculation Procedure

$$x = \frac{\sin(C).N.\cos(A)}{\sin(B)} \quad (1)$$

$$y = \frac{\sin(C).N.\sin(A)}{\sin(B)} \quad (2)$$

For any calculation the angles received will be 90° at angles A and C respectively, which means the above calculations need to be expressed in terms of the two base angles. Using geometric properties of triangles

$$B = 180\text{-}A\text{-}C \quad (3)$$

substituting into (1) and (2)

$$\Rightarrow x = \frac{\sin(C).N.\cos(A)}{\sin(180 - A - C)} \quad (4)$$

$$\Rightarrow y = \frac{\sin(C).N.\sin(A)}{\sin(180 - A - C)} \quad (5)$$

Before any realistic path planning algorithms can be implemented it is essential to obtain a global robot orientation. For example, to move from point A to B, the robot must know which way it is currently facing so as to decide in which direction to move. The purpose of including two receivers on the robot is to make it possible to determine the robot orientation. By obtaining an x and y differential from the calculated coordinates the arctangent of the gradient provides the orientation referenced to the x axis.

Obstacle avoidance: Before the robot has been integrated to the positioning system a main controller algorithm was developed. The controller regards robot driving as a default activity unless an obstacles is detected. The controller constantly monitors the status of the local IR subsystem and bump switches. In the event of an obstacle being detected with the local IR, the robot arcs around the object. If the robot bumps into an unforseen object it manoeuvres away from the obstruction and continues in a clear space.

4. INTEGRATION OF ROBOT WITH THE INFRARED POSITION SYSTEM

If the robot is to be able to locate it's global position at any instant in time it follows that a data flow procedure must be executed as a process to run cyclically, providing the current location information. To this end, there are four variables which determine the effectiveness of real time positioning; the rate of transmission of the infra red control byte from the positioning system into the operation area, the TDM switching speed in the receiver module, the speed of data processing and trigonometric calculations on the 68HC11 microcontroller, and the robot velocity.

In this project the control byte transmission rate and speed of data processing on the robot are fixed. However it is possible to vary the TDM switching rate and robot velocity to obtain the most accurate results. As the multiplexer (MUX) switching rate is increased the integrity of the received data from the positioning system decreases. This arises as the top boundary for the switching speed which allows at least one grid refresh to occur whilst a single field IR probe is monitoring the data. If the IR data is corrupted on this single transmission, then erroneous coordinates are supplied to the robot. Conversely if more than one grid refresh is monitored per receiver the received data integrity is increased. However, if a slower MUX switching rate is used to achieve this increased data integrity the robot velocity must be decreased so it has not overshot it's position by a large margin before the position is calculated.

Once the TDM field IR data signals and robot velocity are calibrated, values of x, y coordinates and orientation are available to the robot every 0.5 second. At this stage, the robot has the ability to know where it is within the positioning system at any instant in time. The next step is to develop a process which controls the path planning inputs to the robot controller. When an input signals the robot to locate it's position and move to a coordinate within the field, a global flag can be set and a prioritised path planning algorithm attached to the motor control process.

5. IMPLEMENTATION OF SYSTEM

Initially, a first test scenario has been used to justify the operation of the data processing stages. By working within the Interactive C environment it is possible to change the value of global variables whilst processes are running.

Having established a connection between the host PC and the robot board, the main controller and associated files were down loaded onto the robot's memory. The processes were activated and the ideally received control bytes were entered for 140 possible positions within the 3 by 3m work area. Ideally 4 control bytes are received by each field IR receiver per MUX switching time. In this way eight 'received' control bytes were entered for each position tested (see figure 1). The 68HC11 performed all processes in real-time to provide each x, y value and orientation result. It is noted that every orientation at a single coordinate within the work area provides the robot's field IR receivers with different control bytes. However, the number of transmitters per station and the nature of infrared dispersion within the positioning system reduces the possible accuracy for a trigonometrically calculated orientation value to ± 90^0 in some positions. For this reason only four possible orientations for each position were investigated; NORTH, SOUTH, EAST and WEST, meaning 90^o, 270^o, 0^o and 180^o from the positive x axis respectively. By comparing the actual coordinates and orientation to the calculated coordinates and orientation a set of position error margins can be calculated. In this ideal analysis the error margin is an absolute quantity, meaning the errors obtained when the robot is oriented north, will be identical to the errors obtained when facing south. Likewise the error margins obtained when the robot is oriented east will be identical to those obtained when the robot is oriented west. By plotting the error margins as a function of robot position an analysis of the best possible results obtainable from the current positioning system configuration can be presented.

Figure 5 shows a three dimensional plot of the x coordinate error for each field position tested in the north/south orientation. Plotted in a 12×12 matrix form, the axes lying on the horizontal plane indicate the position of the robot with respect to station 0. Figure 6 represents the 12×12 error matrix for x-coordinate calculations, in a two dimensional contour map. This assist also in viewing the error characteristics of the positioning field.

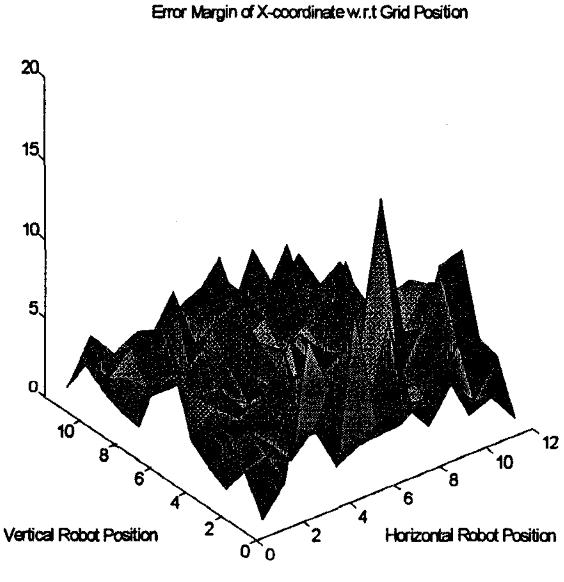

Figure 5: x coordinate error (3D)

The polar grid illustrated in Figure 1 shows the method by which the robot positions are numbered. It can be seen that in 12 positions the robot has covered the 3 metre distance in the x direction. Interestingly, the oscillations of the average error margin have a period of approximately 12 in all measurements analysed, with the maximum error occurring at the edges of the field.

Assuming ideal control byte reception it can be summarised that the average error in the calculated position of the robot is ±5cm for all robot orientations in a 3 by 3 metre work area. Likewise the average angle error for all positions in the field is $\pm 40^0$. All plots have a cyclic pattern.

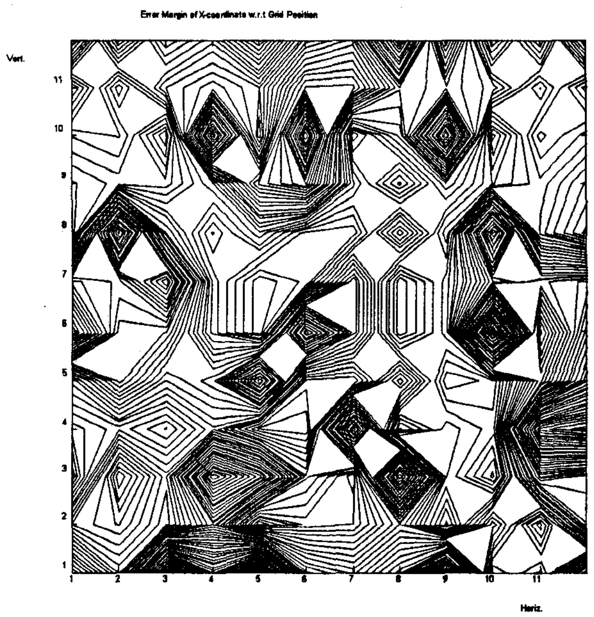

Figure 6: x coordinate error (2D)

When the autonomous robot is placed in the positioning system it successfully monitors it's global position in real-time whilst avoiding obstacles. The coordinate calculated when in the IR field is not consistent or accurate. This arises as the received data integrity is low. The IR signals are reflected off surrounding surfaces, corrupted by light and adjacent control bytes from the transmitting stations are mixed. If a reflected or mixed control byte is sampled by the serial intrface SCI then an inaccurate coordinate is passed to the data averaging function which alters the final coordinates. The measurements observed do not completely agree with the results when the robot is in motion but the work is continuing in the following lines: 1) increase data filtering to cater for mixed and reflected IR signals, 2) develop error control coding for the control byte transmission system, and 3) develop a better data modulation scheme.

For the first two solutions the processing power and memory of the existing robot need to be increased to produce real-time positioning results. If a more sophisticated data modulation scheme is to be implemented the existing receiver and transmitter hardware will need to be redesigned.

A consistent error pattern emerges within the positioning work area. The perimeter of the work area induces positioning errors of up to 8cm whereas in the centre of the work area the positioning error is rarely greater than 2-3cm. Since the diameter of the robot chassis is 15cm, an error margin of 2-3cm from the geometric centre of the robot is still well within the robot's chassis, whereas an error margin of 8cm may be outside the robot's chassis.

6. CONCLUSIONS

A micro robot has been built and integrated into a structured infrared position sensing system. The robot monitors its position whilst in motion and makes its own logical decisions. It can autonomously decide for the next action to be executed. It avoids both dynamic or static obstacles by either sensing a possible collision or by anticipating obstacles using its position and position of other objects. Errors in the system have been discussed and recommendations are made. A consistent error pattern has been observed to be up to 8 cm at the perimeters and 2-3 cm at the centre of the field, well within the dimensions of the robot. Work is progressing for the operation of multiple robots within the same system.

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