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A Novel Approach to Swarm Bot Architecture

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***Abstract*— Emergent behavior in social insects has inspired a new class of robots called swarm robots. However computational and economic constraints regarding inter-robot communication still persist. This paper introduces a low cost architecture facilitating co-operative searching and transport through a master-slave swarm robot concept. Especially, we focus on the directional movement of the slave robots depending on the position of the master robot without using a camera. Experimental results show that the architecture is an economic solution for macro level inter-robot communication involving positional data on an even terrain.**

Keywords-Biologically inspired systems, Co-operative transport, Multi-Robot systems,

I. INTRODUCTION

The quest for a fully autonomous, robust, flexible multi-robot system has for years been a dream for roboticists. Designing such a system, even if semi-autonomous, requires precise planning to meet the aspects of miniaturization and cost-effectiveness. Despite overwhelming research effort in the field of self-reconfigurable robots, developing a user-friendly multi-robot system [2], [5] has been a tough nut to crack. Faced with a challenging task, many researchers have taken a clue from nature's very own biological systems [1].

Biology provides a plethora of ideas and inspiration for robot design. There are millions of species of social insects who have developed self-reliant techniques for locomotion and navigation [8]. Ants and termites, in particular, show ability to self-organize in colonies [10] and assist each other to perform tasks that are way beyond the capabilities of a single individual. A few examples include co-operative behavior among ants in carrying food-grains to their colonies, building bridges between branches of trees, termites building complex moulds and so on. This emergent behavior in social insects has given birth to what lies at the heart of swarm robotics: swarm intelligence [6].

Swarm robotics makes use of local communication between the members of the group that builds a system of constant feed-back. A key concept in swarm robotics is that it stresses on achieving meaningful behavior at swarm-level, rather than at individual level. Using simple transmission-reception protocols, controlled behavior [9] among the member robots can be easily established. Thus, the main effort of swarm robotics is directed at building a robust, simple, low- cost multi-robot system [7] capable of performing tasks such as adaptive division of labour, all-terrain navigation [3], [4] and co-operative transportation of heavy objects. One master bot and three slave bots are depicted in figure 1.

II. BASIC FEATURES OF HARDWARE IMPLEMENTATION

The hardware implementation of our system is based on a Master-Slave relationship between the robots. For experimental purposes, we used one 'master-bot' along with three 'slave-bots'.

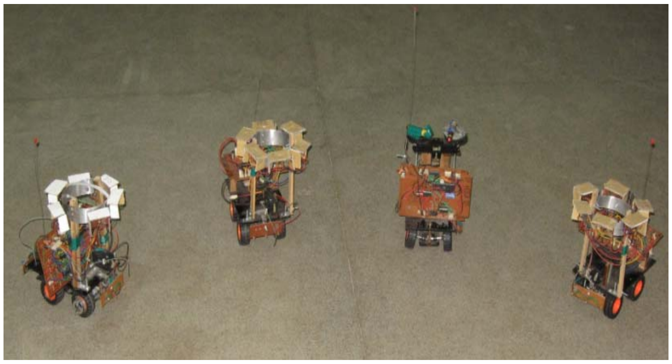

Figure 1. The Multi-Robot System

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The master-bot has a micro-controller based processing unit, a wireless trans-receiver unit, two laser diodes, a clamping mechanism consisting of aluminum rings, and a differential drive system for locomotion purposes. The slave-bots have a circular array of LDR-based sensory blocks instead of the laser diodes. Apart from this, they are identical to the master-bot. Though a master-slave model has been implemented, compatibility of the communication and directional movement aspects with de-centralized swarm architecture has been ensured. The intricacies of the architecture have been discussed in the next section.

III. OVERVIEW OF THE DESIGN

In this section, we describe the basic functionalities of our architecture involving aspects of locomotion, wireless communication, directional movement and the clamping mechanism.

A. Locomotion

The locomotion of each four-wheeled, mobile swarm robots, with two degrees of freedom, is based on a differential drive system. The same configuration is used for both the master-bot and the slave-bots. The wheels on each side of these bots can be driven at various speeds in forward and reverse directions. All wheels on a side are driven at the same rate. There is no explicit steering mechanism. Rather, steering is achieved by actuating each side at a different rate or in a different direction. The front and rear wheels on the left and right side are mechanically connected by a gear box, which helps in transmitting the power source to the wheels. Two continuous rotating DC motors are attached in the middle of the gear box on each side. Continuously rotating DC motors work in the same fashion as that of servo motor. Here the shaft obstacle has been removed which facilitates to move it continuously irrespective of a confined motion as may be the case with the servo motor. The gear box used in this chassis is designed specifically to take care of speed reduction and to increase the torque. The gear- box consists of five spur gears of different sizes (diameters) with two gears on each side of motor shaft and one at the centre. The gear box connects the wheels on each side and each gear is mechanically connected to the platform of the swarm bot in such a way that it can be dismantled at any time. This type of locomotion system helps in achieving straight-line motion.

B. Wireless Communication

Due to the harsh operating environmental conditions for the robots, the communication protocols have to be optimized. The following communication protocol was implemented considering the case with one master robot and three slave robots. However, the protocol is expandable for future modifications with minimal effort.

The master-bot sends an instruction to the slave-bots serially using two channels of transmission. One is the clock channel and the other is the signal flag. The slave robots are programmed to automatically start counting the number of pulses in the clock channel as long as the signal flag is high. This is implemented using a level triggered counter. Each instruction contains two parts: 1) the robot enable flag and 2) the operating instruction. For a three slave swarm system in which each slave has eight different functionalities, we need an instruction length of six bits (since there are eight possible ways to enable three robots and there are eight possible operating instructions).To transmit the six-bit instruction, we need 64 clock pulses in the worst case.

However, this is not an optimum solution and considering the fast communication requirements, the implementation of fast transmitters and receivers will increase the cost. So, a good solution is to reduce the transmission length by sending the instruction in two parts. In the first part, the robot enable flag (3 bits max) is sent and in the second part, the operating instruction (3 bits max) is sent thus requiring only 16 clock pulses in the worst case for transmitting a complete instruction. This may not seem to be a significant improvement for this case, but it will definitely be beneficial when the number of slave robots as well as the number of operating instructions increase. The figures 2, 3 and 4 represent the different aspects of wireless communication and control system.

The client robots are programmed to be in one of the following three states to identify the parts of an instruction as there is physically no difference between the robot enable flag and the actual operating instruction.

- State 1: Ready to receive the enable flag.
- State 2: Ready to receive the operating instruction, process it (on receiving enable signal in the first part of instruction) and go back to state 1.
- State 3: Ready to receive the operating instruction, do nothing (if enable signal is not received in the first part of instruction) and go back to state 1.

For these three states, two flags are defined in the slave robots, i.e. Enable Flag, and Execute Instruction.

Enable Flag = 0 and Execute Instruction = 0 =>State 1
Enable Flag = 1 and Execute Instruction = 1 =>State 2
Enable Flag = 0 and Execute Instruction = 1 =>State 3

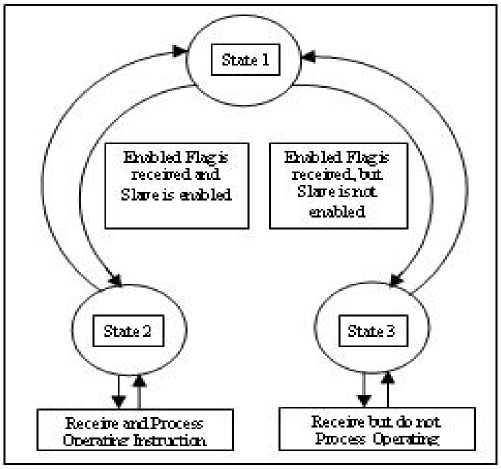

Figure 2. Block Diagram representing Wireless Communication

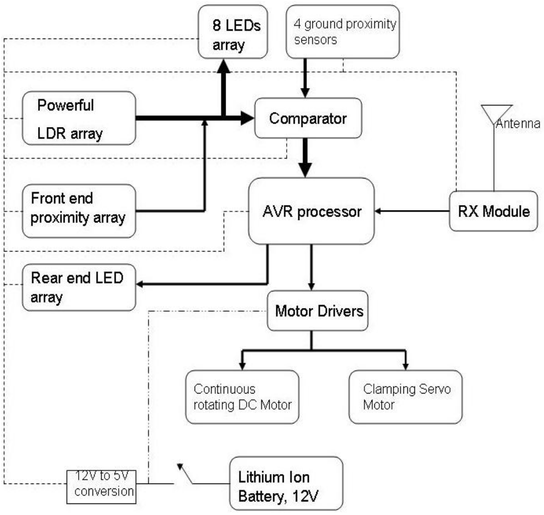

Figure 3. Control System at the Slave-bot end

C. *Directional Movement*

At the master-bot end, the laser diodes on the rotary platforms are spatially orthogonal to each other and the platforms rotate in the same phase. The rpm of the platforms is regulated by pulse width modulation at the motor end of the platform. The slave–bots have a circular array of sensory blocks. Each block has 3 LDR s spatially arranged across the block to maximize the probability of incidence of the laser beam on the LDR s, when the rotating beam faces the block. When the rotating laser beam falls on a sensory block, the LDR(s) associated with the block send a signal to the comparator unit which has a manual threshold adjustment for fine tuning the sensitivity of the LDR s depending on the lighting conditions of the operating environment. Upon receiving such a signal (prior to which the concerned slave-bot should receive a wireless signal from the master-bot for responding to the laser beam) the slave bot rotates from its initial position to the position facing the incident laser beam as shown in the figure. It then proceeds in the direction of the master- bot till the proximity sensors signal the master-bot's vicinity. Cameras are generally used for directional movement in a swarm based robotic environment but the use of laser diode-LDR combination in this case has lowered the cost of the system significantly with only a slight decrease in the precision required in directionality.

The two issues that cropped up in this optical method for determining the direction of movement are the need to adjust the threshold in the comparator setup every time there is a change in lighting conditions and the increase in probability of mismatch of the laser diode's height and the sensory blocks for uneven terrains.

But the directional movement architecture in even terrains and uniform lighting conditions particular to indoor complexes and industrial storage facilities make it an economic candidate for swarm based operations.

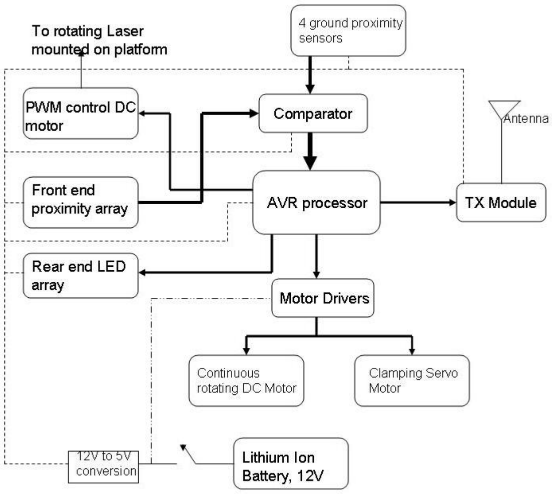

Figure 4. Control System at the Master-bot end

D. *Clamping Mechanism*

The master-bot and the slave–bots have a hook based clamping mechanism at the front end. This functionality is used for dragging other robots in the system or heavy objects in a co-operative manner. The hook which is held in an upright position is lowered when a linear array of LDR s senses the presence of LED s at the rear end of another bot (both master-bot and slave–bots have this functionality) and thus hooks a metallic arc provided at the rear end of the robot. This mechanism is useful in dragging heavy objects which have protruding rings to facilitate their attachment.

IV. EVALUATION OF THE PROTOTYPE

The swarm robot system is built to be useful in real-life applications and hence is required to give consistent and good quality results. We conducted certain experimental tests on the prototype. The results are summarized as follows.

A. *Co-operative Searching*

The basic aim behind co-operative searching is to ensure that all the slave-bots needed for carrying out a certain task, co-operatively, arrive at the site of action, as identified by the master-bot.

The master-bot was programmed to send 3 different wireless messages at an interval of 5 minutes, meant for the 3 slave-bots placed at a distance of 5 meter from the maser-bot at different angles. The slave-bots reacted to the rotating laser beam after getting their "activation messages" and proceeded towards the master bot. This experiment was carried out under two different conditions, first in a square arena of 8 meter squares with a fluorescent light of 40W, and second on an open platform in broad daylight. For a high value of rpm (200) of the laser diodes, the reaction time of

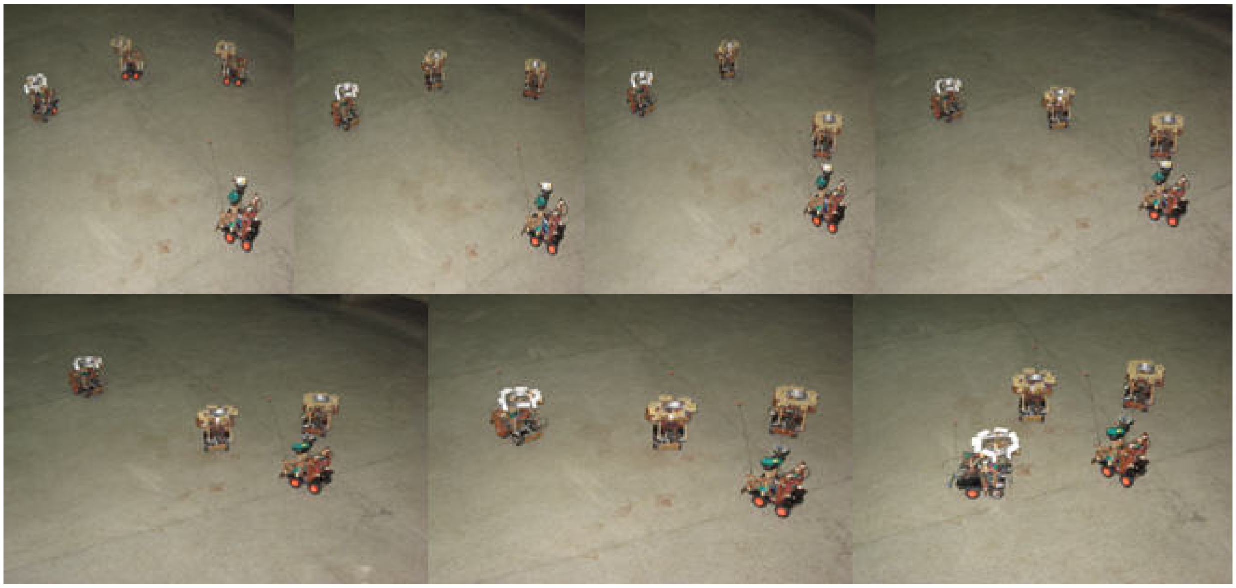

Figure 5. Cooperative searching by Master-Slave bot system

the bots was better under the fluorescent light in the room, than in the open under natural lighting conditions, due to better sensitivity of the LDR s. However, for a low value of the rpm (70), the performance in daylight was much improved and almost comparable to that of the previous case owing to the fact that the exposure time of the laser beam on the LDR setup was increased. Cooperative searching by master-slave bot system is depicted in figure 5.

B. *Co-operative Transport*

The need of co-operative transport arises in situations where a heavy object is to be moved from a certain place to another, but it is too heavy to be done individually by a single bot. Hence, more than one bot (the actual number depends on the object size), is used to perform the task by using a particular type of clamping mechanism, which in our case is a hook-ring arrangement. We carried out the test on a cardboard box of dimensions (30 cm x10 cm x 10 cm), weighing approximately 100gm. It was kept on the laboratory floor at a distance of 3 meters from the master-bot. The master-bot moved towards the object and stopped on sensing the vicinity of the box by its proximity sensors. Then, it followed the principles of co-operative searching to send out a message to a slave-bot. On receiving the information from the master-bot, the slave-bots re-aligned itself in the required direction and proceeded towards the object. When the master-bot received the required number of slave-bots for support, they made use of the clamping mechanism available on each of the bots. To provide assistance in clamping, a metallic arc, shaped as a half-ring, was attached to the box (lengthwise). The hooks provided on the bots were lowered, thus clamping the object. After 2 minutes, the master-bot gives a wireless message to the slave-bots to move backwards, thus dragging the box in a co-operative manner which is shown in figure 6.

Fig. 6(a) [Left] shows initial position of the bots
(b) [Right] shows the two hooking the box

V. CONCLUSION

This paper presents a novel approach to the Swarm-bot concept. We also implemented a prototype to realize certain useful applications of swarm technology. The design of the prototype was quite economical. The cost incurred in developing it was much less than that would have been for designing a system using cameras, instead of sensors, for detection purposes. The novel concept of light sensing LDR arrays is really the trademark of our design. The smart communication protocol also ensured the smooth running of our design.

Admittedly, as the reader would have guessed, our system is at a very young level of robustness and these robots do not have the full repertoire of abilities we want of the eventual design. There is definite scope to enhance our existing design. Especially, improvements can be made in the mechanical clamping system, to make it much stronger to deal with heavier real-life objects. The prototype can be modified to be used in several other applications like crossing a gap, underground mining rescue operations and all-terrain exploration. The possibilities of simultaneous wireless transmissions rather than the master-slave model

TABLE I. ROBOT SPECIFICATIONS

Weight	1.1 kilograms
Motors	Continuous Rotating Motor, Servo Motor
Length	17 cm
Width	12 cm
Height	22 cm for Master-bot, 24 cm for Slave-bot
Operational Time	30 minutes with one 12 V, 2200 mAh Lithium Ion Battery
Laser Diode (affixed on master bot)	630-680 nm, max o/p < 1 mW

which escapes interference issues at the cost of reduced speed are yet to be explored.

Nonetheless, this represents an innovative design of the swarm-bot concept, that opens up new avenues for bio-inspired research in the fields of swarm intelligence, collective robotics and distributed electronics, and with enormous potential for use in major industrial applications

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