FLOCKING BY THE FUSION OF SONAR AND ACTIVE INFRARED SENSORS ON PHYSICAL AUTONOMOUS MOBILE ROBOTS.

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ABSTRACT

In this paper we present a group of small autonomous mobile robots which are equipped with simple ultrasonic sonar for detecting obstacles and an active infrared communication and localisation system. The infrared system can be used for both transferring information between the robots and finding the relative positions of the other robots with respect to each other. By fusing the information from these two different sensors the robots have been programmed to flock using a simple reactive architecture.

1 INTRODUCTION

For certain tasks the lack of reliability of any single robot is unacceptable [1], therefore recently considerable interest has emerged in systems with multiple co-operating autonomous mobile robots. Such systems have applications in, but not limited to, the following fields :

- handling objects, such as the transportation of large pallets [2];
- work in hazardous environments, such as detecting pollutants [3];
- cutting costs, e.g. sending a group of robots to explore another planet instead of sending (and returning) humans [4].

In order for robots to co-operate with each other, some form of communication is required. In complex environments where robots work alongside people, sensors are required that can detect both stationary and moving objects. An example of such a sensor is ultrasonic sonar. Sensors are also required to distinguish other robots from obstacles. Fusion of the information from all of these sources is required if the robots are to co-operate on any non-trivial task. Flocking is interesting from the view-point of sensor fusion since its goals require two opposite behaviours, the robots have get close to each other, but should also avoid collisions. Flocking and the required sensor fusion forms a non-trivial task to test our latest robots.

2 THE ROBOTS SENSORS

Ten autonomous mobile robots, equipped with simple ultrasonic sonar and an active infrared communication and localisation system, have been constructed. For obstacle detection each robot is equipped with three sets of ultrasonic sonar transducers, one set looking forward, another to the front-left and the third set looks to the front-right. Our sonar system returns the range to the nearest obstacle from each set of transducers, by using a simple threshold detection scheme. To allow the robots to detect close obstacles, echoes have to be detected whilst the ultrasonic pulse is being transmitted, thus requiring a high threshold. For the detection of objects further away, a much lower threshold is required to allow for the large signal loss. In order for the robots to be able to detect both near and distant obstacles, a varying threshold system is used which is initially large and exponentially decreases with time to a pre-set minimum. A time-out system is used to determine if there are no objects within range. Each set of ultrasonic sonar transducers is scanned ten times per second, and has a range of 30mm to 1m and a resolution of better than 5mm.

An active infrared light system is used for robot communication and localisation. This system is frequency division multiplexed, with each robot having its own channel. The carriers of these channels range from 220kHz to 400kHz, and the transmission medium is 950nm infrared light. In order to obtain more transmission power, and hence range, from inexpensive Light Emitting Diodes (LEDs) at these frequencies, a ring of twelve 60 degree LEDs are used. Due to supply voltage limitations the LEDs are arranged in four banks, each bank having three LEDs in series. Further, the front and back banks of LEDs can be independently switched on and off.

Information is transmitted by frequency modulating the carriers, with the decoding being carried out using an off-the-shelf radio frequency (RF) integrated circuit. Data can be sent at 1200 baud (120 bytes per second), using differential phase shift keying (DPSK), thus allowing automatic frequency control. To allow ten updates of each robots position and status every second a simple modem is used. For flocking the only information required, other than each robots position, is whether the robot is a leader or a follower. This one bit of information is transmitted by modulating the robots carrier by one of two different frequencies.

The relative direction and range to any robot can be found by tuning to that robots carrier frequency. A comparison of the received signal strengths of four photo diodes arranged 90 degrees apart (each with a half power angle of 120 degrees) allows the relative range and direction of the robot to be calculated. The range of this communications system is over 5 metres, with each of the LEDs being driven by 50mA. The transmitter, therefore, requires a maximum current of about 200mA, at 5V whilst the receiver requires less than 20mA, again at 5V. The communications system can scan ten channels through each of its four photo-sensors at a rate of ten times each second. The total update rate is therefore 400 samples per second which allows a maximum of 2ms to switch photo-sensor or tune from one channel to another. The communications and localisation system in fact takes 800μs, at worst, to tune from one frequency to another.

The robots are physically small, measuring 140mm by 130mm with a height of 140mm. Motion is provided by two small d.c. motors with in-line gear boxes connected to the back wheels. The front of each robot is supported by a single castoring wheel. At present motor control is provided by open-loop pulse width modulated controllers providing speeds up to 1m/s and direction control. Each robot is equipped with a single 8MHz Z80 CPU. The actions of the robot are controlled by the Z80 which is also used for sensor reading under interrupt. Rechargeable 1.8Ah batteries provide over five hours of life per single charge.

3 FLOCKING

Flocking is achieved using a subsumption like architecture [5] with four levels of control :-

0) Avoid objects (most basic behaviour with highest priority),
1) if no other robots are visible become a leader and wander,
2) if in a flock try to maintain position,
3) if a flock can be seen in the distance, speed up and head towards it.

Avoiding objects and wandering is achieved using information from the ultrasonic sonar, with the position and distance to other robots being determined from the infrared communication and localisation system. The localisation system forms an attractive force, which brings the robots together, whilst the ultra-sonic sonar acts as a repulsive force to prevent collisions. To help prevent head-on collisions only the LEDs facing backwards are switched on, thus the robots are only attracted towards the rear of other robots. The communication system is used for each robot to inform the other robots whether it is a leader or a follower.

Leaders are required because unlike Reynold's boids [6] we do not have a global goal for our flock. Without a leader (or a global goal) the robots would tend to clump, i.e. the robots would head towards each other, but as soon as they joined there would be no motive to keep moving. Hence, if a robot tries to escape from the clump, it would see the other robots again and head back towards them. Clearly this clumping is unacceptable, since it offers very little protection from predators, and is not a very interesting behaviour.

The selection of the leader has to be dynamic because like Reynold's boids (and flocks of animals) our flock should be able to split up to go around obstacles, and rejoin once past the obstacle. With a pre-defined leader this is not possible. Also since our robots operate in a finite bounded environment (i.e. a room), there would be problems when the flock meets the edge of the environment. In this case the leader would have to fight its way through the other robots. Thirdly if the pre-defined leader should stop working (i.e. die or is killed) then the whole of the flock would also fail. Clearly a pre-defined leader cannot be utilised.

Under a system where any robot can become a leader and can relinquish leadership when required, one or more leaders can coexist-exist. In this case the flock can split up into two smaller flocks to go around both sides of an obstacle and then rejoin once past the obstacle. If the leader should get trapped between other robots then by definition it is now in the flock, and therefore simply gives up leadership. One of the robots on the outside of the flock now takes over the leadership and the rest follow it. To ensure that this new leader does not simply turn around and rejoin the main body of the flock there is a short period of time for which it is not allowed to relinquish leadership to any robots that are followers. During this period of time new leaders will relinquish leadership to another leader that is in front of it.

Initially if a leader could be seen then the following robots would follow it and ignore the other robots in the flock, except that the other robots would still be seen as obstacles to avoid collisions. This strategy produced a very poor flocking behaviour, in open space the robots would follow each other in a straight line instead of flocking and would still tend to clump for short periods of time. By assigning a higher priority to following the leader than the other following robots eliminates the clumping problem and with a large enough group of robots would lead to true flocking patterns even in open space. So that this priority system is flexible to varying numbers of robots the weighting given to following to leader is given by the number of robots in front of any given robot.

4 RESULTS

Using the above algorithm, the robots do display emergent flocking. A typical flocking sequence is shown in figure 1. With the current number of robots a true flocking behaviour is shown in the presence obstacles. In clear space though, with so few robots, the robots tend to follow each other in a line. This could be overcome be increasing the number of robots.

Currently only the ultrasonic sonar is used to prevent collisions within a flock. However, since all the ultrasonic receivers are tuned to 40kHz, false echoes occur when many robots are in close proximity. These false echoes cause robots to occasionally avoid non-existent obstacles, thus hindering the flocking behaviour. This problem could be overcome by using the infrared localisation system to determine whether the robots are too close to each other instead of the ultrasonic sonar system. In this case the sonar system would still be used, but for detecting much closer objects.

5 CONCLUSIONS

This work shows that co-operation can occur between many robots with a low bandwidth communication system and that by fusing the

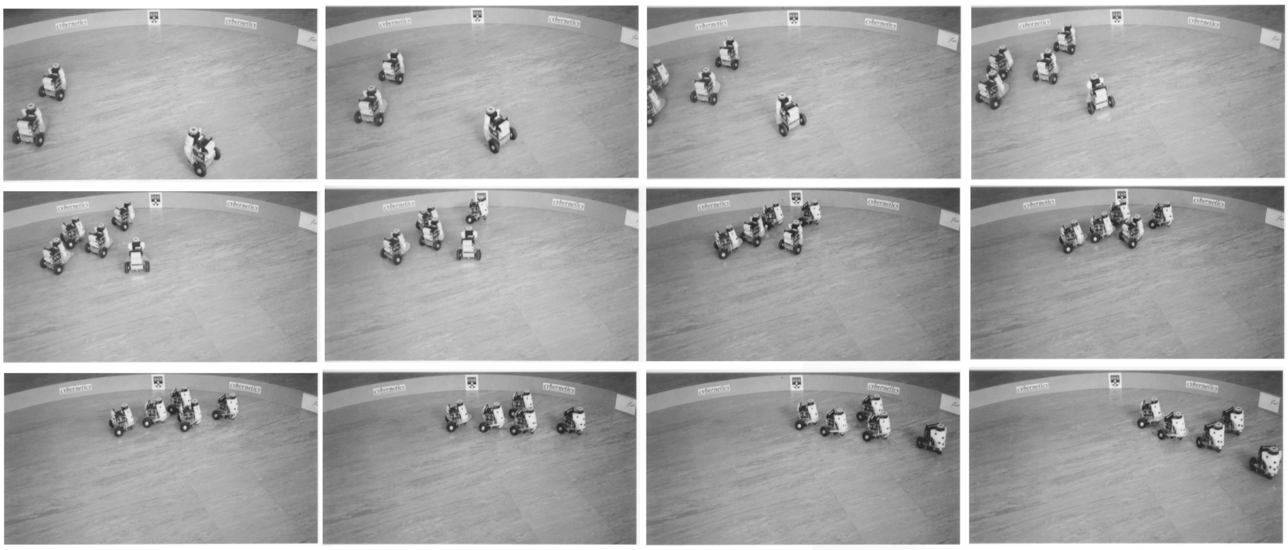

Figure 1, A typical flocking sequence.

data from a few simple sensors, complex behaviours can occur. Taking this work further, groups of simple robots can be utilised to perform tasks where the use of a single robot would be undesirable.

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