Gradient Ascent with a group of Minimalist Real Robots: Implementing Secondary Swarming

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Abstract--This paper addresses and highlights some of the problems facing designers and those who engineer small scale robots in the future. It specifically looks at the problem of small-scale robots ascending a gradient field. In particular the performance of an individual, minimalist robot can be improved when a group of similarly limited robots is employed; being a member of a collective confers benefit to the individual. The paper describes the implementation of simulation work with a group of real 'blimp' robots, with a severely restricted payload, demonstrating that spatial integrity of a group of agents around a target can be improved when employing the mechanism of secondary swarming

Index Terms— collective behaviour, swarming, minimalist, autonomous.

I. INTRODUCTION

The principle aim of this paper is to describe the implementation of a set of collective minimalist algorithms on a group of real autonomous robots, severely limited in their computation, communication and sensing capabilities in order to realise the ideas demonstrated in earlier simulation work. The minimalist challenge was faced 'head on' with the decision to employ a helium balloon robots with a payload of 93g.

There may be advantages in the use of *collective robotics* to perform a task reliably with minimal computation, sensing and communication. A collective group has built in redundancy, in that it can withstand a certain amount of agent loss and still achieve its goal, whereas a solitary complex robot may be disabled by the loss of a single sub-system, making the task impossible. Recently, engineers have drawn on such lessons from Nature and developed groups of simple autonomous mobile robots, which use simple rules to act co-operatively in the pursuit of a shared goal. The roots of minimalism spring from the study of what are sometimes called 'lower animals', where 'lower' relates to the degree of behavioural sophistication. Through what we *perceive* to be simple behaviours, collections of such animals can perform incredible tasks, transcending the capability of the individual. Recently great interest has arisen in the area of collective systems, and many researchers are using techniques inspired by nature to implement multiple robotic systems [Kube & Zhang (1992), Mataric (1994), Beckers, Holland & Deneubourg (1994), Kelly & Keating (1996), Melhuish, (1999)]. For example, 'studies of social insects show us that groups of individuals, limited in their ability, can collectively achieve remarkable feats … [which] appear to be achieved without recourse to many of the aspects often considered necessary for intelligent behaviour' [Melhuish, 1999].

Strategies were developed which involved no interaction between agents (referred to as pseudo-swarming) as well as those which required simple interaction between agents in the form of the transmission and detection of a simple secondary field generated by the agents themselves (referred to as secondary swarming). Holland and Melhuish (1996) showed that performance improvements for the task of homing on a beacon could be achieved but at the cost of incorporating additional capabilities to the simulated robots.

It was argued that an agent could 'home-in' on the target if it could detect it. On detection of the target it would also generate a secondary 'localised' field.

This secondary field could be of considerably less ‘broadcasting power’ than the primary target (in fact the power requirements of this secondary field can be reduced further by the use of synchronous short broadcast bursts (Melhuish and Holland 1997a,b; Melhuish *et al.* 1998). An agent unable to detect the primary target (the signal being less than some threshold) would attempt to use the same locomotion strategy but employ the summed secondary fields, generated by those agents which can detect the primary target, rather than the primary target itself.

It was shown that employing such strategy provided a cohesive effect for a moving swarm (Melhuish 1999), where the agents nearer the target occluded their neighbours further away – even though those ‘near’ agents were not comprised of a fixed set of agents. They actually consisted of an ever-changing pool of agents within the swarm. It was also shown that, for the model employed, as more robots could find the target and become secondary field sources, the range of the combined secondary field increased, which resulted in the recruitment of more robots. Creating an aggregation based on this principle was referred to as secondary swarming.

In the context of biologically inspired mechanisms secondary swarming constitutes the employment of minimal communications combined with positive feedback. The positive feedback can extend the range of the pre-existing environmental template (an heterogeneity in the environment (Holland and Melhuish 1997b, Melhuish *et al.* 1998), implemented as a primary target, by the addition of a robot generated template.

II. MATERIALS AND METHODS

For this research a group of four autonomous blimps have been designed and constructed using microelectronics technologies. The blimps have an onboard computer, propulsion system and an infrared localisation and communication system. A lithium-ion battery that gives an operational time of 2½ hours provides the power. The following is a brief description of the robots used.

The physical implementation of the robot uses a lighter than air vehicle (LTAV) in the form of a helium filled balloon (blimp). The blimp consists of a two-panel metalised nylon envelope 96.5cm in diameter uninflated, which once filled has the shape of a squashed sphere (see Figure 1.A & B) 0.75m in diameter. The volume of the envelope is approximately $0.3m^3$ giving a net lifting capacity of 93g when filled with Helium/Air balloon gas, this gas is only 93% Helium making it much cheaper than pure Helium with a negligible difference in its lifting capacity.

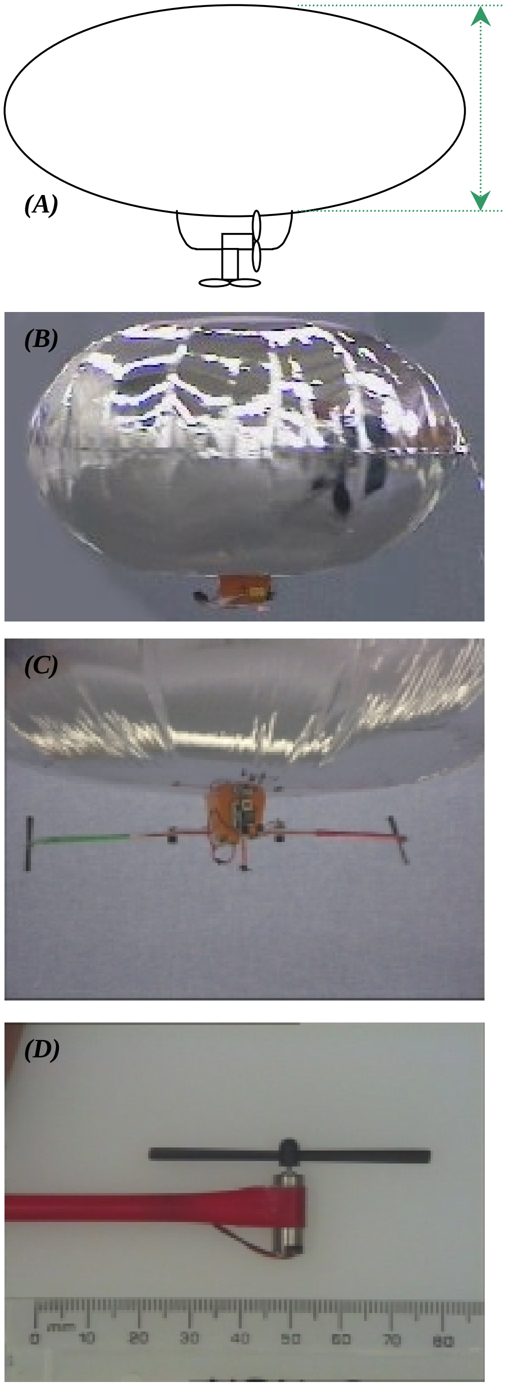

Figure 1. The Robot Blimp

The blimp gondola is made of lightweight plastic ‘blister packs’ which are commonly found holding products to cardboard backing. Plastic drinking straw arms fixed to the plastic housing attach the motors to the gondola (figure 1.C).

Thrusting on the blimp is achieved with three small fan units capable of supplying approximately 4g of thrust at full power. Each of these units consists of a small 2g DC electric motor fitted with a small, 0.3g plastic propeller 5cm in diameter (figure 1.D). Each motor is PWM controlled via an H-bridge. One fan was mounted beneath the gondola for vertical motion.

A lightweight ultrasonic ranging system that gives the blimps the ability to control their height to within a few centimetres with a maximum range of 3-4 metres has been designed. The sensing system has a very good accuracy, however, the dynamics of the blimp and its propulsion system do not allow for accurate height control. The system uses small separate ultrasonic transducers for the receiver and transmitter to enable short-range measurements. The Infrared localisation system is based on a design by Kelly and Keating [1996] that gives the relative position and distance of the other blimps and allows for low bandwidth inter-blimp communications. There are three types of analogue board that make up the infrared localisation system: the receiver, transmitter and two sensor boards. These boards are fed from a voltage supply that has been filtered to minimise the noise induced by the high speed switching of the digital devices.

The design employs the Li-Ion ‘Sony Minidisc’ battery (LIP-12B), which gives 1500mAh at 3.6v for a weight of 50g. minus its plastic casing. This would allow an operational time of up to 2.5 hours.

The electronics are split into two distinct parts; digital and analogue in order to minimise the coupling of noise from the digital board to the much more sensitive analogue boards. The digital circuit consists of the power generation, motor drives, frequency generators and a microcontroller all of which work at high frequencies producing a lot of noise and therefore, electrical interference. All the circuits are manufactured from 0.5mm fibreglass board, which is one third the thickness of a standard circuit board. This thin board coupled with the very compact layout and the use of surface-mount technology helps to reduce the weight by a considerable amount.

The motor drivers are HIP4020 full bridge drivers and are capable of delivering 500mA in an SO20 surface-mount package.The frequency generators (figure 3.8a) used by the transmitter and receiver use direct digital synthesis (DDS) technology to produce near perfect sine waves with minimal external components. The ICs used are AD9832s that are controlled via a three wire serial interface and come in very small (TSSOP) surface mount packages.

The heart of the system is an 8-bit Arizona Microchip PIC 16F877 microcontroller, which runs at a frequency of 20MHz giving ample computational power. This microcontroller has 8Kbytes of onboard flash memory, which can be programmed in-circuit via a three-wire serial interface, three 8-bit digital I/O ports as well as an 8 channel 10-Bit AD converter. The unit also features two PWM and three timer modules.

III. EXPERIMENTAL DETAILS

This set of experiments attempts to discover whether a collective strategy can increase the performance of a group of robots when homing on a static beacon. Two different strategies were implemented and compared; pseudoswarming (when robots act as completely independent agents) and secondary swarming. When pseudoswarming, the robots individually home in on the beacon with no interaction between each other. However, they can still give the impression of collective behaviour as they move toward the beacon. With a small change to the algorithm the robots can be made to interact with each other changing the way in which they home on the beacon.

The experiments were conducted in the experimental arena with the beacon fixed in one corner at a set height of 1.5m and the robots started in the opposite corner (see figure 2A below) to give a separation distance of approximately 10m, (just within the blimps maximum sensing range.) Four robots were started together and their positions recorded at one second intervals by the overhead camera system. A time limit of two minutes was placed upon each trial to limit the amount of data collected, it was expected that on a good run a robot would reach the beacon within 30 seconds if it could initially detect the beacon and did not lose its signal.

The following secondary swarming algorithm was implemented on each robot**:**

```
If robot can detect the beacon:
    Ascend gradient field generated by the beacon and transmit a secondary field
Else
    Ascend strongest gradient field generated by another robot
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The ascension of the gradient field was implement thus:

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If signal is above noise threshold and below max threshold:
If Left signal > Right signal
        Slow the right motor (turn left)
Else
        Slow the left motor (turn right)
If signal is above max threshold:
        Back away (both motors reverse)
Else If signal is below noise threshold:
        Stop (randomly move with air currents)
```
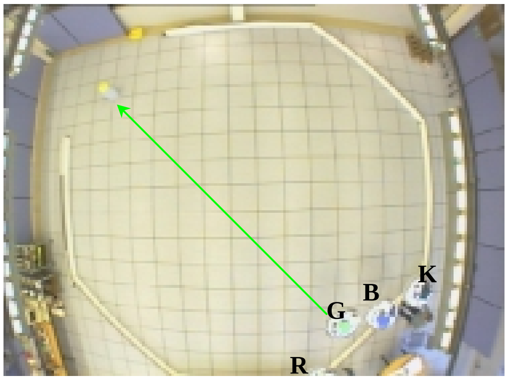

Eight trials were run with a time limit of two minutes**.**

IV. RESULTS

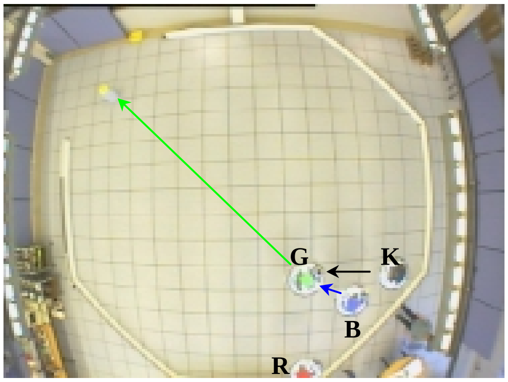
To show the secondary swarming process in action 4 images from the overhead camera have been used, these are shown in Figure 2 frames A-D. Coloured arrows have been added to the pictures to indicate what the blimps are homing in on. As shown in frame A all the blimps start in the same position as the previous. When the beacon is switched on the green blimp acquires the signal and starts to home in (frame B), at the same time it starts emitting a secondary field from its rear facing IR transmitter. The nearby blimps that cannot detect the beacon soon lock onto the signal from the green blimp and follow it closer to their shared goal. By frame C the black blimp acquires the beacon signal and starts emitting its secondary field, which in turn attracts the red blimp. The blue and black blimps continue homing in on the beacon dragging the red blimp closer as they do so.). Finally in frame D the red blimp detects the beacon and quickly homes in on the beacon.

Frame A



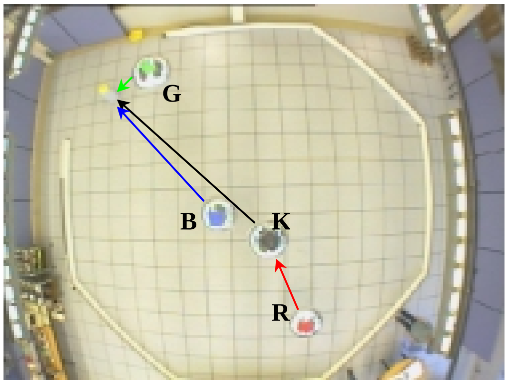
The green blimp acquires the beacon signal first and starts to transmit its secondary field and home in on the beacon.

Frame B



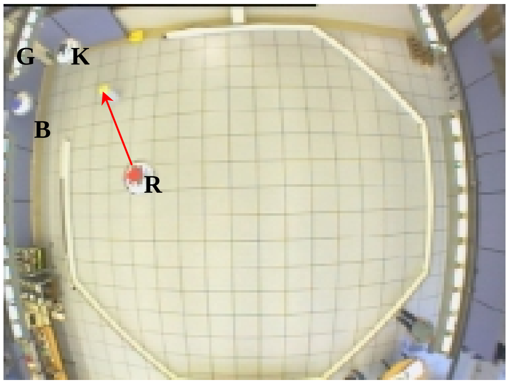
The blue and black blimps immediately detect the secondary field from the green blimp and start to follow it toward the beacon.

Frame C



With the green blimp out of the way the black blimp is able to detect the beacon and start transmitting its secondary field.

Frame D



With the blue, green and black blimps having found the target, the red blimp homes in on the detected beacon.

Figure 2. A sequence of frames showing secondary swarming. Blimps are labelled R,G,B and K for red, blue green and black respectively.

V. CONCLUSIONS

From the results shown in Figure 3 it can be seen that for each trial all robots reach their objective within the given time limit. This indicates therefore, that there is a significant advantage in using collective strategies over purely individualistic techniques when homing on a static beacon. For all the trials that used the secondary swarming technique, 100% of the robots managed to manoeuvre to within two blimp diameters of the beacon within the given time period. In contrast using pseudoswarming a maximum of 75% of robots made it to the beacon within the time period. The difference in performance of the two algorithms is shown clearly in the graph in Figure 3) below.

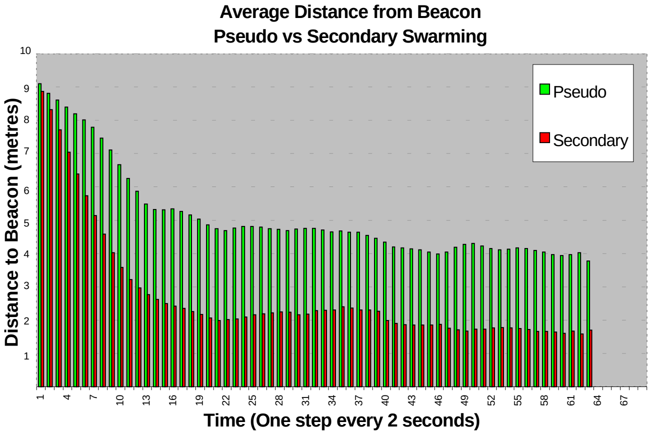


Figure 3. Showing average distance from the beacon for Secondary swarming and Pseudoswarming

VI. DISCUSSION

The paper has shown that it is possible to implement the strategy of secondary swarming, initially studied in simulation, in real robots. The blimp robots were chosen because they represented a challenging platform with a severely restricted payload. Minimalist strategies were therefore appealing since the weight (and therefore, importantly, portable power) restriction forced us to use simple sensing, locomotion and communication techniques.

The experiments showed how it was possible to significantly increase the performance of a group of 4 blimps when homing in on a static beacon starting in a low signal to noise domain. Two sets of experiments were conducted, the first using a purely individual homing strategy and the second using a collective strategy. Examination of the results showed that if a robot could not initially detect the beacon it had a very slim chance of finding it. However, using the collective strategy any robot detecting the beacon would transmit a secondary field effectively increasing the beacon's radius of influence, which would in turn attract robots outside the initial beacon range. The increase in performance between the two techniques is considerable since the use of a purely individual homing strategy (pseudoswarming) led to no trials being completed within the given time limit of 2 minutes. By comparison, every trial was completed within the given time using a collective strategy of secondary swarming.

VII. REFERENCES

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