Vision-Based Segregation Behaviours in a Swarm of Autonomous Robots

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The accelerating development and usage of autonomous robots has led to increased interest in decentralised systems and the cooperation of individual elements within a swarm, in particular the ability to self-organise and form patterns or self-segregate. Such segregation is readily exhibited in nature, as highlighted by prior work looking at the collective sorting of brood items by ant colonies [1,3]. This work focuses on the ability of robots to spatially segregate themselves. In particular, it takes inspiration primarily from the Brazil nut effect [6], which is responsible for the emergent striped patterns observed when a container holding particles of different sizes is agitated.

Previous work has concentrated on simulating recognized elemental segregation behaviours in synthetic environments. This study extends a specific series of simulation work [2] in which a relatively simple algorithm involving three basic behaviours and no communication between agents was used to create annular and stripe patterns in groups of virtual mobile robots where each robot mimics a particle of a certain size. The aim is to validate the results already obtained by implementing the identified constituent behaviours on the e-puck desktop mobile robot [4].

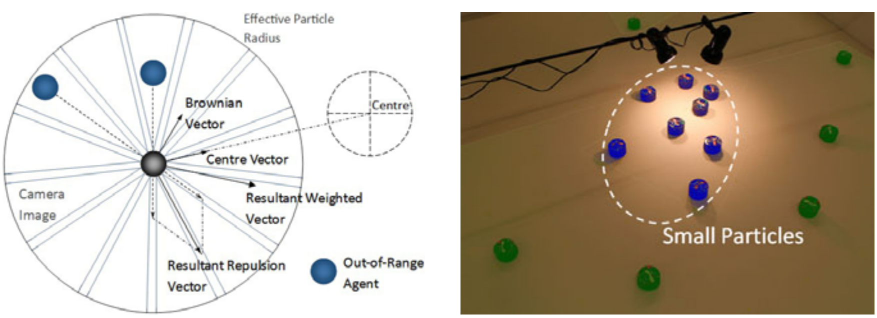

Fig. 1. Left: Brazil nut sub-behaviour integration. Right: Typical final segregation pattern for 14 robots assigned to 2 distinct groups of particles (image post-processed to improve visibility).

Each robot calculates a new vector to follow once every control cycle based on a weighted sum of the unit vectors produced by each constituent behaviour (see Figure 1, Left). The first behaviour simulates a particle's random movement in a container subjected to vibration (similar to *Brownian* motion). It was implemented around Marsaglia's MWC algorithm [7]. The second behaviour simulates a particle's attraction

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towards a gravitational *centre*. It was implemented using the e-puck's passive IR sensors to locate a light source. The third behaviour simulates a particle's *repulsion* from other particles upon collision. The e-puck detects (virtual) particle collisions by taking a series of thirteen camera images while turning on the spot.

Testing of the integrated behaviour involved placing a group of identical robots inside an empty arena measuring 3.0mx2.5m, with the initial positions and bearings for each experimental run being randomised beforehand. The environment is predominantly white, with the robots being made to appear as a constant diameter, matte-black object to improve image contrast, and with an IR-intensive light source being placed in the middle of the arena to define the centre of the gravitational field. The resulting patterns produced at the end of each run were then measured based on the final positions of the robots, where ideally the robots representing small particles should group together in the centre of the simulated gravitational field with a small inter-robot spacing, while the robots representing large particles should form an annular group around the central cluster with a larger inter-robot spacing.

We conducted 45 runs of 600s in length using two groups of robots (14-19 robots in total) representing particles of radius 0.20m and 0.20xβ m respectively (β=1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.25, 2.5 and 3.0, five trials per setup). A unity size ratio (i.e., β=1.0) produced patterns where no segregation was present (control runs). For higher size ratios, two distinct annular groups were consistently formed. The average segregation errors were 14.5% and 16.6% for ratios β=1.2 and 1.4 respectively and below 3.7% for all ratios β>1.4. A typical arrangement is shown in Figure 1, Right. Full results, including video material, can be found at [5].

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