Social Insect-Inspired Multi-Robot Coverage (Extended Abstract)

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1. INTRODUCTION

Coordination is one of the most interesting and complicated research issues in distributed multi-robot systems (MRS), aiming to improve performance, energy consumption, robustness and reliability of a robotic system in accomplishing complex tasks such as coverage. Social insect-inspired coordination techniques achieve these goals by applying simple but effective heuristics from which elegant solutions emerge. Previous research investigated ant-inspired stigmergy (*StiCo*) and bee pheromone signalling (*BeepCo*) for multi-robot coverage [1, 2].

This paper tries to improve on previous approaches by introducing a hybrid ant-and-bee inspired approach, i.e., *HybaCo*. The proposed hybrid approach is evaluated in multiple scenarios using a high-level simulator and is compared to both *StiCo* and *BeePCo*. Experimental results from various scenarios identify strengths and weaknesses of the various algorithms and indicate that *HybaCo* effectively improves the area coverage uniformly.

2. BACKGROUND

For a detailed description of the *StiCo* and *BeePCo* algorithms we refer the reader to [1, 3]. The differences between the two techniques are described in Table 1.

property	*StiCo*	*BeePCo*
communication	Indirect	Direct
movement	Circular	Vector-based
speed to converge	Normal	Fast

Table 1: Differences between *StiCo* and *BeePCo*

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In the *StiCo* approach, communication between agents is implemented using *indirect* pheromone trails. In contrast, *BeePCo* pheromone signalling is implemented by *directly* sending signals to robots within a specific range. When robots employ *StiCo*, their motion is applied in a circular fashion, where the robots only change their rotational direction. When robots employ *BeePCo*, their motion is guided by vectors which influence the straight-line direction and distance for each move.

3. HYBRID BEE-ANT COVERAGE

The most performance-limiting characteristic of the pheromone signalling approach (*BeePCo*) occurs when the robots lose their communication network by moving too far apart from each other. This prevents pheromone exchange and, as a result, robots stop moving. The biggest problem with the *StiCo* approach is the extended time to converge. In order to solve these two issues, *HybaCo* begins with *BeePCo*, but changes dynamically to *StiCo* when the communication network between the robots is lost. Pseudocode is shown in Algorithm 1.

Algorithm 1 Hyba-Co Algorithm

```
time==0
loop
  if Links to Neighbours Exist then
    Apply BeePCo using BEE pheromones
  else
    Apply StiCo using ANT pheromones
  end if
end loop
```

4. EXPERIMENTAL EVALUATION

We evaluated all three algorithms (*StiCo*, *BeePCo* and *HybaCo*) using a custom-built simulator. The set of experiments presented in this section compare three important evaluation metrics: the *area covered* by the robots, the *distribution* of robots in their environment, and the *time* it takes to converge (or stabilise). The experiments were carried out with sets of 20, 30 and 40 robots, each robot having a sensing and communication radius of $25cm$. The robots' environment (arena) size is $300cm \times 300cm$. We consider the following five algorithmic variations of *StiCo* and *BeepCo* in our comparisons: (1) ***StiCo***: the robots use stigmergy; (2) ***BeePCo***: the robots use bee-pheromone signalling; (3)

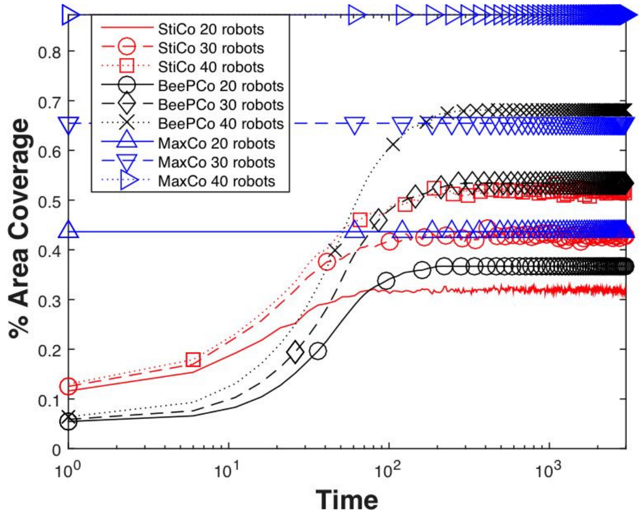


Figure 1: The percentage of area coverage using MRSs with 20, 30 and 40 robots: StiCo versus BeePCo

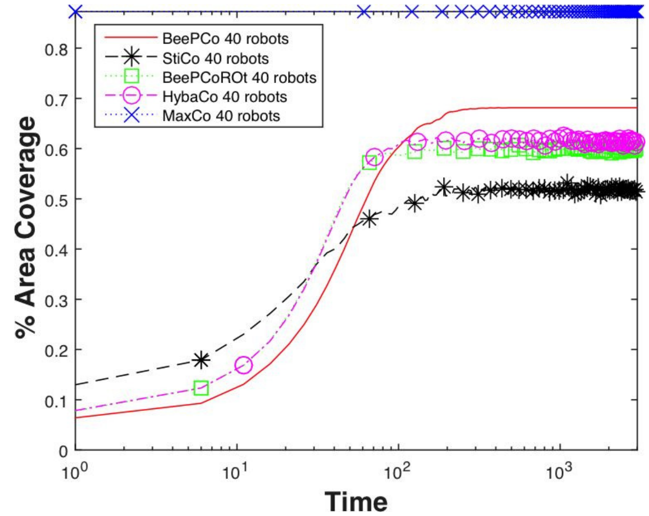


Figure 2: The percentage of area coverage using MRSs with 40 robots: StiCo, BeePCo, BeePCo with rotation and HybaCo approaches.

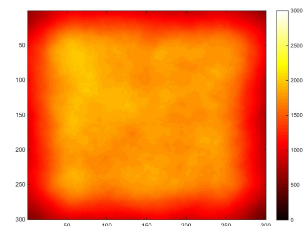
BeePCo with rotation: *BeePCo* extended with a rotational move; (4) ***HybaCo***: the robots use the hybrid algorithm; and (5) ***MaxCo***: the optimal case, where the robots' transmission range does not intersect with each other. This can also be referred to as *potential* coverage.

All results are averaged over 30 independent runs to assure statistical significance. We only show a selection of experiments due to page constraints. In Figure 1, the *StiCo* and *BeePCo* algorithms are compared against each other with respect to area coverage using 20, 30 and 40 robots. For both *StiCo* and *BeePCo*, we observe that the percentage of area covered increases as the number of robots increases, as expected. *BeePCo* provides considerably higher area coverage in comparison to *StiCo*.

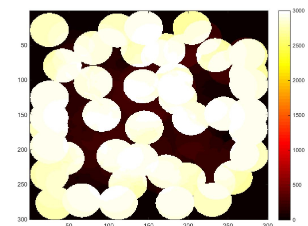
Figures 2 and 3 illustrate the experimental results on a MRS with 40 robots and compares the performance of the *StiCo, BeePCo, BeePCo with rotation* and *HybaCo* approaches against each other in terms of the percentage of area coverage (due to space limitations, we do not show the results of the comparable experiments for 20 and 30 robots, but results are similar). These results illustrate that *HybaCo* improves performance and achieves better area coverage than the *StiCo* and *BeePCo with rotation* approaches. The distribution of the robots is illustrated using heatmaps (Figure 3). These plots show that *HybaCo* and *BeePCo with rotation* improve robot distribution and encourages robots to spread around the arena more, as opposed to the *StiCo* and BeePCo approaches. Although *BeePCo with rotation* performs worse than *HybaCo*, the improvement over the *StiCo* and BeePCo approaches is still significant.

5. CONCLUSIONS

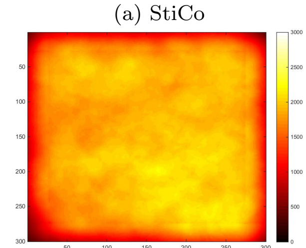
We have shown the performance of *StiCo*, *BeePCo* and *HyBaCo* in regard to a number of criteria, including area coverage, uniformity of distribution and speed of convergence, and we also developed a hybrid bee-and-ant inspired approach that merges the strengths of *StiCo* and *BeePCo* into one algorithm. The advantages and disadvantages of these two techniques have been highlighted. In the second set of experimental results, we evaluated the effectiveness of the proposed hybrid bee-and-ant inspired approach, i.e., *HybaCo* and reported our observations.



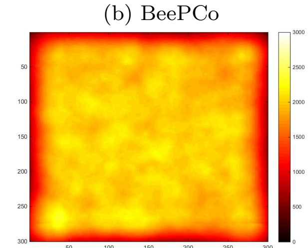
(a) StiCo



(b) BeePCo



(c) BeePCo with Rotation



(d) HybaCo

Figure 3: The distribution of robots in the arena using a MRS of 40 robots on different techniques.

6. REFERENCES

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