CSSE490: Bio-Inspired Artificial Intelligence
Project Proposal

Development of Blended Swarm Communication Methods

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Abstract

This proposal seeks to improve communication channels and navigational strategies within a group, enabling effective conveyance of the value and direction of a goal or reward while enhancing the collective's ability to pursue and attain these objectives. The success of these collective systems hinges on effective communication, adaptive response to environmental stimuli, and the synergistic interaction of individual units to achieve outcomes that surpass the capabilities of any single component. This work will blend methods of transition properties, robot density distribution, and recognition of environmental and cooperative patterns. Improvements to swarm communication is integral to all future swarm applications.

Introduction

In the field of collective systems, optimizing the ability to locate and pursue rewards or goals is a pivotal aspect influencing efficiency, productivity, and overall success. This proposal seeks to address an important facet of collective intelligence: the improvement of communication channels and navigational strategies within a group, enabling individuals to effectively convey the value and direction of a goal or reward while enhancing the collective's ability to pursue and attain these objectives.

The primary objectives of this proposal are twofold: to empower individual entities within the collective system to convey nuanced information regarding the value and direction of a given goal or reward, and to augment the collective's ability to interpret and act upon these signals, resulting in more effective and targeted movement towards the desired location. Swarms capable of maintaining cohesion and direction should be able to accomplish tasks, rescue operations, structure assembly, or resource distribution, much more efficiently. Greater levels of communication will direct the resulting actions of the swarm as it sets out to achieve its goal.

This proposal falls within the scope of CSSE490: Bio-Inspired Artificial Intelligence through its use and implementation of collective systems inspired by biological systems such as ants, fish, or birds.

Background

Collective systems represent an amalgamation of individual entities or agents working collaboratively towards shared objectives, often mirroring natural behaviors observed in social organisms such as ants, fish or birds. These systems are characterized by decentralized decision-making, emergent behaviors, and the coordination of numerous individual components to achieve common goals. Ranging from social insect colonies to artificial swarm robotics, collective systems leverage the collective intelligence of their members to solve complex problems, optimize resource allocation, and adapt to dynamic environments. The success of these systems hinges on effective communication, adaptive response to environmental stimuli, and the synergistic interaction of individual units to achieve outcomes that surpass the capabilities of any single component. Examples of beneficial behavior in goal orientation within collective systems can be seen with ants emitting a pheromone trail that leads other ants to a food source once located. Understanding and enhancing the mechanisms that drive these collective systems is pivotal in improving artificial collective systems and their potential applications in various industries.

Related Work (Literature Review)

The challenges in multi-robot communication are numerous. As outlined by Gielis et al. in 'A Critical Review of Communications in Multi-robot Systems,' key challenges include synchronicity, dynamic topologies, message frequency, connectivity, dynamic routing, and operational environment. This proposal primarily seeks to improve upon the challenges within the 'connectivity' umbrella. The review describes this as an issue with spatial density, where the swarm members need to maintain contact with other robots to communicate without a weakened signal, but also not cluster or have such a range that there are too many incoming signals from neighbors. [1]

When researching task allocation using inter-robot encounters, Mayya et al. developed a stochastic task allocation for a swarm of robots, enabling autonomous distribution using the interactions. By implementing transition probabilities, the method ensured stable and desired task allocations, leveraging an encounter model based on Enskog's dense gas theory and uniformly ergodic trajectories. The decentralized algorithm allowed robots to estimate task allocation, adjust task-switching rates, and respond to deviations, enabling uninterrupted task execution while remaining robust to failures, with future goals set on incorporating local task load perception and spatially inhomogeneous robot distributions. [2]

By utilizing an implicit communication strategy based on recognizing dynamic environmental patterns and employing coarse-grained dynamic properties to coordinate actions among a group of robots in simulated soccer games, the Simulated Soccer Robot Team at the University of Padua created an approach that successfully addressed the coordination problem without direct reasoning about the robots' intentions, resulting in a cooperative multi-robot system tested showcasing promising experimental results and harmonious performance within the RoboCup Simulation League. [3]

Another RoboCup team, Iocchi et al., presents a distributed coordination approach for a team of diverse mobile robots, emphasizing explicit communication, autonomy, and the management of robot heterogeneity. The method's success in highly dynamic and challenging environments was evident in the team's strong performance. The system architecture effectively integrated diverse robot capabilities and facilitated inter-robot coordination. The approach specifically accommodates heterogeneity in robot capabilities while ensuring that all robots can perform tasks, albeit with varying performance considered in the coordination protocol. Key contributions include methods for experimental evaluation, confirming the efficacy of the communication and coordination protocols, especially in achieving area coverage and role assignment. The article also stresses the necessity for further research on the method's robustness and effectiveness in handling failures and diverse coordination properties within multi-robot systems. Ongoing efforts aim to improve evaluation techniques and analyze a wider range of coordination-related aspects for enhanced team performance. [4]

Implications of suboptimal communications within a swarm are discussed by Tarapore et al. Their study investigates the concept of a 'sparse swarm' where agents within the swarm are over ten body lengths apart. Their work concluded that, while communication is feasible in this range and beyond, the necessity for complex autonomous behaviors in an agent increased with separation from other agents in the system. The study concludes that it is often against the swarm's best interests to have large gaps between them in real-world applications, thus the need for effective communication and planning is exacerbated to both keep the swarm congealed as well as making progress. [5]

This proposal will investigate the possibilities of the combination, development, and implementation of a blend of communication schemes, seeking to create a stronger communication and control mechanism than those before it, rather than iterating on a single method previously published. While all these studies have been worthwhile, they each have gaps in that they are wholly focused on the specific subject of study, whereas this proposal seeks to fill that gap by providing a mix of the subjects.

Proposed Work (Methodology)

- Research into what individual robot would be best to be used in the swarm (5 hrs)
    - Possible Platforms: Kilobots, Droplets, MIT M-Blocks, E-Puck
- Research useful libraries and softwares for implementation and simulation (5 hrs)
    - Possible Simulators: Stage, TeamBots, Open Dynamics Engine, Webots
- Recreate task allocation algorithm with swarm (40 hrs)
    - Completion upon generation of similar results as [1]

- Recreate implicit communication algorithm with swarm (40 hrs)
    - Completion upon generation of similar results as [2]
- Combine methods (50 hrs)
    - Completion upon creation of an algorithm capable of exhibiting characteristics of both methods [1] and [2]. At this stage if the behaviors conflict or override each other, it is still a success.
- Use genetic algorithm to optimize prioritization on different methods (50 hrs)
    - Completion upon determination of an algorithm whose performance exhibits characteristics of methods proposed in [1] and [2], but can perform better than the lone method can in the opposite testing setting.

Summary

The proposal aims to enhance communication and navigational strategies within collective systems, emphasizing effective conveyance of goal value and direction. It blends transition properties, robot density distribution, and recognition of environmental and cooperative patterns to improve collective intelligence. Improved swarm communication has potential to impact all future swarm robotics efforts in all fields. The possible swarm applications to construction, distribution, search and rescue, and many other tasks will all benefit from beneficial results from this work.

It highlights the significance of effective communication and synergy among individual components in collective systems. The proposal aims to address challenges in multi-robot communication, particularly focusing on improving connectivity within swarms. Notable prior works in task allocation and implicit communication strategies in robot teams serve as the foundation for this proposal.

The proposed work details a step-by-step methodology, encompassing research on individual robots, software selection, recreation of task allocation and implicit communication algorithms, combining methods, and employing genetic algorithms for optimization. The completion criteria involve achieving results similar to previous methods and creating an algorithm that outperforms individual methods in respective test settings.

Sources

[1] Gielis, J., Shankar, A. & Prorok, A. A Critical Review of Communications in Multi-robot Systems. *Curr Robot Rep* 3, 213–225 (2022). https://doi.org/10.1007/s43154-022-00090-9
[2] Mayya, S., Wilson, S. & Egerstedt, M. Closed-loop task allocation in robot swarms using inter-robot encounters. *Swarm Intell* 13, 115–143 (2019). https://doi.org/10.1007/s11721-019-00166-x
[3] Enrico Pagello, Antonio D'Angelo, Federico Montesello, Francesco Garelli, Carlo Ferrari, Cooperative behaviors in multi-robot systems through implicit communication, Robotics and Autonomous Systems, Volume 29, Issue 1, 1999, Pages 65-77, https://doi.org/10.1016/S0921-8890(99)00039-1.
[4] Iocchi, L., Nardi, D., Piaggio, M. et al. Distributed Coordination in Heterogeneous Multi-Robot Systems. *Autonomous Robots* 15, 155–168 (2003). https://doi.org/10.1023/A:1025589008533
[5] Tarapore D, Groß R and Zauner K-P (2020) Sparse Robot Swarms: Moving Swarms to Real-World Applications. Front. Robot. AI 7:83. doi: 10.3389/frobt.2020.00083