Heterogenous Swarming of RVR and BOLT Robots:

**Abstract**

**Contents**

Heterogenous Swarming of RVR and BOLT Robots: 1

I. Introduction 1

II. Background Info 2

A. Swarming model and formations 2

B. Swarming algorithms 2

C. Symmetric & asymmetric swarms of heterogenous robots 2

III. Literature Review 2

A. Swarming Models 2

B. History of Heterogeneous Swarms 2

C. Applications of Heterogeneous Swarms 2

D. Benefits of Heterogeneous Swarms 3

IV. Project Management 4

V. Conclusion 4

VI. Bibliography: 5

# Introduction

*Start with an attention-getting broad statement that establishes a general topic for the article.*

*Narrow the topic in successive sentences that outline the state of the art and introduce a gap in knowledge.*

*End the introductory paragraph with a general statement of the problem and optional supporting/specifying statements. Specify the general direction of the paper.*

(field of research, context and importance) As the field of robotics moved forward with advances in both the efficiency and capability of embedded systems utilised in robots so did the scope extend for robots to tackle an ever-growing set of larger and more complex challenges. An approach to these new challenges can be made through the implementation of swarm robotics, which is a branch of multi-agent robotics systems that is characterized by its emphasis towards the emulation of natural biological swarms, such as packs of wolves hunting prey; multi-agent swarms utilise a multitude of smaller and simpler agents that act together towards a global intent.

(Focus/scope) Heterogeneous swarming presents an opportunity to broaden the scope and applications of robotic swarms, enabling robots with differing degrees of computational power, sensors and mobility to work together. While many classical tasks of robotics swarms, which are loosely based on patterns found in nature, such as path finding and

Research needs (gap in knowledge)

purpose/aim (objectives of research)

# Background Info

## Swarming model and formations

## Swarming algorithms

The **boids** model was initially conceptualised by Craig Reynolds in 1986, which simulated the flocking motions of birds,

## Symmetric & asymmetric swarms of heterogenous robots

# Literature Review

## Swarming Models

Swarm robotics is defined and characterized by its attempt to emulate the swarm intelligences seen in the natural world through the lens of robotics; robots interact on a local level with simple rules, through this it is possible to design collective behaviors which are both scalable and robust [1]. One of the approaches towards this is the Boids Swarming model, which was originally conceptualized by Craig Reynolds in 1986, it sought to model the flocking of birds through a set of rules: separation – boids must not move too close to each other to avoid collisions, alignment – boids must move in the general direction of the rest of the flock, and cohesion – boids must move towards the center of the flock. By implementing these three rules Reynolds created a simulation that modelled the flocking of birds [2]. While Reynolds’ work in 1987 was centered from the view of computer graphics, the Boids model proved useful in the understandings of swarm intelligence and was first realized in the realm of robotics by Turgut et al. who developed a system for robots to determine the heading, position and velocity of their peers thus enabling them to form “flocking” swarms utilizing the Boid rules of separation, cohesion and alignment [3].

Collective behaviour within swarm intelligence is crucial to the real-world application and control of swarms, a key form of this is in creating defined formations. In recent history this challenge has been approached in many ways, however this paper aims to provide an extension of the existing formation control methods through the application to the real world in readily accessible and low complexity robotics, which present both easy access research [4], [5], practical [6] and educational opportunities [7]. Emergent behaviors of formations in swarms proves desirable as it seeks to provide swarms with optimal positioning for various tasks while maintaining the robustness and scalability of the swarm model. In the past swarming formations have been achieved through a variety of different methods, however many of these methods relied fully or partially on central controllers [8], [9], [10], this reduces the robustness and scalability of the swarm, additionally there have been many decentralized based approaches, those that utilised different forms machine learning through the use of a graphical/potential field type techniques seen in [11], [12], [13]. In addition to this there exists some prevailing research into formation control through emergent behaviours, which are implemented in a variety of methods seen in [14], [15]. These methods exist as a large wealth of knowledge in the development and implementation of swarming formation control systems. However the current research into formation control through emergent behaviours is pervaded by homogeneous swarms [14], [15].

## History of Heterogeneous Swarms

Swarm intelligence and robotics is heavily steeped in the thought of biomimicry, a practice that seeks to learn and copy nature to solve a variety of problems, with many problems having existed in nature and with the evolution of swarm behaviour within less singularly cognitive species, these provide an example to how lower complexity robots can complete challenges requiring higher level thinking through collective behaviour [16]. While studies are largely dominated with the use of homogeneous swarms [1], the idea of heterogeneous swarms, swarms made of different types of robots, has become increasingly researched in recent times as the challenges posed to robotic swarms have evolved [17]. An approach to the widely opened horizons of heterogeneous swarming can be seen within the experiment by Dorigo et al. [18], where three different classes of robots, “eye”, “hand” and “foot” robots, in which different elements of the swarm provide significantly different and more capabilities to the heterogeneous swarm, other novel approaches to develop useful heterogeneous swarms include ones using a “shepherding” method in which a more powerful, less mobile robot collected and slaved groups of less powerful, more mobile robots [19]. Additionally, other research has shown success in formations of heterogeneous swarms with differing levels of diversity within the swarm populations [20], [21], [22].

## Applications of Heterogeneous Swarms

Heterogeneous swarming provides a wide range of benefits over homogeneous swarms from its basic heterogeneous nature, with new challenges being posed to the field of swarm robotics, heterogeneous swarms provide the opportunity for

## Benefits of Heterogeneous Swarms

# Project Management

## Methodology

asd

## Research Design

asd

## Background Theory and Analysis

asd

## Timeline

[insert Gantt chart]

## Current Progress

* Investigations into SPHERO BOLT and RVR capabilities
* Testing SPHERO BOLT running off of RVR Pi
* Testing full swarm under ViCON

## Future Work

* Final Product and Evaluation

# Conclusion

Objective

Summarise the research proposal

Summarise work done and future work

Value of research, including responding to the gap in literature

# Bibliography:

[1] M. Brambilla, E. Ferrante, M. Birattari, and M. Dorigo, “Swarm robotics: a review from the swarm engineering perspective,” *Swarm Intell*, vol. 7, no. 1, pp. 1–41, Mar. 2013, doi: 10.1007/s11721-012-0075-2.

[2] C. W. Reynolds, “Flocks, herds and schools: A distributed behavioral model,” in *Proceedings of the 14th annual conference on Computer graphics and interactive techniques*, in SIGGRAPH ’87. New York, NY, USA: Association for Computing Machinery, Aug. 1987, pp. 25–34. doi: 10.1145/37401.37406.

[3] A. E. Turgut, H. Çelikkanat, F. Gökçe, and E. Şahin, “Self-organized flocking in mobile robot swarms,” *Swarm Intell*, vol. 2, no. 2, pp. 97–120, Dec. 2008, doi: 10.1007/s11721-008-0016-2.

[4] R. B. Walton, F. W. Ciarallo, and L. E. Champagne, “A Unified Digital Twin Approach Incorporating Virtual, Physical, and Prescriptive Analytical Components to Support Adaptive Real-Time Decision-Making.” Rochester, NY, Jun. 28, 2023. doi: 10.2139/ssrn.4494073.

[5] V. R. Nagarajan and P. Singh, “Obstacle Detection and Avoidance For Mobile Robots Using Monocular Vision,” in *2021 8th International Conference on Smart Computing and Communications (ICSCC)*, Jul. 2021, pp. 275–279. doi: 10.1109/ICSCC51209.2021.9528162.

[6] R. Singh, A. Gehlot, A. Thakur, V. A. Shaik, and P. Das, “A Review on Implementation of Robotic Assistance in Covid-19 Epidemics: A Possibility Check,” vol. 29, pp. 7883–7893, Jul. 2020.

[7] G. Dietz, J. King Chen, J. Beason, M. Tarrow, A. Hilliard, and R. B. Shapiro, “ARtonomous: Introducing Middle School Students to Reinforcement Learning Through Virtual Robotics,” in *Proceedings of the 21st Annual ACM Interaction Design and Children Conference*, in IDC ’22. New York, NY, USA: Association for Computing Machinery, Jun. 2022, pp. 430–441. doi: 10.1145/3501712.3529736.

[8] F. Ducatelle, G. A. Di Caro, and L. M. Gambardella, “Cooperative self-organization in a heterogeneous swarm robotic system,” in *Proceedings of the 12th annual conference on Genetic and evolutionary computation*, Portland Oregon USA: ACM, Jul. 2010, pp. 87–94. doi: 10.1145/1830483.1830501.

[9] T. Balch and R. C. Arkin, “Behavior-based formation control for multirobot teams,” *IEEE Transactions on Robotics and Automation*, vol. 14, no. 6, pp. 926–939, Dec. 1998, doi: 10.1109/70.736776.

[10] S. Wan, J. Lu, and P. Fan, “Semi-centralized control for multi robot formation,” in *2017 2nd International Conference on Robotics and Automation Engineering (ICRAE)*, Dec. 2017, pp. 31–36. doi: 10.1109/ICRAE.2017.8291348.

[11] T. Balch and M. Hybinette, “Social potentials for scalable multi-robot formations,” in *Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No.00CH37065)*, Apr. 2000, pp. 73–80 vol.1. doi: 10.1109/ROBOT.2000.844042.

[12] L. Barnes, M. Fields, and K. Valavanis, “Unmanned ground vehicle swarm formation control using potential fields,” in *2007 Mediterranean Conference on Control & Automation*, Jun. 2007, pp. 1–8. doi: 10.1109/MED.2007.4433724.

[13] D. Kengyel, H. Hamann, P. Zahadat, G. Radspieler, F. Wotawa, and T. Schmickl, “Potential of Heterogeneity in Collective Behaviors: A Case Study on Heterogeneous Swarms,” in *PRIMA 2015: Principles and Practice of Multi-Agent Systems*, Q. Chen, P. Torroni, S. Villata, J. Hsu, and A. Omicini, Eds., Cham: Springer International Publishing, 2015, pp. 201–217. doi: 10.1007/978-3-319-25524-8\_13.

[14] “Learning Decentralized Control Policies for Multi-Robot Formation | IEEE Conference Publication | IEEE Xplore.” Accessed: May 09, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/8868898

[15] D. H. Stolfi and G. Danoy, “Optimising autonomous robot swarm parameters for stable formation design,” in *Proceedings of the Genetic and Evolutionary Computation Conference*, in GECCO ’22. New York, NY, USA: Association for Computing Machinery, Jul. 2022, pp. 1281–1289. doi: 10.1145/3512290.3528709.

[16] H. Van Dyke Parunak and S. A. Brueckner, “Engineering Swarming Systems,” in *Methodologies and Software Engineering for Agent Systems: The Agent-Oriented Software Engineering Handbook*, F. Bergenti, M.-P. Gleizes, and F. Zambonelli, Eds., Boston, MA: Springer US, 2004, pp. 341–376. doi: 10.1007/1-4020-8058-1\_21.

[17] M. Dorigo, G. Theraulaz, and V. Trianni, “Swarm Robotics: Past, Present, and Future [Point of View],” *Proceedings of the IEEE*, vol. 109, no. 7, pp. 1152–1165, Jul. 2021, doi: 10.1109/JPROC.2021.3072740.

[18] M. Dorigo *et al.*, “Swarmanoid: A Novel Concept for the Study of Heterogeneous Robotic Swarms,” *IEEE Robotics & Automation Magazine*, vol. 20, no. 4, pp. 60–71, Dec. 2013, doi: 10.1109/MRA.2013.2252996.

[19] C. Pinciroli, R. O’Grady, A. L. Christensen, and M. Dorigo, “Coordinating Heterogeneous Swarms through Minimal Communication among Homogeneous Sub-swarms,” in *Swarm Intelligence*, M. Dorigo, M. Birattari, G. A. Di Caro, R. Doursat, A. P. Engelbrecht, D. Floreano, L. M. Gambardella, R. Groß, E. Şahin, H. Sayama, and T. Stützle, Eds., Berlin, Heidelberg: Springer, 2010, pp. 558–559. doi: 10.1007/978-3-642-15461-4\_59.

[20] F.-J. Mañas-Álvarez, M. Guinaldo, R. Dormido, R. Socas, and S. Dormido, “Formation by Consensus in Heterogeneous Robotic Swarms with Twins-in-the-Loop,” in *ROBOT2022: Fifth Iberian Robotics Conference*, D. Tardioli, V. Matellán, G. Heredia, M. F. Silva, and L. Marques, Eds., Cham: Springer International Publishing, 2023, pp. 435–447. doi: 10.1007/978-3-031-21065-5\_36.

[21] M. Nakamura, “Dynamic patterns formed by heterogeneous boid model composed of agent groups moving reversely,” *Artif Life Robotics*, vol. 27, no. 2, pp. 373–383, May 2022, doi: 10.1007/s10015-022-00743-0.

[22] A. Prorok, M. A. Hsieh, and V. Kumar, “The Impact of Diversity on Optimal Control Policies for Heterogeneous Robot Swarms,” *IEEE Transactions on Robotics*, vol. 33, no. 2, pp. 346–358, Apr. 2017, doi: 10.1109/TRO.2016.2631593.