Heterogenous Swarming of RVR and BOLT Robots:

**Abstract**

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# 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

asd

## 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

asd

# Literature Review

## The Boid Swarming Model and Swarming Formations

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], with the new research presented in this thesis, we utilise deep learning to create completely emergent behaviour within heterogeneous swarms, this type of formation has been previously seen within homogeneous swarms and other types of multi-agent scenarios. For example, Hüttenrauch et al. controls the entire swarm through the use of deep reinforcement learning [16], while in a conference paper in 2021, Bezcioglu et al. demonstrates flocking through a global state space matrix utilizing deep reinforcement learning [17], these papers show that there is significant interest and investment in the conceptualization and realization of swarming formation control through a variety of different approaches, however there is not much literature to show research on a wide variety of formation control techniques being applied to heterogeneous swarms.

## Applications of Heterogeneous Swarms

Throughout nature both homogeneous and heterogeneous swarms develop to solve distinct and unique problems [18], [19], these are emulated within swarm robotics, with many papers demonstrating swarms of robots solving natural problems with key benefits being those of robustness, flexibility and scalability [6], [20], [21], [22], [23], [24]. These key features of swarming homogeneous and heterogeneous systems make them well suited to solving novel challenges and scenarios that traditional single and multi-agent systems do not perform as well in. Swarm robotics can be applied to a multitude of different applications, the applications that are typically well suited to this are ones that cover regions, involve high risk, scale up or down in time required, or in applications that required redundancy [24]. For example, swarm robotics have been increasingly researched as a useful asset in mine clearing, this is due to both the high risk and large time and size scales, as minefields are both vast but also having by having a large swarm accidental mine detonations do not result in significant losses to a project’s capability [25], heterogeneity could be applied to this through utilizing more complex drones to perform mission planning while swarms are used to collect data on a smaller scale.

Both physical and behavioural heterogeneity within swarms opens up new dimensions in terms of capabilities and possibilities for swarm intelligence [26]. While hallmark papers such as Swarmanoid [27] conceptualize and implement some of the possible applications of heterogeneous swarms as well as

## Benefits 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 [28]. 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 [29]. An approach to the widely opened horizons of heterogeneous swarming can be seen within the experiment by Dorigo et al. [27], 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 over that of a homogenous swarm, other novel approaches to develop useful heterogeneous swarms include ones utilizing a “shepherding” method in which powerful, less mobile robots collect and slave groups of less powerful, more mobile robots [30], synergizing the benefits robustness and scalability of swarm robotics with the complexity and power of classical single agent systems. Furthermore, it has been demonstrated by Prorok et al. that heterogeneous swarms can use decentralized control to divide and conquer across multiple ‘species’ specific tasks, which shows how larger heterogeneous swarms can provide significantly more modularity and the ability to solve multiple problem types simultaneously [31].

Formations within swarms can provide both crucial placements to optimize efficiency as well as organization within swarms, this is particularly crucial to heterogeneous swarming. These could be seen useful across **talk about the applications of heterogeneous swarms here and how these benefits can apply**

Additionally, in particular interest to the developments within this paper, recent research has shown success in formations of heterogeneous swarms with differing levels of diversity within the swarm populations [31], [32], [33]. However, many of these heterogeneous swarm formations implement centralized, semi-centralized or computationally heavy decentralized formations in comparison to the implementations presented in this paper, these can be seen within

# 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

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