



Degree Project in Computer Science

Second cycle, 30 credits

3D Boids in Safety-critical Collapsed Building Search and Rescue Scenarios Represented by Artificial Potential Fields

LINUS WALLIN

3D Boids in Safety-critical Collapsed Building Search and Rescue Scenarios Represented by Artificial Potential Fields

LINUS WALLIN

Master's Programme, Computer Science, 120 credits
Date: September 3, 2025

Supervisor: Christopher Peters
Examiner: Tino Weinkauf
School of Electrical Engineering and Computer Science
Swedish title: Detta är den svenska översättningen av titeln
Swedish subtitle: Detta är den svenska översättningen av undertiteln

Abstract

Search and rescue (SAR) teams are a key part of finding missing people in the event of a natural catastrophe. To increase the likelihood of finding the missing people in SAR scenarios and reduce the time to do so, autonomous or teleoperated robots and multi-robot systems have become a key tool in aiding the SAR teams. The robots can help SAR teams map the area, monitor, or search for the victims in multiple different types of SAR scenarios.

A common factor for the SAR scenarios is that time is of the essence, since the missing person might be in a critical health state. To increase the likelihood of finding the missing person in time, drones can be used by the SAR team. The issue with having a SAR team controlling the drone/drones is that only one drone can be controlled by one person. With swarm robotics it is instead possible for SAR teams to use a large amount of drones. This allows for covering larger areas and increasing the chances of finding the missing people faster.

There are different swarm robotics algorithms and it is in the public's interest to test them all on SAR scenarios, to see which is the best. One algorithm that could be used in SAR scenarios is the boids algorithm in combination with a control barrier function (CBF) that reduces collisions. This paper aims to explore the possible benefit of guiding the boids algorithm with an artificial potential field (APF).

The boids algorithm combined with CBF and APF will be evaluated on X SAR scenarios that highlight different aspects of real SAR operations.

The findings suggest that boids with APF that has high influence on the boids alignment in combination with a CBF results in the fastest time to find the target in complex SAR environments.

Keywords

Boid, Search and Rescue, Safety-critical, Artificial Potential Field

Sammanfattning

Nyckelord

Boid, Räddningsaktion, Säkerhets Kritisk, Artificiellt Potential Fält

Acknowledgments

I would like to thank xxxx for having yyyy. Or in the case of two authors:
We would like to thank xxxx for having yyyy.

Stockholm, September 2025
Linus Wallin

Contents

1	Introduction	1
1.1	Background	1
1.2	Problem Defenition	1
1.2.1	Hypothesis	1
1.2.2	Research Questions	1
1.2.3	Research Methodology	2
1.3	Purpose	2
1.4	Delimitations	2
1.5	Structure of the thesis	3
2	Background	5
2.1	Summary	5
3	Methods	7
3.1	Overview	7
3.2	Implementing Boids	7
3.3	Implementing Control Barrier Function	7
3.4	Implementing Artificial Potential Field	7
3.5	Combining Boids with Control Barrier Function	7
3.6	Combining Boids with Artificial Potential Field	7
3.7	Hardware/Software	7
3.8	Assessing reliability and validity of the data collected	8
3.8.1	Validity of method	8
3.8.2	Reliability of method	8
3.8.3	Data validity	8
3.8.4	Reliability of data	8
3.9	Planned Data Analysis	8
3.9.1	Data Analysis Technique	8
3.10	Scenarios	8

3.11 Parameters	8
3.12 Evaluation	8
4 Results and Analysis	9
4.1 Major results	9
4.2 Reliability Analysis	9
4.3 Validity Analysis	9
5 Discussion	11
5.1 RQ1	11
5.2 RQ2	11
5.3 RQ3	11
5.4 General Research Question	11
5.5 Limitations	11
5.6 Ethical Implications	12
5.7 Future work	12
6 Conclusions	15
6.1 Conclusions	15
6.2 Reflections	15
References	17

Chapter 1

Introduction

1.1 Background

1.2 Problem Definition

1.2.1 Hypothesis

The expected outcome of the study is that the target-seeking behavior will make the 3D boids explore less and focus more on moving toward the target, similarly to the results in the paper by Hengstebeck, et al.[1]. This will likely lead to more boids reaching the target, but it will also increase the number of collisions during the simulation with increasing strength of the target-seeking behavior.

The addition of an APF representing the search area will likely result in an outcome where fewer boids collide with obstacles and have a higher likelihood of reaching the target as they are guided by a HLP. This will slightly reduce the amount of exploration that the boids do, which would be something to have in mind if applied to a scenario with less prior information about the search area.

1.2.2 Research Questions

The hypothesis is tested by comparing the boids algorithm with the different combinations of CBF and APF.

The study is exploring a core research question which then is divided into three sub-questions. The core research question of the thesis is defined as:

Does the addition of a HLP in the form of an artificial potential field improve the boids algorithm in SAR simulation scenarios.

RQ1: *How does target-seeking and CBF affect the 3D boids algorithm in terms of coverage, safety, and number of boids that are able to find the target location? [1]*

RQ2: *How does adding a CBF to the boids algorithm affect the 3D boids algorithm in terms of coverage, safety, and number of boids that are able to find the target location? [1]*

RQ3: *How does adding a high level planner in the form of an artificial potential field affect the 3D boids algorithm in terms of coverage, safety, and number of boids that are able to find the target? [1][2]*

1.2.3 Research Methodology

The research will have a quantitative approach, where the different algorithms will be compared to each other in simulations on various SAR scenario environments.

1.3 Purpose

The purpose of the thesis is to provide insight into the potential of APF in combination with the *boids algorithm* to find missing people in SAR scenarios with collapsed buildings.

1.4 Delimitations

Although the goal is to provide valuable information about how well APF in combination with the boids algorithm could do in real collapsed building SAR scenarios, the focus of the project will not be to create realistic scenarios nor take into account everything that could affect the agents in real life.

One of the delimitations for the project will be that it will not take into account how the drone would have to adjust in real life to achieve the movement in the simulation. This could lead to the agent's movement not being completely realistic.

Another delimitation of the project will be that delays in signal processing will not be considered for both the communication between the different agents in the scene and the potential delays in the hardware of the real life drones. This should not make much of a difference, since the delays in today's drone hardware is quite low.

1.5 Structure of the thesis

Chapter 2

Background

2.1 Summary

6 | Background

Chapter 3

Methods

3.1 Overview

3.2 Implementing Boids

3.3 Implementing Control Barrier Function

3.4 Implementing Artificial Potential Field

3.5 Combining Boids with Control Barrier Function

3.6 Combining Boids with Artificial Potential Field

3.7 Hardware/Software

The thesis was implemented in Unity 6 and the simulations were run on a windows based computer with AMD Ryzen 5 CPU and a Nvidia 1080ti GPU.

3.8 Assessing reliability and validity of the data collected

3.8.1 Validity of method

3.8.2 Reliability of method

3.8.3 Data validity

3.8.4 Reliability of data

3.9 Planned Data Analysis

3.9.1 Data Analysis Technique

3.10 Scenarios

3.11 Parameters

3.12 Evaluation

Chapter 4

Results and Analysis

- 4.1 Major results**
- 4.2 Reliability Analysis**
- 4.3 Validity Analysis**

10 | Results and Analysis

Chapter 5

Discussion

5.1 RQ1

5.2 RQ2

5.3 RQ3

5.4 General Research Question

5.5 Limitations

The aim of this study was to explore the benefit of using an artificial potential field to guide the boids algorithm in SAR scenarios. This is done by testing the algorithm on scenarios that represent challenges that the robots would face in real SAR environments, with the limitation that they are not a complete representation of real life. The reason for this limitation is that the algorithm's performance becomes lackluster when the scenario space is too cluttered with obstacles and other boids, leading to long computation times. This limited the size of the scenarios, the number of obstacles, and the number of boids.

To combat the performance issues and allow for larger scenarios with more obstacles and boids, the separation ratio of obstacle boids was increased. Although this improved the performance of the algorithm, it could also impact the precision of the boids algorithm.

5.6 Ethical Implications

Although the goal with developing better SAR methods is to save more lives, there is a possibility it could be used to cause harm. With drones becoming popular in warfare, the likelihood of drone based SAR methods being used in unethical ways increases. One potential ethical implication would be that the boids SAR method is used to find and kill people in an active warzone, leading to loss of life in opposition to the goal of saving lives.

Using swarm robotics in these types of operations might be less useful since it requires multiple drones, making it easier for the targets of a potential attack to spot them and take them down.

There is also a possibility that the boids algorithm could be used to save lives in war. It could be used to find injured soldiers on the battlefield to help the SAR teams on the ground save the soldiers life.

5.7 Future work

Evaluation is a key part of research, and it is important that there is a common way of evaluating implementations of multi-agent algorithms in SAR scenarios. Although there are a set of standard values to evaluate multi-agent algorithms on, there exists no benchmarking for the algorithms in SAR scenarios. The closest to benchmarking SAR algorithms is RoboCup. It would be very useful to have standard scenarios to allow for easy implementation with different software. This would also make it easier to compare different multi-agent SAR algorithms with each other.

There exists a large number of multi-agent algorithms and this thesis does not cover many of them. To improve on the work of the thesis, a comparison between different multi-agent algorithms and the boids algorithms presented in this paper could be done. This would lead to a better understanding of whether the boids algorithm would be useful in real SAR scenarios.

Another way to explore how good the boids algorithm would be in real life SAR scenarios would be by implementing the algorithm on a physical swarm of robots. This would give insight into their performance and viability in real life SAR scenarios compared to their performance in the virtual environments explored in this thesis.

This thesis implements an artificial potential field as a HLP, but since there are multiple other HLPs that could be used to enhance the performance of the boids algorithm a possible extension to this thesis would be to compare

different HLPs to find the best one.

Chapter 6

Conclusions

6.1 Conclusions

6.2 Reflections

References

- [1] C. Hengstebeck, P. Jamieson, and B. Van Scy, “Extending boids for safety-critical search and rescue,” *Forensic Analysis and Operations Research*, 2024. doi: 10.1016/j.fraope.2024.100160 [Pages 1 and 2.]
- [2] F. Bounini, D. Gingras, H. Pollart, and D. Gruyer, “Modified artificial potential field method for online path planning applications,” in *2017 IEEE Intelligent Vehicles Symposium (IV)*, 2017. doi: 10.1109/IVS.2017.7995717 pp. 180–185. [Page 2.]