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

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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

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I would like to thank xxxx for having yyyy. Or in the case of two authors:
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Stockholm, September 2025
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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 a 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

Altough 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 for 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 agents 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 todays 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

5.6 Ethical Implications

Altough 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 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 to spot them and potentially shoot them down.

Another potential use case for swarm robotics in warfare is finding 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.

Altough there are a set of standard values to evaluate multi-agent algorithms on, there are exists no benchmarking for the algorithms in SAR scenarios. The closest to benchmarking SAR algorithms is RoboCup.

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 algorithms would be useful in real SAR scenarios.

The boids algorithms in this thesis were only simulated in a virtual environment in the form of Unity and it would be of interest to implement the algorithms on a physical swarm of robots to give insight into their performance and viability in real life SAR scenarios.

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 extention to this thesis would be to compare different HLPs to find the best one.

Chapter 6

Conclusions

6.1 Conclusions

6.2 Reflections

References

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