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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.

This thesis addresses the potential improvement to SAR methods with the help of swarm robotics through implementation of a modified boids algorithm. To further improve the performance of the boids by reducing the number of collisions, a Control Barrier Function (CBF) is applied to the algorithm. An Artificial Potential Field (APF) is then added with the goal of further reducing collisions and guiding the boids with higher precision through the scenario space towards the target. The different versions of boids algorithms are then evaluated on scenarios that highlight different aspects of real SAR scenarios, taking into consideration the metrics time to reach the target, number of collisions that occur, and coverage of the scenario space.

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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Chapter 1

Introduction

1.1 Background

1.2 Problem Definition

Natural catastrophes can cause great destruction to cities and lead to deaths due to buildings collapsing and trapping people in them. It is important to find the missing people as fast as possible, since they might have sustained serious injuries and need medical treatment.

The objective of this thesis is to provide insight into the possibility of using boids as a multi-agent system for collapsed building urban SAR scenarios.

The research will have a quantitative approach, where the different algorithms will be compared on the metrics: time to reach the target, number of collisions, and coverage. Various different scenario environments, highlighting different aspects of urban SAR, will be used to compare the boids algorithms to each other.

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.

1.3 Research Questions

The hypothesis is tested by evaluating the boids algorithm, with the different combinations of CBF and APF, on scenarios highlighting important aspects of real SAR scenarios.

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 high-level planner in the form of an artificial potential field improve the boids algorithm in simulated SAR scenarios.

The purpose of the thesis is to contribute to the SAR research field by exploring boids aided by an APF as a HLP taking inspiration from the suggestions made by Hengstebeck et al. [1] on potential improvements for safety critical boids in SAR.

Analysis and discussion on the general research question can be found in Section 5.3.

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

The boids algorithm is modified and implemented on SAR scenarios in the paper by Hengstebeck et al. [1] with the goal of finding a potential improvement to current state of the art swarm robotics SAR. This research question aims to reimplement the work done by Hengstebeck et al. [1] in Unity and add a third dimension.

The analysis and discussion of RQ1 can be found in Section 5.1.

RQ2: *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?*

APFs can be used to guide agents through an environment with obstacles and find the shortest path to the given goal [2].

This research question aims to explore the possibility of using a APF as a HLP to reduce the risk of agents becoming stuck by obstacles.

The analysis and discussion of RQ2 can be found in Section 5.2.

1.4 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.

1.5 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.

This thesis does also not take into account the processing power of the drones and the goal is only to have a simulation that can run on a computer with the specified specs, see section 3.7.

1.6 Structure of the thesis

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Chapter 2

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2.2.1 Urban Search and Rescue

2.2.2 Swarm Robotics in Search and Rescue

2.2.3 Multi-Agent Systems for Search and Rescue

2.3 Boids

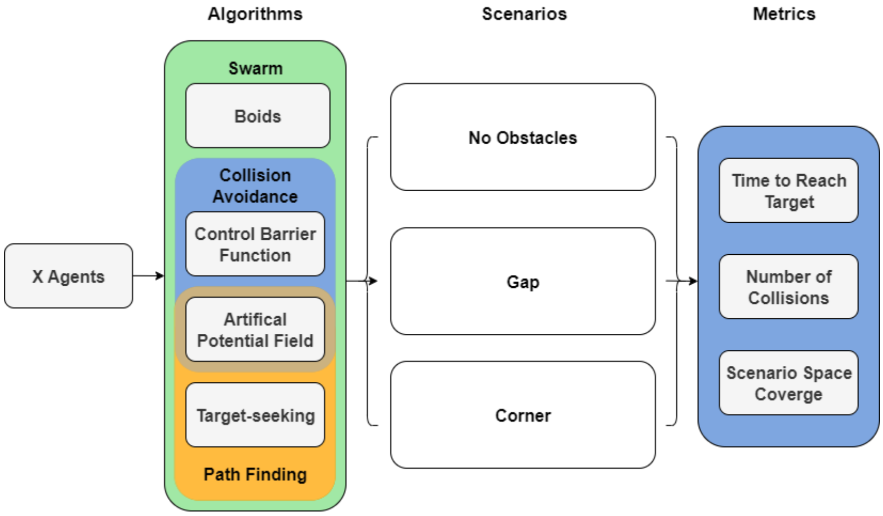
2.3.1 Control Barrier Function

2.3.2 Artificial Potential Field

Chapter 3

Methods

3.1 Overview



3.2 Boids

3.3 Control Barrier Function

3.4 Artificial Potential Field

3.5 Boids with Control Barrier Function

3.6 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 Geforce GTX 1080ti GPU.

3.8 Assessing reliability and validity of the data collected

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3.8.2 Reliability of method

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3.8.4 Reliability of data

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5.1 RQ1: Target-Seeking with Control Barrier Function

5.2 RQ2: Artificial Potential Field as High-Level Planner

5.3 General Research Question

5.4 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.

5.5 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.

5.6 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 Scoy, “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.]