Ship hull inspection using a swarm of autonomous underwater robots: a Search algorithm

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Ship Hull Inspection Using a Swarm of Autonomous Underwater Robots: A Search Algorithm

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Abstract— **Emergency ship hull repair is a vital damage control procedure that makes the difference between reaching the next port and losing a ship. For repairs to be made, ship hull breaches must be quickly located and patched. In this paper, we propose a searching algorithm to be used by a homogeneous swarm of autonomous underwater robots to inspect a ship hull and identify breaches. Inspired by methods tested in 2D environments, we combine aspects of previous studies and implement them in a 3D environment. We compare two approaches designed to achieve complete area coverage of a large section of ship hull and identify the approach that yields the shortest discovery time and highest accuracy. Our system is verified within the Webots software[i] simulated environment and shows that the system is resilient to sensor noise and failure of a fraction of the robot population.**

I. INTRODUCTION

Emergency ship hull repair is one of many stages of damage control in the event of a hull breach while at sea that requires immediate attention. The conventional approach to repairing ship hull breaches, known as shoring, amounts to three general methods [1, 2]: (i) plugging the hole from the interior of the ship using soft wooden plugs, (ii) covering it with prefabricated patches from the exterior of the ship, and (iii) establish and maintain flooding boundaries within the ship to prevent further progress of the flooding.

These techniques mitigate damage but are far from optimal, given the delay between detecting a breach, assessing the damage, transporting materials, and carrying out the repair. These are dangerous, time constrained procedures and with modern naval services moving towards greater autonomy with fewer crew members [3], it stands out as a point of vulnerability. To remedy this situation, a modern approach to emergency ship hull repair is proposed, using a swarm of autonomous underwater robots to investigate the ship hull and carry out repair. If realised, this solution could remove the requirement for engineers to deal with most of the repair and reduce the number of vessels lost due to hull breaches. This would promote greater autonomy of large sea-faring vessels and further safeguard the lives of ships' crew.

In this study two co-ordinated complete area coverage (CAC) search algorithms are proposed and compared to determine which approach yields the superior results in terms of time taken to complete hull inspection, and the probability of observing the true state of the ship hull. Random search algorithms are omitted from the comparison, since such comparisons have already been studied in other already been studied in other CAC experiments and found less effective than co-ordinated searches [4, 5]. Ultimately, providing an CAC algorithm that is robust to sensor noise and partial population failure, shows how coordinated swarms outperform un-coordinated multi-robot systems, and used to formulate an automated solution for emergency ship hull inspection and repair.

II. METHODOLOGY AND EXPERIMENTAL SETUP

The lawnmower search is an un-coordinated search method which serves to measure the performance of a swarm of homogeneous robots, each acting independently of the actions of their neighbours. In this method, the robots are evenly distributed along one side of the vessel at the waterline, allowing for an initial overlap of their forward-facing camera field of view. Each robot performs a search that stretches under the vessel until the waterline on the other side of the ship hull is reached. At which point, the robot moves forward along the ship hull and performs the same search under the vessel once more until the original side is reached. This pattern then repeats until the entire hull has been examined.

The sweeping search is the coordinated method intended to outperform the lawnmower approach in terms of time to complete the search, and robustness to sensor noise and population failure. The population of robots is initially evenly distributed underneath the vessel, forming a line that follows the curvature of the hull. However, in this approach the robots are instructed to stay within sensor range of one another while performing their search. The robots use PID controllers to obtain and maintain equal values on opposing proximity sensors, which indicates equal distance between the robot and each of its neighbours. The maximum allowed space between each robot is defined by the point at which the overlap of their forward-facing camera field of view falls to zero. The sweep search stretches the length of the ship hull from front to back and terminates once the main body of the ship hull has been examined. If any of the robots fail and leave a space in the line of robots, the system works to fill that space by expanding the space between the remaining robots. This method minimises gaps in coverage and reduces the need for backtracking.

The experiments were carried out in the open source robotics simulator Webots[1]. The ship modelled is that of a generic cargo tanker, measuring 100m×80m×10m. The swarm consists of 20 robots, each of which measure 50cm×50cm×5cm and can move at a speed ≤ 5 m/s.

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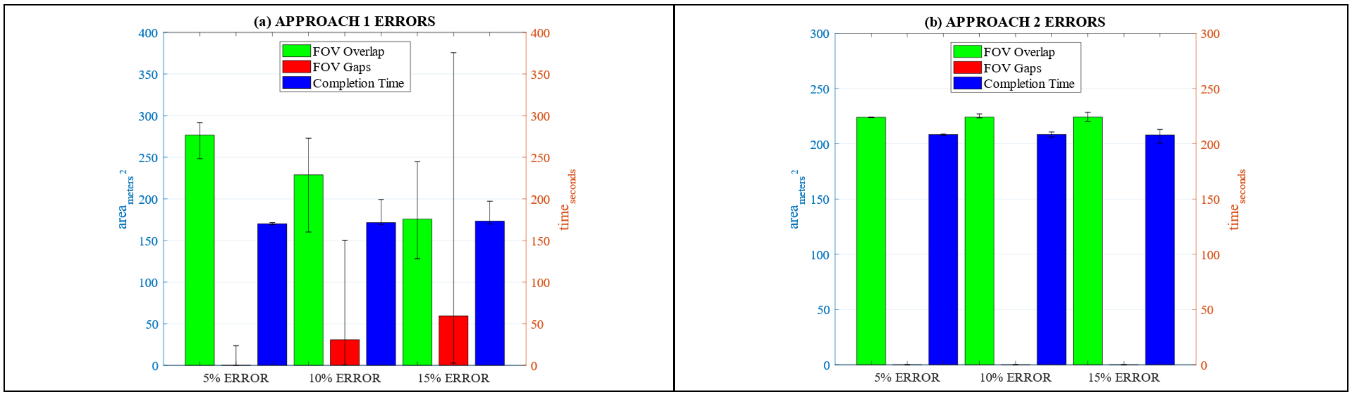

Figure 1. **Error Scenario Comparison: (a) Sweeping search; (b) Lawnmower search.**

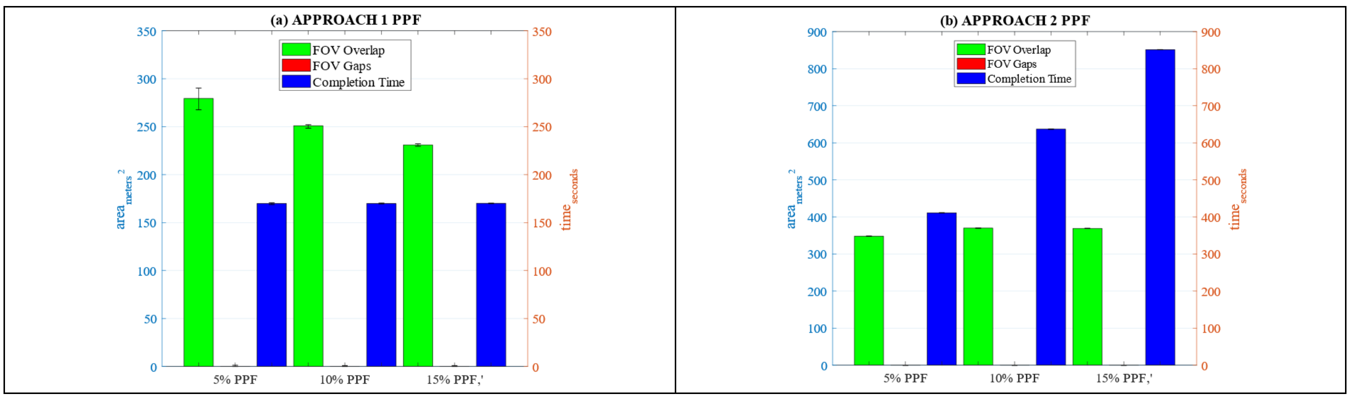

Figure 2. **Partial Population Failure Comparison: (a) Sweeping search; (b) Lawnmower search.**

III. RESULTS

Fifty simulations were carried out for each variable that was changed. We use these results to compare the coordinated and uncoordinated approaches and identify the search method that yields the shortest discovery time and highest accuracy. In the figures, each bar represents the median result of 50 simulations. Error bars are included, indicating the maximum and minimum values obtained. Fig.1 compares scenarios where sensor measurements have errors of 5%, 10%, and 10% for the Lawnmower and Sweeping searches. Fig.2 compares scenarios where all the robots operate with ideal sensor readings, but 5%, 10% and 15% of the population fails. Full codes and videos of the simulations can be accessed via the GitHub repository [6].

IV. CONCLUSION

In this paper we have presented coordinated and un-coordinated complete area coverage algorithms that may be used by a decentralised swarm of autonomous underwater robots to perform emergency ship hull inspection. The results from our simulations in Webots indicate that the coordinated approach outperforms the uncoordinated approach in terms of time taken to complete the inspection, and robustness to partial population failure, but not to impaired sensor readings. Provided the coordinated method is modified to better withstand sensor noise, these behaviours could be implemented on real world systems, leading to an autonomous ship hull inspection system. The next stage of the repair process concerns aggregation and self-assembly of the robot swarm to form a repair patch, which is addressed in [7].

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