UGV Backtracking Recovery With Active Visual Landmarks Navigation: Literature Review (Assignment)

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1 Introduction

Motivation for the topic of unstructured environments is multifaceted. Industries such as agriculture, mining, and military technology require advancements in autonomous systems, yet are hindered by the lack of open-source tools.

Problem Statement: Defining unstructured environments and their specific challenges will provide clarity. These environments lack predefined landmarks, pose navigation difficulties, and require robust adaptable systems.

2 Methodology

This section outlines the approach to gathering and analyzing the literature.

2.1 Specifc traits of domain literature

- Inclusion of large-scale reviews or almanacs (250+ papers for aggregation).
- Amount of publications are orders of magnitude lower than in mainstream AI.
- Challenge-based (DARPA, MBZIRC) research initiatives. "Clusters" of connected around single problem.
- Long-term researches done by large, well established teams.
- Lack of benchmarks or datasets.

From this we derive conclusion that snowballing approach is not the most effective in those field. Instead regular almanacs, big reviews, and challenge-based researches are sufficient to give navigation in the field.

Naturally, as problems in a field of robotics include lots of disection reasons: indoor/outdoor, aerial/ground, realtime/non-realtime, etc. – answering all those quelification questions mean that the tackable "frontier" of research is pin-tip scale. It is marely enough community members to place the large-scale benchmarks and meaningful datasets. This is one of the reasons , why the problems are usually condensed to obvious tasks, that happen to lie beyond the frontiers of modern robotics. "Returning back home" is one of such an everyday problems.

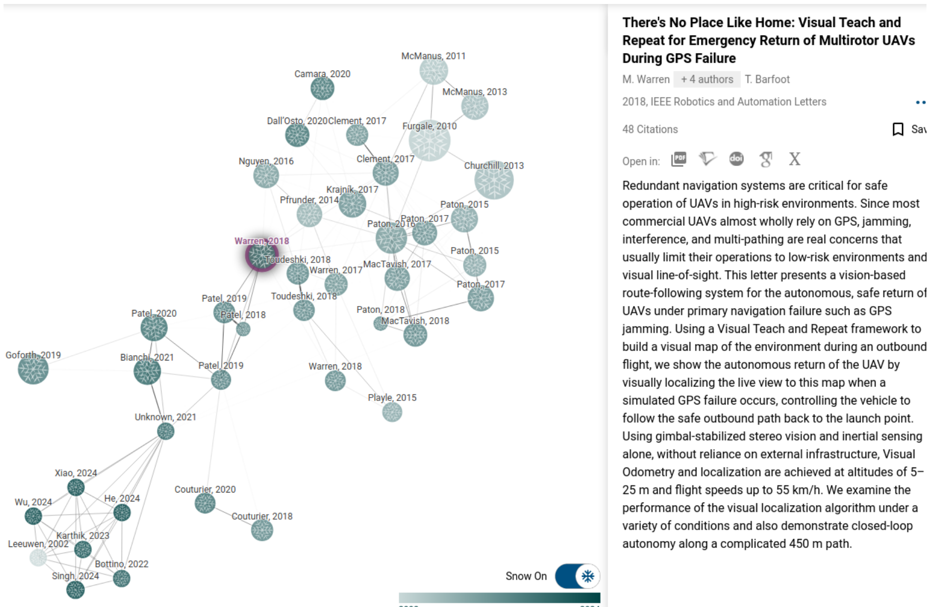

Fig. 1: Visual Teach-and-Repeat approach for emergency return of multirotor UAVs during GPS failure [1]. More information is available on Connected Papers: `https://www.connectedpapers.com/`.

Sinse there is not much place for terminological mislabeling of such a tasks, it is easy to find the track of the relevant papers. They are always clustered around research centers, datasets or individual experts. Subsequently, we marely can expect to see the terminological saturation in the field of particular, defined problem. The most cited papers in field of Robotics rarely have 500+ citations ("FastSLAM: A factored solution to the simultaneous localization and mapping problem" (2002): 3,500 citations in 20 years.) , while for AI the 50'000 citations are not incredible anymore ("BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding" (2018): 50,000 citations by 2023.). Therefore the scale of the task is not large enough for the snowballing approach.

The papers are well connected, and the research is done in the "clusters" of research groups. The example of such is the work of Warren et al. 1 and we see here the modest in size and tight in connections are the works in the field. Classic citation network analysis is not the best tool for the field, as the papers are well connected and the clusters are small.

Thing that metters here is the formulation of the problem, the requirements, that are solved by the design of the solution. The implementation and validation are the next steps, that replace the "benchmarks" in the field of robotics.

2.2 Selection Criteria

- Availability of implementations adaptable for our platform or published ground truth data.
- Papers demonstrating superior benchmark performance.
- Industry standards and tools with robust GitHub presence.

2.3 Analysis Framework

The review leverages a structured "Task-Requirement-Design-Implementation-Validation" methodology.

Challenges-based research in robotics emphasizes organized progress, such as DARPA competitions, driving iterative advancements in solutions.

3 State-of-the-Art

3.1 The Critical Role of the ROS Platform

The Robot Operating System (ROS) has emerged as a cornerstone technology in the robotics field, providing an open-source framework that standardizes development and fosters collaboration across academia and industry. Its modular architecture allows researchers and developers to integrate diverse hardware and software components, enabling rapid prototyping and scalability for a wide range of applications.

One of ROS's most significant contributions is its community-driven ecosystem, where shared libraries, tools, and documentation accelerate innovation. ROS supports real-time applications, bridging the gap between laboratory research and field deployment. This feature has proven particularly valuable in unstructured environments, where dynamic conditions demand robust and flexible solutions. Moreover, the adoption of ROS by industry leaders has enhanced its relevance, making it a platform that seamlessly connects academic research with practical deployment.

In the context of this review, ROS plays a pivotal role in the development of modular designs, such as the MeROS framework. By leveraging ROS's tools for sensor integration, motion planning, and communication, MeROS exemplifies how a standardized platform can streamline the design and validation of complex robotic systems. However, despite its strengths, ROS is not without limitations. Challenges such as real-time processing constraints, hardware compatibility, and dependency management persist, leaving room for further enhancements.

3.2 Mapping Approaches

Summarize current techniques in mapping for unstructured environments.

3.3 Visual Perception and PTZ Cameras

Discuss the role of PTZ cameras in UGV platforms, emphasizing modular design and requirement-based development.

3.4 Public and Private SOTA

Contrast public SOTA with proprietary solutions. Highlight the reproducibility crisis in robotics academia due to platform-locked tools.

4 Research Gaps

4.1 Task-Requirement-Design Identification

Core research gaps

- PTZ camera integration challenges.
- Long-range navigation in unstructured environments:
  - Representation of places.
  - Route following between places with minimal memorization.
- Encapsulation of independent software-hardware modules.
- Cross-platform interfacing and requirements management.
- Calibration and processing for open-source tools.

4.2 Constraints and Challenges

- Planning and power management. Long-range navigation is limited by the energy capacity of the UGV and the efficiency of its spending.
- Environmental factors such as weather, light, and terrain complexity. This parameter has to be mentioned, to clearly denote limitations of considered conditions.
- Real-time processing requirements. The real-time processing of sensor data and decision-making are important for the robotisc, but we outline the problem and design solution in such a manner to allow for the relaxations on this requirement.
- Scalability and integration with ROS platforms. As we touch lots of system aspects with limited resources, we will focus on the iterative implementations and open solutions.

5 Conclusion and Motivation

The proposed research aims to:

- Emphasize modular design and cross-platform usability.
- Identify critical bottlenecks halting advancements.
- Validate the feasibility of addressing these bottlenecks through:
  - Open-source calibration and integration tools.
  - Testing on Husky UGV or equivalent platforms.
  - Clear documentation and interfaces following MeROS philosophy.

6 Datasets and Resources

A few datasets can serve as a basis for this research or as a sign of missing data:

- Wild Scenes Dataset: `https://arxiv.org/pdf/2404.18477`
- Wild Places Dataset: `https://csiro-robotics.github.io/Wild-Places`
- Freiburg Forest: `https://paperswithcode.com/dataset/freiburg-forest`

References

[1] Michael Warren et al. "There's No Place Like Home: Visual Teach and Repeat for Emergency Return of Multirotor UAVs During GPS Failure". In: *IEEE Robotics and Automation Letters* 4.1 (2019), pp. 161–168.