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

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Table of Contents

: does this type of work require "annotation" kind of block?

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.

Elaborate on why open tools are pivotal for industry advancements and research progress.

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.

Discuss what constitutes "unstructured environments" and why they are a significant research challenge.

2 Methodology of review

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

2.1 Specific Traits of Domain Literature

Research in unstructured UGV robotics exhibits several distinguishing traits:

- Large-scale reviews or almanacs (aggregating 250+ papers) play a critical role in providing comprehensive overviews of the field.
- The volume of publications is significantly smaller than in mainstream AI, where research output is orders of magnitude higher.
- Research initiatives, such as DARPA and MBZIRC challenges, drive progress by clustering studies around specific problems.

– Long-term research is typically conducted by well-established teams with access to substantial resources.
– The field lacks standardized benchmarks or datasets, making cross-comparisons between studies challenging.

2.2 Specific Traits

Discussion on specific traits of domain literature.

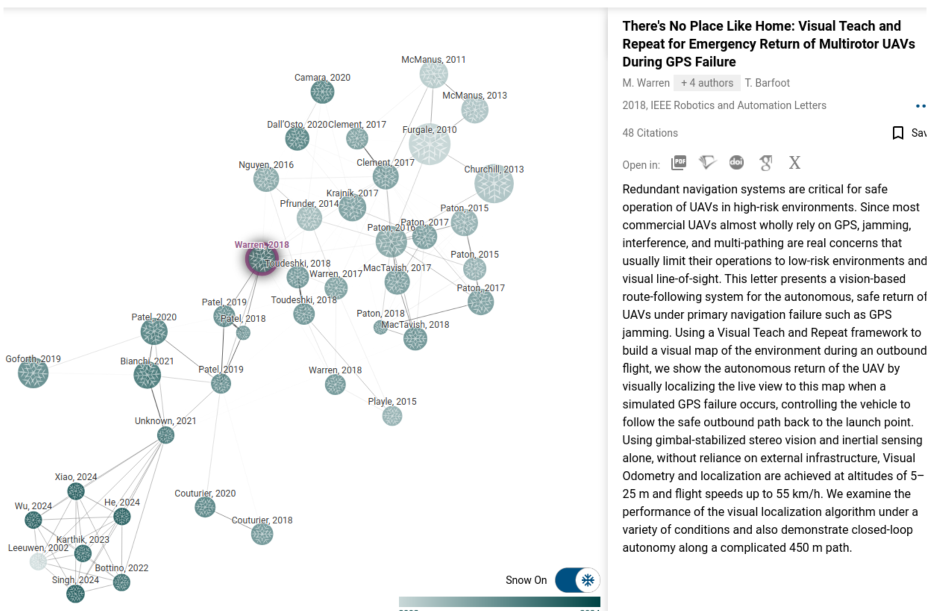

Fig. 1: Visual Teach-and-Repeat approach for emergency return of multirotor UAVs during GPS failure [1]. More information is available on Connected Papers: `https://www.connectedpapers.com/`.

Citations Connectivity in Robotics Research The papers in this field are well connected, and the research is often conducted within "clusters" of research groups. An example of such clustering can be seen in the work of Warren et al. (Figure 1), which demonstrates the modest size but tight connections of research within this domain.

Robotics research often fragments across variables such as indoor versus outdoor environments, aerial versus ground platforms, and real-time versus non-real-time systems. Addressing these distinctions narrows the scope of each research problem, creating a "pin-tip" scale for the research frontier. With a smaller research community, large-scale benchmarks or datasets are often absent.

This fragmentation explains why research frequently focuses on specific, everyday tasks that extend beyond current robotics capabilities. One example is the "returning home" problem, a fundamental yet challenging task. Relevant papers on such tasks tend to cluster around research centers, datasets, or individual experts.

Unlike mainstream AI, which experiences terminological saturation, robotics remains more fragmented. For instance, the seminal robotics paper "FastSLAM: A factored solution to the simultaneous localization and mapping problem" (2002) has accrued approximately 3,500 citations in 20 years. In contrast, the AI paper "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding" (2018) achieved 50,000 citations in just five years.

Add reference to resources with citation statistics.

These differences show that citation-based snowballing approaches are less effective for navigating robotics literature. Instead, comprehensive reviews, challenge-driven studies, and large-scale almanacs are better suited to understanding the field.

What matters most in this field is the careful formulation of problems and the requirements they impose. These requirements drive the system design of solutions, followed by implementation and validation. Unlike AI, where isolated benchmarks play a central role, robotics focuses on real-world conditions, versatility, robustness, and iterative improvements.

Challenge-Driven Clusters There are expected "clusters" or "clogs" in the robotics research publications. Not only around the dedicated fields, problems, and laboratories which occur in a natural way in each field of research. The non-typical thing is research streamlined by strategic governmental organizations. The most well-known is DARPA. Now there are more of them, like MBZIRC.

Add more later, support with citations.

Similar clusters are streamed by non-governmental organizations: technical giants.

describe the case of Kinect. Examples by Intel, OpenCV, Cameras series...

Think of more examples, that list could be extended for sure.

Amplify with examples of explosive technology disruptions, e.g., Kinect or ROS2.

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

2.3 Selection Criteria

Here we will meticulously deconstruct the whole challenge into a set of requirements, investigate the available set of approaches, tradeoffs, and design the solution aspects. The CORE of literature analysis in robotics will be here. In such a manner we will ensure that we are solving the actual large-scale problem applicable beyond our setup. :

The following criteria guided the selection of papers for this review:

- Preference was given to studies with implementations adaptable to our platform or those offering detailed ground truth data demonstrations.
- Industry standards and widely adopted tools, especially those with robust GitHub repositories, community, and version updates were emphasized to ensure practical relevance and reproducibility.

2.4 Analysis Framework

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

Steps that we do: - Task: Select the problem we are dealing with: from the needs to the vision of the solution. - Requirement: Decompose task into some basic tasks, stages, states. Constraints also come here as the type of requirements. Decompose single iteration at once, maintain a higher level of abstraction. - Design: Here we have to envision the idea of the system that can satisfy those requirements on the highest level. In Robotics, reusability is the key, so here we have to narrow the application domain and look for existing solutions. - Search the literature for the solutions that can satisfy the placed requirements. - Filter the results. - Prioritize the experiments or stages of implementations. - "Allocate" the requirements to system components.

Include visual diagrams or reference placeholders for MeROS-based design layers.

3 State-of-the-Art

Comment: This is a Larger piece of text for ROS. Other aspects will be detailed in a similar fashion + add references

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.

Discuss strengths and limitations of existing methods.

3.3 Visual Perception and PTZ Cameras

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

Include examples of modular designs and calibrations.

3.4 Public and Private SOTA

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

Explore the coined term "Public SOTA" and its implications.

4 Research Gaps

4.1 Task-Requirement-Design Identification

Here, when the Landscape of the research field is mapped, we should understand why this problem is not solved till this moment in selected conditions. This will give us a hypothesis that we will work with. For sure, when we are launching the research in any direction, the surrounding problems are also might be an issue. So beside of core research gaps (our main focus) we will need to pay attention to factors that are making risks for the solution. Some limitations of given design we should see from the design phase: we incorporate them consciously. They are derived from the whole collection of requirements in the most explicit way – designed limitations are "the requirements that are not allocated or even mentioned". But the big part of limitations will come up only after the validation stage of research.

Clarifying our goal as well (new ideas and vision of the problem has to rise from the first validation stage), we will map them as unallocated requirements and address them in the next iterations of the work.

The first iteration should include the bare minimum of the requirements. This is the most dangerous part of the project, where we have the most uncertainty. From the first pilot implementation state, we will be able to map the iterations towards the desired system with all requirements satisfied.

Each iteration of the process will satisfy one or more new requirements.

Place the example of work phases scheme. Example on how we will get to the PTZ camera is the best candidate.

Core research gaps

We will concentrate our research efforts on them specifically:

- 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.

Explore solutions like 360-degree cameras or alternative configurations.

4.2 Constraints and Challenges

Those are factors that can have a decisive impact on the feasibility of the work and they require our attention, but those fell out of the main focus of the research:

- 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 robotics, 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.

Discuss relaxations on real-time requirements and focus on iterative implementations.

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.

Highlight the significance of open-source contributions and iterative validation in advancing the field.

6 Datasets and Resources

Place this as the SUBsection to the "Secondary goals and limitations" block

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`

Note the gaps in available datasets and propose directions for addressing these limitations.

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.