Marker-based FastSLAM on the AlphaBot2

Autonomous Systems Project 2023/2024

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Presentation Overview

Introduction and Motivation

What is SLAM?

- Simultaneous localization and mapping, or in short, SLAM.
- Key enabling technology of mobile robot navigation.
- **Perception challenge**.
  - Navigation in unknown environments.
  - Simultaneous tasks:
    - Map acquisition;
    - Self-localization using the map.

Examples

Figure: VR/AR device (Quest 3)

Figure: Vacuum cleaning robot

Examples

Figure: Autonomous drone

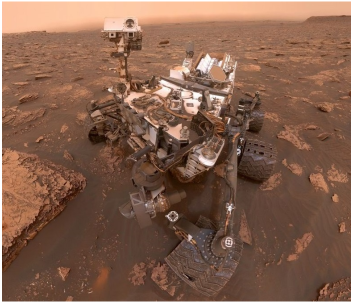

Figure: Space rover (Curiosity)

- **Inputs**:
  - Robot's controls: $U_T = \{u_1, u_2, \dots, u_T\}$
  - Environment observations: $Z_T = \{z_1, z_2, \dots, z_T\}$
- **Outputs**:
  - Map of features: m
  - Sequence of locations (path): $X_T = \{x_0, x_1, \dots, x_T\}$

$$\boxed{p(X_T, m \,|\, Z_T, U_T)}$$

What is SLAM?

Problem statement

"The SLAM problem is recovering a model of the world, m, and the sequence of robot locations, X_T, from the odometry and measurement data." [1]

Major Paradigms

- **Extended Kalman Filter (EKF).**
  - First approach to solve the SLAM problem probabilistically.
  - Linearizes around the current estimate to handle the non-linear nature of robot dynamics and measurements.
- **Particle Filter.**
  - Utilizes a particle filter to represent the posterior distribution of the map and robot pose.
  - Each particle represents a hypothesis of the map and robot trajectory.
  - In **FastSLAM**, each particle is updated through EKF, enhancing map accuracy and computational efficiency.
- Graph-based Optimization.
  - Forms graphs with nodes as poses or landmarks, and edges as constraints.
  - Optimizes node configuration to minimize mapping errors.

EKF-SLAM vs. FastSLAM

EKF-SLAM vs. FastSLAM

Table: Comparison of EKF-SLAM with FastSLAM

Method	Pros	Cons
EKF-SLAM	Good for smaller maps	Struggles with many landmarks
	Easier implementation	Prone to linearization errors
	Real-time updates	Needs careful tuning
FastSLAM	Scales well	Risk of particle depletion
	Landmark-independent scalability	Dependent on #particle
	Handles noise well	Implementation complexity

Our Project

Hardware

Hardware

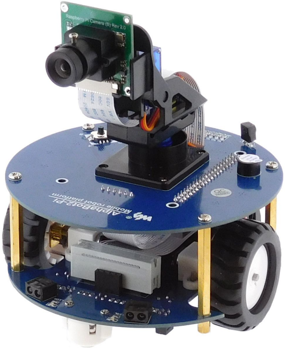

Figure: AlphaBot2

Marker-based FastSLAM

Marker-based FastSLAM

- AlphaBot2 can only implement **visual** SLAM algorithms due to its available sensors.
- Visual SLAM is poised to be key in advancing low-cost robotic systems.
- To gather measurement data:
  - Artificial landmarks as fiducial markers (ArUco);
  - Additional environment feature extraction.

Marker-based FastSLAM
ArUco landmarks

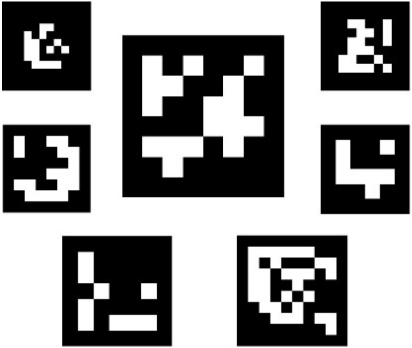

Figure: Example of marker images (ArUco)

- ArUco markers are binary squares with unique white patterns on black backgrounds for identification.
- Serving as **fiducial markers**, they provide reference points in the imaged scene.
- They determine the pose (position and orientation) of the camera relative to the markers.

The markers' IDs and poses are detected and processed in real-time, supporting robust and **stable** interaction with the environment.

Figure: Example of feature extraction from a road using ORB

- Feature extraction involves identifying important parts, or **features** of an image or dataset that are relevant for solving computational tasks like mapping, localization, navigation...
- It detects points, lines, or areas in an image, these could be edges, corners, or specific textures.
- We then convert these points or areas into a mathematical form which help to match and track features across various images.

Work Plan

TÉCNICO LISBOA

Table: Planning table

Period	Objective
22-25 Apr	Define scope, review relevant literature, and outline the project
29-10 May	Explain the algorithms in detail and process robot sensor data
13-17 May	Validate the algorithms in a micro-simulator with synthetic data
20-24 May	Confirm the SLAM algorithm with sensor data from the real-world
27-31 May	Conduct comparative experiments and analyze the results

Note: Subject to change!

References

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[5] M. Montemerlo, S. Thrun, D. Koller, and B. Wegbreit, “FastSLAM: A Factored Solution to the Simultaneous Localization and Mapping Problem,” in *AAAI National Conf. on Artificial Intelligence*, 2002.

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[7] G. Grisetti, R. Kümmerle, C. Stachniss, and W. Burgard, “A Tutorial on Graph-Based SLAM,” in *IEEE Trans. Intell. Transp. Syst.*, 2007.

[8] R. Munoz-Salinas and R. Medina-Carnicer, “Ucoslam: Simultaneous localization and mapping by fusion of keypoints and squared planar markers,” 2019.

Questions

Thank You!