SS 2023-2024, SMT-ROB, BLUEBOTICS-DISAL-MP55 Project Summary

A Probabilistic Error Model of ArUco Features

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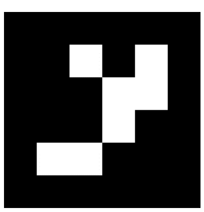
Estimating the pose of a system in its environment is a core requirement for several localization applications, and in particular for Automated Guided Vehicles (AGVs).

The most common applications only use lidars and GNSS to obtain a global position estimate of the AGVs in their environment. While these exteroceptive sensors are efficient in most cases, in some situations their usage becomes challenging. Moreover, compared to cameras, these sensors are not suited to track efficiently objects. Hence, the primary goal of this Master thesis was to build a custom computer vision system with a monocular camera, and implement a mathematical error model to obtain a new localization and object tracking solution based on the detection of binary square fiducial markers.

In particular, the objective was to leverage the detection of the markers' features in images, to accurately estimate their 6DOF pose and covariance matrix, with respect to the camera frame. Moreover, a particular focus was given to ArUco markers, as they yield more precise pose estimations for long range measurements.



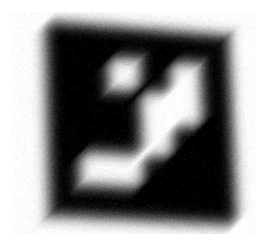
ArUco marker

Nonetheless, the main objective of this project was to provide a probabilistic mathematical error model, able to precisely predict the uncertainty of each marker pose estimation.
The mathematical model that was implemented during this project is the first of its kind, in the whole current state-of-the-art in the field of binary square fiducial markers' pose estimation. In fact, while previous attempts to predict the pose uncertainty were all based on specific experimental measurements and hardware, this model is totally generic as it yields accurate and precise results independently of any hardware or experimental setup.

Additionally, this report also introduces a new blur and noise image standard deviation measurement metric, that is perfectly suited to be applied along simple geometric shapes like squares.

All the assumptions made to build this model were verified theoretically and experimentally. Moreover, the model was also confronted with all the possible extreme use cases, like varying high speeds and challenging light conditions. Hence, this validation process allowed to detect and correct three OpenCV ill-posed convention and errors, while improving the robustness of the model.

To improve the robustness of the model, a corner deviation detector was also implemented from scratch to detect when a marker detection is incorrect. This corner deviation detector can be used for any fiducial marker, and removes considerably the risk of erroneous corner detection, that can yield totally random results. This useful property has also allowed to push further the limits of the model, by correcting the errors due to high motion blur and image noise, till some reasonable extent.



ArUco marker with high motion blur

Finally, the model was validated both theoretically and experimentally, by proving that it is conservative, while predicting errors that are accurate and precise to the centimeter and the degree, compared to the real errors. Consequently, this demonstrates the validity and accuracy of this model, making it a strong tracking and localization solution, to use for example in a Kalman filter.