Testing Procedures Architecture for Establishing a Fiducial Marker Recognition Quality in UAV-based Visual Marker Tracking Task in Gazebo Simulator

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Abstract

Fiducial markers could be used in different tasks, including UAV and UGV marker-based localization. In most cases developers do not consider features of fiducial markers' systems (FMS) while selecting a particular FMS for a project. However, this selection might significantly influence results of experiments and thus the quality of a resulting product, an algorithm or a software. In this work, we define an architecture of experimental framework that allows finding an optimal marker for a UAV in a mobile ground object following task. The proposed framework estimates an average deviation of a detected Aruco marker position and an accuracy of the UAV landing on the marker. The framework uses Robot Operating System and employs UAV PX4 LIRS model in the Gazebo simulator.

Keywords: UAV, ROS, Gazebo, PX4, Fiducial Markers, ArUco.

1. Introduction

Fiducial markers are used for a wide range of tasks, including mapping, localization, and navigation in mobile robotics. For example, a robot can determine its current location using markers in a camera stream. Markers have different parameters, and thus it is important to use a marker that serves a particular function in a better way.

Several examples of the most popular markers are listed in Fig. 1. ArUco marker[1] (Fig. 1 (a)) is a square image containing a square binary matrix. A robot detects the marker using its black boundary and uses the internal matrix to identify the marker and obtain additional transformations' data. AprilTag marker[2] (Fig. 1 (b)) successfully overcomes issues with rotations and false positive detections, but its computational efficiency is lower relatively to the ArUco. ArTag marker[3] (Fig. 1 (c)) attempts to maximize the minimum Hamming distance between each instance of the family and has an improved search algorithm. Stag marker[4] (Fig. 1 (d)) employs a black square frame that helps to detect it, yet uses a circular internal pattern, which increases recognition stability of the algorithm.

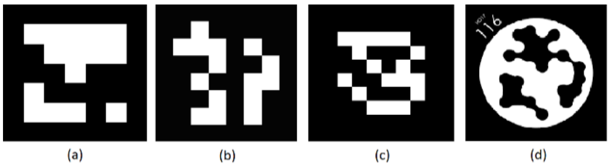

Fig. 1. Fiducial marker types: ArUco (a), AprilTag (b), ArTag (c), Stag (d).

Thoughtless choice of a marker can negatively affect performance results, therefore it is important to choose criteria for markers' comparison. For example, in[5] authors proposed to use marker resistance to rotations (with regard to different axes) as a metric and performed virtual experiments in Gazebo simulator in order to compare different families of markers.

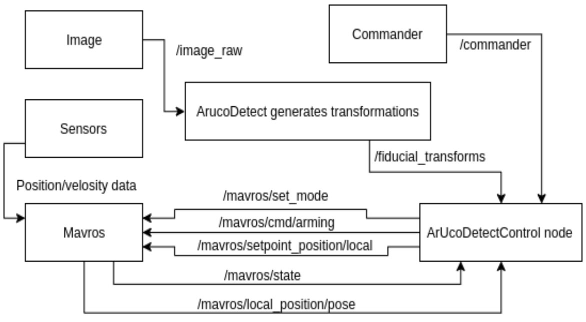

Fig. 2. UML diagram of the solution architecture.

In[6] the authors employed an overlap quality, a frequency of false detections, and a probability of inter-marker confusion as criteria for comparison. In some cases, it might be more reasonable to compare technologies within a specific application, e.g., authors in[7] compared fiducial markers in medical field using accuracy and noise as criteria since in such applications immunity is more important than computational costs.

This work presents an architecture of experimental framework that allows finding an optimal marker for a UAV in a mobile ground object following task. The framework estimates an accuracy of the UAV landing on the Aruco marker.

2. System Setup

We used Ubuntu 20.04 operating system with Noetic version of Robot Operating System (ROS)[8]. ROS is a set of tools, conventions, and libraries for robot software. ROS consists of two main parts: a system for interfacing software code and a set of packages with some standard robotics functions, e.g., planning, localization, getting data from sensors, etc. For virtual experiments Gazebo 11 simulator is employed. The Gazebo is an open-source 3D robotics simulator[9] that allows constructing robot models in SDF format, simulating various real-world conditions and sensors for tracking data about these conditions.

We use the PX4-LIRS model as UAV simulation[10]. This model contains four motors, where the opposing motors rotate in opposite directions. The model uses a camera with 800x800 resolution and 30 FPS, and a GPS sensor. The UAV employs PX4 open-source firmware[11] for UAV control, which provides a set of libraries to create custom solutions and scale them. Robotics APIs allow the PX4 to be controlled from outside the flight stack computing environment using a companion computer or other computing environment. The APIs interact with the PX4 using Micro Air Vehicle Link (MAVLink[12]), which is a protocol for communication

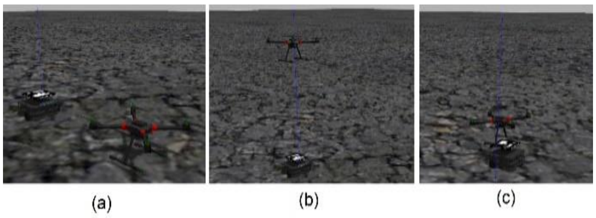

Fig. 3. UAV modes: initial pose (a), following (b), landing (c).

with UAVs. The MAVROS package provides MAVLink communication between computers running ROS.

3. Solution architecture

A scheme of the experimental framework architecture for selecting an optimal marker for a UAV in a mobile ground object following task is illustrated in Fig. 2. A heart of the scheme is an algorithm for UAV landing and following. We used *aruco_detect* node[13] from fiducials package for marker recognition. It contains a set of tools for searching and recognizing fiducials markers. After image processing, it sends data to */fiducial_transforms* topic. Next, the information about the recognized markers could be obtained from this topic.

Node *aruco_detect_control* subscribes to topics */commander*, */mavros/state*, */fiducial_transforms*, and */mavros/local_position/pose*. From */mavros/state* topic the node obtains data about the state of the UAV; from */mavros/local_position/pose* - a current position of the UAV using GPS; from */fiducial_transforms* - data about recognized markers from *aruco_detect* node.

Node *commander* receives data from the keyboard and sends it to *aruco_detect_control* node allowing to control the UAV flight. The initial position of the UAV at the simulation start is shown in Fig. 3 (a). The node starts sending data to *mavros/setpoint_position/local* topic with the starting position when *commander* topic receives data with “start” command. If *commander* topic receives “follow” command, the UAV starts following the marker (Fig. 3 (b)) and uses transformation data from *fiducial_transforms* topic. Fig. 4 presents a scheme of the following method of *aruco_detect_control* node. After "land" command, the UAV performs landing (Fig. 3 (c)). An altitude gradually decreases as long as the marker is in the field of view during the landing. The vertical landing is activated when the marker disappears from the field of view.

To compare markers, several metrics were selected[14]:

1) Ratio of time when the marker was recognized to time when it was not recognized
2) Average distance between the marker and UAV
3) Variance
4) Average speed of the UAV. Knowing the average speed of the target, we can estimate quality of communication.
5) Landing accuracy

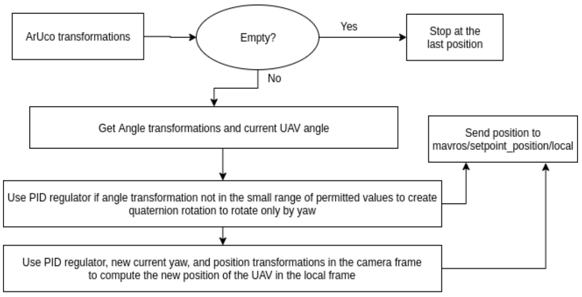

Fig. 4. UAV following UML.

To store these metrics, we created a special statistics node. It obtains data from all topics from the *aruco_detect_control* node, prepares them, and saves into a file.

To automate the marker movement, in our experiments we attached it to a top of the TurtleBot3[15] robot and recorded topics of its movement, including velocity topic and the commander topic.

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References

1. S. Garrido-Jurado, R. Muñoz-Salinas, F. J. Madrid-Cuevas, M. J.Marín-Jiménez, “Automatic Generation and Detection of Highly Reliable Fiducial Markers Under Occlusion”, Pattern Recognition, Vol. 47, No. 6, pp. 2280-2292, 2014.
2. E. Olson, “AprilTag: A Robust and Flexible Visual Fiducial System”, IEEE International Conference on Robotics and Automation, pp. 3400-3407, 2011.
3. M. Fiala, “ARTag, a Fiducial Marker System Using Digital Techniques”, IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05), Vol. 2, pp. 590-596, 2005.
4. B. Benligiray, C. Topal, C. Akinlar, “Stag: A Stable Fiducial Markersystem”, Image and Vision Computing, Vol. 89, pp. 158-169, 2019.
5. T. Tsoy, A. Zakiev, K. Shabalina, R. Safin, E. Magid, & S. K. Saha, “Validation of Fiducial Marker Systems Performance with Rescue Robot Servosila Engineer Onboard Camera in Laboratory Environment”, 12th

International Conference on Developments in eSystems Engineering (DeSE), pp. 495-499, 2019.

6. M. Fiala, “Comparing ARTag and ARToolkit Plus Fiducial Marker Systems”, IEEE International Workshop on Haptic Audio-Visual Environments and their Applications, pp. 148-153, 2005.
7. C. Kunz, V. Genten, P. Meißner, B. Hein, “Metric-based Evaluation of Fiducial Markers for Medical Procedures”, Medical Imaging Image-Gui|ded Procedures, Robotic Interventions, and Modeling, pp. 690-703, 2019.
8. M. Quigley, K. Conley, B. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, A. Y. Nget al., “ROS: an Open-Source Robot Operating System”, ICRA workshop on open-source software, Vol. 3, No. 3, pp. 1-6, 2009.
9. N. Koenig, A. Howard, “Design and Use Paradigms for Gazebo, an Open-Source Multi-Robot Simulator”, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vol. 3, pp. 2149-2154, 2004.
10. A. Khazetdinov, A. Aleksandrov, A. Zakiev, E. Magid, K. H. Hsia, “RFID-Based Warehouse Management System Prototyping Using A Heterogeneous Team Of Robots”, Robots in human life, pp. 263-270, 2020.
11. K. D. Nguyen, C. Ha, “Development of Hardware-in-the-Loop Simulation Based on Gazebo and Pixhawk for Unmanned Aerial Vehicles”, International Journal of Aeronautical and Space Sciences, Vol. 19, No. 1, pp. 238-249, 2018.
12. A. Koubˆaa, A. Allouch, M. Alajlan, Y. Javed, A. Belghith, M. Khal-gui, “Micro Air Vehicle Link (MAVLink) in a Nutshell: A Survey”, IEEE Access, Vol. 7, pp. 87658-87680, 2019.
13. A. Khazetdinov, A. Zakiev, T. Tsoy, M. Svinin and E. Magid, “Embedded ArUco: a Novel Approach for High Precision UAV Landing”, 2021 International Siberian Conference on Control and Communications (SIBCON), pp. 1-6, 2021.
14. J. A. Ward, P. Lukowicz, H. W. Gellersen, “Performance Metrics for Activity Recognition”, ACM Transactions on Intelligent Systems and Technology (TIST), Vol. 2(1), pp 1-23, 2011.
15. H. A. Ahmed, J. W. Jang, “Cloud Based Simultaneous Localization and Mapping with Turtlebot3", Proceedings of the Korean Institute of Information and Communication Sciences Conference, pp. 241-243, 2018.

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