Pilot Virtual Experiments on ArUco and AprilTag Systems Comparison for Fiducial Marker Rotation Resistance

Aufar Zakiev, Ksenia Shabalina, Evgeni Magid
Laboratory of Intelligent Robotic Systems (LIRS), Intelligent Robotics Department, Higher Institute of Information Technology and Intelligent Systems, Kazan Federal University, 35 Kremlyovskaya street, Kazan, 420008, Russia
E-mail: zaufar@it.kfu.ru, ks.shabalina@it.kfu.ru, magid@it.kfu.ru
http://kpfu.ru/robolab.html

Abstract

There exists a large number of fiducial marker system types and both researchers and industry have difficulties to select among this variety a single system that could provide optimal behavior for a particular task. This paper presents design and results of pilot virtual experiments that were conducted in order to compare a performance of two marker systems, ArUco and AprilTag. Experiments were designed to estimate and compare marker systems resistance to rotation with regard to different principal axes in 3D space. Pilot experiment design eliminates influence of external environment, including light conditions, camera resolution, sensor noise, distance between camera and marker, etc. Experiments were implemented in ROS/Gazebo environment. In total over 300,000 virtual experiments were performed and analyzed in order to collect statistically significant data amount.

Keywords: robotics, fiducial marker system, recognition algorithms, experimental comparison, ROS, Gazebo.

1. Introduction

Fiducial marker systems (FMS) are systems of planar graphical markers that are designed to be detected by corresponding machine vision algorithms. FMS are widely used in physics, medicine, robotics, augmented reality, metrology, robotics, etc. Broad range of robotic tasks including navigation[1], localization[2], mapping[3] and camera calibration[4] use FMS as a main element. Our long-term goal is to calibrate several Russian robots, including humanoid AR-601 robot (Fig. 1), and FMS usage is way to accomplish this task in automated manner. Modern FMSs have different designs and are developed for various purposes: each of them has its own advantages and drawbacks. Therefore, a suitable FMS choice requires to compared systems for various criteria, paying attention to criteria that are important for a particular task of interest. Our goal is to auto calibrate robot cameras: markers are placed on the humanoid robot's manipulator (e.g., palm) and the humanoid observes this marker in order to estimate and programmatically eliminate camera distortions. For this task the FMS should be resistive to manipulator rotations and partial occlusions being caused by marker overlap with various objects (e.g., robot's parts).

Early approach to systematically compare the FMSs was conducted through multiple manual experiments in order to estimate different markers' resistance to rotation and overlapping (both systematic and arbitrary). However, this approach has a number of significant disadvantages, which make manual experiment results hardly reproducible:

- Overwhelming time consumption. Multiple iterations are required in order to collect statistically significant amount of data.
- Complexity of experiments' fairness control. Multiple environment conditions, e.g., inclination angle, marker position with regard to a camera, lighting conditions, etc. are hard to monitor and control.
- Limited hardware choice. Hardware has unavoidable noises and often do not possess desired properties, e.g., camera resolution, lens distortion level, optical sensor sensitivity, etc.

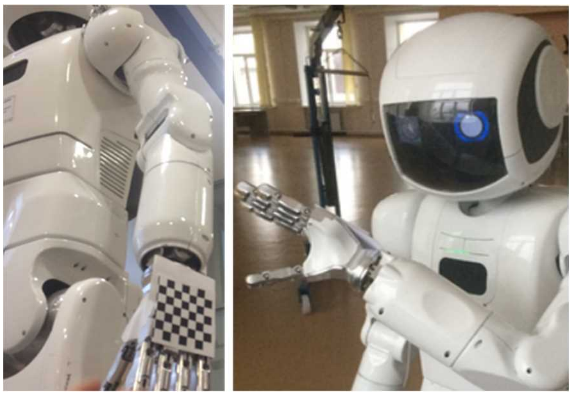

Fig. 1. Fiducial marker placement on robot manipulator (left); marker observation by robot (right).

This paper presents virtual experiments design and ArUco[5] and AprilTag[3] systems comparison for rotation resistance results. Section 2 presents previous research results. Section 3 briefly describes ROS/Gazebo virtual environment used for experiments. Section 4 is dedicated to experiment setup; Section 5 shows experiment results. Finally, Section 6 concludes our work.

2. Related Work

As it was mentioned, in our previous research[6, 7] we had conducted manual experiments with several fiducial marker systems. We had chosen AprilTag, ARTag and CALTag[8] for comparison and designed our experiments to validate their resistance to rotations, systematic occlusions and arbitrary overlaps. These experiments were conducted using Genius FaceCam 1000X web-camera first to get data about FMS applicability on low-cost equipment. Then experiments were continued with AR-601 humanoid robot, using its integrated Basler acA640-90gc cameras. The experiment results analysis revealed that AprilTag and ARTag are resistive to marker rotations, however, are very sensitive to marker edge overlaps. This could be explained by the detection algorithm sequence: one of the first steps is edge detection, and if it fails, the entire detection process stops. On the opposite, CALTag demonstrated high detection rate on various rotation angles and different occlusions.

3. ROS/Gazebo environment

Robot Operating System (ROS) is a fast-growing framework for robotics development. Its architecture consists of *nodes* and *topics* between them for communication. Such distributed structure allows creating various data and command flow schemas, making sensor data analysis and robot motion control easy. ROS is distributed in the form of minimally functional units called *packages.*

The following FMS have their detection algorithms encapsulated in ROS packages: AprilTag, ArUco, Alvar[9] and ChiliTag[10]. Actually, ArUco is universal detection library, that could be used to detect ArUco markers and, in addition, AprilTag, ARTag[11,12], ARToolKitPlus[13], and ARToolKitPlusBCH (Binary Coded Hexadecimal). Gazebo is 3D-simulator that could be integrated with ROS as a tool to visualize simulations and apply real world properties, including light and collision processing to the objects within the simulation.

4. Experiment Setup

We created two robots in virtual environment: a robot-performer with marker and R2D2-like robot with a camera. The robot-performer is designed to modify a marker appearance between distinct detections: it rotates the marker for a predefined angle within user-defined angle limits (the scheme is shown in Fig. 2). The robot with the camera simulates a static camera stand (Fig. 3). Numerous experiment parameters were kept constant through all the experiments (see Table 1) in order to eliminate their influence on comparison results.

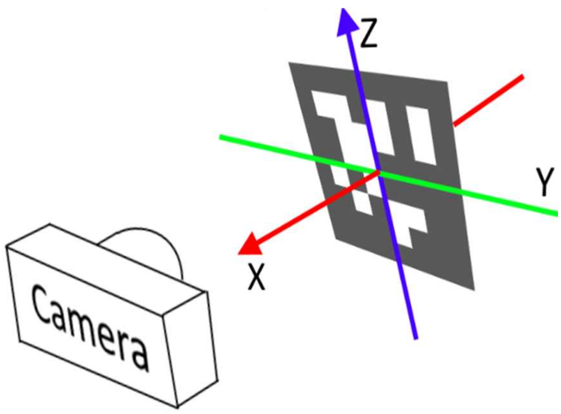

Fig. 2. Virtual experiment rotation scheme.

Table 1. Virtual experiment constant parameters.

Parameter	Value
Camera resolution	640 x 480 px.
Camera distortion level	0 (ideal lens)
Camera noise level	0 (ideal device)
Distance	2 m.
Rotation range (X-axis)	[-180˚; +180˚)
Rotation range (Z-axis)	[-90˚; +90˚]
Marker side size	0.4 m
Light angle of incidence	45˚
Light spectrum	White light
Light conditions	Uniform at whole marker area

Rotation experiments flow works as follows:

1. The robots spawn at constant distance from each other. Initially, the marker inclination angle around a (particular) rotation axis is zero.
2. The logger waits for a half of second for the marker detection.
3. The logger logs an inclination angle and a result of detection procedure.
4. The robot-performer rotates the marker for 1 degree around a user-defined axis (X-axis or Z-axis).
5. If the rotation limit is not reached, the algorithm goes to step #2; else the experiment ends.

The logger logs all results twice: first output goes to a console, second goes to a file with proper name including tag family (e.g., ArUco), tag type (e.g., 25h7), tag ID, the distance to the camera and the date of the experiment.

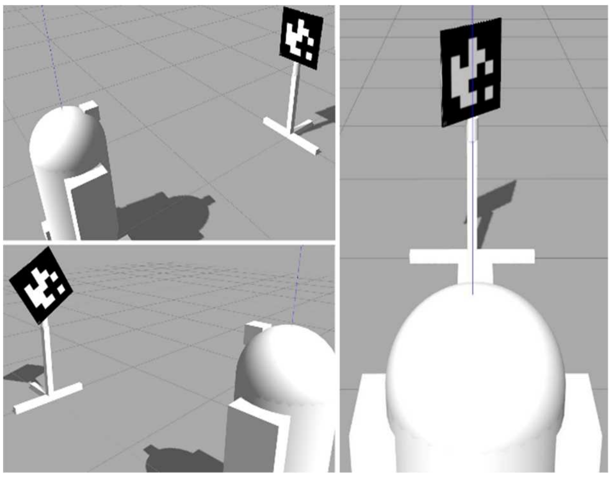

Fig. 3. Virtual experiment design: initial marker position (top left); rotated 30 degrees around X-axis (bottom left); rotated 45 degrees around Z-axis (right).

5. Experimental Results

All markers of a selected type are tested to collect statistically significant amount of data: 100 ArUco (type is 25h7) markers and 242 AprilTag (type is 25h7) markers. Markers of this type have 25 encoding pixels and Hamming distance between any of them is equal or more than 7. Equal marker types eliminated difference between FMS encoding properties and encoded data amount. Experiments were conducted with each distinct marker twice to collect reliable data about each detection angle. Experiment results are presented in Table 2.

Table 2. Average detection rate through all the markers in rotation experiments by FMS type and rotation axis.

Marker family and type	Rotation axis x	Rotation axis z
AprilTag – 25h7	99.94%	69.96%
ArUco – 25h7	99.97%	86.07%

The experiment results allow concluding that AprilTag family markers are practically insensitive to X-axis rotations; however, ArUco family markers have significantly better resistance to Z-axis rotations. In addition, failed detections distributions for each marker family are presented in Fig. 4 and Fig. 5.

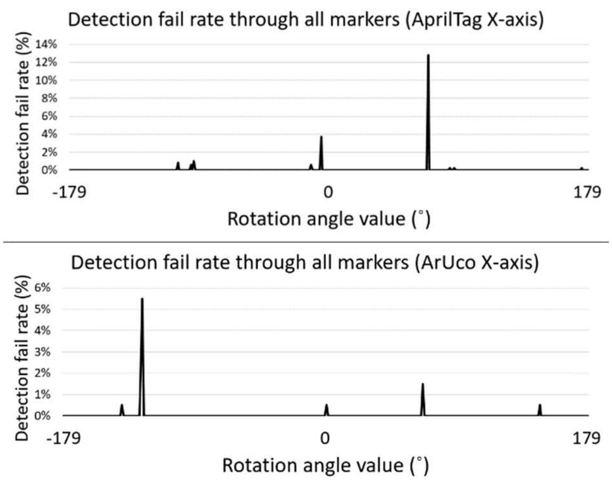

Fig. 4. Virtual experiment results for X-axis rotation: detection rates through all markers depending on rotation angle for AprilTag (top) and ArUco (bottom).

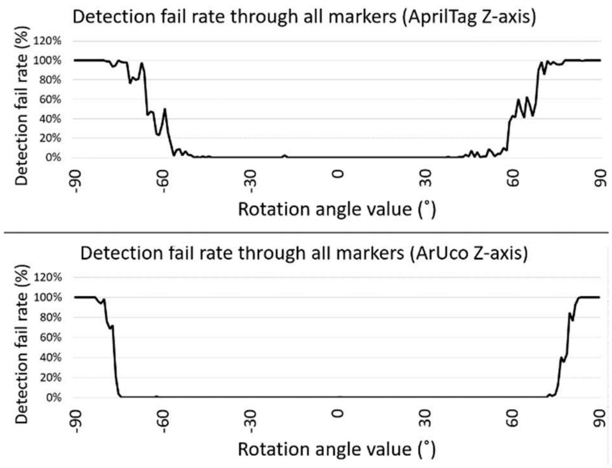

Fig. 5. Virtual experiment results for Z-axis rotation: detection rates through all markers depending on rotation angle for AprilTag (top) and ArUco (bottom).

Z-axis diagrams show a rather predictive FMS behavior: increasing rotation angle decreases marker area that is visible to the camera, leading to unsuccessful detections. Both FMSs showed highest resistance to rotations around X-axis: nearly ideal detection rate has been logged for all rotation angles.

6. Conclusions and Future Work

This paper presents a set of pilot experiments with AprilTag and ArUco marker systems in virtual environment and their performance comparison for rotations. The created virtual environment could be used as a framework for further comparative research because new FMS addition to the project is easy. In addition, the virtual environment experiments could be easily distributed for multiple cores: this gives a chance to qualitatively peer-review and reproduce these experiments without limitations. Our future work concentrates on different FMS comparison for their resistance to occlusions (both systematic and arbitrary) and exploring dependence of maximum detection distance on camera resolution.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research (RFBR), project ID 18-58-45017. Part of the work was performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

References

1. R. Kuriya, T. Tsujimura and K. Izumi, Augmented reality robot navigation using infrared marker, in *Proc. 24th IEEE Int. Symposium on Robot and Human Interactive Communication*, (2015), pp. 450-455.
2. V. Dhiman, J. Ryde and J. J. Corso, Mutual localization: Two camera relative 6-DOF pose estimation from reciprocal fiducial observation, in *Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, (2013), pp. 1347-1354.
3. E. Olson, AprilTag: A robust and flexible visual fiducial system, in *Proc. IEEE Int. Conf. on Robotics and Automation*, (2011), pp. 3400-3407.
4. M. Fiala, Comparing ARTag and ARToolKit Plus Fiducial Marker Systems, in *Proc. IEEE Int. Workshop on Haptic Audio Visual Environments and their Applications*, (2005), pp. 148-153.
5. F. J. Romero-Ramirez, R. Muñoz-Salinas and R. Medina-Carnicer, Speeded Up Detection of Squared Fiducial Markers, in *Image and Vision Computing* (2018).
6. A. Sagitov, K. Shabalina, R. Lavrenov and E. Magid. Comparing fiducial marker systems in the presence of occlusion, in *Proc. Int. Conf. on Mechanical, System and Control Engineering*, (2017), pp. 377-382.
7. K. Shabalina, A. Sagitov, L. Sabirova, H. Li, and E. Magid. ARTag, AprilTag and CALTag Fiducial Systems Comparison in a Presence of Partial Rotation: Manual and Automated Approaches, *Lecture Notes in Electrical Engineering*.
8. B. Atcheson, F. Heide, W. Heidrich. CALTag: High Precision Fiducial Markers for Camera Calibration, in *Vision, Modeling, and Visualization Workshop*, vol.10, (2010), pp. 41-48.
9. C. Woodward, S. Valli, P. Honkamaa and M. Hakkarainen, Wireless 3D CAD viewing on a PDA device in *Proc. 2nd Asian International Mobile Computing* (Langkawi, Malaysia, 2002), pp. 83-87.
10. Q. Bonnard, S. Lemaignan, G. Zufferey, A. Mazzei, S. Cuendet, N. Li and P. Dillenbourg, Chilitags: Robust Fiducial Markers for Augmented Reality (Switzerland, 2013).
11. M. Hirzer, Marker Detection for Augmented Reality Applications, *Seminar/Project Image Analysis Graz*, (2008), pp. 1-25.
12. M. Fiala, ARTag, a fiducial marker system using digital techniques, *Computer Vision and Pattern Recognition*, vol.2, (2005), pp. 590-596.
13. D. Wagner and D. Schmalstieg, Artoolkitplus for pose tracking on mobile devices (2007), pp. 139-146.