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Automated Testing of Workshop Robot Behavior

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Abstract—Autonomous mobile robots can be found in a wide field of applications. Their types range from household robots over workshop robots to autonomous cars and many more. All of them undergo a number of testing steps during development, production and maintenance. This paper describes an approach to improve testing of robot behavior. It was inspired by the RoboCup @work competition that itself reflects a robotics benchmark for industrial robotics. There, scaled down versions of mobile industrial robots have to navigate through a workshop-like environment or operation area and have to perform tasks of manipulating and transporting work pieces. This paper will introduce an approach of automated vision-based testing of the behavior of the so called youBot robot, which is the most widely used robot platform in the RoboCup @work competition. The proposed system allows automated testing of multiple tries of the robot to perform a specific missions and it allows for the flexibility of the robot, e.g. selecting different paths between two tasks within a mission. The approach is based on a multi-camera setup using, off the shelf cameras and optical markers. It has been applied for test-driven development (TDD) and maintenance-like verification of the robot behavior and performance.

Keywords—Supervisory control, Testing, Markers, Mono Vision, Automation.

I. Introduction

Testing robot behavior on a high level mostly relates to external tracking of the robots pose, which includes positions and orientation, over time. There are approaches for tracking with a stereo vision setup and machine learning to recognize the robot within the observed space[5][4][6]. These approaches have been described to be considerably accurate[2]. However, they typically require very sophisticated equipment and high effort for definition and execution of tests and later evaluation of the results. In this paper we present an approach that is based on the typical RoboCup @work competition setup. Here optical markers are attached to the workshop floor, to be perceived by the robots on-board camera system. The markers represent possible waypoints, of which the robot has to pass a number of during a challenge. Scoring for navigation is related to how well and how fast the waypoints are reached. The navigation challenge of the competition reflects the navigation task of a workshop robot to autonomously move between two work stations and possibly move over specific waypoints as in a real production environment. The fact that optical markers are already used in the RoboCup @Work league, lead to the approach of also using an optical marker attached to the robot to track the robot pose. For our approach, we used so-called AR-markers[3]. With AR-marker its possible to determine the relative rotation and translation of a marker with respect to a single camera [9]. For an automated testing, in addition to the robot marker, only a simple overhead vision system is required. However, in order to cover the entire operation area, which is larger than the field of view of a single of our cameras, we combined two cameras. It is necessary that the two cameras have an overlap to see at least one common marker on the ground such that the two images can be related and a relative pose between any two markers in the operation area can be computed. To be able to control and to evaluate the performance of a robot during a mission, two programs are needed. The first one is the tracking software to identify relative displacements and orientations between the optical markers[8] and to evaluate the robot performance. The second one is a high-level task scheduler to initiate the respective actions of the robot, like return to start position or start a mission[12]. Using an automated, vision-based test of real robots, significantly helped to improve the quality of the control software. Simulation, as used before, provided some information, but with cumbersome or typically imprecise modelling of random effects like slip on the ground, only helped during initial software development. Real robots in contrast, even if started from the presumably same initial situation, typically behave differently in some parts of two consecutive repetitions of the same mission. However, since mission goals being the same, it is the task of the control software to compensate these differences. With our approach of automated testing we were able to significantly improve the quality and reliability of our robot control software. The remaining paper is structured as follows. In section II we will shortly present the RoboCup @work competition. Then we will present the vision-based tracking system with the optical markers. Section IV is dedicated to the tracking and evaluation software. We end this paper with an outlook to possible improvements of our approach and a conclusion.

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II. The RoboCup @Work Workshop robot benchmark

The RoboCup @work competition is the most recent enhancement of the RoboCup robotic competitions. KUKA and Locomotec are providing the educational youBot robot[20] that was derived from industrial Kuka robots. It is based on a carrier platform with omnidirectional mobility. The platform typically has a scaled down industrial robot arm, but can be equipped with two of them. The robot control software is based on the ROS-Framework[19]. The challenges of this competition are related to navigation, manipulation, transportation, precision placement and interaction[18]. The competitions take place in a so called arena with service areas, work stations and a conveyor belt. In addition obstacles are placed in the arena. Waypoints and locations are marked with optical markers on the floor. For the navigation challenge the robot is placed at a start point outside of the arena. When the competition starts the robot will receive a list of waypoints with related robot orientation it has to navigate to in the given order and stay there with the given orientation for 5 seconds. Every successfully reached location while having the correct orientation scores points. After all locations are reached, additional points can be gained if the robot leaves the arena on its own within the time limit. The challenges are observed and scored by human referees. Manipulation and transportation challenges add picking up static work pieces and moving them to other spaces in the arena to pure navigation. The conveyor belt challenge adds dynamic pick-up. The challenges are targeted to reflect real work situations are are constantly refined. The main objective of the control software development are overall speed and reliability, as they are reflected in a high score for the competition and a high performance in a real workshop situation. Fig. 1 shows the youBot robot with AR marker in front of one of the waypoint markers.

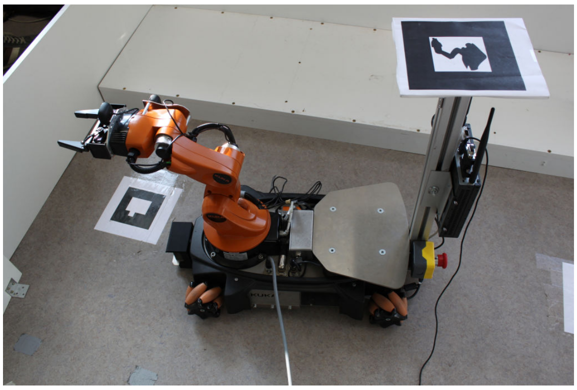

Fig. 1 Robot prepared with it's markers

III. Vision - based hardware setup

For tracking the robot, a number of approaches were considered. Among them was a calibrated stereo camera system with optical circular markers attached to the robot as used in photogrammetry[16][17]. This would make the robot a co-planar target which is trackable by means of its recognized features. Photogrammetry is known as a very accurate method. However, this approach requires at least two cameras for every camera position. Tracking by means of AR markers in contrast can be achieved with only one camera. Using AR markers the x, y, z positions relative to the origin are know[11]. A marker, attached to the robot allows measurement of the robot pose that then can be related to the pose of a reference marker which e.g. marks the origin of the world coordinate system or any other AR marker[14]. Fig. 2 shows an image

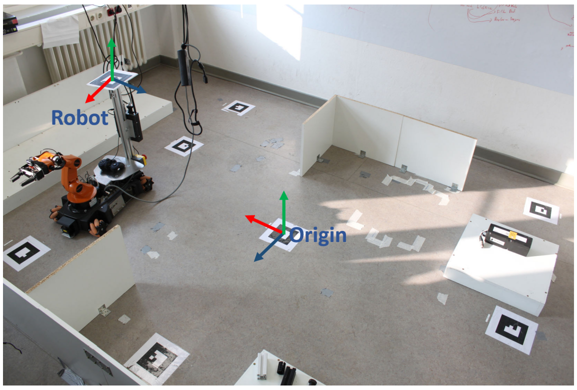

Fig. 2 Overview of the arena and the robot with its corresponding markers

taken by a single camera from an arbitrary position. The optical markers are identified by the detection software and the pose is calculated from the image. In Fig. 2 the marker, representing the origin, at the center of the image and the robot marker are superimposed with the respective cartesian coordinate system. The calculation of the relative displacement and orientation between the origins of the two coordinate systems then is straightforward[15]. Calculation of poses of the waypoint markers follows the same principle[7]. Coordinate systems of the markers are stored and can be referenced even if they should be obstructed temporarily, e.g. by the robot passing over. When the robots pauses its movement, according to competition rules for 5 seconds or for possibly carrying out a manipulation task[13], the pose of the robot relative to the markers in its vicinity, even if partially or totally covered, is stored in a database. In order to cover a sufficiently wide area, two cameras were combined. Combining multiple cameras in general allows to use low-cost cameras, cameras with limited optical resolution or cameras with a high frame rate, since this typically affects the field of view[1]. In the presented system two cameras were mounted to a rigid structure, that itself was mounted to the ceiling above the work area (Fig. 3). Cameras are adjusted with a very small overlap to cover one common marker. In our case, both cameras cover the marker at the origin.

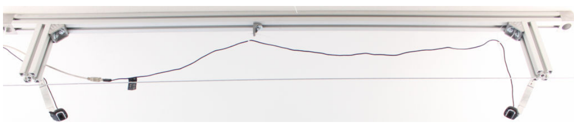

Fig. 3 AR-Marker tracking mount with cameras

IV. Evaluating robot performance

Robot performance is related to reaching the waypoints in a predefined order and as fast as possible. According to RoboCup rules, reaching a specific pose is related to the robot pausing with that pose for a minimum timeof 5 seconds. Since the marker of the robot is elevated above the surface, the z-value has to be normalized to determine its projected position on the ground. After this, the pose of the robot is compared with the pose defined by the closest marker on the ground. The distance in position and deviation in orientation is recorded. Translation, rotation and deviation are saved whenever the robot is pausing for a sufficient amount if time. For RoboCup competitions the closest match will be used for scoring. The software structure used for automated

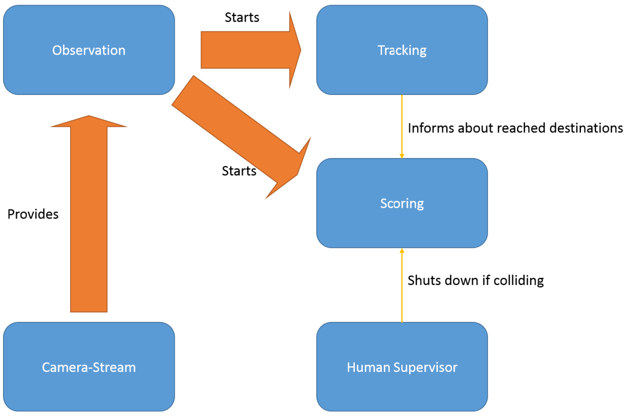

Fig. 4 Software structure of the approach

assessment of the navigation challenge consists of five major components (see Fig. 4). The camera stream component provides the continuous video stream. The observation module starts the tracking module to assure an ordered following of the waypoints. If valid waypoints are reached, a score is calculated from the distance and deviation and stored in the scoring module. Initially a human supervisor is responsible for shutting down the robot in case of collisions. However, with additional means collisions can also be detected automatically, such that an automated emergency switch-off can be implemented. Fig. 5 shows a screenshot of the monitoring tool. The upper half shows the active video image, i.e. the image with the robot in the field of vision. The markers are highlighted and augmented by circles. Circle diameter is chosen such that the robot could reach the marker position by turning only. The bottom part shows the relative poses of the markers on the robot, projected to the ground plane and the ground.

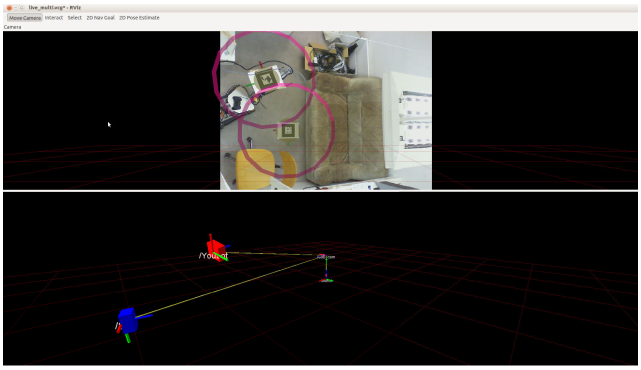

Fig. 5 Screenshot of tracking visualisation using rviz

V. Summary and Future Work

The automated test system, presented in this paper was implemented with low-cost of the shelf components. The only external components required have been two USB webcams and some cables. Test definition was straight forward by a set of optical markers attached to the floor, representing waypoints of the robot and an ordered list of markers respectively positions to be passed by the robot during its mission. With start- and end points also defined by markers, repeated, automated test could be carried out[10]. The vision-based test system provided a powerful means for a concurrent test-driven development of robot control software by a group of four and more developers. It also provided a blackbox testing platform for detection of intermittent malfunction and for quality assurance. Whilst previous a number of failures occurred also during competitions, after introducing the automated test approach, failures after completing the tests could be eliminated almost completely.

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