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Accuracy Evaluation of Landmark-based Visual Positioning of a Collaborative Robot

Abstract: This paper presents research work completed for the TeknoHUB project. The research problem is how accurately a robot can be positioned using a landmark (visual tag) and an optical sensor. An example of this use case would be a machine tending solution, where the robot cell frequently switches its operating position between workstations. The goal of this research is to localize a landmark fixed to a rigid body, such as a machine or a fixture, using a wrist camera attached to the robot, and then measure the error of optical localization based on the camera data. This information is then used to reposition the working frame of the application. This research studies and reports how accurately this can be performed on the selected test case.

Keywords: vision based positioning, landmark, visual tag, collaborative robot, accuracy measurement

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1 Background

Collaborative robots are increasingly used in changing working locations at factories. Temporal setups would benefit if the robot can be automatically positioned accurately relative to the process, e.g., in a machine tending solution. There are a few ways to implement this. One is to have mechanical positioning with accurate position features on the floor or flanges in the machine. Another method uses landmarks (or visual tags) and cameras as positioning features. This paper focuses on the latter and its accuracy evaluation in the selected test case.

2 Aims

The research questions for this case study are:

RQ1. How accurately can a landmark be localized for the purposes of optical positioning of the collaborative robot?

RQ2. What are the main challenges and error sources of landmark based optical positioning?

3 Materials and Methods

This experimental research studies the 3D positioning accuracy of collaborative robot with a landmark and 2D camera. The hardware for this research consists of a collaborative robot, vision system, measurement tools, and a framework for optical positioning of the robot. The robot used in this research is Doosan M1013 collaborative robot, capable of handling weights up to 10 kg with a 1300 mm reach [1]. The robot is equipped with a Smart Vision Module (SVM), which operates as the vision system for this research. This wrist camera has a resolution of 2,5 megapixels and is equipped with an internal LED lighting system [2].

The wrist camera of the robot is used to localize a landmark, which is used as an origin point (frame) in relation to the other positioning features. The landmark is a small board with distinguishable features, which can be used to determine the location, orientation, and distance of the landmark in a 2D image. Thus, the pose of landmark can be defined in relation to pose of SVM and eventually in the robot's coordinate system.

The positioning target and its positioning features used in this research are three metal balls, which are attached firmly into a rigid metal frame. The landmark is attached into the same frame with an aluminum profile. See fig. 1. The goal is to place the whole target frame within the reach of the robot, where it can effortlessly localize the landmark from Field of View (FOV) of the SVM, and reach all three positioning features.

The measurement procedure for the research is as follows. First, the frame is placed in a new pose and rigidly mounted on the robot table. Then, at the beginning of the robot program, the robot first moves to the imaging pose and localizes the landmark using the SVM. It extracts the coordinates of the landmark origin to the robot program. The robot is programmed to move next to the ground truth coordinates of each positioning target relative to the found origin of the landmark. The robot approaches each of the position-
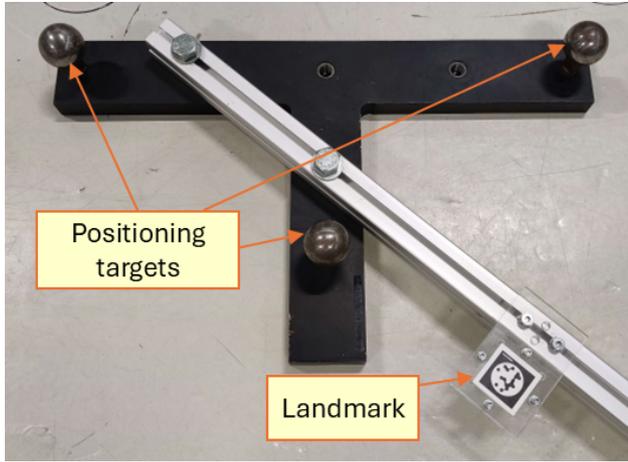
Fig. 1. Target frame with a landmark and positioning targets

Fig. 2. Robot's measurement tool aligned over a position target

ing targets five times from above before moving on to the next one. In an ideal world, the robot's measurement tool, mounted on the flange of the robot, would always have the same position (pressure) applied to all the measurement probes, considering that there are no inaccuracies. The position applied to the measurement probes can be used to measure the inaccuracy of the optical positioning.

Two different level measurement tools are used for the research. First, the reference distances between the landmark and the centers of all metal balls (D 50 mm) need to be known (i.e., the ground truth), which can then be utilized to assess the optical positioning capabilities of the robot and the vision system. This is completed with a coordinate measurement device, which in this study is the 6-axis Romer arm from Hexagon Metrology with a touching probe. It is capable of ±0.029 mm probing accuracy [3]. The second is the robot's measurement tool implemented with the Sylvac E25 system, which consists of three measurement probes and signal processing devices. One probe is capable of measurement accuracy of 1.5 m in one Degrees of Freedom (DOF). The three probes are mounted perpendicular to each other on a frame, which is mounted on the robot's tool flange, forming a measuring tool for the robot (Fig. 2). The tool itself is also measured with the Romer arm to find the exact positions and orientations between the mounting tool flange and each of the three probes. This information was used to define more accurately the Tool Centre Point (TCP) for the robot tool. Why we ended up with this approach will be explained in the full paper. The setup, including the camera and tools, required different calibration procedures. These are also discussed in the full paper.
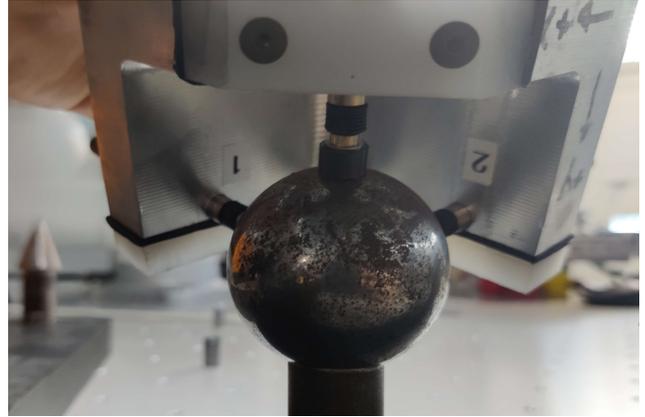
4 Results

The target frame was measured in six different poses under the robot. The measurements were executed five times in each of the target frame poses, i.e., the full measurement procedure was repeated five times.

Measured results include 1) the pose (position and rotation) of the landmark found from the captured image; and 2) both relative and absolute errors calculated at each position target. Relative error is represented with the range across the five measurement iterations. Absolute error is correspondingly represented as the Mean Absolute Error (MAE) within the iterations.

The research provided quantifiable data that could directly be linked to RQ1, for which the research provided results from several different configurations. The landmark can be located with an accuracy of ±0.1 mm or better in the XY-plane and slightly less in the Z-plane. However, the locating procedure had two outliers where these figures were exceeded. The results show that, within the scope of this research, optical localization was completed with varying results. There were two notable observations that could explain these results. First, the localizations where the landmark was near the center of the camera FOV seemed to yield better results. This could be explained by the camera calibration, which was better at estimating depth at the center of the FOV compared to the edges of the FOV. Secondly, the two balls near the landmark (366.12 mm distance for ball 1 and 344.37 mm for ball 2) had better results than the one ball further from the landmark (718.64 mm for ball 3). Overall, the results from all cases combined resulted in an MAE of 0.5 to 3.0 mm.