Central Office of Measures

A multi-camera photogrammetric system for tracking the position of Pozyx target, aircraft and the pose of the robot arm

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The multicamera photogrammetric system was prepared for the EMPIR 20IND02 DynaMITE project which scope was focused on traceable dynamic measurements. The software recognizes and determines the position of targets with ArUco codes. The system calibration can be performed using a checkerboard or coded targets with position determined by a CMM, laser tracker or total station. The system was used for dynamic validation of the Pozyx indoor positioning system based on UBW, the IMUMETER aircraft performance monitoring device and to track the robot arm's pose.

1. INTRODUCTION

Dimensional measurement systems such as Cartesian coordinate measuring machines (CMMs), laser trackers, terrestrial laser scanners (TLSs) rely on standardized tests to assess the performance of their systems. Documentary standards, such as those from the American Society of Mechanical Engineers ASME B89.4, ASTM International, and the International Organization for Standardization ISO 10360 provide detailed description for the placement of reference lengths in the measurement volume of the stereo vision system under test to clearly capture systematic errors in these systems. In the case of stereo vision systems, there is an international standard, the ISO 10360-13 [1] for evaluating the performance of 3D optical systems. Guideline published by the Association of German Engineers and the Association of German Electrical Engineers (VDI/VDE), the VDI/VDE 2634-1 [2] prescribes test procedures for performance evaluation of imaging systems with point-by-point probing.

2. METHODS AND PROCEDURES

The multicamera photogrammetric system was prepared for the EMPIR 20IND02 DynaMITE project which scope is focused on traceable dynamic measurements. The measurement system consists of a camera, lens and coded targets. Each element requires calibration or dimensioning with an accurate measuring device. The software was written in Python (3.9), using the current version of the OpenCV library (4.7).

The system uses monochrome FLIR BFS-PGE-23S3M-C Blackfly S cameras. The cameras have a 1/2.3" chip with a resolution of 1920x1200 pixels, which is slightly higher than the FullHD standard. The cameras are connected to the computer via a giga ethernet connector.

Due to synchronization with flickering lighting in the laboratory, the cameras usually worked at 5, 25 or 50 frames per second. Communication with cameras is possible thanks to the camera manufacturer's library, Spinnaker SDK (PySpin), which works well in OpenCV. Lenses with 6 mm fixed focal length and manually adjustable aperture and focus were used. Selected lenses ensure good sharpness across the entire field of view. The cameras are mounted on rigid Benro Mach3 tripods with 3-axis heads. Camera axes are usually set directly on the observed object and spaced from 45 to 90 degrees between them, which minimizes the uncertainty in determining spatial coordinates.

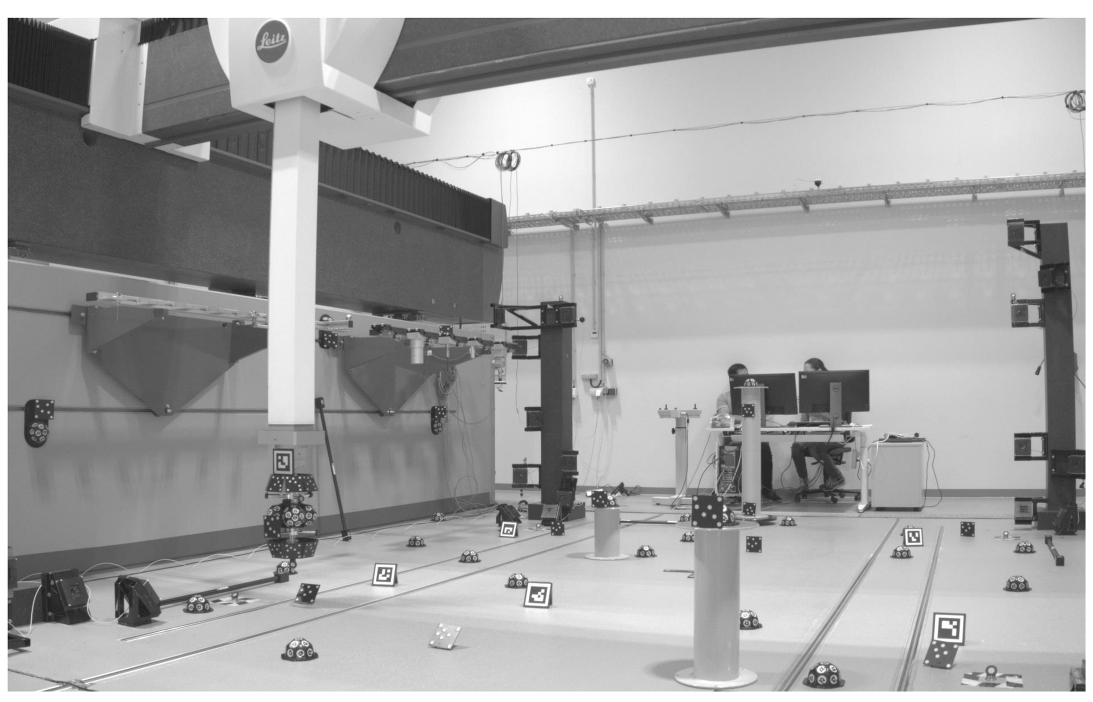

Figure 1. Determining the position of the ArUco target using a large CMM at PTB.

Target recognition

ArUco coded targets are part of the OpenCV library. Depending on the set, it is possible to encode a different maximum number of target numbers. The sets differ in the density of coding elements placed inside the target. In addition to single targets, entire target arrays can be used. This allows us to increase the accuracy of the determined coordinates by using the positions of several markers simultaneously as one.

System calibration

The stereo vision system was calibrated using implementation of the Zhang method [3-4] for the pin-hole model with a number of collected images of a checkerboard pattern.

Number of collected images of a checkerboard pattern. The stereo vision calibration process results in estimates for camera model parameters and associated standard errors determined from the residuals in the least-squares fitting process.

The calibration of the multi-camera system was carried out in two ways. The first approach used the standard OpenCV procedure of placing a chessboard in the field of view. During calibration, several dozen positions of the board in the field of view of both cameras are used. Chessboard size is used as a reference to scale scene.

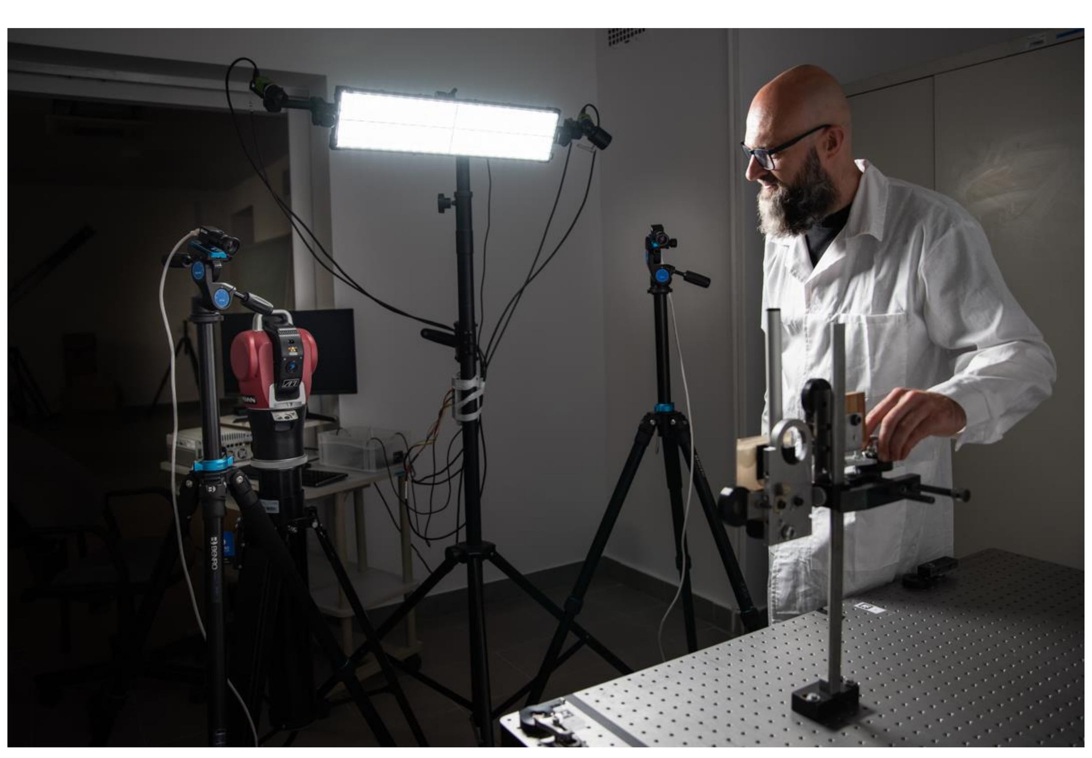

Figure 2. A station for calibrating photogrammetric systems using a laser tracker and a stand with a common target.

Calibration using a checkerboard was performed for two cases. For a scene with dimensions of 500 x 500 x 500 mm, the checkerboard filled most of the space regardless of the position. The obtained RMSE was 1,2 mm. For a scene with dimensions of 3000 x 3000 x 1600 mm, the checkerboard was a small fragment of the calibrated space. The obtained RMSE was 9.4 mm.

In the second approach, an ArUco target was used, the position of which was measured for several dozen points with a large CMM at PTB for a scene with dimensions of 3000 x 3000 x 1600 mm. The obtained RMSE is 2.6 mm (Figure 1).

Validation of multi-camera system

GUM does not have a CMM suitable for calibrating photogrammetric systems by moving the target in the workspace. An alternative method has been proposed. Validation was performed by comparing the position indicated by the multi-camera system with the position obtained using a laser tracker. API Laser Tracker Radian R-50 was used in the measurements. A direct connection between the coordinates indicated by the laser tracker and the photogrammetric system is not possible because the laser tracker provides the location of the SMR centre. To perform the validation, a special rigid stand equipped with three SMR nests was prepared. The stand was placed on an optical table, allowing it to be moved and rigidly screwed to various places on the table. Additionally, the height of the stand can vary within the range of 600 mm (Figure 2).

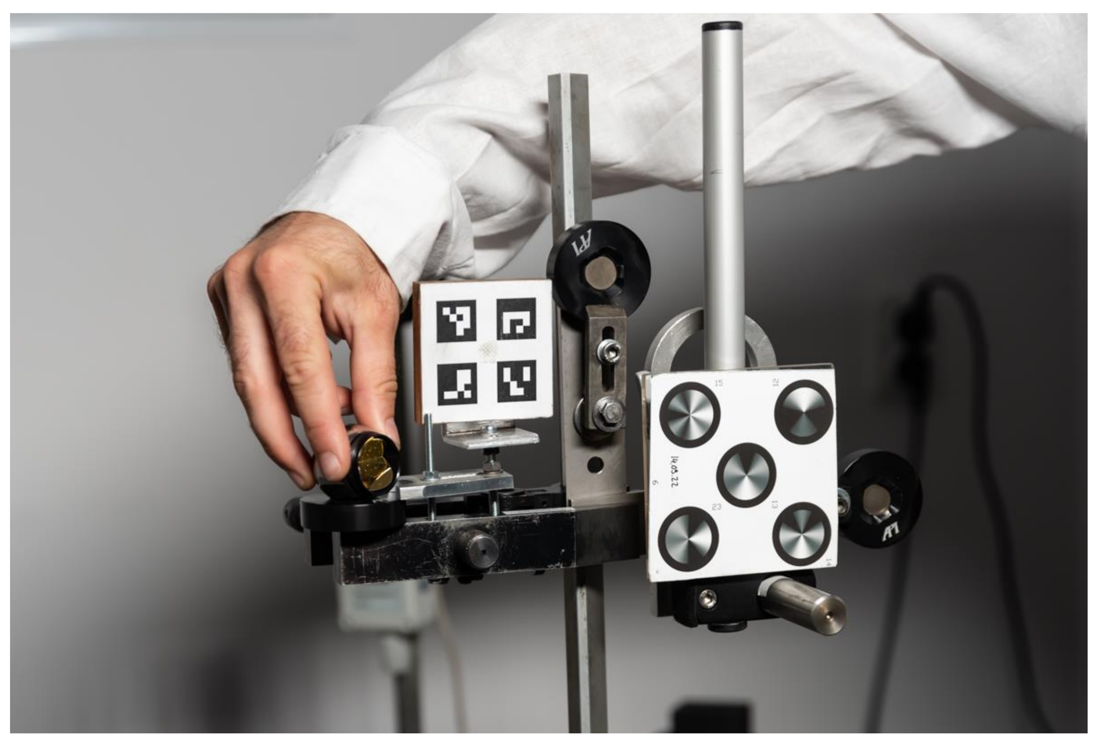

Figure 3. An artifact containing nests for placing a laser tracker SMR retroreflector, combined with photogrammetric targets, enabling the results to be converted to a common coordinate system.

SMR nests were placed on the sides and above the coded target of the validated photogrammetric system so that they were not in the cameras' field of view and at the same time the target did not intercept the laser beam (Figure 3). The position of the target in relation to the SMR nests was determined using standard dimensional measurement procedures using a laser tracker. Several measurement series were performed before, during and at the end of validation. Linking the position of the nests with the position of the coded target allows you to compare the readings from both devices

3. APPLICATION OF THE SYSTEM FOR DYNAMIC MEASUREMENTS

Pozyx UWB indoor positioning system

The Pozyx system is a commercial indoor positioning system based on the Ultra-Wide Band (UWB) technology. It is composed of five modules: four anchors with known positions (defined by the operator) and one target called tag. The target is driven by an Arduino microcontroller as suggested by the manufacturer. The algorithm used for the localization is based on the knowledge of the distances between the target and the different anchors. The latter is estimated by TOF. In fact, the UWB technology uses a 500 MHz band which makes a temporal resolution of 0.16 ns allowing the detection of the different reflections (i.e. multipaths) of the radio signal [5].

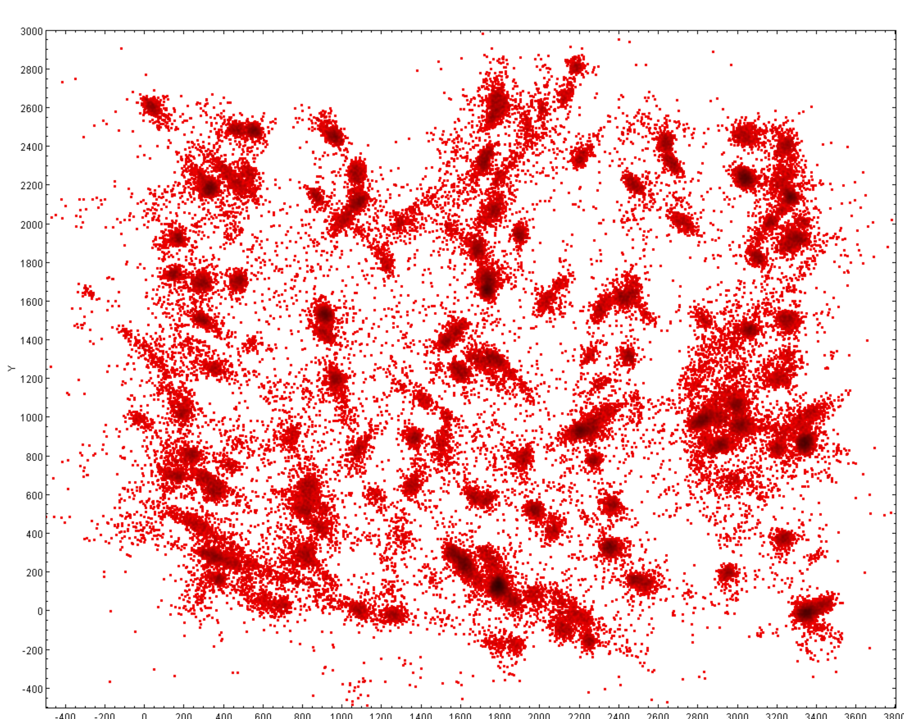

Figure 4. Horizontal terget positions indicated by the Pozyx system.

Measurements of the common target were taken at five heights above the floor throughout the entire scene. Multicamera system readings were collected for each static position. Pozyx locations were recorded continuously with timestamps. Measurements from Pozyx were cleaned with a 1 second wide median filter. Time moments corresponding to measurements from other systems were used to analyze system errors. The mean position errors was 110 mm, 112 mm and 406 for errors in X, Y, and Z, respectively. The standard deviation of position errors was 135 mm, 134 mm, and 448 mm for errors in X, Y, and Z, respectively.

IMUMETER aircraft performance monitoring device

Takeoff and landing belong to the most critical maneuvers of airplanes, especially when operated on unpaved, short grassy runways. The IMUMETER is measuring device based on an analysis of aircraft ground speed and airframe vertical acceleration during takeoff or landing [6,7]. The use of deep learning methods automatically detects the required feature representation directly from the data. In order for the neural network to be trained, reliable reference data is needed recording flight parameters along with the take-off and landing location. A multi-camera system monitoring the position of the aircraft was used to measure the take-off and landing site. Camera-based techniques can be easily assembled in-situ, they are low cost and provide accuracy sufficient for several industrial metrology needs. In the case of passive systems, 3D point coordinates are derived by triangulation from image points. The system was adapted for measurements at the airport. The photogrammetric system was used as aircraft ground performance monitoring for to collect training data and validation of device. During the measurement campaign, a series of test flights will be performed at the grass airport.

Figure 5. Measurement campaign to determine aircraft landing positions for the validation of the IMMUTER system.

Dobot Magician robot arm

A multi-camera photogrammetric system was used in 23IND08 DI-Vision project to track the robot arm's pose. ArUco markers were placed on the arm. The robot was programmed to perform repetitive sequences of movements. Tracking the targets' position allowed for observing the accuracy, repeatability, and smoothness of the robot's operation. Further work will focus on finding objects and precisely grasping them with the robot's gripper.

4. CONCLUSIONS

The developed system achieved accuracy sufficient to perform measurements. The system calibration can be performed using a checkerboard or coded targets with position determined by a CMM, laser tracker or total station. A system validation method using a laser tracker was developed and tested. The system has been successfully used on a wide range of measurement scales, from 500 mm to 100 m.

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