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PROPOSAL OF CAMERA CORRECTION FOR TOOL POSITIONING IN A ROBOTIC MILLING PROCESS

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Abstract: Nowadays, automation is a dominant process in the engineering industry using several modern technologies, one of which is machine vision. Machine vision is a technology used to control processes performed in automated manufacturing, based on the recognition of geometric shapes of an object and measuring their distance using only a camera sensor. Object recognition is a common practice in all industrial cameras. Many industrial cameras can determine the shape of the imaged object, orientation, and position with maximum accuracy. In this paper, we will present the error correction of Cognex camera. The Cognex camera will be used in conjunction with an IRB 1100 robotic arm, where the resulting correction will be applied for accurate tool positioning in the milling process.

KEYWORDS: Correction, Cognex camera, Geometry, Robotics,

1 Introduction

Robotics is an interdisciplinary field of engineering and science that encompasses mechanical engineering, electronic and electrical engineering, computer science, and others. Robotics deals with the design, construction, operation, and use of robots as well as computer systems for their control, sensory feedback, and information processing [1]. Researchers have begun to look more closely at individual applications of robotic arms and have explored the limits of the systems in question. With gradual development came the possibilities of moving increasingly smaller objects with improved tool endpoint positioning. These applications did not do without the use of peripheral devices such as sensors or cameras that allowed precise guidance of the robotic arm to a given position. This publication deals with the issue of collaboration between a robotic arm and an industrial camera. The industrial camera was used to identify the calibration object and determine its position. The robotic arm is then moved to the position obtained by the camera. An important factor in such an application is the accuracy of the position of the identified object. The second part of this publication deals specifically with the inaccuracies of the obtained object position and the actual position of the object. The inaccuracy incurred when the camera is at a stable distance from the workspace as a function of the height of the identified object has been shown. At the end of the publication, an equation for eliminating the position inaccuracies arising depending on the height of the identified object and the distance of the camera from the working space was presented.

2 Robotic arms and their usage

Robots can be used in any situation and for any purpose, and nowadays many are used in industrial, medical, military and many other sectors. Robots are most divided into two applications, assembly robots and non-assembly robots [2]. Currently, there are much research focusing on the applications of robotic industrial arms. Robotic arms have various advantages that make it possible to replace human workers in monotonous work activities. Robotic arms

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also help to increase productivity due to significantly shorter cycle time and production flexibility [3]. In industrial practice, robotic arms are mainly used for simple pick and place (pick and place) applications to move objects from point A to point B. Initially, the integration of a robotic arm into pick and place applications was used to relieve the burden on human workers. Hence, high demands were not placed on the accuracy and repeatability of the process. Since the first introduction of the robotic arm into simple applications, the technology has advanced rapidly and has started to be used in various industries and implemented into more demanding applications. Robotic arms have come to the fore mainly in the medical, military but especially in the engineering industry [4].

Advanced applications cannot do without a variety of sensing devices to control and monitor the environment in which the application is executed for safety and security. These sensing devices are also under continuous improvement to increase the accuracy and productivity of the work performed [5].

3 Machine vision

Machine vision gives the robot the ability to perceive its surroundings. The goal of machine vision is to digitize the object under study into an image that is processed using software tools. Individually used machine learning methods based on machine vision can be used to achieve the best prediction results [6]. Machine vision is a system engineering discipline that can use also multiple cameras to automatically detect objects in the production area [7]. The data extracted from the image analysis is also used to control the production process [7]. The result of the analysis is information for the robotic system about the quality of the product, the position of the part for its grasp by the robotic arm. The main advantages of using industrial camera systems are accuracy, speed, robustness, and repeatability. Camera systems have found their use in the areas of location, identification, measurement, and inspection applications. Machine vision is composed of functional blocks, with each block providing one part of a complex system. The functional blocks are [8]:

- Camera system
- Lighting
- Data processing unit
- Communication module

The camera system consists of the selected image sensor and lens. Through the lens and the sensor, the transformation of the image into digital form is ensured. For the transformation of the image into digital form, it is necessary to ensure constant lighting conditions by adding additional lighting to the camera system. Lighting is an important element in machine vision as it determines the overall quality, stability, and reliability of the camera system. Once the image is acquired and transformed, it is necessary to process and evaluate the acquired data. This function is provided by a central evaluation unit (vision processing), which can be embedded directly in the camera system or externally in a computer. The last element of the camera system is the communication module ensuring the transfer of information between the camera system and the higher-level control system (robot, PLC).

4 Image processing

Machine vision image processing is based on transforming the object under study into a digital form. Each object, a photo of an object, is represented in the Digital Image by an array of samples of luminance intensities, where each sample is constrained by precision, a range of intensity values [9]. The range of values, or intensity accuracy, is expressed in bits that represent the number of brightness levels. An 8-bit range corresponds to a range of luminance values from 0 to 255, 4-bit 0-15, 2-bit 0-3, 1-bit 0-1. Depending on the type of image, the intensity value for a single pixel also varies. In a black and white image, a pixel is characterized by a single intensity value. For colour images, each RGB base colour is represented by an intensity value. In simpler object recognition applications, camera systems with 8-bit range operating with a black and white image are used. The first step to identify an object is to know the template and the boundaries of the search space based on which the camera system should search. The principle of object search is in comparing the histograms (graphical representation of the brightness intensity field) of the template and the captured image [10]. The captured image is sequentially compared with an array the size of the search space. The goal of the search is to find a region of the captured image with an identical histogram to that of the master.

After successful tracking of the object, it is followed by its modification by thresholding, where the captured object is transformed according to a predefined constant (threshold) [9, 10]. Thresholding is followed by binary morphology to increase contrast and remove noise. The last step to object detection is the use of edge and object detection algorithms such as Hough transform or canny edge detector.

5 Workspace preparation

The industrial robot used for the application will be the ABB IRB 1100. This robot will be placed on the workbench where the COGNEX camera will also be placed. The position of the camera is determined by the reachability of the robot. The height of the camera is determined by the detection accuracy and the required field of view but also by the working envelope of the robot arm.

With the help of the Cognex smart camera, the parts can be detected quickly and sent to the robot control unit in time [8]. The location of the camera is situated above the robot workspace where the test rollers will be placed. Figure 1 provides an overall view of the robot arm workspace along with the smart camera.

Fig. 1 Robotic centre workspace

6 COGNEX camera calibration

An important step for correct measurement is the actual calibration of the equipment used. In our measurement we will use the mentioned COGNEX camera. The whole procedure of calibration and program creation will be implemented in the integrated vision add-on environment, which is part of the robotstudio program. Calibration is the process of converting pixel measurements into meaningful, realistic values. In this process, a two-dimensional (2D) transformation is used to mathematically map points from image pixel coordinates to real-world coordinates. Once the image is calibrated, other vision tools can refer to the calibration as input and report results in calibrated (real-world) units. Using a user-configurable calibration grid pattern, the calibration grid produces a 2D transformation to convert between pixel and real-world coordinate systems. The calibration grid (Fig. 2) computes a 2D transformation between the set of points identified by the points located in the calibration grid points, or vertices of the checkerboard pattern of the calibration grid, and the camera coordinate system is also determined based on the irregularity of the checkerboard grid.

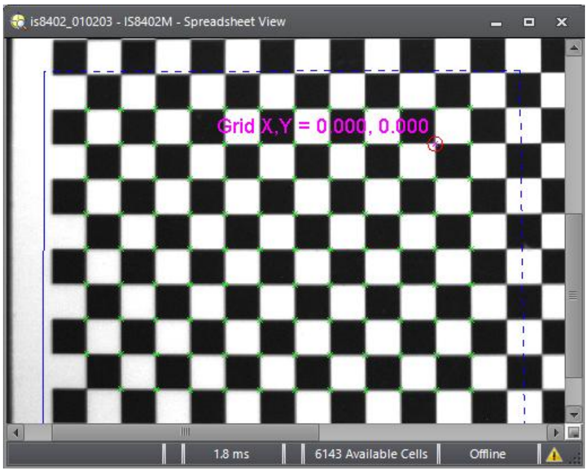

Fig. 2 Calibration grid

The second essential part of camera calibration is the actual non-illumination of the exposure being taken, or the overexposure of the area under the camera. In this step, the non-illumination of the sensed environment is correctly adjusted (Figure 3), otherwise an undesirable phenomenon may occur, which would lead to obtaining incorrect values of the position and orientation of the sensed object.

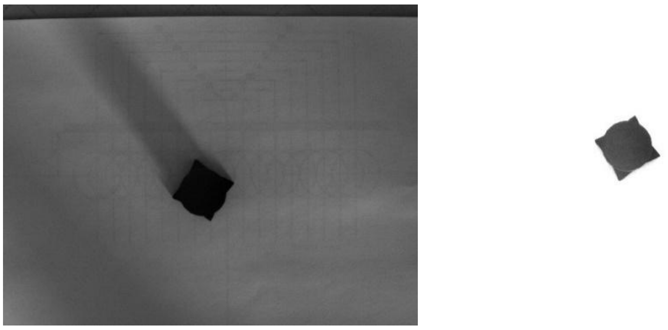

Fig. 3 Exposure difference between bad and good lightning

7 Object identification by PatMax Pattern

The FindPatMaxPattern function uses a two-step process to find and evaluate a pattern. In the first step, the raw image is searched using a coarse pattern filter to find potential candidates that might be a good match. All parameters are taken into account: Acceptance, Contrast, Angle, Scale, Aspect, XY Overlap, etc. Each parameter is assigned a weighted score and the final score is the combination of all the individual scores. Even if one or more parameters are scored very poorly, it is possible for the remaining parameters to give a score that exceeds the value of the Acceptance parameter. The data for each candidate that exceeds the value of the acceptance parameter is placed in a memory array.

8 Object identification by PatMax Pattern

The Cognex camera used in our measurement is designed to search for objects in the XY plane, which means that the height of the searched object cannot be identified with the camera. When searching for objects with different heights, shape distortion and projection error occur. The projection error is caused by the object itself, the taller the object is, the greater the difference in the distances of the pad and the surface of the object from the camera. The difference in distances, together with the convexity of the lens, cause deviations in the real coordinates of the object and its imaged, calculated, coordinates with respect to the camera coordinate system. The magnitude of the deviation depends on the position of the object relative to the centre of the camera lens. In the centre of the lens the deviation is negligible, in the extreme positions the deviation is significant.

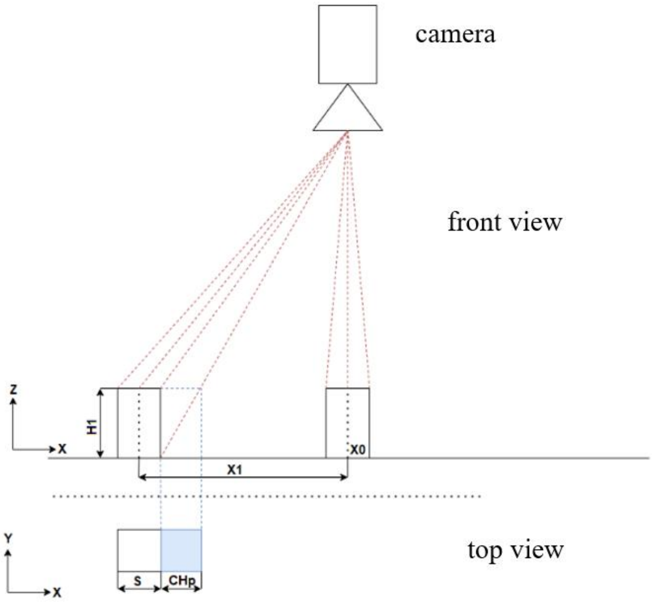

Fig. 4 Projection error for object with height H1

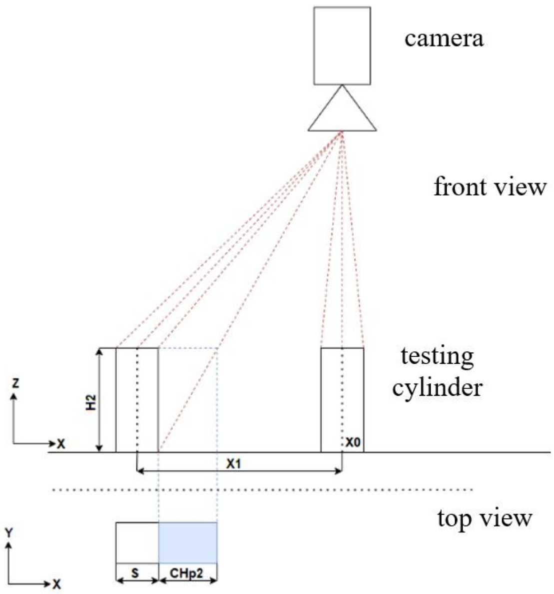

Fig. 5 Projection error for object with height H2

This phenomenon can be seen in the figure where two different distances are compared while keeping the same cylinder height. This error causes the robot to be unable to reach the correct position to remove the part. This error can also be seen in the figure which represents two different heights of the test cylinder. From the figures (Figure 4 and Figure 5), we can confirm the statement that the higher the test cylinder is H2 > H1, the larger the projection error $CH_{p2} > CH_{p1}$ becomes.

9 Measurement and calculation of deviation

Detection of the bias (projection error) consisted of moving the search object, a cylinder, over the area under the camera in 10 mm increments from the centre of the camera. The displacement was performed in both directions with limit values of 80mm from the camera centre (Fig. 6).

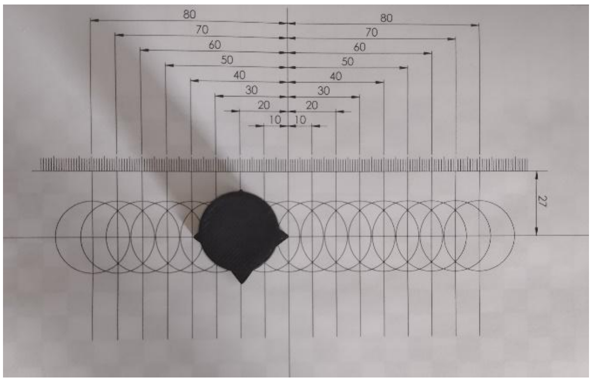

Fig. 6 Error measurement with test object

The actual X_R coordinate of the object was recorded and the X_k coordinate value from the camera was captured. Then the value of the deviation, o_d, was determined according to the formula:

$$od = |X_R - X_k| \tag{1}$$

The resulting deviation values for the given positions are shown in Figure 7. To eliminate the given deviations, a corrective conversion of coordinates depending on the height of the camera above the substrate H, the height of the measured object h and the coordinate obtained by the camera X_k was proposed. The whole situation is shown in Figure 8.

Using the basic trigonometric functions and the similarity of the triangles, we derived the final formula to calculate the coordinate in the form of:

$$X_R = X_k - \left(\frac{hX_k}{H - h}\right) \tag{2}$$

The resulting correction formula (2) was applied to the source code of the robotic arm. The correctness of the formula was verified by computation before implementation in the robotic arm. The results obtained are shown in Figure 9. The numerical values are shown in Table 1, where the effect of the correction on the coordinates of the search object can be seen. The effect of the correction is particularly visible at the extreme positions of -80 and 80 mm, where it was possible to reduce the original deviation of 8.2 mm to 0.171 mm (in the case of the positive extreme point) and 7.2 mm to 1.121 mm (in the case of the negative extreme point).

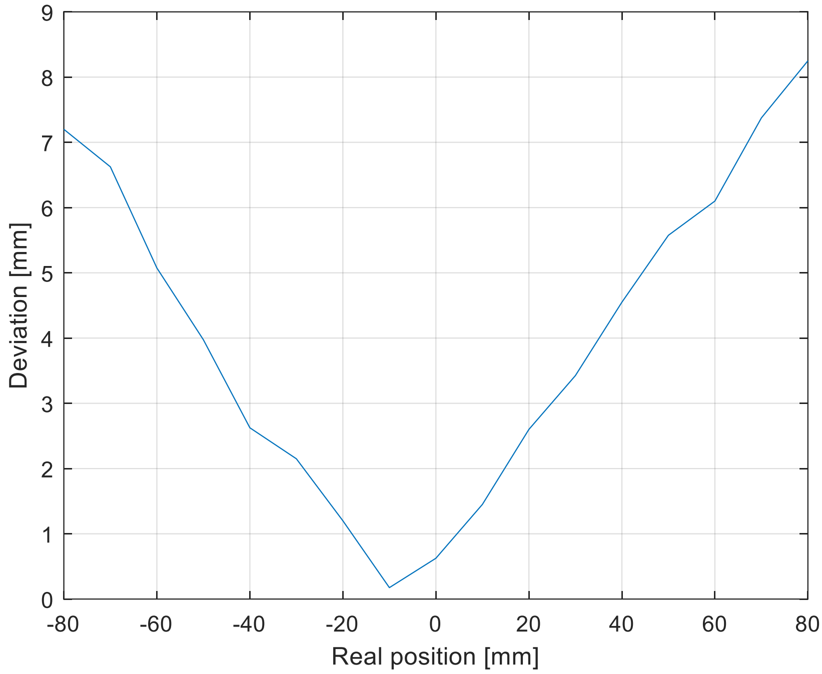

Fig. 7 Deviation size dependency on real distance from the camera centre

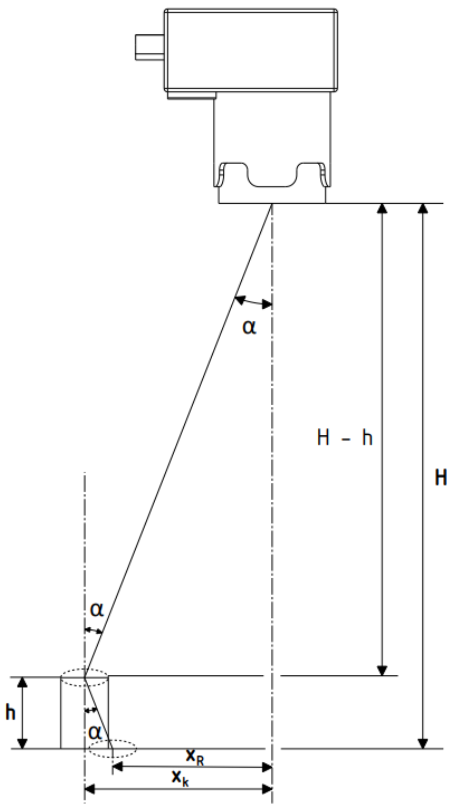

Fig. 8 Deviation measurement

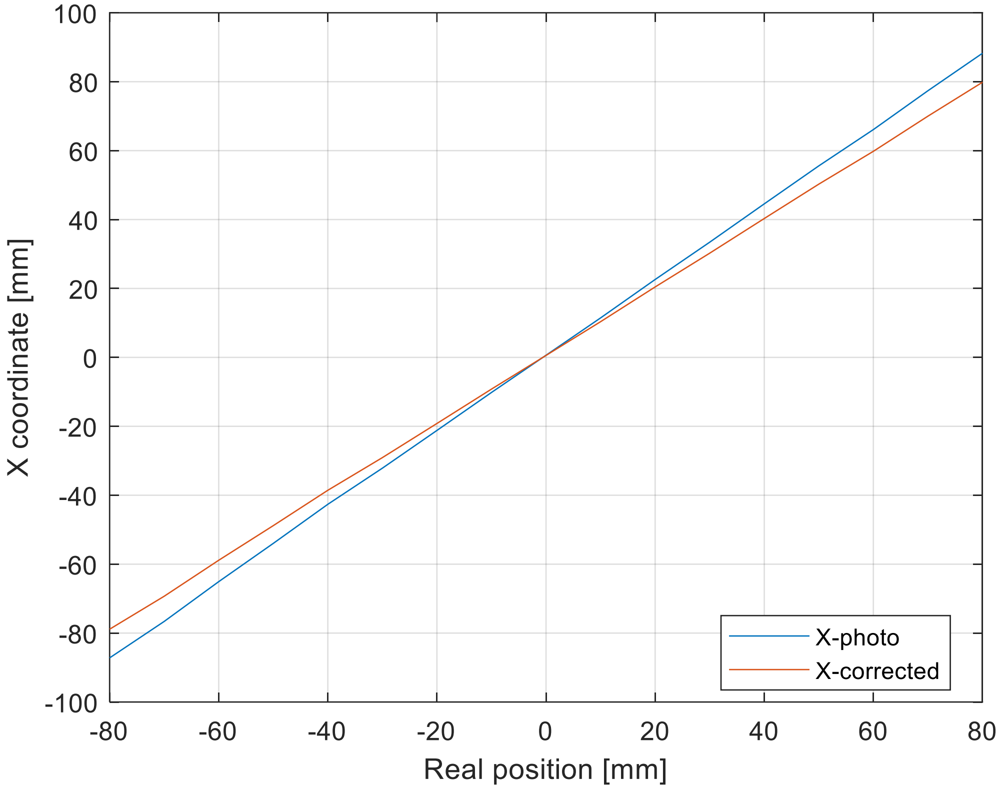

Fig. 9 Comparison of coordinates obtained by camera before and after correction.

Tab. 1: Comparison of coordinates X_R – real, X_p – camera, X_k – correction

X_R [mm]	X_p [mm]	X_k [mm]
-80	-87.200	-78.879
-70	-76.625	-69.314
-60	-65.075	-58.866
-50	-53.975	-48.825
-40	-42.625	-38.558
-30	-32.150	-29.082
-20	-21.200	-19.177
-10	-10.175	-9.204
0	0.625	0.565
10	11.450	10.357
20	22.600	20.444
30	33.425	30.236
40	44.550	40.299
50	55.575	50.272
60	66.100	59.793
70	77.375	69.992
80	88.250	79.829

CONCLUSION

In this publication, the use of camera systems with robotic arms in robotic milling applications has been presented. In the introduction, the possible applications of robotic arms, the basics to machine vision and camera systems were mentioned. Subsequently, a workstation consisting of an ABB IRB1100 robotic arm and a Cognex industrial camera was presented. The programming and communication of the industrial camera and the robotic arm was also shown. The main point of the paper was the possibility of removing inaccuracies, deviations, when using the industrial camera and taller objects. A correction equation was shown to remove the aberration, which reduced the value of the aberration from the order of units of millimetres to 0.2 mm. The value of 0.2 mm represents the resolution of the camera used, in our case the value of 0.2 mm corresponded to 1 pixel. If a higher resolution camera is used, the resolution is increased and thus the overall deviation of the camera system is reduced.

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