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# CONFIGURATION AND PROGRAMMING OF THE FANUC IRVISION VISION SYSTEM FOR APPLICATIONS IN THE DYNAMIC ENVIRONMENT OF MANIPULATED ELEMENTS

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***Abstract:*** The article presents the configuration process of the vision system with a fixed camera and identification of position of manipulated components related to robot's scene coordinates system. In the research phase, a 2D vision system was used, which determines the location of the detail in the form of X and Y coordinates, as well as the orientation around the Z axis (defined as the R parameter). The description of the camera configuration, defining the TCP point of the robot, the definition of the robot's scene and the camera calibration procedure were discussed in detail. Subsequently, a teaching process of the calibration pattern and a definition of the reference position were described. The authors presented also the basic steps of elementary image analysis related to processing, recognition of the learned patterns and their locating in captured images.
***Key words:*** vision systems, robotics, Artifical Intelligence, image analysis, automation of manipulation processes.

## 1. INTRODUCTION

The main tasks of modern industrial robots are palletizing, packaging, welding, pressure welding, cutting, gluing, assembly and many others. The robot can accomplish required tasks using knowledge about the environment, which is defined by the control algorithm in an unchangeable manner (Cubero, 2006). Such an approach assumes the total invariability of the robot scene or possibility of modifications occurring in a strictly predictable way. Modern industrial robots (Rashitov and Ivanou, 2019) usually work in a dynamically changing environment, in which positions of manipulated components do not show the features of repeatability and additionally occurs extraordinary cases that could not be anticipated by the programmer (Connolly, 2007). Current development trends require the implementation of devices characterized by an increasing degree of an intelligence, an autonomy as well as an interaction with the dynamically changing industrial environment. To the main assisting systems that enable partial meet of these needs could be classified industrial vision systems (Golnabia and Asadpourb, 2007). Vision systems allow to interact with the environment (Košecká et al., 2015), orientation in it, simple determination of the basic properties of objects and provide a higher level of autonomy (compared with other groups of industrial sensors).

The manufacturers of industrial robots meet the growing market expectations by the implementation of vision systems solutions dedicated for their own robot controllers. One such example is the FANUC iRVision vision system (B-82774EN-3/03, 2019). The use of the iRVision system minimizes the time and number of activities performed during the implementation phase, eliminating at the same time the need to develop advanced image analysis algorithms (Jiang et al., 2019, Cholewa, A., 2018), as well as configuring the communication between the vision system and the robot controller. The user has to perform only basic configuration tasks, teach the vision system, as well as develop the structure of the robot's control algorithm (B-82774EN-3/01, 2019). The process of a initial preparation and running of the application should also take into account many additional factors, related mainly to the functional safety and an optimization of work.

## 2. SYSTEM CONFIGURATION

### 2.1. Identification of main functional parameters and selection of a vision camera

As a part of the research scope, it was assumed configuration of the 2D vision system for the purpose of recognition and location of two types of objects (showing significant similarity features, Figure 1), in order to sort them on separate storage palettes (Lyshevski, 2008).

The selection of camera (especially optical system parameters) is a crucial for the satisfactory reproduction of features of real objects (Xinguo and Guangjun Zhang, 2013).

In particular, parameters such as the minimum size of the detail reproduced in the recorded image, the maximum field of a view and the distance of the camera lens from the surface of the detail should be taken into account (Yahui and Xianzhong, 2011).
Based on the described data it is possible to select the resolution, size of the matrix, as well as the focal length of the camera lens (Zhuang and Roth, 2018).

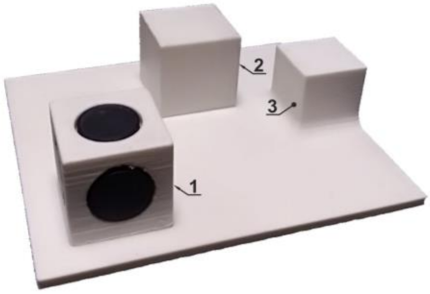


Fig. 1. View of objects subjected to the sorting process using a vision system, where: 1, 2 - objects of the first and second type, 3 - storage pallet

The functional parameters of the camera were selected on the basis of the following equations (1÷4), in the case of:

- height of the field of view ($P_W$):

$$P_W=[(d_{OC}\cdot C_W)-(d_W\cdot C_W)]/d_W \quad (1)$$

where:
$P_W$ - height of the field of view [mm],
$C_W$ - height of the CCD matrix [mm],
$d_W$ - focal length of the lens (selected in relation to the $P_W$ height) [mm],
$d_{OC}$ - distance of the observed object from the camera [mm],

- width of the field of view ($P_S$):

$$P_S=[(d_{OC}\cdot C_S)-(d_W\cdot C_S)]/d_S \quad (2)$$

where:
$P_S$ - width of the field of view [mm],
$C_S$ - width of the CCD matrix [mm],
$d_S$ - focal length of the lens (selected in relation to the $P_S$ width).

- minimum height of the observed object ($w_H$):

$$w_H=P_H/(0.5\cdot L_{PH}) \quad (3)$$

where:
$w_H$ - minimum height of the observed object [mm],
$P_H$ - height of the field of view [mm],
$L_{PH}$ - number of pixels on the matrix height dimension,

- minimum width of the observed object ($w_W$):

$$w_W=P_W/(0.5\cdot L_{PW}) \quad (4)$$

where:
$w_W$ - minimum width of the observed object [mm],
$P_W$ - width of the field of view [mm],
$L_{PW}$ - number of pixels on the matrix width dimension.

Based on the overall dimensions of the test station, the parameters of the video camera were calculated (Table 1).

Table 1. Calculated configuration parameters of the vision system (on the basis of equations 1÷4)

| Parameter | Calculated value [mm] |
|---|---|
| Height of the field of view ($P_W$) | 356.4 |
| Width of the field of view ($P_S$) | 475.2 |
| Minimum height of the observed object ($w_H$) | 1.4 |
| Minimum width of the observed object ($w_S$) | 1.4 |

In the application the Sony XC-56 monochrome camera connected to the robot controller was used. Specification of the camera is shown in Table 2.

Table 2. Specifications of the SONY XC-56 camera

| Parameter | Value/ feature of the parameter |
|---|---|
| Image device | 1/3 type IT progressive scan CCD |
| Effective picture elements | 659(H) x 494(V) |
| CCD vertical drive frequency | 15.734 kHz ± 1% |
| Scanning system | Normal: 525 lines<br>Non-Interlace: 1/30s<br>Binning: 263 lines, 1/60s |
| Output signal frequency | 29.97 Hz (normal mode),<br>59.94 Hz (binning mode) |
| Sensitivity | 400 lux (F8 Fix Gain (0 dB)) |
| Min. illumination | 0.5 lux (F1.4, Manual Gain Max) |
| S/N ratio | 58 dB |
| White clip | 820 mV ± 70 mV (F1.4, Fix Gain) |
| Normal shutter speed | OFF to 1/15000s switchable at rear panel |
| Extrenal shutter speed | 1/4 to 1/100000s |
| High-rate scanning | R/R mode binning off: max 120 frames/s,<br>R/R mode binning on: max 180 frames/s,<br>External trigger shutter mode (MODE 1) binning off: max 120 frames/s,<br>External trigger shutter mode (MODE 1) binning on: max 180 frames/s |

An industrial robot can also carry out manipulation tasks without utilization a vision system, using the knowledge of the environment contained in the control programme. However, this approach assumes the invariability of the sequence of performed tasks or making changes in a algorithmized manner.

**2.2 Configuration of the vision system in the aspect of cooperation with the industrial robot**

The main tasks of the vision system in the presented application include: identification and verification of geometric features of objects located on the robot stage, determining the location and orientation of objects, navigation and control of the robot's

kinematic system and gripper.
The measurement of the robot's displacement, relative to the reference position, can be estimated in the coordinate system associated with (Figure 2): robot scene (Fixed Frame Offset; in the case of displacement of the gripped detail), tool (Tool Offset; approach used when it is possible to change the position of the detail relative to the gripping tool or the possibility of relative displacement during grasping e.g. vacuum, needle and magnetic grippers).

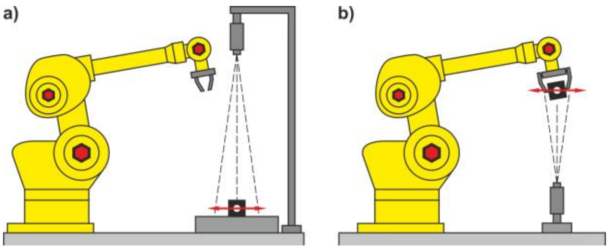


Fig. 2. The methods of identifying the position of objects in the coordinate system: a) Fixed Frame Offset, b) Tool Offset

The vision camera can be permanently mounted to a fixed bracket or directly to the wrist of an industrial robot (Figure 3).

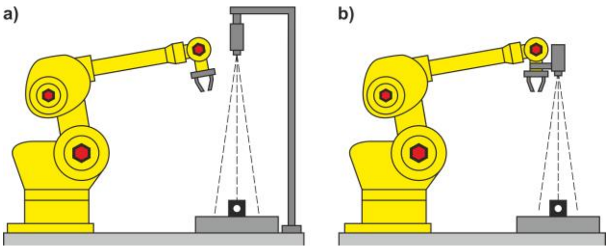


Fig. 3. Vision camera mounting methods: a) fixed bracket oriented relative to the global coordinate system of the robot, b) mounting on the robot wrist

Mounting on a robot wrist results in maximization of the area covered by the camera lens once, as well as the ability to capture images from different positions and distances. In this case, the position of the detail depends not only on the location of the camera, but also on the current position of the robot wrist (which increases the complexity of the calculations). In addition, the movement of the robot during shooting may cause blur (Michalski, 2018).
Due to the characteristics and requirements of the application, the vision system configuration with the fixed camera and determination of detail position related to the coordinate system of the robot scene was used (Figure 4).
The advantages of permanent mounting include image recording with a fixed value of camera parameters (e.g. distance, focal length etc.). The described solution allows additionally for acceleration of the objects identification process, due to the possibility of performing image processing during the robot's other activities.

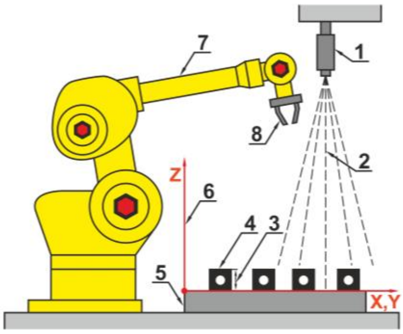


Fig. 4. View of the vision system configuration used for the research; where: 1 - camera, 2 - optical axis of the camera, 3 - height of workpiece in Z direction (Z coordinate of measurement plane viewed from XY plane of application user frame), 4 - manipulated object, 5 - storage pallet, 6 - reference axis system (Application User Frame), 7 - robot, 8 - gripper

Figure 5 shows the view of the complete stand, including robot instrumentation (Michalski, 2017). In addition, a SICK WTB4S photoelectric sensor with adjustable output threshold value was mounted on the gripper (Figure 5b). The photoelectric sensor was used to control the distance between the robot's wrist and manipulated parts, which enables precise positioning of the gripper's jaws.

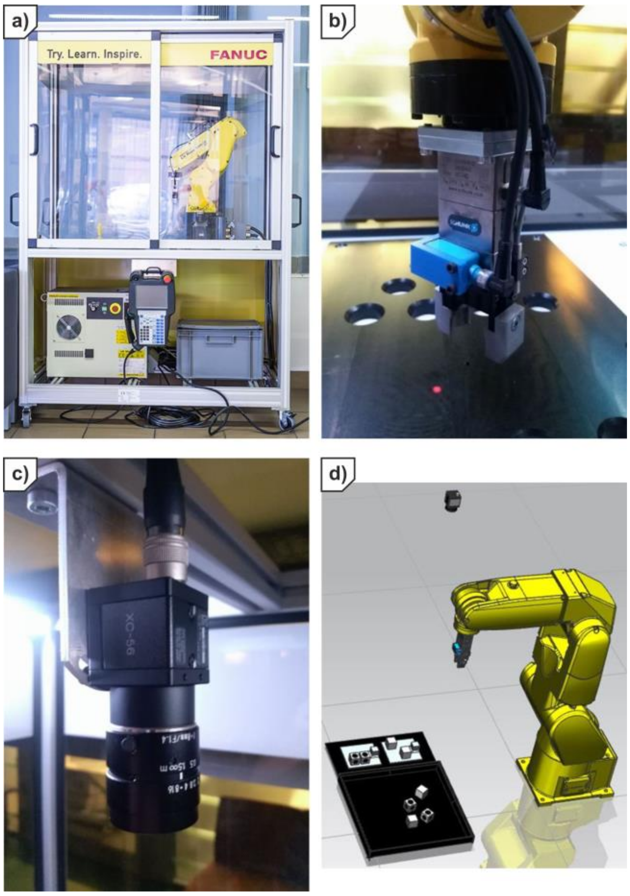


Fig. 5. Views of: a) the test stand with the FANUC LR Mate 200iD/4S series robot, b) the robot wrist with the SCHUNK EGP 40 gripper and the SICK WTB4S photorelay, c) the SONY XC-56 camera, d) a 3D model of the test stand built in the SIEMENS NX11 environment

## 2.3 The procedure for configuring vision system and industrial robot

The image processing algorithm presented in Figure 6(a) has been adopted in the field of vision system operation. The assumed algorithm for configuring the vision system (connected to the industrial robot controller) includes all the necessary steps leading to obtain a fully functional system (Figure 6(b)).

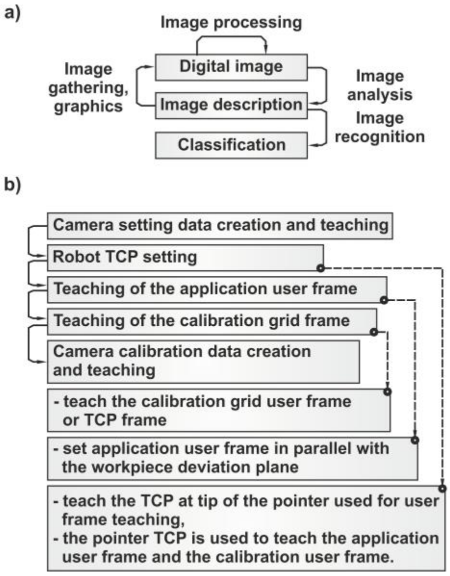


Fig. 6. View of: a) the vision processing algorithm, b) the vision system configuration procedure

A correct operation of the vision system required configuration of the connection to the robot controller via Ethernet network (the controller is identified by the IP address). All the necessary steps have been carried out using the WEB SERVER application (which allows also to view configuration data, current parameter values as well as launch the iRVision system). The first stage was the configuration of the camera type and its parameters (Figure 7).

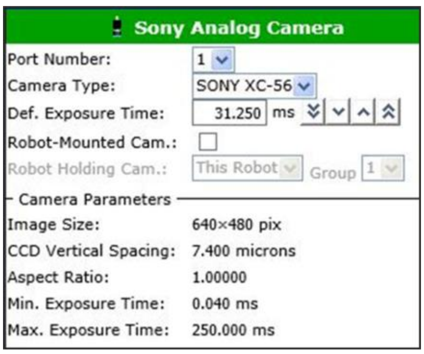


Fig. 7. View of the camera main parameters configuration screen

The next configuration step includes the definition of the TCP (Tool Center Point) of the auxiliary tool, which at a later stage was used to determine the coordinate systems of the manipulator working space and the vision system associated with the calibration screen (in this case the four-point method was used; Figure 8). In the next step the AUF coordinate system (Application User Frame) has been defined, using the three-point method (Figure 9). The three positions define, respectively: the landmark of the coordinate system center, the positive direction of the X axis and the positive direction of the Y axis.

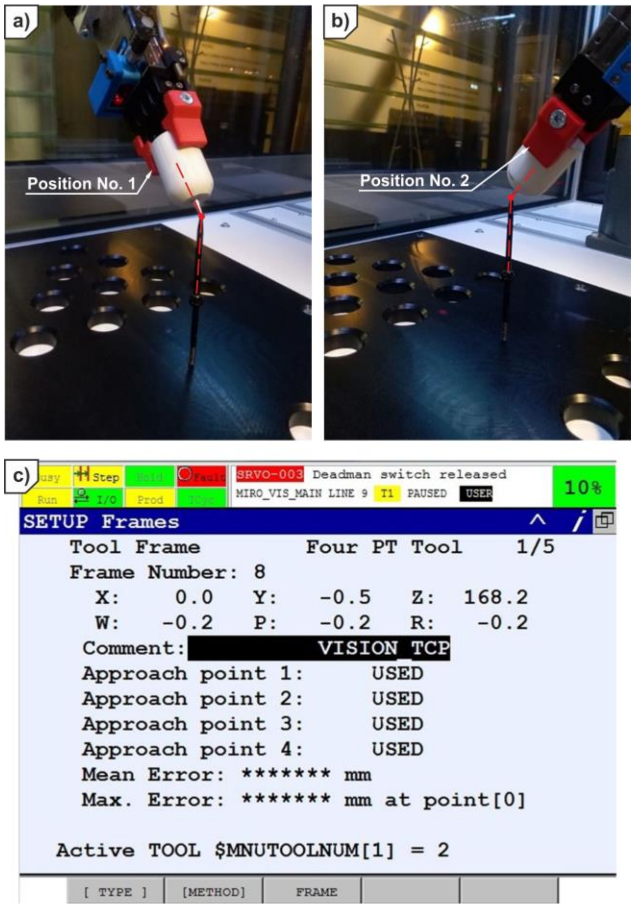


Fig. 8. View: a) a definition of the TCP point relative to the calibration pin in a position No. 1, b) the definition of the TCP point relative to the calibration pin in a position No. 2, c) the dialog box with the saved TCP point

In accordance with the proposed conceptual models, additional instrumentation was made, including a pin that allows accurate determination of coordinate systems (cameras and robot scenes) and a vision system calibration board.

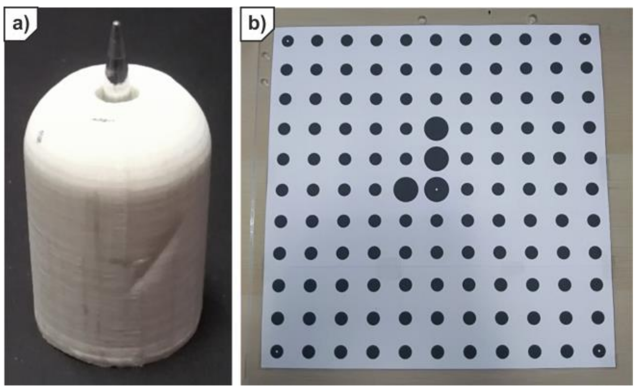


Fig. 9. View: a) the pin designed for definition of coordinate systems, b) the board with a calibration pattern

The calibration board has been glued onto a flat and rigid surface to minimize distortion and calibration errors. Completed auxiliary tools allow for correct configuration and teaching of the vision system.
The direction of the Z axis is determined according to the rule of clockwise coordinate system (Figure 10).

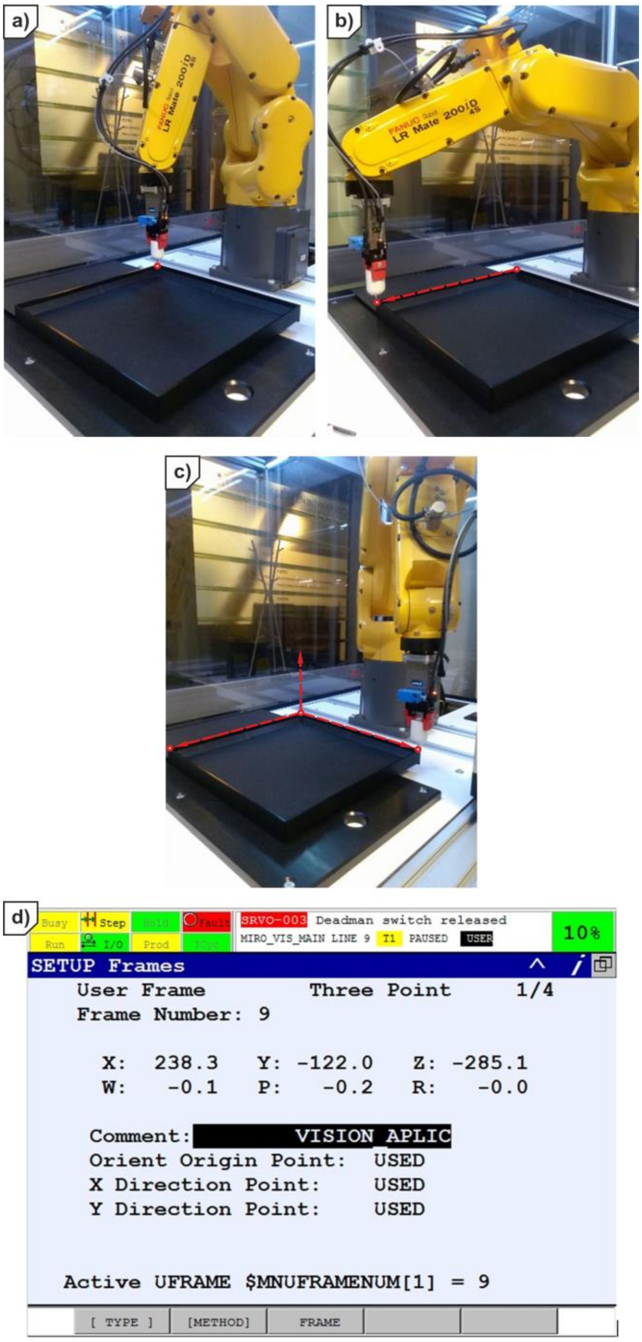

Fig. 10. View of the robot wrist orientation in the phase of defining the characteristic points of the coordinate system of the robot scene: a) landmark of the coordinate system, b) defining point of the X axis, c) defining point of the Y axis, d) the dialog box with the saved parameters of the coordinate system

The coordinate system of the calibration board was defined similarly. In accordance with the procedure, the four-point method was used, which includes the three-point method extended by passing to the origin point of the coordinate system (Figure 11).

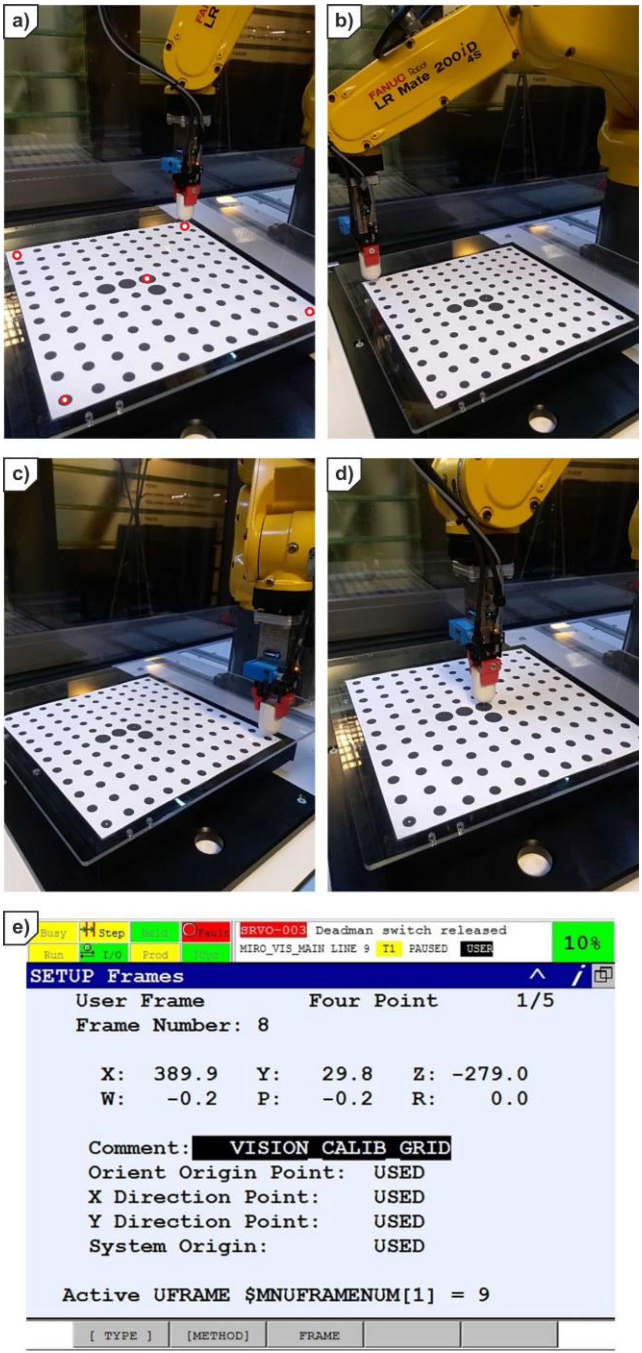

Fig. 11. Definition of the characteristic points on the calibration board: a) landmark, b) defining point of the X axis, c) defining point of the Y axis, d) starting point, e) the dialog box with the coordinate system defined with usage of the four-point method

The last step at the configuration stage is the calibration of the vision system. During this process, the vision system calculates the camera position (relative to the robot scene coordinate system), the position of the calibration board (relative to the application coordinate system) and determines the ratio of one pixel of the image recorded by the camera related to the current distance.

**2.4 The process of patterns learning of the FANUC iRVision vision system**

The vision system programming process involves teaching of patterns that are then sought in a defined mapping area. The vision system assigns each identified image of the pattern a rating (a number from the range of 0÷100), the numerical value of the rating corresponds to the compliance of the image of detail with the defined pattern.

In the first step, a vision mask was defined (defining the area to be searched; Figure 12 (a).

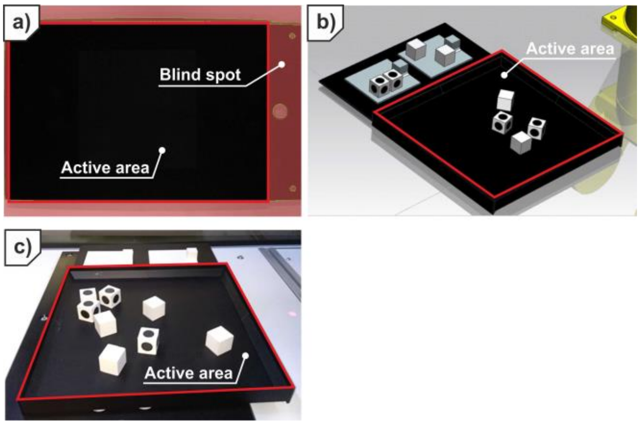


Fig. 12. View of: a) defined robot scene search mask, b) the 3D model of the scene, c) real object

Figure 13 shows the view of the vision system calibration board. The green marker indicates the center of the band, while the red one indicates the central position calculated by the system (if both locations overlap, only the green marker is displayed). Subsequently it was required to assign the calibration board to the robot coordinate system.

The following tasks were performed to configure the parameter set:

- the contrast has been maximized by adjusting the camera's exposure value,
- the value of a distance between the center points of the calibration lines was defined (in the considered case this value was equal 25 mm),
- camera mounting method was set,
- the coordinate system number of the calibration board was selected,
- perspective projection was selected.

Four large bands (marked in blue) provide a reference for the camera indicating the positive direction of the X axis (3 bands) and the Y axis (2 bands).

In the software tabs, it is possible to view also calibration parameters, relative positions of individual coordinate systems and cameras, as well as each of calibration points. The software used in the tests enables also deleting configuration parameters in case of incorrect indication of identification and location of the object.

However, any change in the parameter value necessitates re-calibration.

The next step was to teach patterns of manipulated components. To this end, one element of each type was set in the field of view of the camera.

Teaching began with a white cube with a contrast mark in the center of each wall. The TEACH function was used for the teaching process (its activation causes automatic edge detection and selection on the image).

It is also possible to manually define a contour or edges. Then (using the CENTER ORIGIN function) a characteristic point (i.e. geometric center of the identified element) has been appointed. For each template the reference number was assigned.

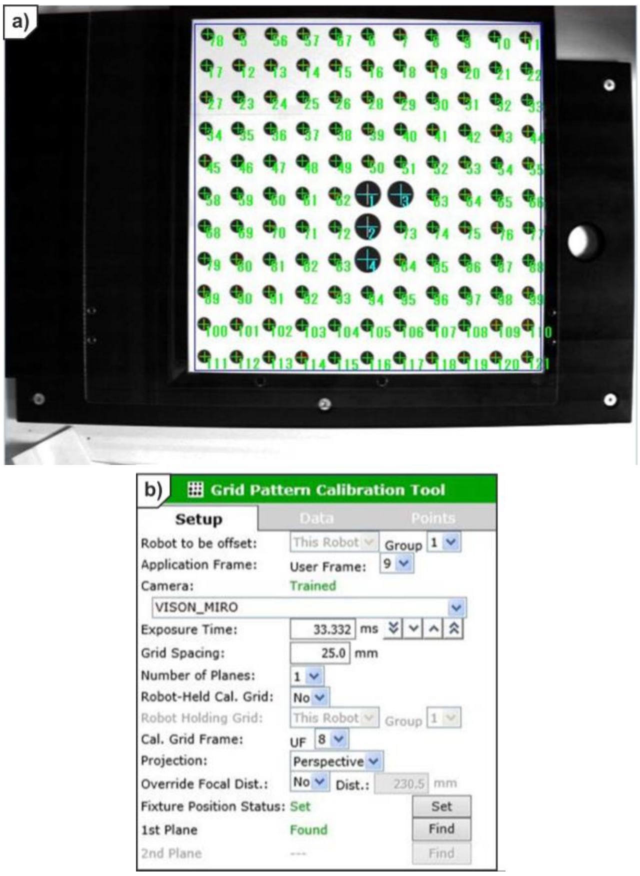


Fig. 13. View of: a) the vision system calibration board, b) the configuration parameters screen

As a result, satisfactory repeatability results of the learned pattern were achieved. The teaching process was repeated many times, changing the parameters of the camera settings to achieve a satisfactory result. An additional difficulty was the lack of additional lighting of the robot scene, which affected the contrast and blurring of the edges of the manipulated details.

The last step specifies the minimum value of the compliance threshold and the acceptable value of distortion of the identified element, below which the search process ends with the lack of identification of the defined pattern. In this case, the algorithm

proceeds to identify the next object or (in the lack of them on stage) reports an identification error.
In order to improve the entire process, the identification area has been limited. The size of the object identification area takes into account the minimum value of the width of the gripping jaws set with the active state of opening the robot gripper.
The learning process of finding a white cube was carried out in a similar way (Figure 14).
In the next step, both patterns were aggregated into one search process. The configured process is implemented from the first pattern, using the relative coordinate system shift function (defined for an industrial robot).

The sort function has been set in relation to the criterion of the maximum value of the result of the pattern compliance assessment.
The algorithm also defines the maximum number of components in the search process and the function of removing duplicates (if the characteristic points of the component coincide within a distance of less than 10 pixels and a rotation angle of less than 180°).
The last step defines the reference position for locating the element. The defined point is the starting position for programming the manipulation of the part. The geometrical center of the element was determined by leaving only one element on the stage and using the SET function (to save the reference position; Figure 15).

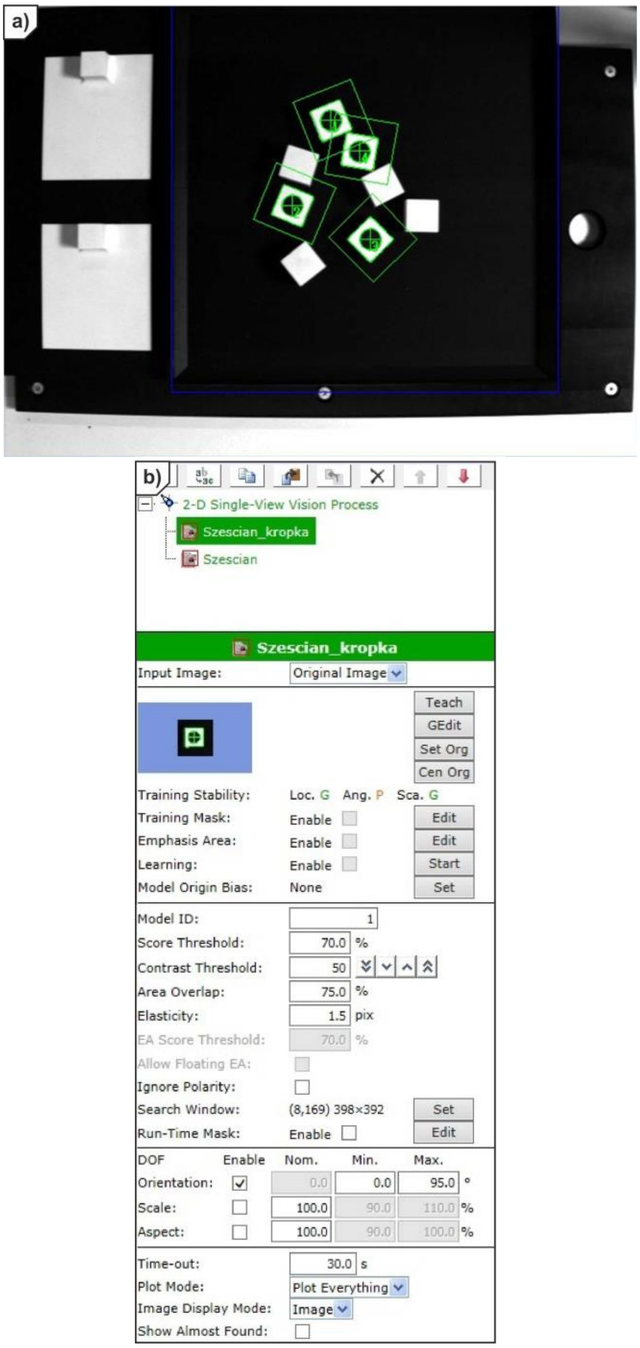

Fig. 14. View of: a) the vision system teaching screen, b) the configuration parameters screen

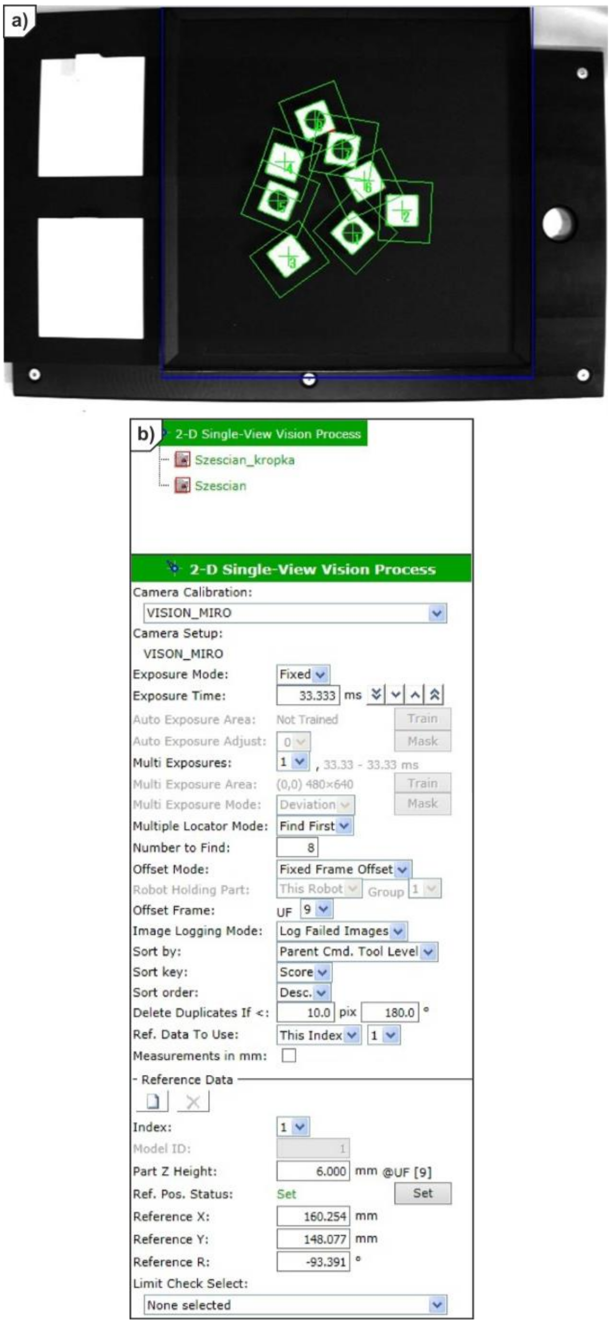

Fig. 15. View of: a) the vision system screen after the completed programming process, b) the configuration parameters screen

The height of the details identified is constant and is not subject to compensation due to the vision system.

## 3. CONCLUSIONS

The article presents the process of starting the vision system, using a number of necessary elements and accessories, as well as making modifications to the construction equipment of the gripper and the robot scene.
After conducting a number of tests, satisfactory results were obtained, as the application seamlessly implements the location of objects in the robot scene and sorts objects.
The correct operation of the entire vision system, and mainly the accuracy of the positioning of the manipulator wrist (in relation to the identified elements) is largely influenced by the optical system of the camera used. During the tests it was possible to notice inaccuracies in collecting and placing parts. This can be caused by the relatively low resolution of the camera and the large distance (approximately 500 mm) of the lens from the surface of objects. The problem can be solved by mounting the camera directly on the manipulator wrist.
Another factor that affects the positioning inaccuracies of gripping tips can be errors that occur when defining the TCP point of a tool and coordinate systems. The values of these errors are added together and, as a consequence, give noticeable negative effects.
During the tests, the calibration process was repeated four times to obtain the satisfactory accuracy.

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