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STUDY OF THE 3D SCANNING ACCURACY USING INDUSTRIAL ROBOT

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Abstract: *In this article, the authors present issues related to construction and configuration of 3D object scanning station using the Kinect sensor and industrial robot R2000 of FANUC Company. At the stand, tests were carried out in order to verify the correctness of adopted assumptions and to measure errors occurring as a result of scanning of the real objects. The authors identified errors resulting from construction of the station, as well as adopted methodology for the analysis of sensory data.*

Keywords: industrial robots, vision systems, vision 3D, kinect, data exchange

1. Introduction

The scanning process of 3D object is very popular today. Commonly available scanners, both handheld and stationary enable to reproduce the geometry of spatial models. In practice, any device that allows physical measurement of the world, based on lasers, lights or X-rays, generating a dense point cloud or multi-sided spatial grids, can be qualified for 3D scanners. They can appear under various names: laser scanners, white light, industrial LT, LIDARs, etc. In most cases, 3D scanner solutions provide satisfactory results for relatively small objects. An element that connects all these devices is the ability to capture physical geometry of objects based on hundreds of thousands or millions of conducted measurements. 3D scanning has found its application in many areas of life and has a key role in reverse engineering, but also in medicine, museums, archaeology and computer graphics. The scanning process offers new possibilities, because the scanned objects can be easily edited using dedicated engineering environments, precipitating designer work. It also has a key role in computer analyses, where the smallest detail can affect results. Scanning capabilities are also used in architectural works for reproduction and archiving of buildings and their interiors. For larger objects, the problem is to provide a specific distance from the object in order to have a common measurement base. The use of handheld scanners gives rise to relatively large errors, especially in case of complex shapes of scanned objects. The solution to achieve constant scanning conditions is to use manipulators that allow the scanning head to be moved in accordance with the trajectory adopted for a given object. The example is use of an industrial robot manipulator as a measuring arm on which the scanning head will be mounted (Baranowski et al.,2017). In order to examine the possibilities and quality of real objects reproduction, a workstation using an industrial robot was built. An aim of the study was also to determine the impact of surface type of the scanned object on accuracy of 3D model construction process.

2. Construction and configuration of the station

The test stand consists of an industrial robot, Kinect sensor placed on the robot's wrist, PLC driver with HMI panel and PC computer that collects and processes measurement data from the sensor. FANUC's R2000 robot was used on the workstation, large work range of manipulator is required to secure the

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proper working conditions of the scanner (Panasiuk and Kaczmarek, 2016). The minimum scanning distance using Kinect is 0.8 [m]. This sensor is a horizontal device that includes a depth sensor, colorful camera and a set of microphones. The main element used in the designed stand is a depth camera, which consists of emitter and infrared sensor. The task of infrared emitter is to project a pseudorandom pattern of infrared light, illuminating the space in front of the sensor. The invisible radiation to the man that illuminates an object is perfectly visible through an infrared sensor, which purpose is to collect information about the distance between objects and sensor. The principle of depth camera operation is based on triangulation, where the emitter and sensor are separated from each other by a known distance, forming the basis of triangulation triangle. When sending a pseudorandom pattern, some of the markers are dropped onto the object. The sensor recognizes the marker on the object, resulting in a third triangle line intersecting with the line emitting marker. Knowing the position of marker on captured image, you can determine the angle of triangle third line, and the emission angle of each marker is known in advance. Knowing two angles and the base of triangle, you can calculate the distance of object using sine law and trigonometric relation. Sensor operation involves the use of PC computer, along with installed programming environment extended to include the relevant libraries – Kinect SDK for Windows (Jana, 2012). The data-processing application enables to capture and process information (Webb and Ashley, 2014). Processed data is then saved to CAD file in *.stl format, so that it can be opened in all popular 3D design environments. The PLC driver, which integrates the work of entire station, will enable to automate the scanning process. The communication between controller and industrial robot will be carried out via PROFIBUS network, while the driver will be connected to application in a client-server structure based on Ethernet (Comer, 1997).

In the first phase, a simulation of robotic 3D scanning station was created in Roboguide environment for the station construction purposes. The simulation uses Fanuc R2000iA robot and all the above mentioned components. Work effects are shown in Figure 1.

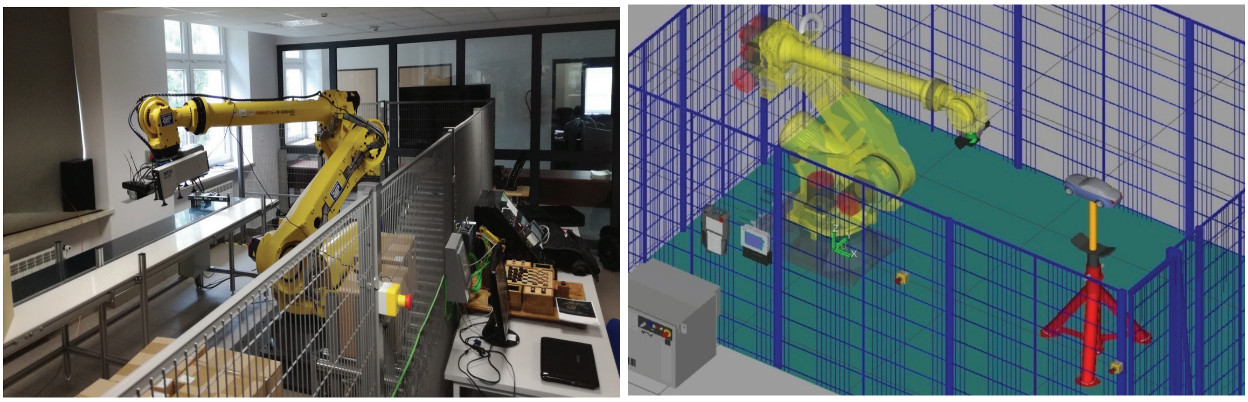

Fig. 1: Isometric view of robotized real and virtual work cell

3. Initiation of the station and carrying out measurements

In order to initiate the station, it is necessary to ensure communication between individual elements. The connection between PLC driver and PC is established automatically when running an application on the computer. Data exchange on PROFIBUS requires a full start of PLC driver and robot controller. Individual registers are read periodically. Scanning is started using the touch panel on which the user interface has been built. Pressing START on HMI panel sends a signal to start scanning to the robot and application. After receiving it, the application starts processing the depth stream and the robot performs its trajectory. When the end point is reached, the robot sends a signal to its outputs, which are then read by the driver. The application supports communication in a separate thread with 1300 ms sleep. After the datagram is read, the scan is finished and you are asked to name the scanned object. Before the next scan, press RESET to set initial parameters.

Figure 2 present trajectory with a pink color along which the robot moves during the scanning process. The robot's work path has been designed in such a way that there is a constant distance from the axis of object being scanned at each point of the robot. In order to maintain a constant distance, specially defined tool layout was used – offset by 1100 mm in X axis (Kaczmarek and Panasiuk, 2017).

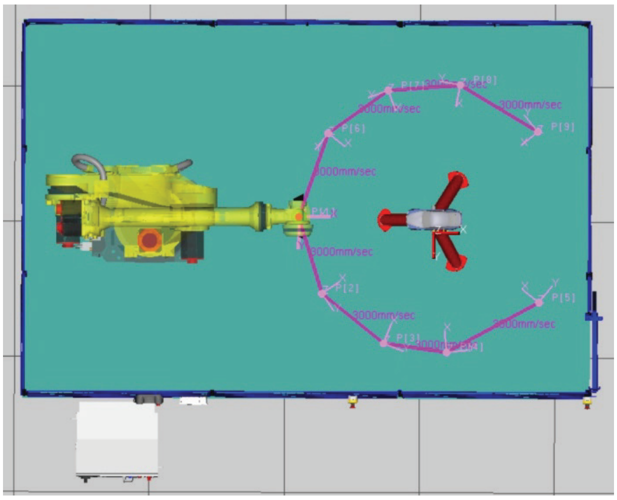

Fig. 2: Scanning trajectory

Testing methodology assumes scanning several objects with a maximum diameter of less than 500 [mm]. Figure 3 shows pictures of exemplary objects with their scanned 3D models.

Fig. 3: Comparison of scanned object with its 3D model

The main part of this study was aimed to show the differences in dimensions between real object and its 3D model. Metal roller with a diameter of 115 mm and 100 mm height was measured and then scanned and remeasured in 3D object generation environment. The following table presents comparison of results and differences in dimensions.

Table 1: Final comparison of received results

	Real dimension [mm]	Scanned model dimension [mm]	Error in dimension entered by scanning [mm]
Aluminum roller with paper label			
Height	115 +/-0.1	113.4	- 1.6
Diameter	100 +/-0.1	104.4	4.4
Aluminum roller without the label			
Height	115 +/-0.1	114.9	- 0.1
Diameter	100 +/-0.1	91.9	8.1
Aluminum roller covered with a thin layer of matte black paint			
Height	115 +/-0.1	115.9	0.9
Diameter	100 +/-0.1	96.6	-3.4

Based on the above table it is possible to state that the smallest overall measurement error occurs when scanning an aluminum roller with matt black paint. The result is confirmed with assumption that the matt surface introduces the least noise in scanning process. In other two cases, the results are worse due to higher reflectivity of the surface, which affected the correct distance reading by the scanner. In case of matt surface, the error in height measurement is less than 1%, which is a satisfactory result, while in case of measuring the object diameter the error is about 3.5%.

4. Conclusion

Achieved scanning quality unfortunately differs from commercial solutions. The presented results are adequate to the price of Kinect sensor, which is several dozen times cheaper compared to professional scanners. The quality of scanning is related to the depth frame resolution of Kinect sensor, which is 640 × 480 pixels. The operating angle of sensor is 57°, while the used measuring range is (500÷1000) mm. Taking into account the width for distance of 500 mm seen by the camera, which is 47.72 cm, and the number of pixels – 640 pixels – the scanning resolution was calculated. This resolution is a quotient of width and number of pixels seen by the camera:

$$\mathrm{r} = \frac{47.72\ \mathrm{cm}}{640\ \mathrm{px}} = 0.0745\frac{\mathrm{cm}}{\mathrm{px}} = 0.745\frac{\mathrm{mm}}{\mathrm{px}}$$

For a distance of 100 cm, the resolution is 1.12 mm.

Another factor adversely affecting the measurement is accuracy of the camera's operation. Measured value is affected by a constant error, at the distance to be measured, and the difference between real and scanned value increases along with distance between the object and sensor. Unfortunately, due to the minimum displacement of 10 mm, an attempt to create a point cloud while scanning by circular trajectory around the object does not represent it perfectly. The obtained model has deformed areas resulting from offset and first intercepted frame at angle 0°, and frames at an angle greater than 270°, when the point cloud starts to close.

The industrial robot is a next factor adversely affecting the measurement. Each robot has two significant parameters: accuracy and repeatability, which describe the precision with which the set positions are reached. FANUC R-2000iC/125L robot with extended arm was chosen due to the required large work range and laboratory capacity. Reproducibility of this robot is +/-0.2[mm], while in case welding/varnishing robots with similar range it is +/-0.08[mm].

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