automation of manufacturing technologies, reprogramming,
industrial robots, offline programming

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AUTOMATION OF MANUFACTURING TECHNOLOGIES WITH UTILISATION OF INDUSTRIAL ROBOTS

Abstract

Industrial robots are important elements of automated production systems. Robots as programmable devices used in automatized batch or mass products production are often reprogramed to adapt themselves on the new product production changes. This time-consuming programming causes a decrease of manufacturing productivity. Therefore today robots can be reprogrammed by "offline" way too. The robot´s new control programme creation doesn´t limit the manufacturing process that is currently in progress at the plant. In addition, offline programming contributes to reduction of the period of the new product production starting. The article presents our practical experiences with utilisation of offline programme Fanuc Roboguide for solution of tasks of automation of welding, deburring and assembling technologies by industrial robots.

1. INTRODUCTION

Automation of the manufacturing process brings several benefits that contribute to improving its quality and productivity. Appropriate and well applied automation provides a solution for the product production costs decreasing and brings multiple gains. Utilisation of programmable devices allows to manufacturers to adapt on the new product production. However reprogramming of these devices takes the time to accomplish. This non-production time makes the products production in batches more expansive. Therefore today flexible production systems designed for variety products production require flexible reprogrammable devices for quick and automatic

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change-over performing. CNC machines and industrial robots are such automatic devices. A flexible manufacturing systems (FMS) consists of several machines (CNC machine tools and/or industrial robots) linked to each other by a material-handling system. All aspects of the FMS are controlled by a central computer. CNC machine tools or industrial robots perform machining operations. But performing of inspection operations is also possible in automated inspection stations. A material-handling system, such as a conveyor system, or handling robots are capable to transport material (row material, work pieces, parts, assembled product etc.) to the required position in the FMS. A central computer system is responsible for coordinating the activities of all automatically operating machines and the material-handling system in FMS. Although the FMS represents a high level of production automation, human labour is still needed to manage the system, load and unload parts, change tools, and maintain and repair the equipment.

In robotized manufacturing operations, the robot manipulates a tool (its end effector) to perform a manufacturing technology on the work part. The most widespread applications of robots for automation of manufacturing technologies can be found in the automotive industry. There a spot welding and spray painting are the most common applications of industrial robots. The other important manufacturing technologies automated by robots are: arc welding, grinding, polishing, deburring, pressworking, product assembly, etc. Robotic arm carries usually the special technological tool at its end and realizes this tool´s movement on very complex paths to perform the required manufacturing technology. The robot programming performed directly at the automated technological workplace is the time-consuming process. This so called “online” programming causes downtime in production and thus contributes to reduction of productivity.

In conditions of batch production the more often reprogramming of CNC machines or robots are required. At the present the different programs of Computer Aided Process Planning (CAPE) are used to get the part program for CNC machine or control program for industrial robot in the shortest time and thus to prevent the production loss due to the occurrence of non-production times. Such programs are as follows [2, 7]: CAM (Computer Aided Manufacturing), CARC (Computer Aided Robot Control), CATS (Computer Aided Transport and Store), CAT (Computer Aided Testing) and CAA (Computer Aided Assembly). Currently the computer aid of manufacturing on NC machines is the most developed. Several worldwide producers offer either complex CAD/CAM systems for aid of a part designing and manufacturing or CAM systems specializing on the certain type manufacturing process (5-asis machining, machining by water or laser beams). These programs enable [1]:

- to create and simulate a technological procedure for machining the part of complex geometrical shape too,
- to transform the created procedure into CL data or to generate the postprocessor for translation CL data into the program for the CNC machine tool.

All these steps help to short the part machining time, to save material and to verify created technological procedure still before the part real machining. There we talk about offline programming of production machines. Computer aid of programming is also applied for industrial robots. Robot offline programing enables to create program for robot outside the production process on an external computer. Nowadays offline programs and their simulation tools help to create the optimal program paths for the robot to perform a specific task. Worldwide producers of robots offer usually offline programs only for own robot types.

2. ROBOT SIMULATION AND OFFLINE PROGRAMMING

Computer modelling and simulation is a very useful tool applicable in the process of designing, creation and evaluation of designed complex systems. Designers, program managers, or engineers can use computer modelling and simulation to understand and evaluate 'what if' case scenarios for models of a real or proposed system using computer software. Offline programming means programming robots outside the production - without stopping the production. It has grown the utilization rate of the robots in a short-run production companies. Finland Company Delfoi Robotics claims that industrial companies manufacturing with Delfoi software have this growth from 30% to over 90% [3]. Software for offline programming exploit data of 3D CAD models for the faster generation of programs. Due to calibration features the created programs can be so precise that the production of new products starts very quickly. The shortening of the time for adoption of new programs from weeks to a single day enables the robotization of short-run production.

Generally, offline robot simulation software is built on the Virtual Robot Controller (Virtual Robot Technology) which is the exact copy of the real robot´s controller. Therefore robot program and configuration parameters can be easily transferred between PC and the robot´s real world. Computer model of virtual robot usually consists of three components (Fig. 1) [5]:

- model of the robot´s arm (1),
- model of the control unit - virtual Teach Pendant (2) and
- program for performing the robot task (3).

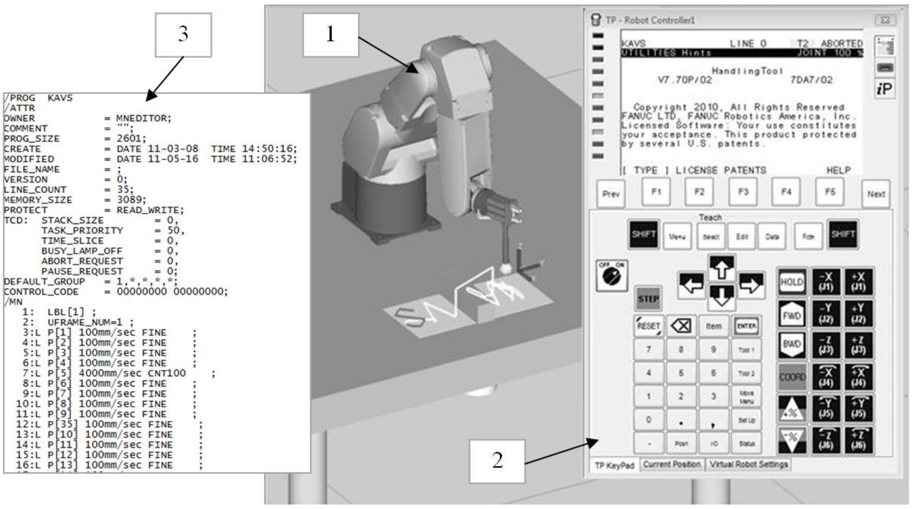


Fig. 1. The virtual robot computer model [8]

The software's simulation and control features enable a validation of the robot program still in preproduction stage and so to eliminate undesirable collisions, to optimise the robot´s working cycle and to verify the robot´s ability to reach all required positions in the work cell.

Robot offline programming software coming from robot manufacturers include RobotStudio (ABB), KUKA.Sim Pro (KUKA), MotoSIM EG-VRC (Yaskawa), RoboGuide (FANUC), etc. [10]: RobotStudio enables robot programs to be prepared in advance, increasing overall productivity. KUKA.Sim Pro is developed for offline programming of KUKA robots. It uses the build-in tools to load CAD data from other systems into KUKA.Sim Pro or build models using the system´s CAD tools. The grippers, welding guns and other kinematic structures are possible to build too. Virtual KUKA controller allows the cycle time analysis. MotoSim EG-VRC (Motoman Simulator Enhanced Graphics - Virtual Robot Control) is a comprehensive software package that provides accurate 3D simulation of robot cells. This simulation software can be used to optimize robot and equipment placement, as well as to perform collision detection, reach modelling and cycle calculations. Fanuc Roboguide is a cost effective software package that enables to design, prove and program robot systems in real time, either concurrently in a new product design or for making modifications to existing equipment or programs. Roboguide can import unique CAD models of process parts and create a virtual work cell which includes machinery, part transfer devices and factory obstacles. Roboguide will then teach robot paths to simulate the operation and performance of the robotic application taking into account the physical obstacles. Reach verification, collision detection, accurate cycle time estimates and other visual system operations are also simulated in Roboguide's 3D environment. These functions can be used to produce a simulation video to help evaluate and approve a project. Delfoi Robotic offline programming includes universal robot support and versatile and effective tool for a several areas in industrial robotics applications [3]: Delfoi ARC for ARC welding and laser welding, Delfoi CUT for cutting, milling and machining and Delfoi PAINT for painting and coating. Act/Weld ALMA (France) is offline program developed only for ARC welding application. It support of different types of robots (OTC Daihen, STAUBLI, ABB, KUKA, FANUC, PANASONIC etc.). The offline simulation software is exploited by small and medium-size enterprises and also by large world-class manufacturers.

3. AUTOMATION OF MANUFACTURING TECHNOLOGIES

The Department of Automation and Production Systems at the University of Žilina has several academic versions of offline programming software Fanuc Roboguide available. Roboguide is a robot system animation tool specifically developed for production and maintenance of robot systems. It can be used in offices or on the factory floor. Roboguide allows users to simulate the entire robotic cell or process in a virtual 3D space. The software is designed so that the robot and teach pendant operate exactly like a real robot. The simulation occurs by using a virtual robot. The standard software's modelling function was developed with the aim to reduce time for modelling devices. CAD data can be imported to create the parts by the modelling function. A large library allows the user to select and modify the parts and dimensions necessary. Roboguide incorporates many application-specific tools into its software options [8]:

- Roboguide HandlingPRO allows users to simulate a robotic process or study feasibility options for applications in a 3D space.
- Roboguide PaintPRO is a graphical offline programming tool for a path teaching and paint process development.
- Roboguide WeldPRO (SpotPRO) enables to simulate the robotic arc welding (spot welding) process in a 3D space.
- Roboguide PalletPRO enables the user to completely build, debug, and test palletizing or depalletizing application offline.

Department of Automation and Production Systems has available the module Roboguide HandlingPRO, which is a full-featured tool for creating automated technological workspaces [5]. This software option is most of all used in educational processes. But some problems of industrial practice were partially solved with support of program Roboguide HandlingPRO. The proposals of robotic cells for automation of arc welding, deburring and assembly technologies were solved.

3.1. Automation of arc welding technology by using a robot

The aim of the project was to propose solution to automate the workspace for welding steel construction using the method MAG (Metal Active Gas) [4]. The whole process of welding was carried out manually. The priority objective was to reduce the time of production associated with arc welding technology. Whole construction with dimensions 1725 x 600 – 700mm, consists of 54 components (Fig. 2), made of steel with guaranteed weldability to 25 mm of wall thickness. Butt and fillet welds were applied. For welding MIG/MAG method the ISO 6947 standard specifies seven welding positions: PA, PB, PC, PD, PE, PF and PG. For the welded construction three welding positions were used: PA, PB and PG (Fig. 3). Welding parameters (a size of welding current, a wire feed speed and a welding speed) were determined from templates of welding parameters for butt and fillet welds (Tab. 1). Based on this specification, the welding parameters were determined by total time required to weld the whole construction. Welding time t_w was calculated with utilisation of equation for the welding speed (v_w) calculation:

$$v_w = \frac{x_i}{t_w} \Rightarrow t_w = \frac{x_i}{v_z} \qquad (1)$$

The calculated total welding time t_w was equal to 30 minutes and 58 seconds.

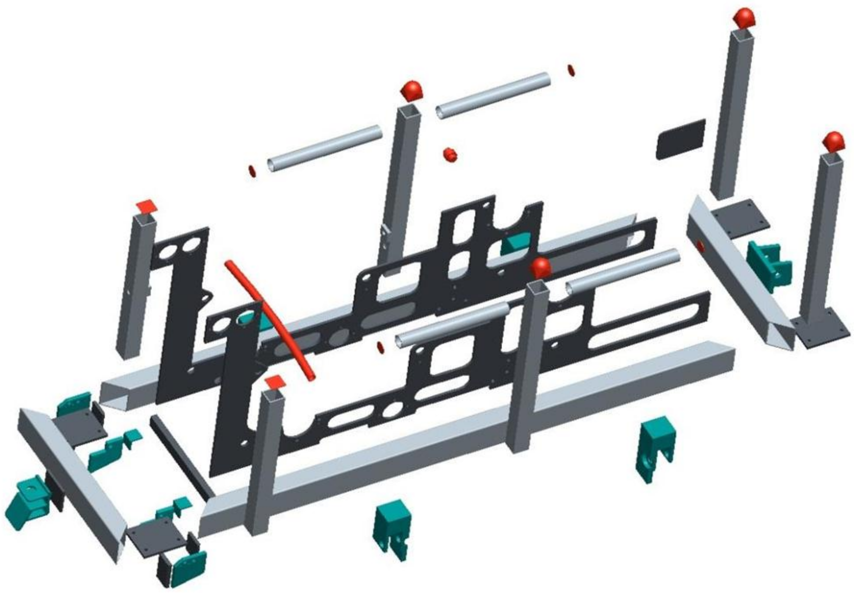


Fig. 2. Components of welded construction [4]

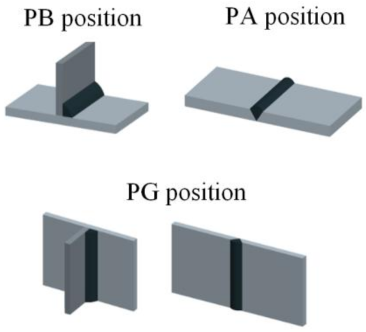
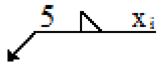
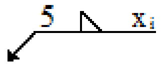
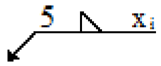
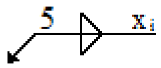
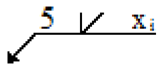
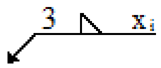
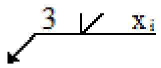
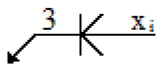
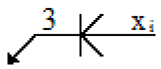


Fig. 3. Applied welding positions [4]

Tab. 1. Welding parameters [4]

i	Type of weld	Welding positions	Total length of welds x_i [mm]	Welding current I_w [A]	Wire feed [m.mm^{-1}]	Welding speed [cm.min^{-1}]
1		PB	2322	290	10,1	40
2		PG	60	230	7,3	28
3		PB	2240	290	10,1	40
4		PG	2560	230	7,3	28
5		PB	580	290	10,1	40
6		PB	1280	210	10,2	76
7		PA	800	120	4,4	27
8		PA	640	120	4,4	27
9		PG	800	150	6	46

During the selection of welding robot the following requirements were applied: a size of the robot arm reach with respect to the welded construction dimensions, robot arm mobility in six axes, routing of wire harness inside the robot arm and possibility to simulate a welding torch path in the simulation program Roboguide. For experimental purposes the robot Fanuc – type ACR Mate 120iC/10L with a size of the arm reach equal to 2009mm was selected [4]. For arc welding technology MAG type was selected with welding head FRONIUS Robacta 400, which meets the requirement of current load 290A. Accuracy of the position of the end point is ±0,5mm. Moreover, this type of welding head is directly designed for welding by using robots Fanuc, so that all welding parameters can be set directly from the Teach Pendant.

The production process of the welded construction is divided into two interlinked workplaces:

– the manually one, where worker performs all preparatory, auxiliary and technological works and
– the automatic one, where the robot performs a welding technology on the construction.

3D model layout of robotic welding cell was created with system Pro/Engineer, in which intended installation of welding robot on a portal construction – above the welded construction. To simulate the path of movement of the robot welding torch during the implementation of arc welding technology the Roboguide HandlingPRO was used. This program offers a virtual library containing models of welding robots. A simplified 3D model of workplace (model of welded construction, simplified model of the fixture for alignment and fixation construction skeleton) and welding head model were imported, in the format IGIS, into created workcell (Fig. 4).

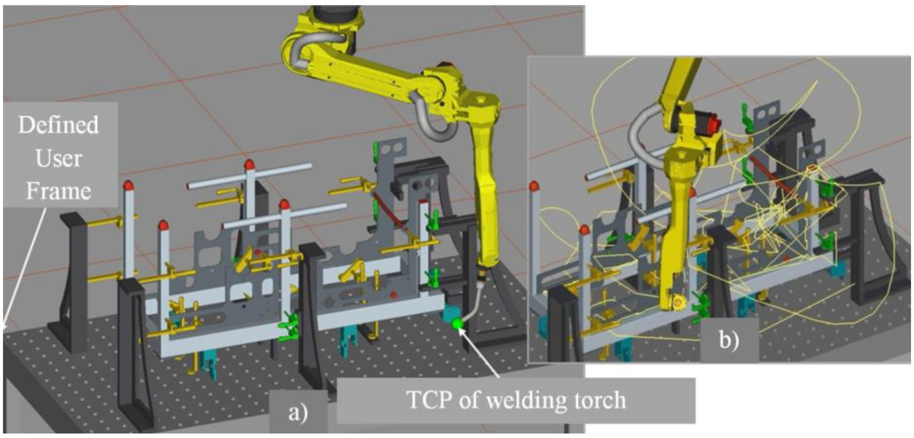


Fig. 4. Model of robotic workcell created in Roboguide Handling/PRO (a); TCP path movement displaying (b) [4]

HandlingPRO does not allow write all necessary welding parameters, bud when a designed robot for arc welding is inserted, the INST (instruction) offer will be extended about possibility of turning on/ turning off welding current and voltage. At instruction “Arc End” the endurance on the end position of the weld before further movement of TCP (Tool Center Point) is written. When in the assembly the welds have identical parameters, size of current and voltage they can be entered in the register labelled ARC. During the simulation of welding robot operating cycle the reachability of all working positions with welding torch was tested. The duty cycle of the robot consists of two parts: stitching the skeleton of the construction and then its welding. Process simulation has shown that the time needed for stitching is t_s = 3 minutes and 30 seconds, and time for welding is t_w = 20 minutes and 48 seconds. The total operating cycle of robot usage for arc welding technology is 74% of t_w and remaining 26% is the time required to change position between welds.

3.2. Automation of deburring technology with robot

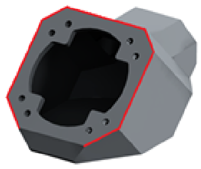
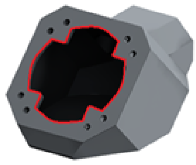
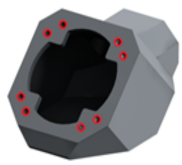
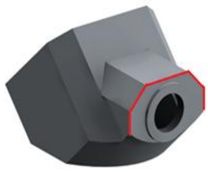
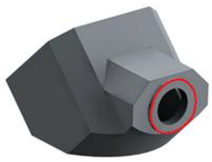
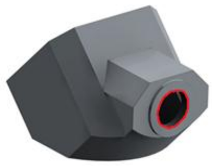
The task of automation of a finishing manufacturing technology used for deburring of a cast was solved for the purpose of preparation a laboratory training workplace at the Department of Automation and Production Systems. For representative workpiece has been proposed structural and layout solution of this workplace consisting of [9]:

- 6 axis robot Fanuc LR Mate 200iC,
- system of automatic exchange of robot´s effectors Schunk,
- deburring head Flexdeburr FDB 300 for radial deburring and
- modular system of clamping elements Siegmund.

3D model of workplace and the workpiece was created in system Pro/Engineer. The proposed workpiece is made from casted steel STN 42 2670/Z1. Considering the complexity of shape and method of workpiece clamping in fixture the technological process of the edge deburring by using a robot was carried out on two sides of the workpiece. Deburred edges and sequence of their machining are shown in Table 2 [9].

For the simulation purpose of the robot Fanuc LR Mate 200iC movement paths a workcell (Fig.5) in Fanuc Roboguide HandlingPRO was created. 3D models of components of designed robotic workstation created in system Pro/Engineer were imported in IGES format into the workcell. Virtual robot model was applied from the off-line program library. During robot programming in Roboguide HandlingPRO the function CAD-To-Path was used by which it is possible to define the coordinate points. By choosing Edge Line function the defining path of the tool along the edge of the workpiece is easier to define, because it automatically detects the edges of the workpiece. It is necessary to select the first point on the edge and proceed in certain intervals as shown in figure 3.Than it creates a selection Feature in which necessary settings can be defined. The main function is to generate Teach Pendant program in which all settings are taken into account and according to these settings the control program is created. Thus all programs were created for deburring of defined edges on the workpiece. The tool path for automatic deburring can be seen in figure 6.

Tab. 2. Sequence of the workpiece´s edges deburring [9]

Machining of the workpiece from the one side	1.	2.	3.
			
Machining of the workpiece from the other side	4.	5.	6.
			

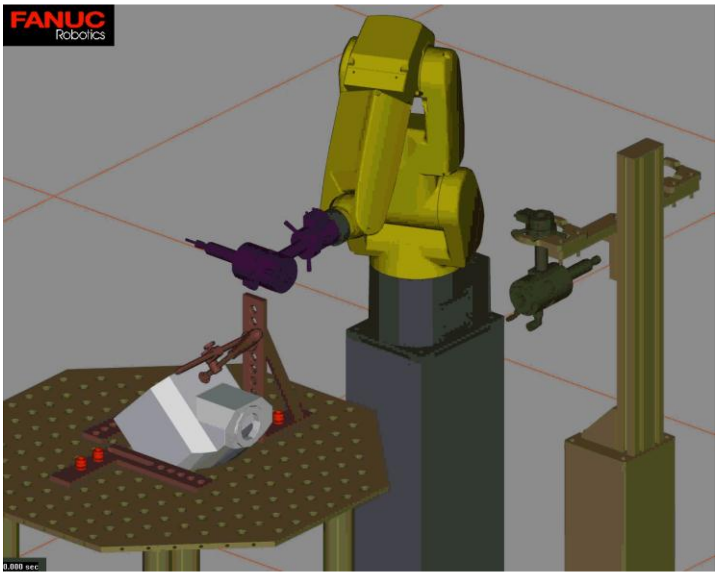


Fig. 5. Designed robotic cell for automation of deburring technology (Roboguide HandlingPRO) [9]

Fig. 6. Utilisation of *Edge Line* for the tool path definition [9]

Simulation of deburring tool path showed that robot is not able to deburre all edges on the workpiece as it was required. Fixation of the wokpiece in a fixture without possibility of its additional rotational movements does not allow the deburring tool to achieve edges at the bottom of the workpiece with respect to required technological conditions of deburring technology.

3.3. Automation of assembly tasks with robot

Automated assembly preparation constitutes a difficult tasks related with shape and dimension diversity of structural elements of assembled products [6]. The type of assembled elements (whether they are simple components or complex assembled subassemblies) and applied assembly methods influence the election of assembly and auxiliary equipment. Industrial robots are flexible assembling devices that are able to automatically preform main and auxiliary assembly operations. In field of automated assembly robots are applied most frequently for:

– Pick&Place applications (SCARA and Delta robots)
– Complex handling with assembled elements (6-axes robots) or
– Realisation methods of assembled elements joining (screwing, pressing, etc.)

At the Department of Automation and Production systems were built laboratory workstation of automated assembly for the purposes of teaching and research (Fig.7a). There the robot Fanuc LR Mate 200iC performs the final assembly operation of assembled product (Fig. 7b) and handling with assembled product. Robot takes it from the output of automated assembly workplace and storages it into the shelf storage. The final assembly operation is an operation of screwing the cover with a diameter 40 mm. The finally assembled product is grasped in its parallel planar surfaces by specialised gripping jaws of the robot parallel gripper MHZ2-20D, SMC Industrial Automation. The grasped dimension is 45mm.

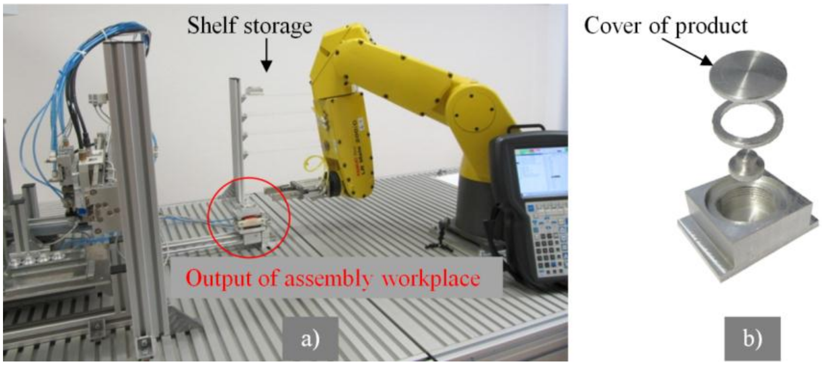


Fig. 7. Real Laboratory workstation of automated assembly (a); the real assembly product (b) [source: own study]

Creation of the robot Fanuc work cycle program was done in simulation program Fanuc Roboguide v.8 with HandlingPro option. 3D model of workplace (excluding the robot Fanuc model) created in CAD/CAM/CAE program Pro/Engineer Wildfire 4.0 was importing into Roboguide in IGIS. In simulation environment of HandlingPRO other additional objects were added into created Workcell to define them a motion by utilisation of function Machines. The virtual model of the robot Fanuc LR Mate 200iC has been implemented into Workcell from the offline program library. The procedure of control program creation has been divided into three separate programs: program of screwing of the cover, program of the assembled product taking out from the position of its final assembling and program of the assembled product storing into the shelf storage. All these programmes were formed the main control program. This approach to the robot control program creation gave us the possibility to edit the control program during its verification at the real laboratory workstation by much easier way. Operating of the shelf storage by the robot Fanuc is a sequential putting of final products on the single positions of each store shelves. Total storage capacity is 20 pieces of final product. Every shelf has 5 store positions. Offline program Roboguide offers special options for this operation type programming as follows: PalletPRO or PaletTool. We could work only with HandlingPRO. Therefore, we have applied the method of a gradual defining of the single store positions through the program´s registers and position registers. The problems with Fanuc robot arm singularities during imposing the final products on lower positions of the shelves storage detected by simulation led to change of the shelves mounting configuration in the real shelves storage.

Figure 8 displays the workplace of robot Fanuc in conditions of HandlingPRO simulation environment (Fig. 8a) and the real robotized workplace (Fig. 8b).

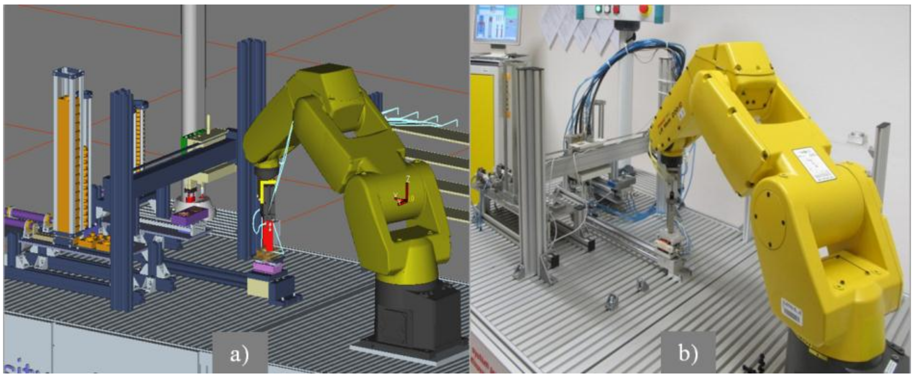


Fig. 8. Off-line robot programming in Roboguide HandlingPRO (a); Robot Fanuc LR Mate 200iC operate the real automated workplace (b) [source: own study]

4. CONCLUSION

Automation of manufacturing technologies with industrial robots is one of ways how to increase the production quality and productivity. Industrial robots as flexible automatically working machines are able to adapt themselves on the changes in the product production very fast by the flexible reprogramming way. Utilisation of computer aid, namely of simulation offline programs for robots programming doesn´t cause a downtime in production by programming and shorts starting of new product production. The article presents the possibilities of the Roboguide HandlingPRO utilisation for the solution of partial tasks of automation of manufacturing technologies with robots on the real examples. Our practical experience has shown that the use of appropriate simulation tools of Roboguide HandlingPRO can help to verify the proposals of robot workcells for automation of welding, deburring and assembly technologies.

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REFERENCES

[1] CUBONOVA N., KURIC I.: *Data structures implementation of the protocol STEP-NC at CNC machines programming.* Communications: scientific letters of the University of Žilina. Vol. 16, No. 3A, 2014, pp. 176-183, ISSN 1335-4205.

[2] ČUBOŇOVÁ N.: *Počítačová podpora programovania CNC strojov*. Computer Aid of CNC Machines programming, Žilinská Univerzita, Vyd. 1, Žilina 2012, p. 114, ISBN 978-80-554-0514-8.

[3] Delfoi Robotics: http://www.delfoi.com/web/solutions/robotiikka/en_GB/offline/

[4] KUBO M.: *Návrh riešenia automatizácie zváracieho pracoviska s využitím zváracieho robota. (Design of the solution for automation of welding workplace with usage of welding robot).* Diploma thesis. University of Žilina, FME, Department of automation and production systems. Supervisor: Assoc. Prof. Eng. Darina Kumičáková, PhD., 2014, p. 69.

[5] KUMIČÁKOVÁ D.: *Využitie prostriedkov počítačovej simulácie pri navrhovaní automatizovaných montážnych pracovísk. (Utilisation of computer simulation tools in automated assembly workplaces designing).* ATP journal plus [elektronický zdroj]: recenzované periodikum vedeckých a inžinierskych publikácií. CD-ROM. Č. 1, 2013, pp. 17-19, ISSN 1336-5010.

[6] KUMIČÁKOVÁ D., ZAHORANSKÝ R.: *Laboratory workplace of automated assembly – contribution to the education quality improvement.* Materials science and technology, Mim. č., 2010, [elektronický zdroj]: internetový časopis. pp. 34-40, ISSN 1335-9053.

[7] KURIC I.et all: *Počítačom podporované systémy v strojárstve. (Computer Aided Systems in Mechanical Engineering),* Žilinská univerzita, Vyd. 1, Žilina 2002, p. 351, ISBN 80-7100-948-2.

[8] ROBOGUIDE – FANUC Simulation Software. Available on: http://robot.fanuc-america.com/products/vision-software/roboguide-simulation-software.aspx

[9] URÍK M.: *Koncepčný návrh tréningového laboratórneho pracoviska pre robotizované obrábanie. (Conceptual design of training laboratory workplace for robotized machining.).* Diploma thesis. University of Žilina, FME, Department of automation and production systems. Supervisor: Assoc. Prof. Eng. Darina Kumičáková, PhD., 2014, p. 74.

[10] YAHUI G., IANZHONG D., DONGWEI L.: *Off-Line Programming Techniques for Multirobot Cooperation System.* International Journal of Advanced Robotic Systems., Vol. 10, 2013, 282:2013. p.17. Available on: http://cdn.intechopen.com/pdfs-wm/45451.pdf