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Virtual environment as a tool for analysing the operation of an industrial robot

Abstract. *The purpose of the article is to analyse the possibilities offered by the use of virtual models of robots and workcells to evaluate the operation of the robot, on the example of the environment for programming and simulation of robot operation. The paper presents a computer model of an industrial robot station designed at K-Roset.*

Streszczenie. *Celem artykułu jest analiza możliwości jakie daje wykorzystanie modeli symulacyjnych robotów i stanowisk zrobotyzowanych do oceny pracy robota przeprowadzona na przykładzie środowiska do programowania offline robotów. W pracy zaprezentowano komputerowy model stanowiska z robotem przemysłowym zaprojektowany w K-Roset. (**Wykorzystanie środowiska wirtualnego do analizy pracy robota przemysłowego**).*

Keywords: offline programming, robot, virtual model
Słowa kluczowe: programowanie offline, robot, model wirtualny

Introduction

The use of robots in the industrial process brings many benefits, such as precision, repeatability, speed of operation, reliability and the ability to operate in harsh conditions. Therefore, to increase the competitiveness of products, robots are used not only in the factories of large corporations, but more and more often by medium and small manufacturing companies. This results in the growing demand for specialists who have the ability to design a robotic cell and, above all, to program its key device - a robot [1]. Programming of robots is traditionally carried out using a Teach Pendant. It is employed by the operator to control the robot's drives and, using the appropriate commands (i.e. programming language), to create a sequence of its movements. To do this, however, it is necessary to disengage the robot from the previously implemented process and to pay special attention when programming, so as not to enter incorrect settings that could result in a malfunction of the robot. To avoid these inconveniences, out-of-the-station methods are used to program the robot. Dedicated computer programs in which you can model the work of a real production system are a very helpful tool in this respect. Specialized software packages not only help in better understanding of how robots work, but also allow to develop offline control program for a robotic station and facilitate testing various working conditions of the created model.

The purpose of the article is to analyse the possibilities offered by the use of virtual models of robots and workcells to evaluate the operation of the robot, on the example of the environment for programming and simulation of robot operation.

Offline programming environments

Virtually every manufacturer of industrial robots, in addition to the application for configuring and programming real robots, also offers an OLP software (*Offline Programming*), environment for programming robots offline - Table 1. This type of environments enables modelling a robotic cell, programming robots and performing offline work simulations. Thus, a computer with specialized software functionally replaces a robot with a controller and a pendant (Fig. 1). For this reason, software designed to create virtual 3D models of robotic stations and simulate their work are a useful and convenient engineering tool used to modernize existing or design new production systems [2,3].

Virtual workstations are prepared thanks to embedded libraries provided by companies or catalogues available online, containing models of robots and their equipment elements (e.g. grippers, painting nozzles), as well as 3D models of objects in the robot environment (e.g. conveyors, positioners, tables, platforms, fences, controllers). Parameterized graphic objects can also be imported from CAD environments or, using the available functions, created directly in specific robot simulation software [4,5].

Table 1. Offline programming software [2,3]

Industrial robot manufacturer	Software
ABB	ABB RobotStudio
Comau	RoboSim Pro
Denso	WINCAPS III
Epson	RC+
Fanuc	ROBOGUIDE
Kawasaki	K-Roset
Kuka	KUKA.Sim Pro
Mitsubishi	MELFA WORKS
Nachi Fujikoshi	FD On Desk
Stäubli	Stäubli Robotics Suite
Yaskawa-Motoman	MotoSim

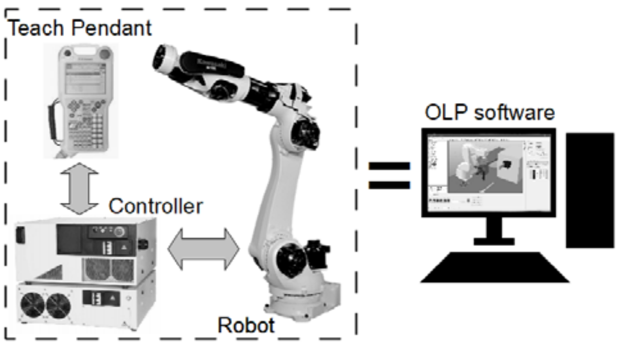

Fig.1. Methods of robot programming []

OLP environments enable planning robot trajectories and create control programs. Implementation of virtual controllers, i.e. the mapping of physical robot controllers, in them allows the program code created in the simulation program to be compatible with the code for the actual robot. This allows direct transfer of applications between a PC and a robot, or between a robot and a virtual environment. OLP programming of a robot can be done in a special editor. However, virtual environment providers, to reflect the actual operating conditions of a specific robot, also make it possible to create programs and operating the computer model of the robot using a virtual pendant [4,5,6]. Figures 2 and 3 present examples of real pendants and their virtual equivalents.

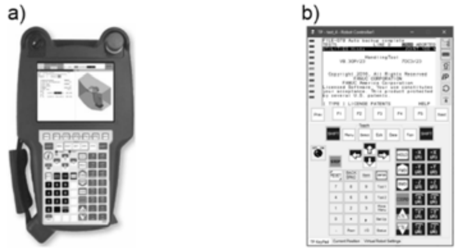

Fig.2. Fanuc Teach Pendant: a) real, b) virtual (Roboguide) [4]

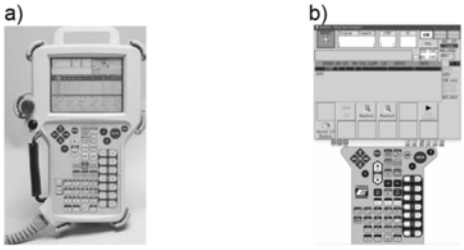

Fig.3. Kawasaki Teach Pendant: a) real, b) virtual (K-Roset) [6]

In addition to programming robots and simulating their work, virtual environments also enable [4,5,6]:
- Cycle time analysis corresponding to the real controller,
- Collision detection,
- Reproduction of the actual kinematics of the robot,
- Definition of zones limiting the robot operation,
- input/output signal monitoring,
- Robot load identification.

Obviously, these are not all the features available in OLP environments. Each of the producers strives to increase the attractiveness of its software by offering functionalities that are not made available by other robot suppliers.

Computer model of the robot workstation

When designing a robotic station, it is essential to select a robot suitable for the planned task to ensure production increase and quality. However, the future user is not only interested in programming the correct work of the robot, its smooth operation in the production process space and ongoing monitoring of the device operation. Already at the concept stage, the investor would also like to know the costs that robotic stations will generate in the future. There are two main factors to be considered in this respect: the failure rate of the robot and the energy intensity of its process. The robot failure may result primarily from the poor condition of the drive systems. Since electric motors are most often used to move the joints, therefore, the condition of the motors will be largely affected by their operation at high current loads. The energy consumption can be measured using the amount of electric energy consumed by the robot in a given work cycle.

Certainly, the most detailed information is obtained by performing operational measurements and analysing the work of a given device or assessing its impact on the condition of other systems [7,8]. However, as many examples show, modelling studies provide equally important insight into the process [9,10]. In the case of robotic systems, this approach is particularly important due to the high price of robots and their rapid development. The main advantage of this solution is the ability to analyse various working conditions even before the physical implementation of the station and to draw conclusions about the expected operation of the robot.

In order to check the functionality of the virtual environment in terms of the preliminary assessment of the robot work, a computer model of the robotic station was designed using K-Roset software (Fig. 1). K-Roset is a tool for modelling, simulation and offline programming of Kawasaki robots, which includes an emulator of a real robot controller (PC-AS module) [6]. This software features a control algorithm that was prepared, followed by a series of simulations, in which quantities characterizing the robot operation quality were recorded. Two 6-axis robots with similar range and load parameters, but differing in design and application, were selected for the simulations. One of the robots is classified as a universal robot by the manufacturer, while the other is especially dedicated to tasks such as assembly, welding and operating machines. Basic technical details of both robots are presented in Table 2.

Table 2. Specifications of simulated Kawasaki industrial robots [11,12]

Parameter	Robot 1	Robot 2
Model	ZX165U	BX200L
Payload [kg]	165	200
Max. Reach [mm]	2651	2597
Repeatability [mm]	±0.3	±0.2
Motion Range [°]/ Max. Speed [°/**s**]		
JT1	±180/ 110	±160/ 105
JT2	+75÷-60/ 110	+76÷-60/ 90
JT3	+250÷-120/ 115	+90÷-75/ 100
JT4	±360/ 140	±210/ 120
JT5	±130/ 155	±125/ 120
JT6	±360/ 260	±210/ 200
Mass [kg]	1350	930

Computer testing consisted in comparing the work of both robots for the same control programs and analysing the results for several parameters describing the robot operation quality. The quantities selected for observation were, among others, estimated currents and speeds of axis motors, cycle times, estimated electrical energy consumption.

Simulation results

The first test was a TCP displacement (movement with joint and linear interpolation) between two points located at the same distance along the X axis, Y axis and Z axis of the World Cartesian coordinate system (Fig. 4). The drawings 5÷8 present examples of estimated time functions of the currents and speeds of motors driving joints of Robot 1 and Robot 2 obtained in K-Roset for joint and linear displacement in the direction of the Y axis. The movement took place at 10% of the maximum speed.

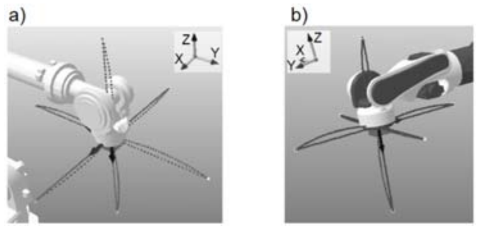

Fig.4. Planned motion trajectories for: a) Robot 1, b) Robot 2

Tables 3÷6 present the values of cycle times and estimated electrical energy consumption calculated in K-Roset with assuming the same number of program execution cycles per day (10 cycles) and the same daily working time (1 hours) for both robots.

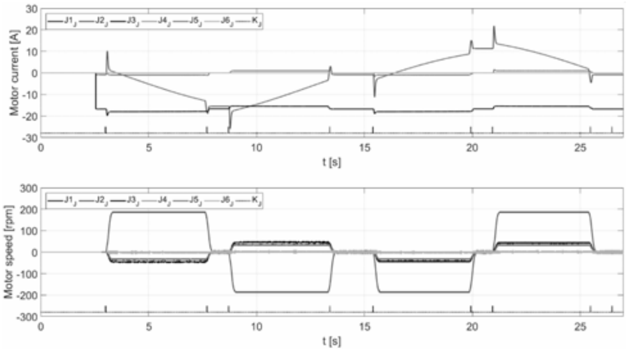

Fig.5. The time characteristics of the motor current, motor speed of the joints – Robot 1, Y axis, joint interpolation

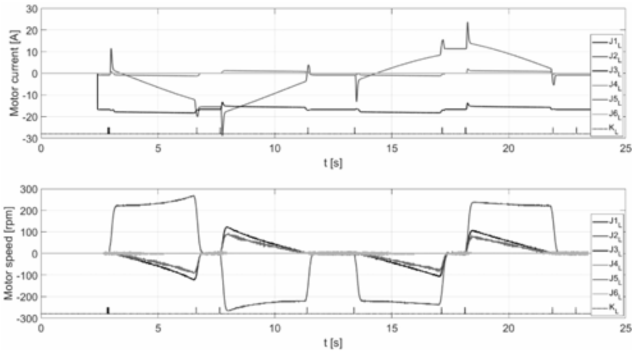

Fig.6. The time characteristics of the motor current, motor speed of the joints – Robot 1, Y axis, linear interpolation

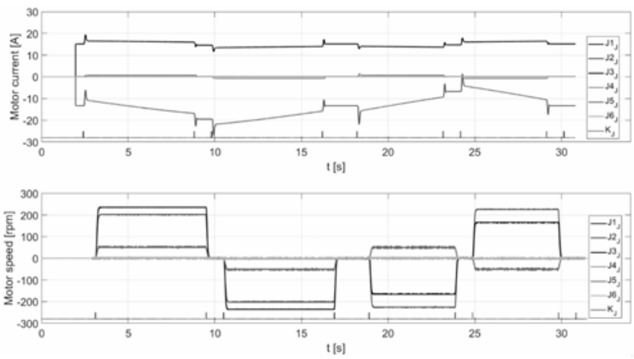

Fig.7. The time characteristics of the motor current, motor speed of the joints – Robot 2, Y axis, joint interpolation

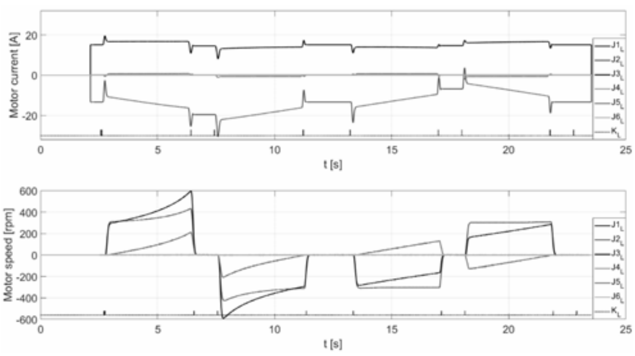

Fig.8. The time characteristics of the motor current, motor speed of the joints – Robot 2, Y axis, linear interpolation

Table 3. The XYZ axes movement of Robot 1 – joint interpolation

Parameter	X axis	Y axis	Z axis
Cycle time [s]	16.894	23.464	19.786
Estimated electric energy consumption per one cycle [Wh]	2.764	3.987	3.469
Estimated total electric energy consumption of whole day [Wh]	406.363	411.366	410.238

Table 4. The XYZ axes movement of Robot 1 – linear interpolation

Parameter	X axis	Y axis	Z axis
Cycle time [s]	20,026	20.019	20.016
Estimated electric energy consumption per one cycle [Wh]	3.222	3.461	3.499
Estimated total electric energy consumption of whole day [Wh]	407.504	409.898	410.289

Table 5. The XYZ axes movement of Robot 2 – joint interpolation

Parameter	X axis	Y axis	Z axis
Cycle time [s]	18.321	27.722	27.462
Estimated electric energy consumption per one cycle [Wh]	3.547	5.406	5.144
Estimated total electric energy consumption of whole day [Wh]	384.903	393.876	391.528

Table 6. The XYZ axes movement of Robot 2 – linear interpolation

Parameter	X axis	Y axis	Z axis
Cycle time [s]	20.082	20.184	20.166
Estimated electric energy consumption per one cycle [Wh]	3.836	4.166	4.066
Estimated total electric energy consumption of whole day [Wh]	385.992	389.185	388.203

The resulting results for current and speed of the axis motors show how the drives operations differ depending on the type of movement. One can, for example, notice a certain increase in the current, especially in joint 2, and higher motor speeds for linear motion. The calculated cycle times and estimated energy consumption also differ depending on directions and types of robot motion trajectories.

After completing the next series of simulations, with the movement speed increased to 90% of the maximum speed, it was found that the cycle time could be shortened by an average of 63% (for joint interpolation) and 61% (for linear interpolation) for Robot 1 and 67% (for joint interpolation) and 57% (for linear interpolation) for Robot 2. In addition, the cycle time in each of the directions (XYZ) is less varied. The estimated energy demand for one work cycle was reduced. Figure 9 presents an overview of the estimated motor current and motor speed values for Robot 1 for joint movement along the Y axis.

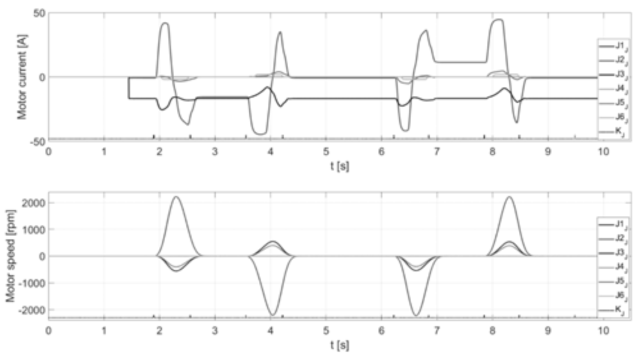

Fig.9. The time characteristics of the motor current, motor speed of the joints – Robot 1, Y axis, joint interpolation, movement speed 90%

Table 7. The Y axis movement of Robot 1 and Robot 2

Parameter	Robot 1		Robot 2	
	Joint	Linear	Joint	Linear
Cycle time [s]	7.588	7.692	8.186	8.728
Estimated electric energy consumption per one cycle [Wh]	2.383	2.251	3.668	3.437
Estimated total electric energy consumption of whole day [Wh]	412.845	411.408	396.474	393.609

Table 7 summarizes the cycle times and energy consumption for Robot 1 and Robot 2 obtained for this displacement and linear motion.

Further simulation studies compared the work of virtual robots with the same sequence of movements programmed at the assembly cell (Fig. 10). The calculated values of the parameters selected for the assessment of the robots operation quality are presented in Table 8.

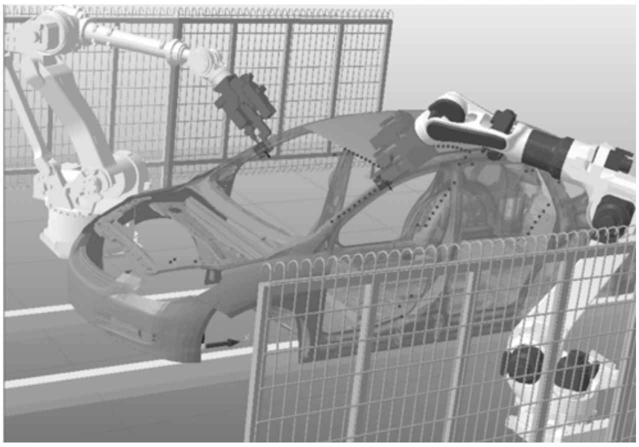

Fig.10. Virtual model of assembly workcell

Table 8. Assembly workcell

Parameter	Robot 1	Robot 2
Number of program execution cycles per day	500	500
Robot operating hours per day [h]	15h	15h
Cycle time [s]	88,491	94,352
Estimated electric energy consumption per one cycle [kWh]	0,015648	0,019183
Estimated total electric energy consumption of whole day [kWh]	9,111	10,268

The presented examples implemented in the OLP environment evidence the interesting functionality of this type of software, which provides great opportunities for multidirectional analysis of the work of an industrial robot.

Conclusion

The conducted model testing indicates that simulation programs of robotic processes are not only a very good tool, useful for the design of industrial stations. They also play an important role in the training of engineering staff in robotics, as well as in research, especially in the absence of access to an industrial robot. Simulation tests of the analysed system can be carried out not only virtually but also in real time. Thanks to this, after a robot program corresponding to the user's requirements is designed it can be transferred to a physical robot controller, with the certainty of working properly in real production conditions.

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