



Position Project to Study Selected Characteristics of the Optoelectronic Heads in RobotStudio

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Abstract. In the article, a project of robotized positions to study optoelectronic heads in the RobotStudio environment was presented. The authors suggested to use industrial robots in order to simulate movement of the head holder as well as tracked objects. Modern RobotStudio programming environment application with virtual controller technology allowed for accurate reflection of the research position functionality. As a part of the carried out works, the control programs were drawn up in RAPID language.

Keywords: optoelectronic head, industrial robot, RobotStudio, air target, inverse kinematics.

1. INTRODUCTION

In human life, robots find wider application day by day. Scientists try to use them almost in all spheres of our life. For this purpose, new structures are designed and tested in order to fully meet the expectations of their potential users. Their development is both in case of control systems – enabling to control robots as well as load-bearing platforms and manipulators.

The level of progress of produced robots is so great that without a problem it is possible to try to use them for research of positions construction [4]. Particular attention must be paid to industrial robots, which were characterized by significant restrictions (especially programming) in the past, today became fully flexible devices. First, it is necessary to mention about manipulators structure diversity. Demand of numerous branches of industry, often characterized by peculiar requirements of individual technological tasks (welding, spot welding, sorting, packing, painting, machine tending, assembly, etc.), had a significant impact on formation of big manipulators family. The same technological tasks had and still have an impact on the possibilities of development and robot controllers shape. From devices of large dimensions and small computing power, control systems became fully flexible devices, equipped with modern operating systems. Programming of these devices is possible with the use of high-level languages. Admittedly, every company having a large share in the world market (among others: ABB, Fanuc, Mitsubishi) offers its own programming language (e.g.: ABB Company – Rapid language, Fanuc Company – Karel language, Mitsubishi Company – Melfa-Basic language), but almost all these languages were drawn based on Pascal or Basic language.

Flexibility of offered languages is so wide that seriously it is possible to consider the possibility of creation of advanced programming applications.

As a result, the researcher obtains 6-axis platform which is fully programmable. This platform allows for positioning the accuracy of 0.05-0.10 mm, what is superbly to study the majority of stabilization systems as well as video trackers, particularly in the optoelectronic heads. Of course, such solutions also have a number of defects (e.g.: maximum acceleration and velocity limitations), however, their price is much lower than specialised research devices.

Application of solutions dedicated for industry still has one special virtue. Before laboratory tests it is possible to conduct a row of computer simulations, using advanced environments for programming robots in off-line mode.

The suppliers of largest industrial robots in the world offer environments which enable to program the robots in off-line mode – without the need to have a real device (e.g.: ABB Company – RobotStudio environment, Fanuc Company – RoboGuide environment, Mitsubishi Company – MelfaWorks environment). These environments, already at the initial research stage, enable to create virtual research positions enabling among others to: determine necessary space for research, develop a research program as well as programmers to control the robot, and finally, to carry out computer simulation proving the assumptions' correctness. Such a solution reduces time to start-up the research position.

2. INDUSTRIAL ROBOTS IN DIFFERENT APPLICATIONS

Industrial robots used for the purposes other than pursuit of industrial processes, is not a new solution. First solution of this type appeared at the end of the last century. In 1997 engineers from one of the factories using Fanuc Company robots developed position using FANUC Robot S420iW, which consisted of robot controller RJ-2, manipulator, and armchair installed on the robot flange, equipped with seat belts. The position built in this way was used to program armchair displace with a man sitting on it (Fig. 1).



Fig. 1. Position built in 1997 on the FANUC S420iW robot [10]

In the world, there are many research positions, built based on industrial robots, which are used for entertainments e.g. theme parks in Dubai and Hanover (Fig. 2).

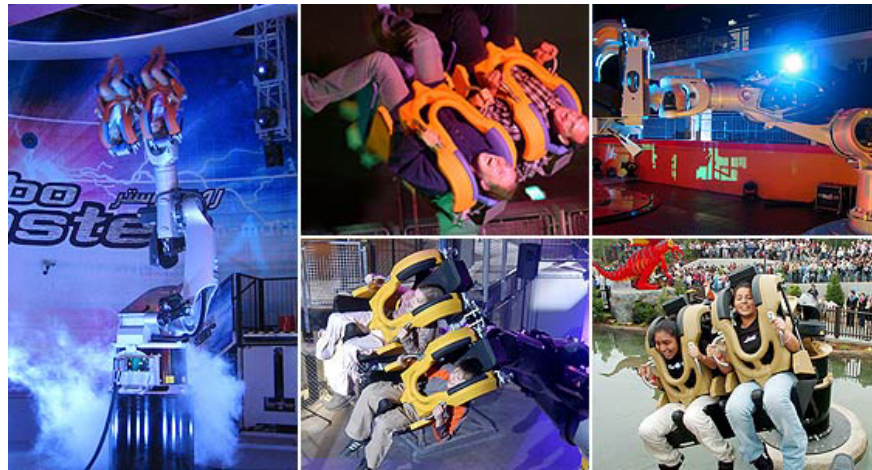


Fig. 2. Robocoaster of the KUKA Company [11]

Similar entertainment usage had a product called „Dynamic show action 6D”, which manipulated the objects in a form of full-dimension cars, for Hollywood film production needs (Fig. 3).



Fig. 3. Dynamic show action of the KUKA Company [12]

A completely new solution using industrial robots to manipulate is application of robots as wheeled vehicles and planes simulators. CyberMotion Simulator is an example (Fig. 4) which was drawn up by the Max Plank Institute for Biological Cybernetics in Tübingen, Germany.

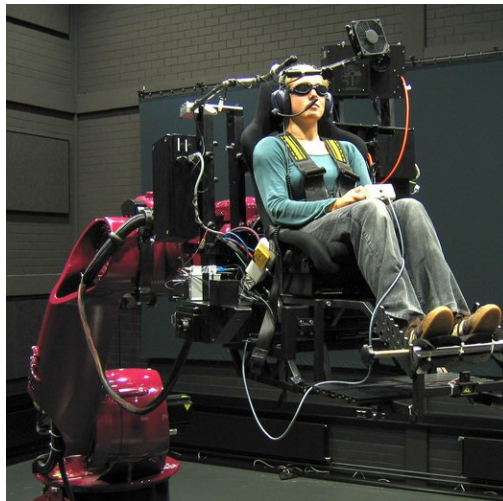


Fig. 4. CyberMotion Simulator of the KUKA Company [13]

3. ROBOTSTUDIO – ENVIRONMENT FOR PROGRAMMING ROBOTS IN AN OFF-LINE MODE

RobotStudio environment (Fig. 5) allows for designing robotized production cells based on the ABB Company robots [6, 8, 9]. Moreover, it enables to perform off-line simulation, programming, and optimization of robotized workstations equipped with IRC5 system controls.

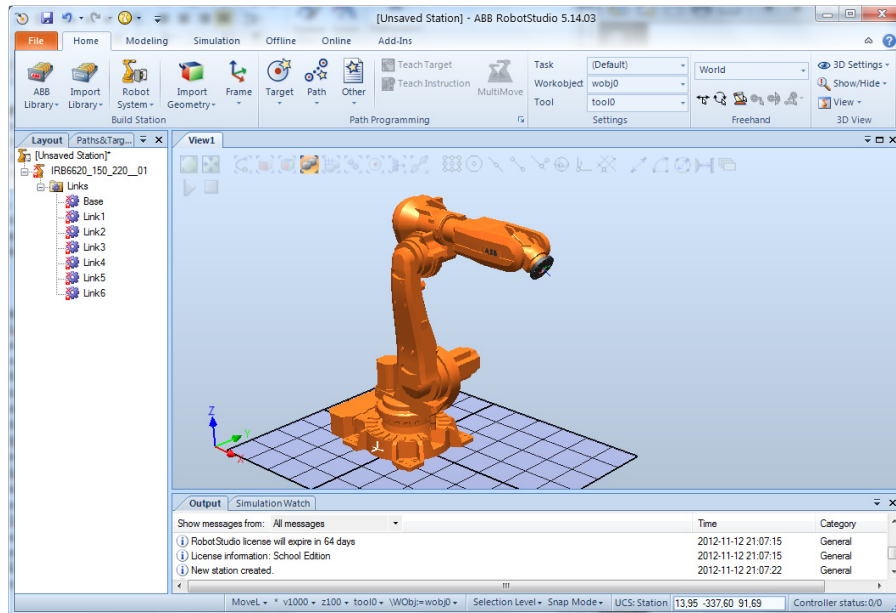


Fig. 5. General view of the RobotStudio environment

In the RobotStudio program, a Virtual Robot Technology was applied, which allows for a full robot simulation. This technology is characterized by a thorough reflection of real software, implemented in the real robot controller. The possibility to generate configuration files, working with the real robot, is one of RobotStudio major advantages [1, 3].

Full use of the RobotStudio environment is possible after installing RobotWare package. This package enables to create robotized cells' systems as during the work with a real device. RobotStudio environment is divided in a few components [1, 6]:

- *Home* – component containing tools for activities such as creating new systems, devices' libraries, importing geometry, creating coordinate systems, creating tools, targets, paths, adding to paths the movement and action instructions.

- *Modelling* – component which enables to create and edit three-dimensional objects, surfaces, curves, as well as to create mechanisms and tools.
- *Simulation* – component responsible for control and simulation of configurations, which enables, among others, to record, playback simulation, as well as to create notifications about collision between objects, and occurrences, e.g. objects movement.
- *Controller* – component which gives a control over the virtual IRC5 control system (offline) and control over the real IRC5 controller (if it is connected to PC computer); component allows, among others, to preview system variables, inputs and outputs of the controller, programming and on-line configuration, as well as file transfer between controller and PC.
- *Rapid* – editor which enables to view and edit the programs loaded into a controller, both real and virtual ones. The integrated RAPID editor is useful for editing all robot tasks, other than robot motion. With the RAPID editor, you can edit the RAPID code of the program modules and system modules. Each module you open appears in an editor window of its own, where you can add or edit RAPID code [7].
- *Add-Ins* – the Add-Ins browser shows the installed PowerPacs (additional Packages of RobotStudio).

As recalled, environment flexibility is possible thanks to high programming level of the Rapid language. Program written in Rapid language consists of row instructions describing robot functions. Specific instructions are designed for robot movement, input/output services, and arithmetical calculations.

4. ROBOTIZED POSITION CONCEPT TO STUDY SELECTED CHARACTERISTICS OF THE OPTOELECTRONIC HEADS

As a part of the carried out research, related with drawing up a new universal optoelectronic head for objects observation and tracking, the conduction of payload research in two stages was planned. First research will be carried out in the laboratory on drawn up research position, second in real conditions in the field.

In the present article, a conception of conducted laboratory tests of selected optoelectronic head characteristics using ABB Company industrial robots was presented.

In the frames of carried out construction research, associated with payload structure (after main sub-assemblies selection and required dynamic parameters determination), guidelines for robots which could to be included in robotized positions for head study were determined. A main purpose of the position is to conduct preliminary research of sensors, video tracker, and head drives.

Assumptions:

1. Drawn up position will enable to conduct the following research [2]:
 - a. Optoelectronic head drives test:
 - inspecting drives – head stabilization,
 - checking impact of parameters' changes of stabilization platform algorithms on its work in the vertical and horizontal plane,
 - checking dynamics of the head displace to an appointed position,
 - checking an accuracy and repetitiveness of working set angles,
 - b. Video tracker test:
 - checking the correctness of trace continuations for various object image parameters (velocity change and object stop),
 - checking maximum angle values, for which video tracker is able to capture indicated object (object scaling, contrast, focal length, object focus),
 - checking track velocity, for which video tracker does not lose a target (object scaling on the static and dynamic background in visible light as well as in infrared),
 - checking the correctness of trace continuations after momentary object image disappearance (also with other objects appearance),
 - c. Entire payload test (simultaneous drives and video tracker inspection),
 - d. Object track on the trajectory about set parameters in daily path and infrared, including optoelectronic head holder movement,
 - e. Interaction study of the head stability and track function.
2. Main position components:
 - a. 6-axial robot about hoisting capacity up to 3 kg for target imitator manipulation (e.g.: radiation source for thermal imaging cameras),
 - b. 6-axial robot about hoisting capacity up to 150 kg – head holder.

Assuming that robot range is not the most important, manipulator will be used as a platform enabling to draw up simulation movement extortions over uneven area, i.e. low frequency vibrations with certain amplitude.

Members of the research team at the Mechatronics and Aerospace Faculty have experience in the industrial robots used for research related with dynamics simulation of such dynamic objects like controlled missiles and UAV (Unmanned Aerial Vehicle). Currently, at the Faculty, research and development works are conducted, in frames of which the position for function correctness inspection of the autopilot rocket was built, as well as optoelectronic heads dedicated for UAV. The obtained results are promising and they allow us to believe that this is a good course of action.

Among advantages of the suggested solution it is possible to rank:

- great movements flexibility (possibility to use different dynamic situations for simulations),
- possibility to define a Tool Centre Point (payload movement simulation relative to freely defined points in space),
- full programmability of payload movements trajectory and tracked object,
- possibility to upload the measurements conducted on real objects and to generate trajectory of movements,
- movements' generation with high accuracy (less than 1 mm).

Main flaws in the presented concept:

- limited speeds and accelerations, depending on the robot type (no possibility to simulate the movements characterized by high frequencies of change).

5. RESEARCH POSITION CONCEPT IN THE ROBOTSTUDIO ENVIRONMENT

In the presented concept, an optoelectronic head model was used. As a part of research works, the full dynamic analyses and endurance (FEM, Finite-Element Method) of the created model were conducted. So, the model is full representation of a real optoelectronic head.

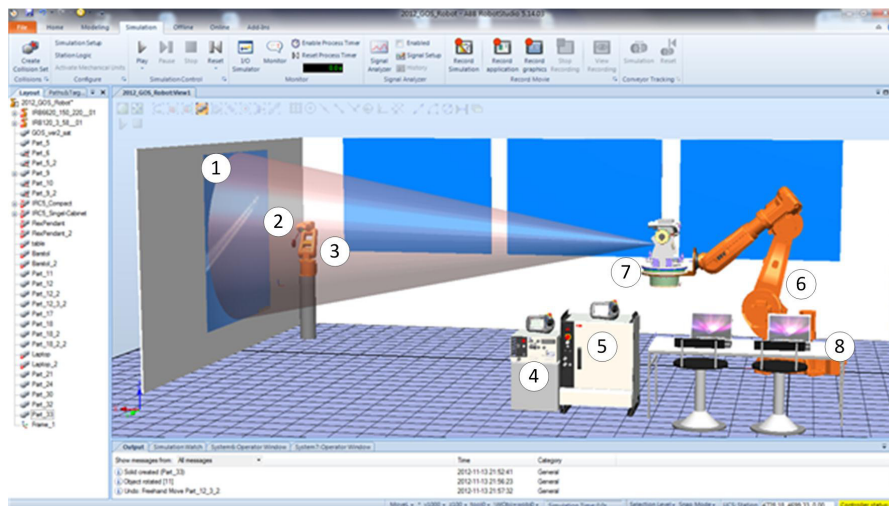


Fig. 6. General view of research position in RobotStudio

1 – screen (depict combat situation from slide projector), 2 – black body – perfect radiator (for IR cameras), 3 – IRB 120 robot of the ABB Company, 4 – IRC5 controller of the IRB120 robot, 5 – IRC5 controller of IRB6620 robot, 6 – IRB 6620 robot of the ABB Company, 7 – optoelectronic head, 8 – operator position

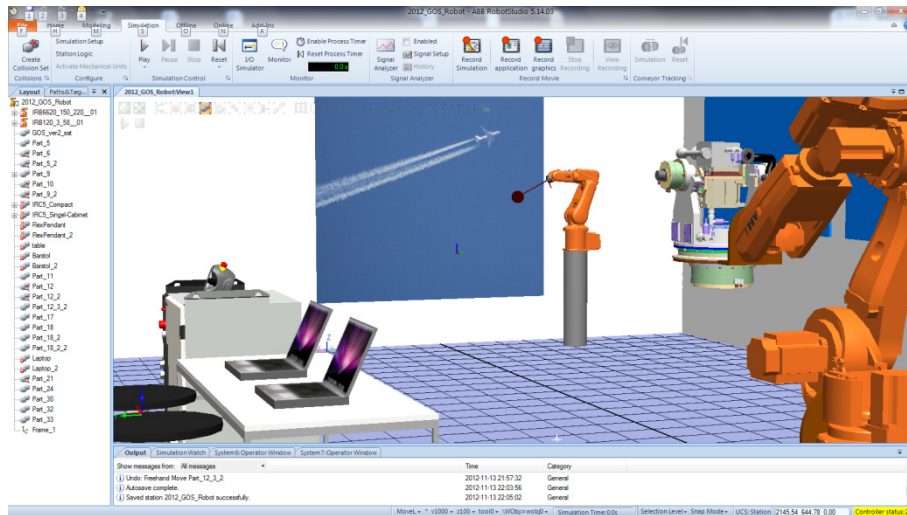


Fig. 7. General view of the research position in RobotStudio (screen to depict air situation and IRB120 robot equipped with a black body – perfect radiator)

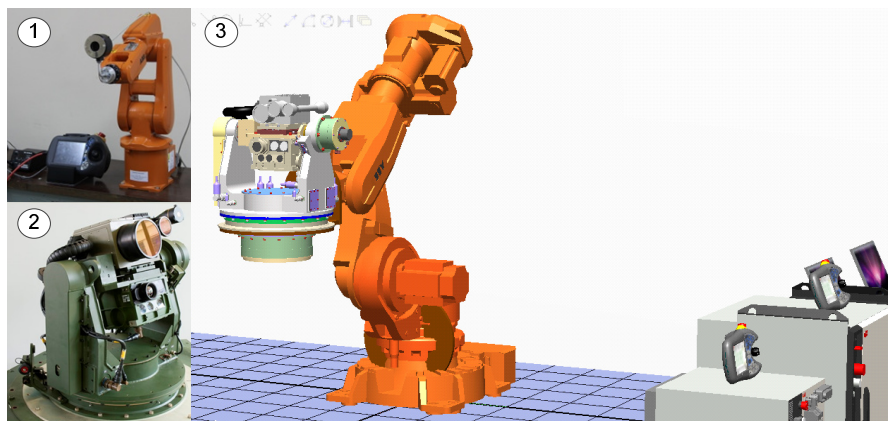


Fig. 8. General view of the research position in RobotStudio (optoelectronic head holder)

1 – real stand – IRB 120 robot with the real black body – perfect radiator, 2 – developed and executed prototype of the optoelectronic head, 3 – view of the optoelectronic head on the IRB6620 robot in RobotStudio

6. PARAMETERS OF AIR TARGET AND INVERSE KINEMATICS OF THE ROBOT

Figure 9 shows a general diagram of the flight of the air target, where v_c is the velocity of the target.

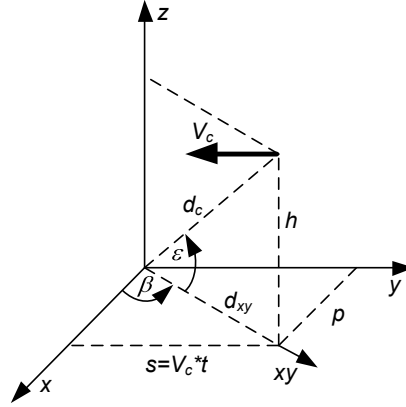


Fig. 9. General diagram of the flight of the air target

The following shows mathematical formulas in the form in which they were used in a computer program. As illustrated in Figure 9:

$$\beta = \operatorname{arctg}\left(\frac{v_c \cdot t}{p}\right)$$

$$\varepsilon = \operatorname{arctg}\left(\frac{h}{\sqrt{p^2 + v_c^2 \cdot t^2}}\right) \quad (1)$$

$$d_{xy} = \sqrt{p^2 + v_c^2 \cdot t^2}$$

which gives

$$\beta' = \frac{v_c}{\sqrt{p^2 + v_c^2 \cdot t^2}}$$

$$\varepsilon' = \frac{\frac{h}{p} \cdot \left(\frac{v}{p}\right)^2 \cdot t}{\left(1 + \left(\frac{h}{p}\right)^2 + \left(\frac{v}{p}\right)^2 \cdot t^2\right) \cdot \sqrt{1 + \left(\frac{v}{p}\right)^2 \cdot t^2}} \quad (2)$$

$$d'_{xy} = \frac{v^2 \cdot t}{\sqrt{p^2 + v_c^2 \cdot t^2}}$$

and second derivative

$$\begin{aligned} \beta'' &= \frac{\beta'[t+dt] - \beta'[t-dt]}{2 \cdot dt} \\ \varepsilon'' &= \frac{\varepsilon'[t+dt] - \varepsilon'[t-dt]}{2 \cdot dt} \\ d''_{xy} &= \frac{d'_{xy}[t+dt] - d'_{xy}[t-dt]}{2 \cdot dt} \end{aligned} \tag{3}$$

The hardest for the optoelectronic head is when the target moves linearly because velocity and acceleration of the motors of the optoelectronic head is changing dynamically (Fig. 10-15). The authors prepared computer programs in C++ language and they generated many simulations.

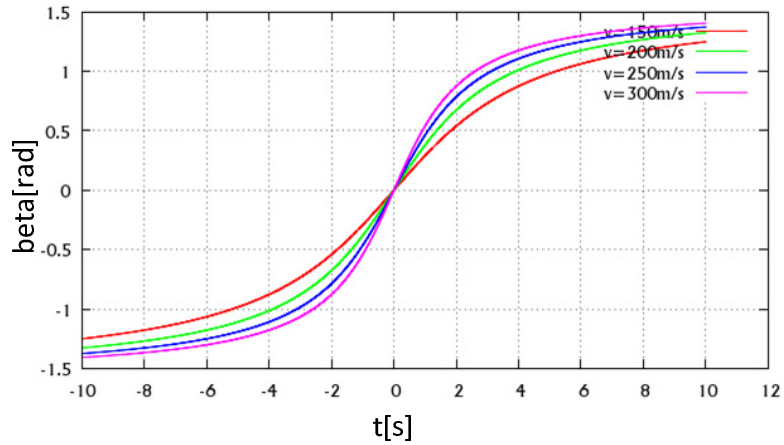


Fig. 10. Change of the azimuth angle with time

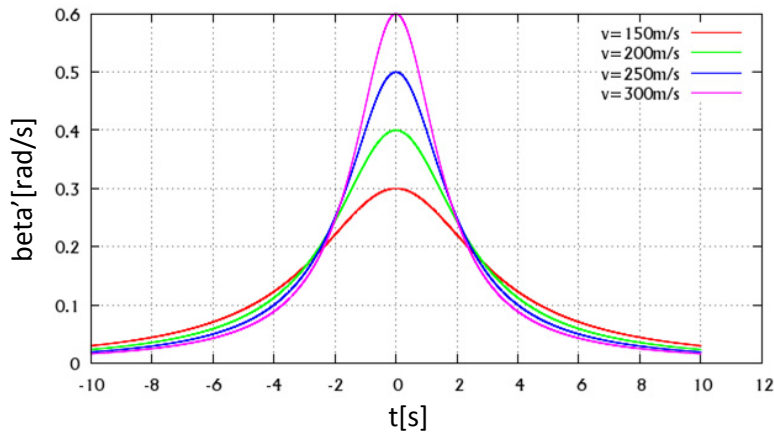


Fig. 11. Change of the velocity of the azimuth angle with time

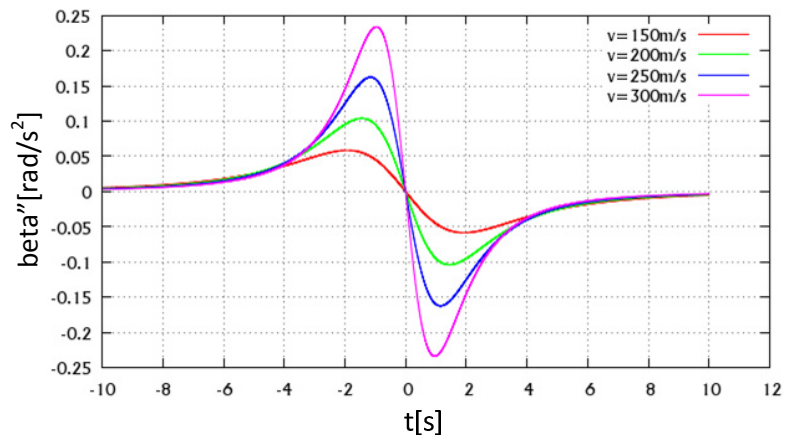


Fig. 12. Change of the acceleration of the azimuth angle with time

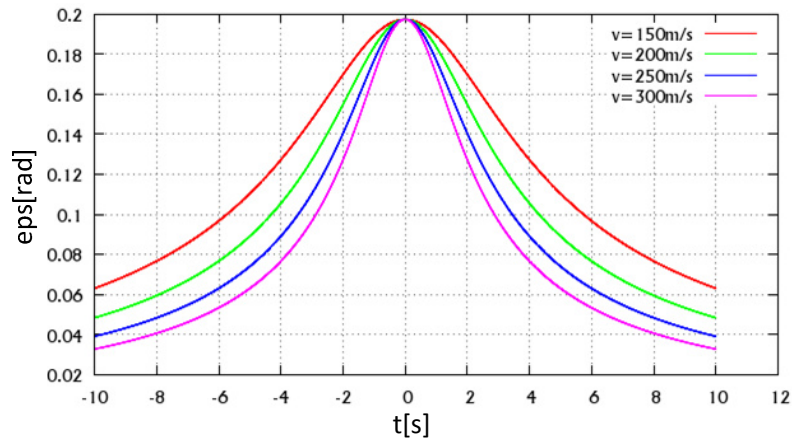


Fig. 13. Change of the angle of elevation with time

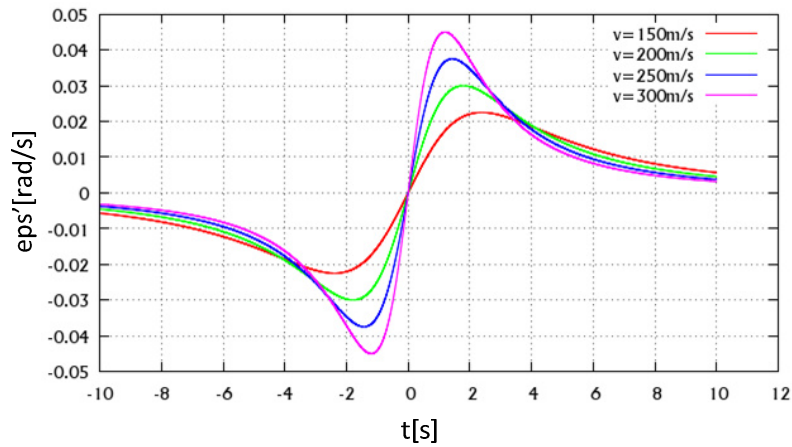


Fig. 14. Change of the velocity of the elevation angle with time

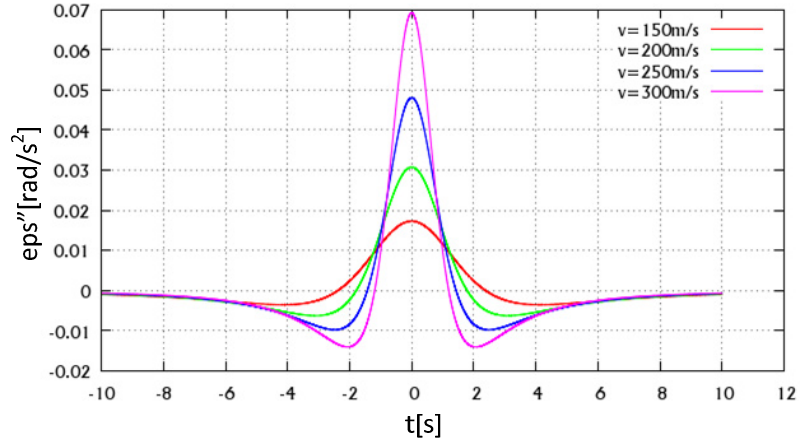


Fig. 15. Change of the acceleration of the elevation angle with time

Figures 10-15 present the results of simulations for linear trajectory of the target (velocity 150, 200, 250, 300 m/s) at a height 100 m and a distance 500 m.

The data obtained from the simulation enabled the development of RAPID language program [7] for a robot (Figure 8 – IRB 120), which is responsible for simulating the movement of the air target.

Mathematical calculation of the position and orientation of the robot tool requires the designation of the inverse kinematics. For a six axial manipulator with 3-R wrist, it is possible to determine inverse kinematics using analytical method [9]. The form of general homogeneous transformation matrix that expresses the position and orientation of the end-effector with respect to a base frame is the following:

$${}^0T_n(q_1, \dots, q_n) = {}^0T_1 \cdot \dots \cdot {}^{i-1}T_i \cdot \dots \cdot {}^{n-1}T_n = \begin{bmatrix} \text{Rotation} & | & \text{Translation} \\ \text{Perspective} & | & \text{Scale factor} \end{bmatrix} \in SE(3) \quad (4)$$

where

q – joint variable.

The form of transformation matrix (DH-convention) that expresses the position and orientation of the O_i frame with respect to the O_{i-1} frame (Figure 16) is the following:

$${}^{i-1}T_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \cdot \cos \alpha_i & -\sin \theta_i \cdot \sin \alpha_i & a_i \cdot \cos \theta_i \\ \sin \theta_i & \cos \theta_i \cdot \cos \alpha_i & -\cos \theta_i \cdot \sin \alpha_i & a_i \cdot \sin \theta_i \\ 0 & \sin \alpha_i & \cos \alpha_i & s_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

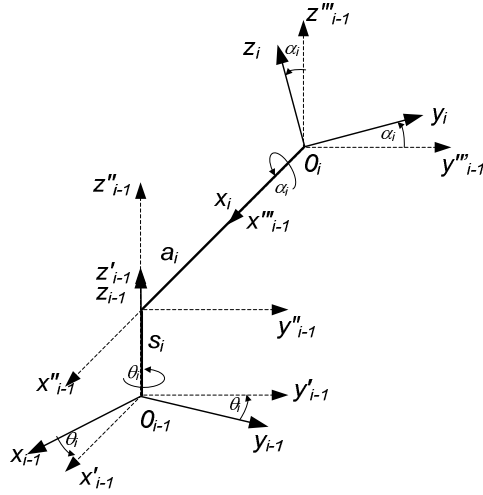


Fig. 16. Change of the acceleration of the elevation angle with time

For manipulators having six joints (6), with the last three joints intersecting at a point,

$${}^0T_6 = \begin{bmatrix} k_{11} & k_{12} & k_{13} & {}^0r_{x6} \\ k_{21} & k_{22} & k_{23} & {}^0r_{y6} \\ k_{31} & k_{32} & k_{33} & {}^0r_{z6} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

it is possible to decouple the inverse kinematics problem into two problems, known respectively, as [5]:

- inverse position kinematics

$${}^0r_6(q_1, \dots, q_n) = r \quad (7)$$

- inverse orientation kinematics

$${}^0rot_6(q_1, \dots, q_n) = rot \quad (8)$$

The origin of the tool frame is simply obtained by a simple translation along the axis z_5 , so, it is possible to write the position of the wrist as:

$$\begin{bmatrix} {}^0r_{x3} \\ {}^0r_{y3} \\ {}^0r_{z3} \end{bmatrix} = \begin{bmatrix} {}^0r_{x6} - {}^3r_{x6} \cdot k_{13} \\ {}^0r_{y6} - {}^3r_{y6} \cdot k_{23} \\ {}^0r_{z6} - {}^3r_{z6} \cdot k_{33} \end{bmatrix} \quad (9)$$

and the orientation of the wrist

$${}^0rot_6 = {}^0rot_3 \cdot {}^3rot_6 \Rightarrow {}^3rot_6 = ({}^0rot_3)^T \cdot {}^0rot_6 \quad (10)$$

7. CONCLUSIONS

Development of the industrial robots possibilities enables us to use them for the purposes not related directly with industry. Along with flexibility development of these devices, especially programming (high-level advanced programming languages), robots are equipped with modern equipment solutions, which among others: increase safety of their use. Due to high technical parameters (e.g.: accuracy, position repeatability, range, six degrees of freedom, i.e. the possibility of any object use in the workspace) already today they seem to be a good solution as devices used for laboratory tests.

The examples presented in the introduction of this article prove that engineers are not restricted to stiffly allocation of these types of devices. Wider application of visional systems and PC computers enables to create flexible software that allows for usage of industrial robots in scientific research. Software created on PC computers can be easily integrated with software developed and implemented in the robot controllers (e.g.: TCP protocol).

The main authors objective is to develop position, which firstly will allow for studying, in the laboratory conditions, selected dynamic parameters of optoelectronic heads created as a part of research by the team of the Military University of Technology in Warsaw, and in the future also for verification (evaluation) of optoelectronic heads as well as their individual components offered by the leading world producers.

It is necessary to note that, thanks to modern programming environments, such as RobotStudio of the ABB Company, it is possible to draw up applications which reflect in almost 100% a real machine, and thus enables, with high accuracy to conduct preliminary simulation research and to indicate limitations of planned research position [2]. Collection of dynamic characteristics of the optoelectronic head holders and parameters of the potential objects movement, which are supposed to be tracked by the heads, will enable to create a base as well as reflect (to some extent) the real conditions. This, in turn, will allow for applicable selection of sub-assemblies parameters (e.g.: drives, cameras) and programmable setting (e.g.: video tracker, adjusters).

Following the robotics development, as well as their wider application range (in almost all industry and sciences fields), it is important to carry out the works on wider use of industrial robots in research.

REFERENCES

- [1] Kaczmarek W., Gospodarczyk K., Some aspects of modelling of robotic manufacturing cells in the RobotStudio using TCP/IP (*in Polish*), *Mechanik*, no. 7, p. 598 (full paper on CD), 2012.
- [2] Kaczmarek W., Panasiuk J., Conceptual project of robotic station for testing of optoelectronic heads (*in Polish*), *Mechanik*, no. 7, p. 602 (full paper on CD), 2012.
- [3] Kaczmarek W., Panasiuk J., Comparative analysis of selected environments for programming industrial robots in off-line mode (*in Polish*), *Mechanik*, no. 7, p. 614 (full paper on CD), 2011.
- [4] Kaczmarek W., Panasiuk J., Station for controlling elements of military equipment and its condition with use of the robot (*in Polish*), *Mechanik*, no. 7, p. 610 (full paper on CD), 2011.
- [5] Spong M.W., Vidyasagar M., *Robot Modeling and Control*, Wiley, 1989.
- [6] *User Guide for RobotStudio*, ABB Robotics Products Vasteras, Sweden 2013.
- [7] *User Guide for Rapid*, ABB Robotics Products Vasteras, Sweden 2007.
- [8] *User Guide for RobotWare*, ABB Robotics Products Vasteras, Sweden 2007.
- [9] *User Guide for IRC5*, ABB Robotics Products Vasteras, Sweden 2004-2010.
- [10] <http://blog.makezine.com>
- [11] <http://www.kuka-entertainment.com>
- [12] <http://www.kuka-entertainment.com>
- [13] <http://spectrum.ieee.org/automaton/robotics/industrial-robots/engineers-turn-robot-arm-into-formula-1-simulator>