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Modeling and control of Mechatronic Devices via the Internet with the use of the Matlab/Simulink software - on example of the manipulator

Abstract. The paper presents remotely controlled system on the example of a manipulator controlled via the Internet by the use of Matlab/Simulink. Individual modules of this control system were presented, with the focus mainly on the description of the control algorithm of the manipulator via the Internet. Analysis of the effectiveness of the proposed method for remote control via the Internet was conducted by using Matlab/Simulink. The analysis was based on comparing the set and recorded trajectory of the manipulator in Cartesian coordinate system.

Streszczenie. W artykule przedstawiono układ zdalnego sterowania przykładowym manipulatorem poprzez sieć Internet z zastosowaniem oprogramowania Matlab/Simulink. Opisano poszczególne moduły systemu z naciskiem na algorytm sterowania. Analizę skuteczności proponowanego sposobu zdalnego sterowania za pośrednictwem Internetu przeprowadzono stosując oprogramowanie Matlab/Simulink. Analizę oparto na porównaniu zadanej i zarejestrowanej trajektorii manipulatora w układzie współrzędnych kartezjańskich. (Modelowanie oraz sterowanie urządzeń mechatronicznych poprzez Internet z wykorzystaniem programu Matlab/Simulink - na przykładzie manipulatora).

Keywords: control via the Internet, Matlab/Simulink, 4 DoF manipulator, real-time simulation.
Słowa kluczowe: sterowanie przez Internet, oprogramowanie Matlab/Simulink, manipulator o 4-stopniach swobody, symulacja w czasie rzeczywistym.

Introduction

The current new wave of technological change is completely transforming the industrial sector. The sector is on the verge of the fourth industrial revolution, which opens up a whole range of potential innovations in the field of intelligent industrial processes. A new wave of Industry 4.0 technology [1, 2] is based on the concept of cyber-physical systems or on strong influence of real and virtual worlds on each other, which becomes the core of the production process.

One of the elements of new solutions is the use of the technology of Internet of Things [3] for remote control of manipulators via the Internet.

The paper proposes the use of Matlab/Simulink software for remote control on the example of a manipulator via the Internet. It is based on the previous work, in which Matlab/Simulink is used to control mathematical models of the manipulator [4] by different delay times of the data packets via the Internet.

The system of remote control on the example of a manipulator controlled via the internet

The remote control system of an exemplary manipulator controlled via the Internet consists of the following components [5] that are presented in Fig. 1:

- Subsystem of control on the server side - the algorithm introduced in Matlab/Simulink software.
- Subsystem of control on the client side, that consists of four cooperating modules: AVR microcontroller; network adapter card ENC28J60; galvanic separator and converter of logic levels for the SPI bus.
- The object controlled by a manipulator with four degrees of freedom.
- System for measuring the angular position of manipulator joints. The recorded data are used to analyze the effectiveness of control.

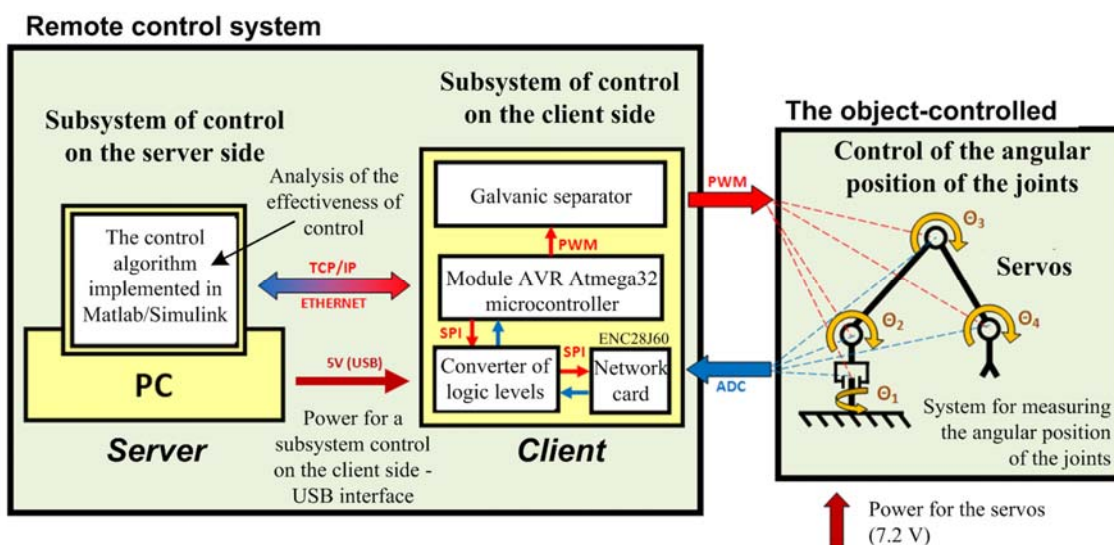The transfer of data between the client and the server was done by the use of TCP/IP protocol.

Fig.1. Block diagram presenting the remote control on the example of a manipulator controlled via the Internet by the use of Matlab/Simulink

Subsystem control on the server side by the use of Matlab/Simulink

The block diagram of the control system on the server side, which was developed in the Simulink is presented in Fig. 2.

The algorithm of the subsystem provides remote control of the manipulator with four degrees of freedom via the Internet. The algorithm is based on generating trajectory of the end-effector of the manipulator in a way that moves sequences in the specified time and includes three defined points in the workspace (Tab. 2). In reality, these points are defined by the user using three matrices that determine the position and orientation of the manipulator in an instant. On the basis of these points the control programme determines the values of the joint parameters (Inverse kinematics), which are then used as input for trajectory generation.

The generator provides the connection of determined values of successive points by using an algorithm based on a third degree polynomial, and on that basis desirable trajectory of the end-effector of the manipulator is generated.
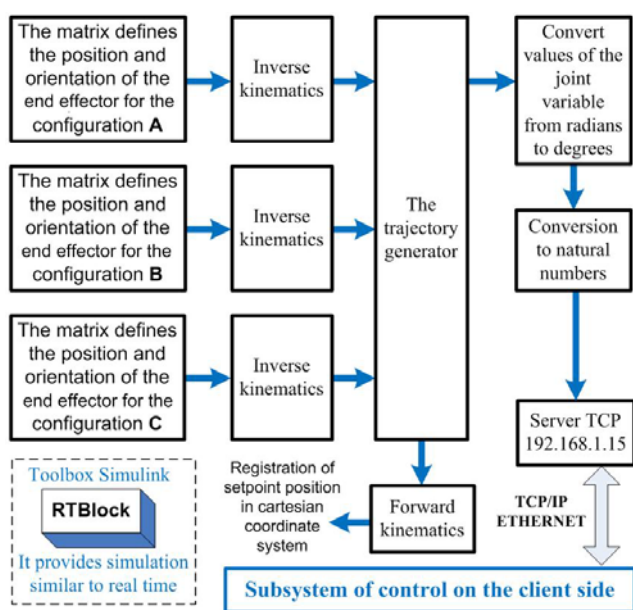

Fig.2. Block diagram of an algorithm developed in Simulink for the subsystem control on the server side

The output data obtained in this way from trajectory generator are converted into degrees and transmitted in the form of natural numbers to the control subsystem on the client side via TCP / IP.

Due to control of real objects the manipulator with the algorithm entered in the Simulink was required to ensure simulations under conditions similar to real-time simulations. For this purpose a special toolbox *RTBlock* has been applied, which provides correct conditions for control. The block wait of the time needed to fill the simulation step, leaves the remaining CPU time to all the Windows Processes that need it.

The structure of the division of tasks for remote control system

The division of developed remote control system on the subsystem control on the server side and subsystem control on the client side requires the assignment of specific tasks for both parts of the controller. Some of these tasks is a direct result of the adopted in the system the network architecture client-server. All other tasks are related to the used method of control of the manipulator with four degrees of freedom (Tab. 1.).

Table 1. The assignment of tasks to control sub-system on the server side and client side

	Subsystem control on the server side	Subsystem control on the client side
Tasks resulting from the application of the method of controlling the manipulator	Carrying out calculations of forward and inverse kinematics of manipulator.	Generating a PWM signal with duty cycle corresponding to the appropriate position of the individual rotors at the joints of manipulator.
	Generating the trajectory of the manipulator.	
Tasks resulting from the adopted in the system of network architecture client-server	The detection a new connection with the client.	Establishing a connection to the server.
	Waiting at the request from the client about the current values of joints variables of manipulator.	Sending a request to the server about the current values of joints variables of manipulator.
	Sending a response to client about the current values of joints variables of manipulator.	Waiting for a response from server about the current values of joints variables of manipulator.
		The end of the connection.

In order to formulate a forward kinematic equations for the 4-DoF manipulator, been used a universal procedure based on Denavit-Hartenberg notation [6]. For formulate inverse kinematic equations for the 4-DoF manipulator, been used geometric approach [7, 8].

Results of the analysis of control efficiency

The measurements necessary in the analysis of the efficiency of the remotely controlled manipulator have been done in Matlab/Simulink. Measurements included registration of the setpoint and actual values of the joint parameters of the manipulator, the setpoint as well as actual position of the manipulator in Cartesian coordinate system (forward kinematics).

On the basis of comparison of set and actual values, absolute error tracking was calculated for each trajectory.

In order to analyze the effectiveness of the control of the manipulator via the Internet, it was necessary to use specialized measuring system [5], which was developed for this project. The purpose of the measurement system was to measure the actual angular position of the manipulator joints, and as a result the measurement of the actual position of the end-effector in the workspace.

These studies were conducted in real time using the Local Area Network. The transmitted data packets of delays were entered with a Transport Delay block in the Simulink.

The study was conducted for five different data transmission delays via the Internet (t_{delay} = 0 ms, t_{delay} = 10 ms, t_{delay} = 30 ms, t_{delay} = 50ms and 80ms) with the setpoint trajectory of movement which included three points at a specified time and which are presented in Tab. 2.

Table 2. Characteristic points of the manipulator trajectory

Coordinates of the point [mm]	The matrix of the position and orientation of the manipulator defines the set point	Time to reach the position [s]
$A = (182,8; 0; 152,3)$	$\begin{bmatrix} 0,87 & 0,5 & 0 & 182,8 \\ 0 & 0 & -1 & 0 \\ -0,5 & 0,87 & 0 & 152,3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	0
$A = (182,8; 0; 152,3)$	$\begin{bmatrix} 0,04 & 0,5 & 0,87 & 95,8 \\ 0,08 & 0,86 & -0,5 & 166 \\ -1 & 0,09 & 0 & 73,9 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	4
$A = (182,8; 0; 152,3)$	$\begin{bmatrix} 0,25 & -0,43 & -0,87 & 12 \\ -0,43 & 0,75 & -0,5 & 20,8 \\ 0,87 & 0,5 & 0 & 549,8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	9

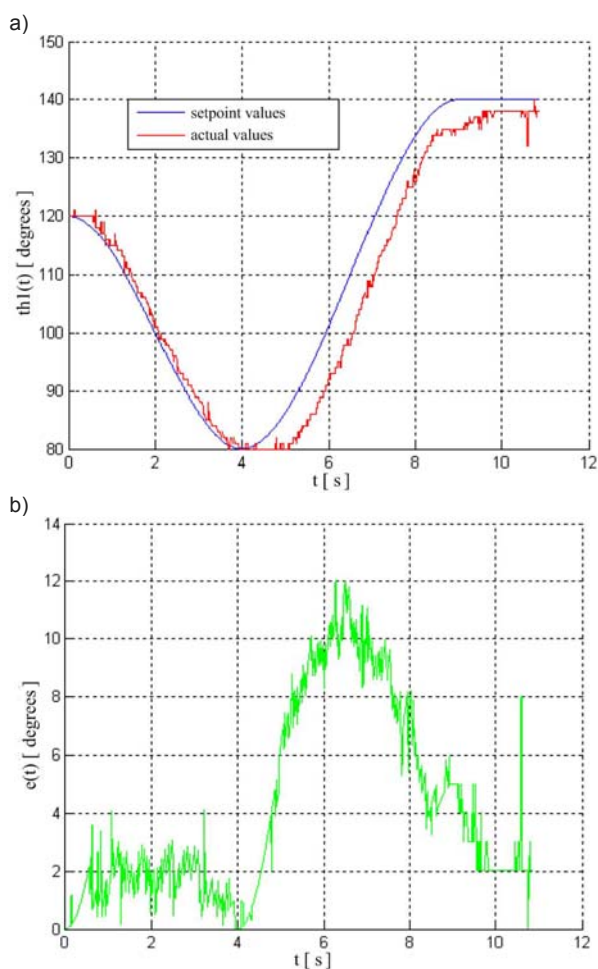Fig 3 presents exemplary results of measurements for the set delay of $t_{delay}=10$ ms.

Fig. 3. The results of the analysis of the effectiveness of controls for delay τ = 10ms: a) tracing the trajectory of joint Θ_2, b) absolute error of tracking the trajectory of joint Θ_2

Conclusions

Based on the conducted series of tests as well as the obtained results, it can be stated that the developed remote control system of the manipulator via the Internet works as planned. By using Matlab/Simulink with additional block *RTblock*, that provides simulation conditions similar to real-time ones, one obtains flexibility to adapt the implemented algorithm in a simulation environment for the controlled object. Flexibility to adapt the algorithm of control is especially important in a case that involves transmission of delays data packet. The test stand where the algorithm is implemented in Matlab/Simulink also provides a possibility to analyze the effectiveness of control during testing.

The calculated trajectory tracking errors for changing the position of individual joints of the manipulator increases with increasing the setpoint delay of the transmission of data packets via the Internet. Analyzing the obtained results is also noteworthy due to the difference in average values of the obtained errors (for the smallest and largest specified transmission of delay data packets), which amounts up to maximally 1.32° (for joints manipulator) and 4,91mm (for the position of the end effector). Greater emphasis on errors is put on the control objects (installed drives), as well as the communication link and equipment.

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REFERENCES
[1] Zhou K.,Taigang Liu; Lifeng Zhou, Industry 4.0: Towards future industrial opportunities and challenges, Fuzzy Systems and Knowledge Discovery (FSKD), 12th International Conference on (2015), 2147 - 2152
[2] Jazdi N., Cyber physical systems in the context of Industry 4.0, Automation, Quality and Testing, Robotics, 2014 IEEE International Conference on (2014), 1 - 4
[3] Bari N., Mani G., Berkovich S., Internet of Things as a Methodological Concept, Computing for Geospatial Research and Application (COM.Geo), 2013 Fourth International Conference on (2013), 48 - 55.
[4] Kielan P., Kluszczyński K., Investigation on controlling mechatronic systems via the internet with use of network emulator, Research and Education in Mechatronics (REM), 2015 16th International Conference on (2015), 154 - 158.
[5] Ludwig M., Design and construction of remote control through Internet for exemplary manipulator, Master's thesis, The promoter: Ph.D. Paweł Kielan, Gliwice 2015
[6] Spong M., Dynamika i sterowanie robotów, Wydawnictwo Naukowo-Techniczne, Warszawa (1997)
[7] Jezierski E., Dynamika Robotów, Wydawnictwo Naukowo-Techniczne, Warszawa (2006)
[8] Kozłowski K., Modelowanie i sterowanie robotów, PWN, Warszawa (2006)