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QUICK PROTOTYPING OF MANIPULATOR CONTROL SYSTEM WITH PLC CONTROLLER

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Abstract: *Presented article depicts new approach to the industrial manipulator's control that simplifies new control algorithms implementation. A prototyping setup consists of RXi BOX IPC and input/output modules RSTi distributed I/O, which are fully compatible with PLC controllers. Control algorithm optimisation is performed on a Box IPC in a high-level programming language that drastically accelerates implementation. Following implementation, a Box IPC and distributed I/O, are substituted with a real-time operating PLC. After algorithm optimisation and programming of the PLC, system is ready to work*

Keywords: PLC controller, Robotic arm, Phantom device, Control, IPC.

1. Introduction

Many kinds of manipulators found implementation in a variety of fabrication lanes. However, robotic arm's use is not only limited to industry. Growing number of mobile platforms is currently equipped with a manipulator. The most arduous task, regarding use scenario, is to implement optimal control algorithm. Authors' goal is to address this problem in this paper.

System's output (execution device) is a Hyperion 2 Mars rover analogue. It was created to compete in an international competition University Rover Challenge 2014. During this challenge, the rover had to perform several tasks, which required the use of an onboard manipulator. Use of joystick to control its robotic arm was imprecise. An optimal control algorithm was a result of numerous experiments and gradual improvements. Currently, it consists of the Phantom device equipped with encoders for precise angle reads and industrial PC. Such setup allows feedforward as well as control in Cartesian cordite system.

2. Robotic arm – Phantom system

System for rapid prototyping of robotic arm controllers (Fig. 1) consists of the Phantom device (1), RXI_IPC_EP, model ICRXIFC7E111A controller (2) with modular input/output interface RSTi I/O, communication devices, a set of 2, SATELLINE-3AS 869 (3), mobile robot fitted out with a robotic arm (4). The computer (5) with Linux operating is used to control drive unit by means of radio modems (6) are additional equipment.

The system can operate in two modes: feed-forward and Cartesian. In the feed-forward mode, the robotic arm recreates temporary positions of individual phantom's joints. Need to create robotic arm's kinematic equivalent in the form of a phantom device is a disadvantage of this method. The Cartesian coordinates system mode requires calculation of end effector's global position, following, calculations of temporary angles between each joint using inverse kinematics on robot's side of the system.

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Fig. 2 depicts the phantom device, that consists of the base (1), three rotational joints (2, 4, 6), three rigid links (3, 5, 7) an encoder (8) and simulated end effector's tip (9). The device has four additional encoders. Each in every joint and one embedded in the base.

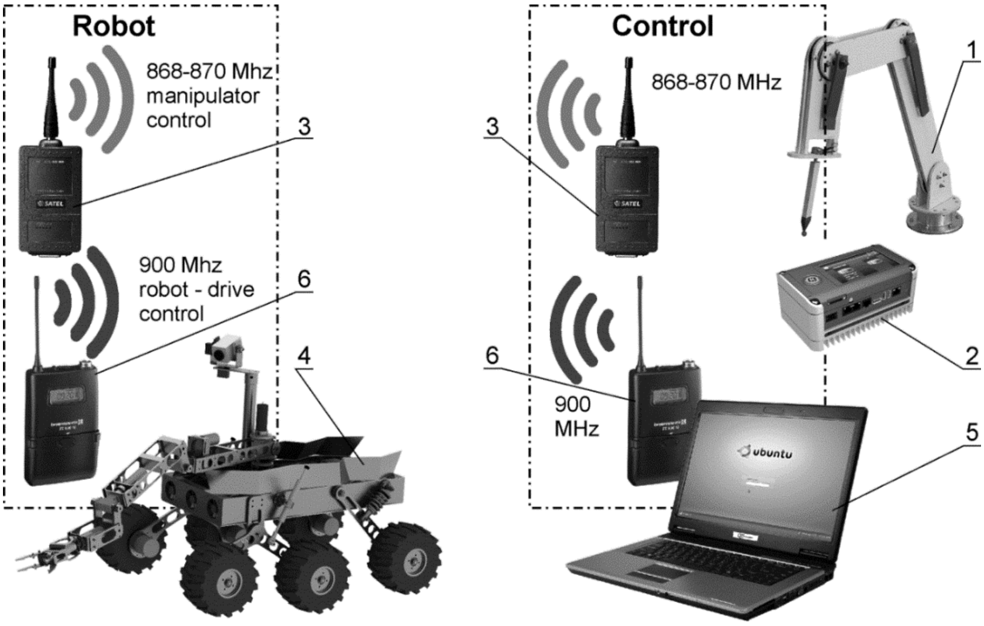

Fig. 1: System scheme.

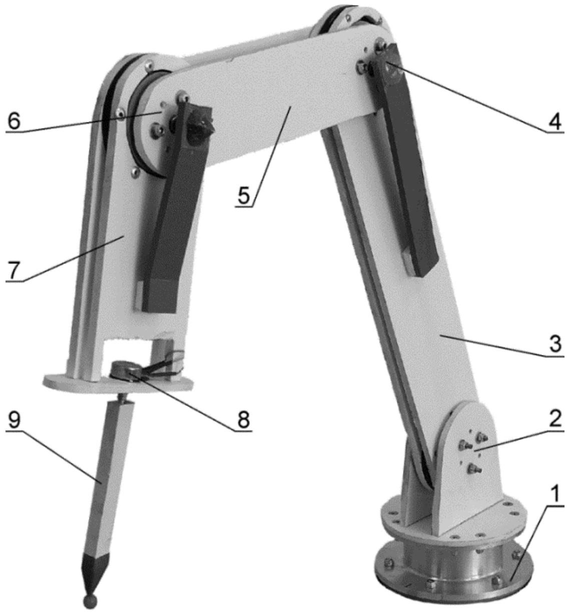

Fig. 2: The phantom device.

3. Robotic arm's and phantom's kinematics

The robotic arm and the phantom device are kinematic "twins". This feature allows easy implementation of feed-forward control mode as well as consideration of Cartesian manipulation scenarios. To calculate the position of the end effector's tip (point P) a forward kinematics calculation is required (Pietrala 2016).

Using a Denavit- Hartenberg parameters, local transformation matrices were obtained that were used to create global transformation matrix. There are numerous methods of calculating forward and inverse kinematics of the robot's chain (Craig, 1999).

$$ {}^{0}_{P}T = {}^{0}_{1}T \cdot {}^{1}_{2}T \cdot {}^{2}_{3}T \cdot \ldots \cdot {}^{i-1}_{i}T \cdot \ldots \cdot {}^{P-1}_{P}T \quad (1) $$

X, Y, Z coordinates are obtained by calculation of the first three elements of the last column of the global transformation matrix (2).

$$ {}^{0}_{P}T = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} \\ f_{21} & f_{22} & f_{23} & f_{24} \\ f_{31} & f_{32} & f_{33} & f_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

That results in position vector (3).

$$ P = \begin{bmatrix} f_{14} \\ f_{24} \\ f_{34} \end{bmatrix} \quad (3) $$

Functions f_{14}, f_{24}, and f_{34} depending on the angles of phantom's joints were pre-calculated and used in the control algorithm.

However, to recreate the position on robot's side of the system, an inverse kinematics calculations are required. To simplify calculations, let's consider manipulator as a kinematic chain in XY-Z plane (Fig. 3).

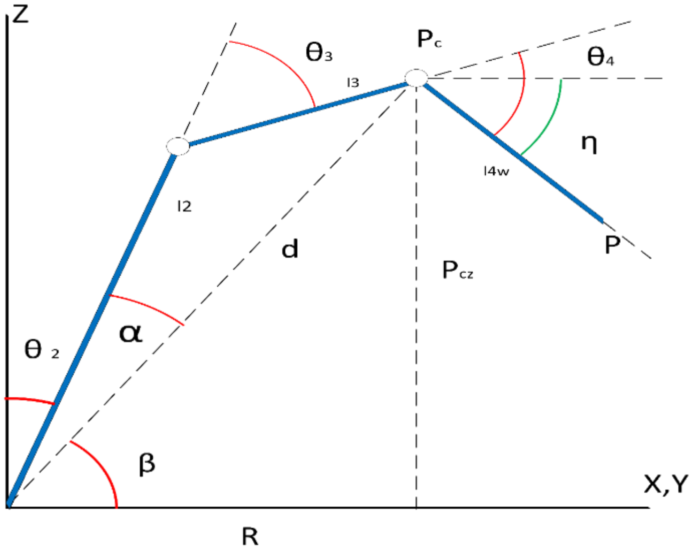

Fig. 3: Robotic arm's simplified model.

This simplification can be used, because of only one angle changes in X-Y plane and it can be calculated using following formula

$$ \theta_1 = atan(P_y, P_x). \quad (4) $$

To calculate angles a mid-point was used, through several transformations, equations can be obtained:

$$ cos\theta_3 = \frac{{P_{cx}}^2 + {P_{cy}}^2 + (P_{cz} - l_1)^2 - {l_2}^2 - {l_3}^2}{2 \cdot l_2 \cdot l_3}. \quad (5) $$

If $M = cos\theta_3$, then $sin\theta_3 = \sqrt{1 - M^2}$ thus:

$$ \theta_3 = \mathrm{atan}(\sqrt{1 - M^2}, M). \quad (6) $$

Next,

$$ \theta_2 = -\frac{\pi}{2} + \alpha + \beta, \quad (6) $$

where:

$$ \alpha = atan2(l_3 \cdot sin\theta_3, l_2 + l_3 \cdot cos\theta_3), \quad (7) $$

$$ \beta = atan2(P_{cz} - l_1, \sqrt{{P_{cx}}^2 + {P_{cy}}^2}). \quad (8) $$

Finally:

$$\theta_4 = \eta - \theta_2 - (\pi - \theta_3). \quad (9)$$

Having θ_1, θ_2, θ_3 i θ_4, a proper setup of the robotic arm is dependent on the robot's on-board.

In order to lower a number of possible solutions to those calculations and also eliminate unobtainable configurations a η- nutation angle is used. It is an angle between X-Y plane and last link. It determines inclination of the last link thus end effector. This approach was inspired by graphical solution of the inverse kinematics found in literature (Spong and Vidyasagar, 1997, and Tchoń et. al., 2000).

4. Conclusions

The considered solution proved to step in a direction leading towards more reliable and precise control of the robotic arm. During series of experiments, proposed system performed above expectations. It not only accelerated control algorithm implementation but also allowed to detect several minor faults that occurred during the design process. The essential advantage of proposed system is its ease of programming and modularity. Performed tests consisted of repeating actions performed using direct connection between phantom and robot controllers.

The main computer, an IPC Box, is connected to the I/O module using MODBUS Protocol. This solution ensures quick access to sensory data and very easy use of this information in prototyped algorithm. Any inconsistencies in system's performance can be easily detected and corrected giving a programmer a sophisticated tool to create optimal algorithms.

Thanks to considered solution, an algorithm that proved to perform correctly can be implemented in a PLC controller operating in real time. Even inputs and outputs can be reused following prototyping phase. This approach reduces the time needed for new equipment implementation and assures its proper functioning.

Development of individual systems would take more time, including fine tuning the algorithm. Moreover, this solution is not only time saving thus cost-efficient, but also guarantees the best possible performance.

Future development of the project may bring even further improvement of usability and increased algorithm prototyping speed. Necessary modifications are currently implemented and will certainly benefit in our further research.

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