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A SYSTEM OF INDUSTRIAL MANIPULATOR EQUIPPED WITH FUNCTIONS FOR ADAPTATION AND RECONFIGURATION

Key words

Industrial manipulator, reconfiguration, adaptation, modular robotics.

Abstract

The article presents a system for an industrial manipulator equipped with advanced functions for reconfiguration and adaptation. Currently standard industrial manipulator systems perform their function in an invariable, planned in advance manner; however, in near future, it is certain that there will be high demand in the market for systems that allow adaptation of their configuration to the variable situation in the production line. The use of mechatronic systems and devices that are capable of reconfiguration and adaptation to changing tasks in the technical process allows an increase in the flexibility and effectiveness of industrial plants.

Presented solution assumes the fitting of a standard industrial manipulator with additional systems to allow its reconfiguration, monitoring its environment, and adaptation of its parameters according to current needs. The described system of reconfiguration and adaptation functions for the industrial manipulator allows the introduction of the robotic technology into the areas where, so far, it was not possible or unprofitable, that is for the production line with a short series of product production.

Introduction

Robotic systems have become very popular on large production plants. Once programmed can perform their operation continuously without making mistakes or fatigue. However, the cost of robotisation is high, so smaller facilities still need to rely on human labour. There is a clear tendency to produce machinery capable of operating on different variants of the same product. Additionally, there are machining centres to perform multiple operations on one product. Using such equipment requires extended changeover times, so quick change of the assortment is not possible [1].

A solution for that problem would be application of a reconfigurable system [2]. Such a system of a modular structure should allow quick changeover of components, thus adapting the system to a new series of products. Automation of changeover processed with independent decision-making and automated adaptation of machine parameters constitutes a flexible and efficient production system.

The system presented in this article is a system with functions of reconfiguration and adaptation based on an industrial robotic arm. It is intended for use in small production facilities with variable production assortment. The concept of the system consists in using a typical industrial manipulator and retrofitting it with additional modules for flexible tool switching and for monitoring the environment of the robot and the production line. In addition, the system includes a software expert system to store the information about the production process and available tools and for making the decisions on subsequent actions.

1. Modular robotics

Robotics is a research area that is currently under rapid development. It has been noticed that the extension of robot capabilities is strictly related to its modularisation. Manipulators built from modules can be optimised in their functionality and costs.

There exist several examples of modular robots developed in laboratories. Such an example might be a Hydrabot – The Modular Electro-Hydraulic Robot Arm (Fig. 1) designed by Abed Alnaif from University of Waterloo [3]. Hydrabot is constructed of several identical links, each of them utilising one degree of freedom.

A similar concept is presented by William J. Schonlau [4, 5]. His Modular Robot (Fig. 2) is built of series of 1 DOF modules, but there exist four types of modules: rotary joint, linear joint, elbow link, and straight link – two of them active and two passive.
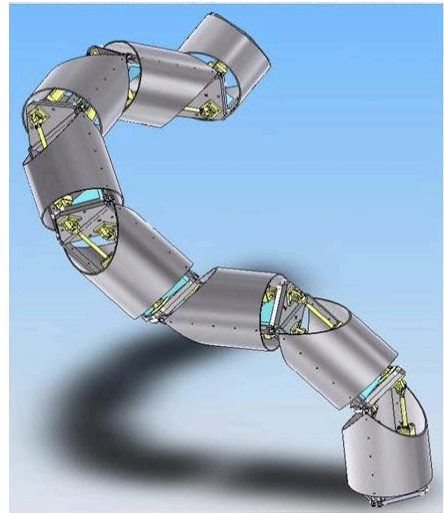
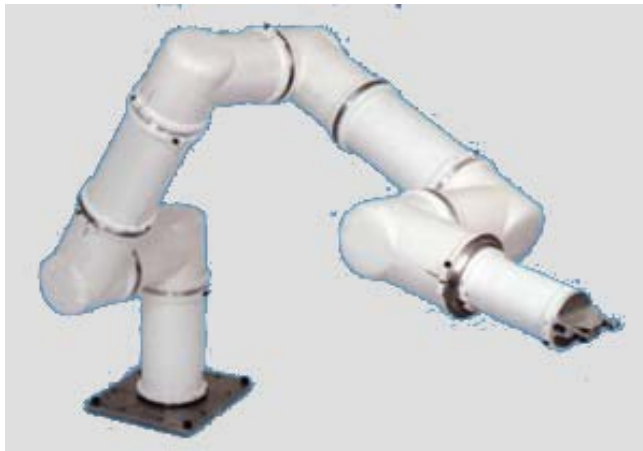Fig. 1. Hydrabot – The Modular Electro-Hydraulic Robot Arm [3]

Fig. 2. The Modular Robot [4, 5]

A slightly different concept is presented by Schunk [6]. Their modular robot, called Powerball (Fig. 3), is constructed from 2 DOF modules with integrated drive control. The modules differ in size but are the same in functionality.

The above concepts referred to standard manipulators and their modular variations. However, the term modular robotic is understood as a system that consists of multiple identical modules joined in various configurations to create robots of totally different structure and performed task. Such a system

was presented by Graham Ryland and Harry Cheng from University of California [7, 8]. Their iMobot (Fig. 4) is built from small modules that link together like a chain to form larger robotic modules. The modules have two joints at the centre that can rotate 180 degrees. The robots have four degrees of freedom, so they can stand themselves up, roll end over end, stack themselves, and inch along like a caterpillar.

Fig. 3. Powerball modular robot [6]

Fig. 4. iMobot [7, 8]

2. The manipulator system

The system of industrial manipulator equipped with functions for adaptation and reconfiguration was developed at the Institute for Sustainable Technologies – National Research Institute (ITeE – PIB) in Radom. It is built on the industrial, available commercially, robotic arm and retrofitted with additional modules and

systems that allow dynamic reconfiguration of the manipulator and its slot (surrounding), depending on the tasks currently planned on the production line. This modification is to allow the robotic system to be used in operations where it was not beneficial or impossible.

The whole system consists of several mechatronic modules, which are the robotic arm, coupler module, tool modules, and tools – finger gripper, pneumatic gripper, smart camera module, laser scanner module, and milling module. The coupler module is a mechatronic module that allows the connection of tool modules. The tool modules are mechanically fixed to the gripper with use of a pneumatic actuator, so the switching of the tool does not require the operator's participation. The coupler module allows the supply of the tool modules with media, such as compressed air, electrical current, and communication with tool modules with use of Ethernet lines. The construction of the tool modules is based on the tool plate equipped with electronic circuits that standardise the communication protocol for different types of tools and allow storage of the tool data. Therefore, it is possible to add new tools to the system, those that were not defined in the system beforehand.

The tool modules are built on universal tool plates with the use of standard, commercially available, components, such as grippers, measurement devices, and motors. The software of the manipulator allows adaptation of its movement parameters depending on the type of the tool and the performed task. The functionality of the coupler module allows building measurement tools that required large data transfers, such as cameras and laser scanners, and controlling the movement and behaviour of the system based on the data acquired from the measurement devices in real time. An extra module was added to the system, which is a tool magazine that allows communication with and testing of the tools.

The system was integrated and tested in the Laboratory of Mechatronics of ITeE-PIB. The system operates in a model work cycle in a simulated industrial environment, which proved the functionality of all elements of the system, such as tool switching with use of coupler module, with full operation of all tools. Verification tests were performed for each module and for each task, such as milling, laser scanning, gripping, and manipulation of elements.

To complete the system of the manipulator, it was equipped with a belt conveyor that allows simulation of a production line. The manipulator with a tool magazine and belt conveyor consist a complete model of an operational slot for a robot.

3. System modules

As the base of the system, a large industrial robotic arm was selected. It is a Kawasaki FS30N (Fig. 5) robot with a gripping range of 1676 mm and load capacity of 30 kg [9].

Fig. 5. Kawasaki FS30N robot [9]

The basic parameters of the robot are gathered in Table 1.

Table 1. Selected parameters of Kawasaki FS30N robot [9]

Parameter	Value
Degrees of freedom	6
Payload	30 kg
Maximum linear speed	8900 mm/s
Maximum reach	1676 mm

The reason for selecting such a heavy robot is that the application of any additional equipment on the robot's wrist enlarges the forces acting on the wrist. There is no problem if the equipment hangs straight downward from the wrist, then the forces act longitudinally to the axis of the wrist. The problem becomes critical when the equipment is positioned away from the vertical axis. The maximum moments of inertia need to be addressed. The producer of the robotic arm provides the chart of wrist load capacity (Fig. 6), which allows the determination of the maximal weight of the equipment and the distance of its mass centre from the centre of the wrist [9].
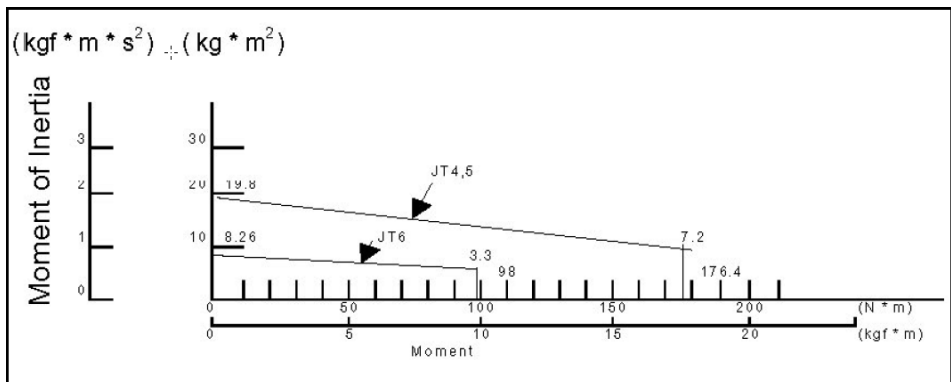
Fig. 6. The wrist load capacity of Kawasaki FS30N robot [9]

The effector modules (tools) are intended for typical tasks: manipulation tasks, technological tasks, and measurement tasks. Below, the tools developed with the system are presented.

The finger gripper module (Fig. 7) was developed in two versions: two finger gripper and three-finger gripper. Its construction is based on a standard pneumatic gripper driver from Festo [10].

Basic parameters:

Supply: pneumatic

Load capacity: 10 kg

Maximum diameter of manipulated elements:

12–14 mm

Exchangeable gripper jaws

Fig. 7. Finger gripper – two finger version and its parameters [10]

The magnetic gripper module is constructed with the use of a standard electromagnet from Stephnson Gobin [11]. It allows manipulation of steel elements of regular and irregular shapes weighing up to 20 kg. In addition, the

pneumatic gripper was developed. It uses a standard Festo gripper [12] and allows manipulation of objects with smooth surfaces weighing up to 30 kg.

As mentioned above, the system of the manipulator is capable of performing measurements that require large data transfers, such optical inspection, and laser scanning. Two modules to perform such measurements were developed.

The vision system module (Fig. 8) uses a smart-camera from Cognex [13]. The camera uses GigE Vision interface based on standard Ethernet protocol. The use of the smart-camera allows the image analysis and inspection process to be performed on the camera with the transfer of only analysis results to the supervisory system. The module allows product inspection and the measurement of the tested object to adapt the operation parameters of the manipulator.

Basic parameters:
Sensor: 1/1.8'' CMOS
Resolution: 800x600 px
Sampling: up to 102 fps

Fig. 8. The vision system module and its basic parameters [13]

The developed laser scanner module (Fig. 9) uses a 3D laser scanner from LMI [14]. The measurement range is 210 mm and the resolution is below 40 µm. This allows precise measurement of the geometry of the tested object. The results of measurements are used to inspect the object and to adapt the parameters of manipulator operations.

Basic parameters:
Measurement range: 210 mm
Resolution: < 40 µm
Field of view: 96–194 mm
Sampling: up to 5000 Hz

Fig. 9. Laser scanner module and its basic parameters [14]

For the machining process simulation, a simple spindle module was developed. It is based on a small DC motor of 230 W and a nominal rotary speed of 11 000 rpm. The module allows simple machining in soft materials.

Conclusion

The developed system of an industrial manipulator equipped with functions for adaptation and reconfiguration constitutes a complete system for an industrial production slot. Retrofitting the robotic arm with additional modules allows easy accommodation of the standard machinery to variable production conditions.

Typical applications of the system can be found in any production branch. However, it is the sector of small and medium enterprises that will mostly benefit from the application of the system, which allows using only one robotic system for different products and tasks on the production line. Therefore, smaller companies will be able to robotise their production lines without sacrificing large amounts of financial resources for investment. In addition, the robots already owned by the enterprise can be retrofitted to allow the reconfiguration and adaptation of the machinery.

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System manipulatora przemysłowego z funkcjami adaptacji i rekonfiguracji

Słowa kluczowe

Manipulator przemysłowy, rekonfiguracja, adaptacja, robotyka modułowa.

Streszczenie

Artykuł przedstawia system manipulatora przemysłowego wyposażonego w zaawansowane funkcje rekonfiguracji i adaptacji. Standardowe systemy manipulatorów przemysłowych wykonują swoje funkcje w sposób stały, z góry zdefiniowany, jednak w przyszłości wzrośnie zapotrzebowanie na systemy, które umożliwiają dostosowanie swojej konfiguracji do bieżącej sytuacji na linii produkcyjnej. Wykorzystanie urządzeń i systemów mechatronicznych charakteryzujących się zdolnością do rekonfiguracji i przystosowania do zmienianych zadań w procesach technologicznych umożliwia zwiększenie elastyczności i efektywności systemów przemysłowych. Przedstawione rozwiązanie zakłada wyposażenie standardowego manipulatora przemysłowego w dodatkowe systemy umożliwiające zmianę konfiguracji systemu, monitorowanie jego otoczenia oraz zmianę parametrów według potrzeb.

Prezentowany system manipulatora wyposażonego w funkcje adaptacji i rekonfiguracji umożliwienia wprowadzenie techniki robotowej do zadań, w których do tej pory było to nieopłacalne lub niemożliwe, tj. na liniach o krótkich seriach produkcyjnych.