Rafał CHOJECKI, Mariusz OLSZEWSKI
INSTITUTE OF AUTOMAIC CONTROL AND ROBOTICS WARSAW UNIVERSITY OF TECHNOLOGY,
FACULTY OF MECHATRONICS

A Mobile Robot for Laboratory Purposes and Its Applications

Mgr inż. Rafał CHOJECKI

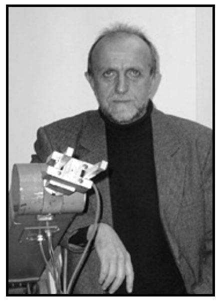
Ukończył studia na wydziale Mechatroniki w Instytucie Automatyki i Robotyki Politechniki Warszawskiej w roku 2000. Obecnie pracuje jako asystent w Instytucie Automatyki i Robotyki w Zakładzie Urządzeń Wykonawczych Automatyki i Robotyki. Główne zainteresowania autora skoncentrowane są na zagadnieniach budowy i systemów nawigacyjnych robotów mobilnych. Jest autorem kilkunastu prototypowych robotów mobilnych stanowisk laboratoryjnych.

e-mail: r.chojecki@mchtr.pw.edu.pl

Prof. nzw. dr hab. inż. Mariusz OLSZEWSKI

Dyrektor Instytutu Automatyki i Robotyki na Wydziale Mechatroniki Pol. Warszawskiej, stypendysta niemieckiej Fundacji Alexandra v. Humboldta, członek konsorcjum Europejskiej Sieci Centrów Techniki Płynowej (FPCE). Specjalista i autor publikacji, książek, podręczników, patentów i wdrożeń z zakresu budowy i sterowania urządzeń wykonawczych automatyki, robotyki przemysłowej i mechatroniki. Ma duże doświadczenie w kierowaniu projektami krajowymi i międzynarodowymi.

e-mail: m.olszewski@mchtr.pw.edu.pl



Abstract

The paper presents the ELECTRON R1 mobile robot and its application to the research of navigation and control of such devices. The robot was designed in cooperation between the Institute of Automatic Control and Robotics and the Institute of Control and Computation Engineering Warsaw University of Technology. It consists of a six-wheeled mobile platform with all of the wheels powered and a controller based on a single-board PC type microcomputer. Due to the modular structure the robot can be equipped with diverse sensor modules, thanks to which it can be comprehensively used for research purposes.

Keywords: mobile robotics, navigation, sensors, laser scanner.

Budowa i zastosowania laboratoryjnego robota mobilnego ELEKTRON

Streszczenie

W artykule opisano laboratoryjnego robota ELEKTRON R1 i jego zastosowania w pracach badawczych nad systemami nawigacji i sterowania robotów mobilnych. Urządzenie zostało opracowane w Instytucie Automatyki i Robotyki i Instytucie Automatyki i Informatyki Stosowanej Politechniki Warszawskiej. Baza jezdna jest sześciokołową platformą mobilną z napędem na wszystkie koła. Podstawowym elementem sterownika robota jest komputer pokładowy o dużej mocy obliczeniowej zbudowany na bazie jednopłytkowego mikrokomputera typu PC. Dzięki modułowej budowie robot może być wyposażany różnorodne wyposażenie sensoryczne, dzięki czemu może być wszechstronnie wykorzystywany w pracach badawczych.

Słowa kluczowe: robotyka mobilna, nawigacja, sensoryka, skaner laserowy.

1. Introduction

The interest in mobile robots is visibly increasing nowadays. This type of robot is being implemented both in new fields of technology and everyday life. Not only are mobile robots used in industry, but they are also present in ordinary households. It is possible due to the rapid development of newest technologies and, consequently, lower costs of a robot construction. Examples of such robots include robo-vacuum cleaners, robo-lawnmowers, etc. The aim is to let a robot work on its own in an environment created by a human. Apart from that, a robot should support people both in every day and emergency situations.

The development of this field is to a great extent dependent on scientific research, particularly on such aspects as AI methods, sensors or navigation.

In research centres, universal mobile platforms are used, on which new algorithms together with sensoric and navigation systems are tested. Making use of those universal mobile platforms reduces considerably the costs and time of research. Apart from that, such robots can be used to perform many different tasks. *ELEKTRON R1* mobile robots were designed and built in cooperation between the Institute of Automatic Control and Robotics and the Institute of Control and Computation Engineering of Warsaw University of Technology. Four identical platforms were built. While designing the robots, three basic assumptions were taken into account: autonomous work, board computers with high level of computing power and a modular structure of hardware and software, due to which a further expansion will be easier if such need arises. Such possibilities are highly limited in commercial solutions of mobile robots. Experience gained during the development of numerous miniature constructions of mobile robots turned out to be of great value while designing *ELEKTRON R1* robots. [1].

ELEKTRON R1 mobile robot is mainly used for educational purposes. It functions as a basis for scientific research on mobile robot navigation and control. Due to the open and modular structure, the robot can be equipped with diverse sensor, effector and control modules, and its software can be easily modified as well. For these reasons, *ELEKTRON R1* mobile robot is an excellent platform providing a wide range of possibilities.

2. Mobile robot structure

The robot is based on a six-wheel drive platform (Figure 1). The following requirements constituted the project assumptions:

- concise modular structure
- load capacity up to 15kg,
- high durability and mechanical reliability,
- ability to move both indoors and outdoors,
- high manoeuvrability,
- autonomy .

The Robot is built from modules and consists of drive units, a central unit – a frame, a control unit, a power supply unit and replaceable sensor units or actuator units. The robot is based on a six-wheel drive platform sized 500 x 380 x 220mm. The chassis is manufactured from light aluminum alloy and covers thoroughly the control and power units. The drive unit consists of two 24 V DC motors integrated with two reduction gearboxes driving left and right wheels independently. Turning is achieved due to the speed differentiation of the left and right wheels of the robot. Each electric motor drives independently three wheels on each side. Both the main control unit and the control modules are placed above the drive unit. The control unit is installed on an special platform that can be easily disassembled, which enables a direct access to the control unit. In the rear part of the robot there is a control panel integrated with the supply system. *ELEKTRON R1* robot is equipped with a number of independent sensors including an odometer system and optical rangefinders embedded around the body of the robot. The odometer system comprises two rotational encoders placed in the drive unit. Additionally, the robot was equipped with a SICK LMS 200 scanning laser rangefinder installed above the control unit on a specially designed turntable mechanism. A servomechanism integrated with the turntable enables a precise rotation of the rangefinder sensor in the horizontal plane. A special bearing system enabled a higher load capacity up to 100 kg. Both electric motors transmit power by means of toothed belt gear systems.

Both systems were designed as independent modules. Each module consists of: a body, an electric motor with an integrated gear, toothed belt gear system, bearing system and an encoder. The body of the drive module comprises inside all the elements listed above. This solution protects the module parts against impurity. Each of the six wheels is of 100mm in diameter. Special screens are used to protect the electronic parts against electromagnetic interference form electric motors and power supply units. The panel is equipped with switches and LED lights responsible for activating particular circuits of the robot. The source of power supply is two 12V chargeable batteries connected in series or one external 24V feeder. The power supply unit is equipped with converters generating voltage of 5V, 12V i 24V.

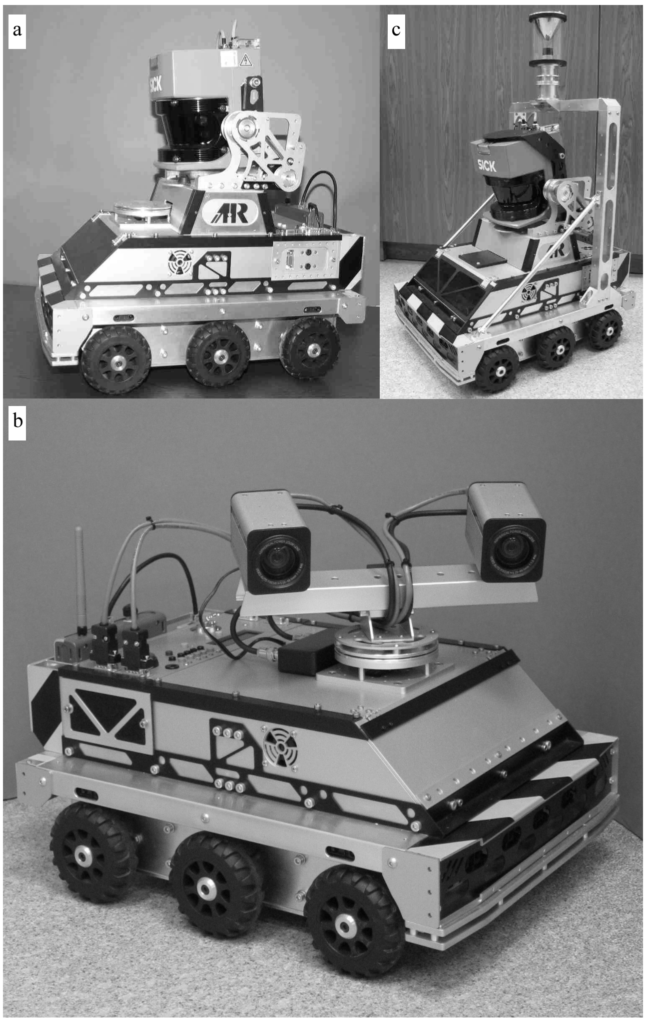


Fig. 1. Mobile robot ELECTRON R1: a) with 3D unit, b) with stereo vision system, c) with 3D scanner unit and omnidirectional vision system

Rys. 1. Roboty Mobilny ELEKTRON R1: a) robot z modułem 3D, b) robot z modułem stereo-wizyjnym, c) robot z modułem skanera 3D i kamerą dookólną

ELEKTRON R1 Robot is equipped with a few independent sensor units. The basic ones include: odometer system and optical rangefinder system embedded around the body of the robot as well as inclinometers and – optionally installed – electronic compasses. The odometer system consists of two optical encoders built in the drive unit.

The optical rangefinder system is used for detecting obstacles in the immediate neighborhood of the robot. The sensors work in the infrared band. Two types of rangefinders were used: short (3-30cm) and long range. (10-120cm). Eighteen sensors are placed on the robot: five long range and thirteen shot-range. In the front part of the robot, there are eleven rangefinders. In order to avoid mutual interference, the short-range and far-range sensors are situated alternately. The rangefinders are operated by one-unit microcomputers attached to the main computer by means of an RS-485 bus. The two-axle inclinometers and the electronic compass unit are connected to the same bus. The inclinometers placed inside the mobile base are used for measuring a tilt in the X-Y axis within ±60° range. The compass is used for determining the absolute (locally) orientation of the robot.

The robot can work with additional sensors and effectors. The open structure of the control unit together with a specially designed mechanic construction enable an easy incorporation of additional modules. In the construction described here, the main attention was paid to designing additional equipment (sensor modules).The first module consists of a SICK LMS 200 scanning laser rangefinder and an omnidirectional vision system stiffly attached to a special bracket installed on the body of the robot. The scanning laser allows us the measuring the distance to the obstacle within 180°. The omnidirectional vision sensor was placed on the top of the rangefinder. It consists of a camera placed vertically and a parabolic mirror mounted above the camera in the optical axis.

The omnidirectional vision sensor provides an opportunity to observe the surroundings within 360° by means of one camera [5]. The optical axis and the camera axis coincide.

The second module prepared for ELEKTRON R1 robots is a head module for 3D scanning. The module consists of a SICK LMS 200 scanning laser rangefinder installed on a rotating head. The head can rotate the scanner around the horizontal axis within the angular range from -15° to +90°.The module is powered by a DC planetary gear motor. The power is then transferred by means of a toothed belt transmission, thanks to which the motor was placed in the bottom part of the robot. Two rotational encoders measure the scanning velocity and angle. The first encoder installed on the motor shaft is used for positioning whereas the other is responsible for measuring the rotation angle directly on the rotation axis of the scanner. The two measuring systems allow us the precise positioning of the sensor, which is not influenced by margins existing in the transmission belt.

The third module is a combination of the two above described solutions. It comprises a 3D scanning head and an omnidirectional vision sensor placed above the head (Figure 1c). The camera was placed on a special construction above the scanning laser due to which the laser can rotate without changing the camera angle vision at the same time. The modular construction of the unit enables using interchangeably the omnidirectional vision camera and the traditional camera installed on a rotating head.

The fourth module is a stereo vision system (figure 1b). It comprises two CCD high-resolution cameras. The cameras were installed in the front part of the robot on a specially prepared beam. Thanks to the rotating basis, the cameras can operate within 0° - 180° range.

3. Control system

The main element of the control system is the main board computer that manages the work of the whole system and implements all the high-level control functions. An *Advantech* single-board PCM-9579 EBX computer was used here. The computer contains a Celeron or a Pentium III processor (650MHz or 900MHz clock respectively) designed for the embedded use and equipped with all elements typical for a PC computer such as graphics and audio controllers, Ethernet, IDE controllers, parallel and RS-232 series ports and a PCI bus. Apart from these, the computer contains also a PC-104 and a PC-104+ buses, an RS-485 bus and a Compact Flash memory slot. The PC-104 and PC-104+ buses that are a standard solution for embedded computers enable the control system to be easily expanded and modified by adding the adapter cards. Such systems are relatively of small size and use little power. Besides, a great variety of ready peripheral modules are available for them. The computers described here were equipped with a wireless network interface card working in accordance with Ethernet 802.11g standard used for fast (52Mb/s) communication as well as a frame grabber.

A specially designed microcomputer is responsible for the direct control of all the robot effectors (engines, sensors, etc.), as well as for detecting and dealing with emergency situations. It is built on the basis of an Atmel T89C51AC2 single-board microcomputer. One of the functions performed by the microcomputer is controlling the electric motors of the robot (velocity or position control). For that purpose integrated PID controllers were used. Specially designed systems are used for the motor control by implementing a digital algorithm of the PID control.

4. Robot's software

Robot software is layer - structured. Basic functions such as data acquisition from the odometric system or IR rangefinders are performed by systems built on the basis of single-system microcomputers connected to the robot main board computer. The main computer executes programs that control the robot and analyze the measurement data.

The main computer works under *Gentoo Linux*. Such choice ensures a rich software (ready device controllers included) available for this platform. The distribution was chosen due to a well-developed configuration system. The whole software compiled with optimization options for a Pentium processor takes about 100MB on the memory card.

Player/Stage [3, 11] environment is used for controlling the robot. A general structure of the software using *Player* is presented in Figure 2. The environment has a three-layer structure. The top layer comprises client programs performing the user tasks. The middle layer is engaged by a Multi Player Server process including interfaces and controllers. The bottom layer consists of program controllers of particular devices. Each client is connected to the Player server by means of a TCP socket. If a client is active on the same computer as *Player*, then the connection is provided by the local loop back interface. Otherwise, it is a physical connection by means of the net (the net can be wireless).

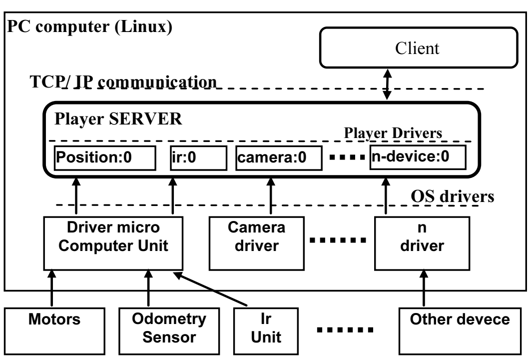


Fig. 2. A general structure of the software using Player
Rys. 2. Ogólny schemat struktury oprogramowania Player

5. ELECTRON R1 robot applications

ELEKTRON R1 robots are used in laboratories for teaching purposes or for research on mobile robots control systems and navigation. During laboratory classes students have an opportunity to get familiar with the robot structure and software and they may test their own programs and control algorithms. Owing to modular structure, the robots can also function as experimental platforms for testing new modules. Within the framework of students' projects and post-graduate the students' tasks, low-level system units and controllers for basic sensors and actuators of the robots are built together with new types of sensors. The projects involve both designing and building electronic control units (of, e.g., data acquisition, actuator control), as well as programming controllers.

The fact that the *ELEKTRON R1* robot is richly equipped with a considerable number of different sensors makes it possible to use the sensors for various tasks. The basic sensor (all the *ELEKTRON R1* robots are equipped with it) is a set of rangefinders embedded around the robot frame. A rangefinder performs one of the basic tasks in robotics, i.e. moving with simultaneous avoidance of obstacles. Complete distance data is taken with the frequency of 25 times a second, which enables the robot to keep on moving without stopping to take measures. Long-distance rangefinders (up to 1.5 m) placed in the front bumper are used preliminarily for localization of obstacles, whereas short-distance rangefinders (up to 0.5m) can accurately determine the robot's position and precisely find a path that is obstacles-free. The sensors use up a great deal of power so it is possible to activate them while the robot is in the working mode. Depending on the direction of robot movement, some of the sensors can be switched off (e.g., while the robot is moving straight ahead, there is no need to control the area behind the robot).

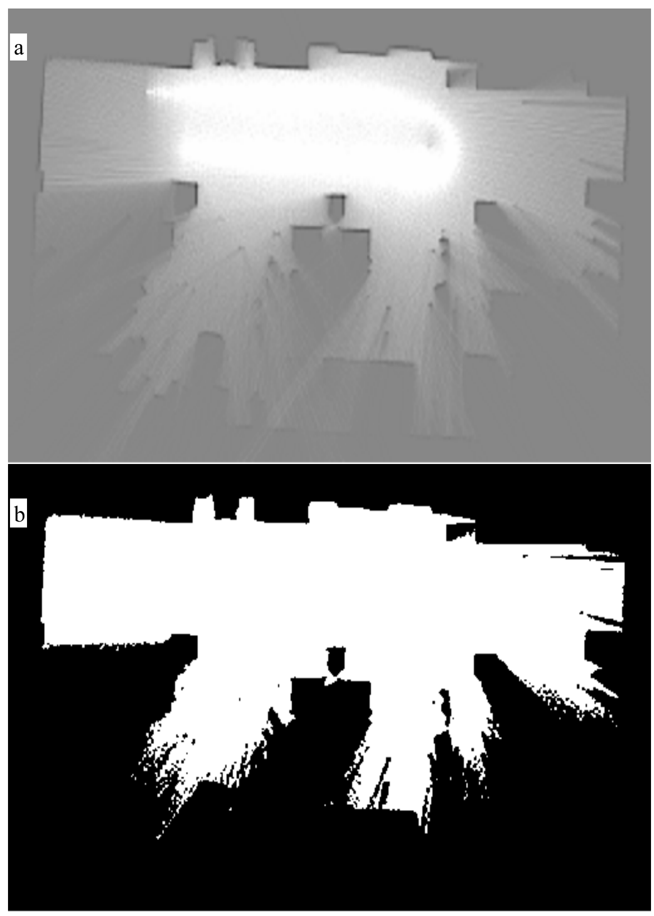


Fig. 3. 2D map building based on the data from a laser scanner: a) initial occupancy grid map, b) occupancy grid map after thresholding
Rys. 3. Budowa dwuwymiarowej mapy zbudowanej na podstawie odczytów ze skanera laserowego. a) wstępna mapa rastrowa b) mapa rastrowa po progowaniu

A laser scanner is one of the most precise and the most universal sensors, and two of the *ELEKTRON R1* robots are equipped with such a device. In mobile robots, a laser scanner is a source of information about the position of the robot, as well as about distances to the obstacles surrounding the robot. A laser scanner is mounted on the robot – either on a non-movable part (then a 2D map can be built) or on a rotational head (then a 3D map can be built). A 3D model of the scene within which a robot moves is essential for implementing, testing and verifying global navigation algorithms. It is important for the navigation system to be provided with a map that in the best possible way reflects the real scene in which the robot moves as well as all the objects within this scene.

Figure 3 presents the result of a program building 2D occupancy grid map based on the data obtained one robot ride performed in a laboratory. The robot made one compete loop around the laboratory. The final map is built in a grey scale – darker areas visible on the map represent free spaces while light places stand for walls, obstacles, etc. In-between areas, i.e., areas which are neither dark nor light denote places where the data collection was either incomplete or obtained results are contradictory, which might be the case when some surfaces or materials create reflections.

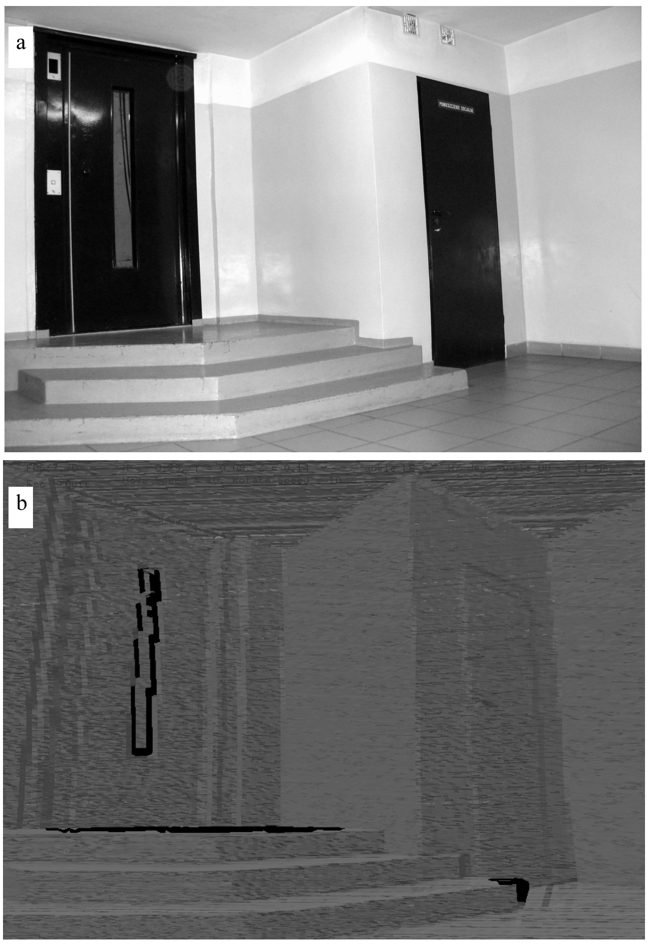


Fig. 4. 3D map building based on data from the head module for 3D scanning: a) a real view of office space ,b) a view of a 3D map
Rys. 4. Budowa mapy trójwymiarowej bazująca na danych z głowicy 3D: a) rzeczywiste pomieszczenie, b) mapa trójwymiarowa

ELEKTRON R1 robots with an installed 3D laser scanning unit are used for creating 3D representations of the environment in which the robot moves. 3D maps are built by putting together all the measures taken by the rotating laser scanner. A complete map is created on the basis of a number of readings taken while the robot is on the move. An example of application of such a map is modeling buildings for architectural purposes. Figure 4 presents an example of a 3D map.

6. Conclusions

Results obtained from the research and exploitation of four *ELEKTRON R1* robots confirmed the rightness of the adopted assumptions and versatility of the devices described. A modular structure of the robot enabled us both an easy testing of a number of control systems as well as the use of the robots in bigger research projects. In the future it is planned to design and to build additional actuator modules such as manipulators which enhance the operational capacity of a group of a heterogeneous robots. Apart from that, such modules will allow us to conduct research on mobile transport and manipulation structures and on teleoperation techniques performed by mobile devices. Good moving properties of the vehicles will also allow us to perform navigation tasks outdoors. The ambition of the research team is to build a group of robots that would directly cooperate with humans, helping them in their every day life and in emergency situations. Such tasks would include transportation tasks, cleaning, constructing monitoring or tasks consisting in searching for sources of danger, or searching for casualties of disasters.

7. References

[1] Chojecki R., Olszewski M., Marcinkiewicz P.: Miniaturowe roboty mobilne w Instytucie Automatyki i Robotyki Politechniki Warszawskiej. Przemysłowe i medyczne systemy robotyczne Red. K. Tchoń. WKŁ 2005, 311–319.

[2] Daniela Rus, Bruce Donald, Jim Jennings.: Moving Furniture with Teams of Autonomous Robots. IEEE/RSJ International Conference on Intelligent Robot Systems (IROS1995), 1995, 235–242.

[3] Gerkey B.P., Vaughan R.T., Howard A.: The Player/Stage Project: Tools for Multi-robot and Distributed Sensor Systems. Int. Conf. on Advanced Robotics (ICAR2003), 2003, 317–323.

[4] Gerkey Brian P., Mataric Maja J.: Pusher-watcher: An Approach to Fault-tolerant Tightly-coupled Robot Coordination. In: IEEE International Conference on Robotics and Automation (ICRA 2002), 2002, 464–469.

[5] Siemiątkowska B., Chojecki R.: Mobile Robot Localization Based on Omnicamera. IAV2004. 5th IFAC Symposium on Intelligent Autonomous Vehicles, Lisbon 2004 / Elsevier Science, ISBN 008 044237 4.

[6] Wang Z-D. et al.: A Pushing Leader Based Decentralized Control Method for Cooperative Object Transportation. IEEE/RSJ International Conference on Intelligent Robot Systems (IROS2004), 2004.

[7] Zielinski C.: The MRROC++ system. First Workshop on Robot Motion and Control, RoMoCo 99, 1999, 147–152.

[8] Advantech. 5.25" Single Board Computer PCM-9579,

[9] http://www.advantech.com/products/

[10] Intel. Intelr Integrated Performance Primitives (IPP), http://www.intel.com/cd/software/products/asmona/eng/perflib/ipp/index.htm

[11] Intel. Intelr Math Kernel Library (MKL), http://www.intel.com:80/cd/software/products/asmona/eng/perflib/mkl/index.htm

[12] Player/Stage 2006. The Player/Stage Project

[13] http://playerstage.sourceforge.net/

Artykuł recenzowany