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Autonomous Omni-Wheeled Mobile Robots

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***Abstract*—The paper considers designing two mobile robots equipped with omni-wheels and autonomous control systems. One of the robots has two different control modes: either with camera-based tracking system or via operator`s remote control. When an operator controls the robot`s motion, the human machine interface provides forwarding camera images to the operator control station. The other robot is an electromechanical robot based on the Nokia PUMA 560 industrial manipulator. The manipulator is mounted on the omni-motor-wheel base. Omni-wheels are designed based on the DC motor-wheels. The PUMA control system provides independent manipulator motion of every degree of freedom and every of three omni-motor-wheels of the robot. For spatial orientation and pattern recognition, PUMA was equipped with the single board computer for sensors` signal acquisition and processing.**

***Keywords*—autonomous control system; mobile robot; computer vision; omni-wheel**

I. Introduction

Nowadays industrial sector gave a wide proliferation for the manipulators designed to replace a human labor executing either monotonous or dangerous work. In recent years, due to the globalization of markets and trade instability in world production there is a need for industrial robots that can quickly change their algorithms work. In this regard, many of the leading universities in the world started projects on developing of autonomous manipulators on a mobile basis. Among these, the most significant developments are the follows.

- Autonomous robot manipulator «Little helper», developed in the University of Aalborg (Denmark) It is equipped with a manipulator with 6 degrees of freedom and mounted on a base with two drive wheels and one support wheel. It has a number of sensors: the laser scanner, ultrasonic rangefinders, encoders in the wheels and monochrome camera mounted on the robot and a PC running the Windows XP operating system [1].
- Autonomous robot manipulator ABBY, developed at Case Western University, Cleveland (USA), equipped with a nonholonomic mobile base with two drive wheels and two support wheels. It uses manipulator ABB IRB-120 Robatic Arm. The robot control system is implemented on the basis of ABB IRC5 Compact Robot Controller and a computer running Linux and Robot OS operating system (ROS). A laser scanner and an infrared depth camera (Microsoft Kinect) is used for spatial orientation [2].
- Autonomous robot manipulator UMan (UMass Mobile Manipulator), developed at the University of Massachusetts, Amherst (USA). Manipulator is mounted on the omni-directional mobile base, which is a robotic mechanism XR4000 with four steering wheels with eight encoders, two processors, five microcontrollers and optical sensors. The manipulator has 7 degrees of freedom. Robot equipped with laser scanner [3].
- Autonomous robot manipulator SAMM, developed at Stanford University (USA). It is equipped with an industrial manipulator Nokia Puma 560, mounted on a base with steering wheels.

High maneuverability of mobile robots is a key of the high interest to its design. However the mobile platform equipped with ordinary drive wheels could be not enough for satisfactory results of maneuverability.

Omnidirectional wheels are becoming more and more popular in robotics, as they allow the robot to move in a straight line from one point to another without turning left or right. Moreover, the translational movement along a straight path may be combined with the rotational providing destination point approximation with the desired angle. Major part of omnidirectional wheels are based on the fact that the wheel is free to slide in the direction of the axis of rotation. To obtain such an effect several small wheels are embedded in the construction of the omni-wheel. Examples of omnidirectional wheels are shown in Fig. 1 [4-7].

All stated in Fig. 1 wheels are intended for simultaneous longitudinal and transverse motion. For example, omni-wheel is shown in Fig. 1, A has movable rollers by means of which it is able to make a lateral movement [4]. Mecanum-wheel, is shown in Fig. 1, B, also has movable rollers, however, they are arranged at an angle of 45º to the axis of the wheel [5]. Omni-ball-wheel, is shown in Fig. 1, C consists of two passive independently rotating hemispheres and active rotating shaft on which hemispheres are fixed [6]. WESN-wheel, is shown in Fig. 1, D has rotatable bearing rollers mounted on the wheel radius. As the wheel is moving in the forward direction the rollers remain stationary in the case of transverse motion of the wheels rolls are applied [7].

In this paper the designing of the omnidirectional robots and a control system are considered. The work was done in the Autonomous Control System department of the Saint Petersburg Electrotechnical University LETI.

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Fig. 1. Kinds of omnidirectional wheels.

II. OMNI WHEELED MOBILE ROBOT WITH CAMERA TRACKING SYSTEM

In Fig. 2 it is shown the image of the robot, equipped with three omni-wheels with DC motors, mounted under the plexiglas. Control actions are sent via the radio channel on a DC motor control board. To determine the position of the robot the capture camera connected to a stationary computer is used. It is also possible to control the robot via the Internet with remote control, forwarding the control action from the joystick (either smartphone or computer) to the Banana Pi microcomputer that is used to control the robot motion.

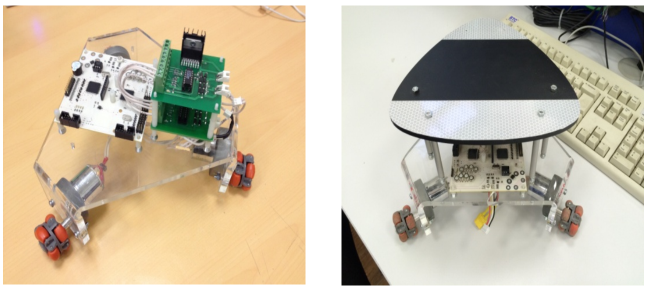


Fig. 2. Omnidirectional LittleBOT.

To determine the position of the robot a tracking camera is applied. It is a camera with infrared filterthat is placed in such a way to see the reflective strips on the top of the robot and the space around it. The camera is equipped with infrared backlighting. Infrared light reflects off the strip on the robot. Due to the infrared filter on the camera the frame is only shows the robot`s reflecting stripes that are show current position of the robot. That helps to avoid further sophisticated digital filtering. For the camera frame acquisition and proceeding the OpenCV library is used [8,9]. As a result of the morphological transformations and the threshold function applying, it is possible to get a binary image with two white stripes on a black background. According to the strips` square and relative position of their centers it is possible to determine the coordinates of the robot`s current position and angle.

To control the position of the robot a desktop computer that is connected to the camera and capture radiotranceiver is applied. Computer software processes the image capture from the camera to determine the position of the robot and receives from a user a desired position of the robot location. Then the robot`s motion control program launches. It calculates the current position of the robot and the vector to the target. Then the angular velocity for left and right wheel are calculated and transmit to the on-board robot control system.

III. MOBILE MANIPULATOR EQIPPED WITH DEPTH SENSOR AND CAMERA FOR PATTERN RECOGNITION

The robot that is shown in Fig. 3, A is based on an industrial manipulator Nokia PUMA 560, mounted on a movable base, which also protects control box with electronic components and omni-directional motor-wheels in the wheel arches. [10] The use of omni-directional wheels allow the robot to move in all directions. Omni-motor-wheels of the robot, the image of one is shown in Fig. 3, B, designed and built on the basis of the motor-wheel with DC motors.

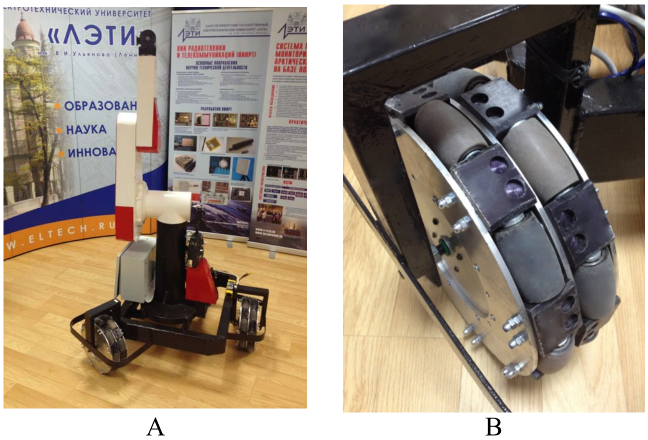


Fig. 3. Omnidirectional LittleBOT.

The structure of each unit of the manipulator includes encoder and DC drive gear. Servo drives are equipped with electromagnetic brakes that are activated when power is turned off the, thereby fixing the manipulator in the position prior to power off, in order to prevent accidents and damage for manipulator and humans. Industrial manipulator motion may be described in several coordinate systems with respect to the different units. Each coordinate system is polar, and will determine the reciprocal movement of the links. However, the resulting system is a rectangular frame. The basic coordinate system is set to the basis. The tool movement is associated with the position of the gripper in space. In this coordinate system, all movements are relative to the implement. To fulfill the requirements of technology, such as debarring, assembly, drilling, and other, the manipulator is equipped with a flange.

The electromechanical system of the robot could be designed in several steps due to the hierarchical structure of the control system and dividing the system into several levels: "high level" single board computer control, "low level" control and peripheral sensors for spatial orientation and pattern recognition.

The low level control provides motor wheels motion and high level control provides acquisition and processing the information about the environment from sensors and generating the control action according to that information. The control action that is generated by the single board computer transmits to the "buffer control board" (the low level control), and then signal transmits to the DC motor control boards.

Functional diagram of the hierarchical control system is shown in Fig. 4.

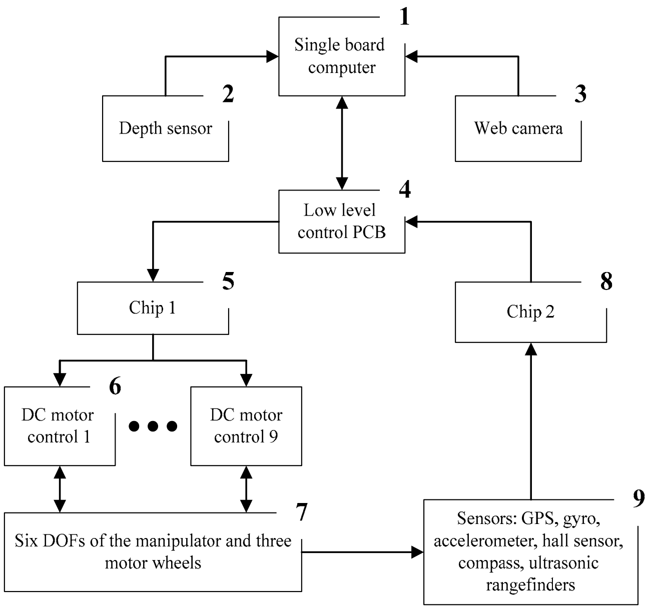


Fig. 4. Hierarchical diagram of the control system.

On the top of the hierarchy it is a single board computer (block 1 in Fig. 4) based on the Intel Celeron chip. Peripheral devices, such as depth sensor (block 2 in Fig. 4) for spatial orientation and web camera (block 3 in Fig. 4) for pattern recognition are connected to the single board computer via standard USB protocol. Low level control PCB (block 4 in Fig 4) has two ATMega128 chips (blocks 5 and 8 in Fig 4) and is connected to the DC motor control system (block 6 in Fig 4) and sensors` PCB (block 9 in Fig 4). Low level control board provides data acquisition, processing and forwarding to the single board computer. After that a single board computer generates the control action for the low level system.

The functioning principle of the electro mechanical system of the manipulation platform lies in the following. The control action goes from the single board computer, according with the information, received from the peripheral devices, like cameras and sensors. Control action is signal sent via RS-232 protocol, that is transmits to low level control board.

The low level control board comprises two Atmel ATmega128 microcontrollers (blocks 5 and 8 in Fig. 4). This board converts the signal into rectangular impulses. These impulses are fed to microcontrollers Atmel ATmega8, which are mounted on the DC motor wheels control printed circuit boards.

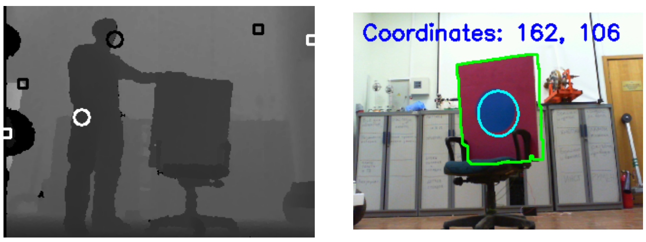
The DC motor control system, realized and integrated into microcontroller, is a three-loop subordinate regulator with a PID-controller in each loop. The control action goes through the control system. Optical transistors, which are mounted on the outlets of the ATmega, are used for the galvanic isolation in the system. Also optical transistors are used for increasing the output voltage that goes from microcontroller`s outputs.

The power unit of the control system consists of the MOSFET n-channel transistor bridge. Transistors are run with drivers. Transistor bridge provides both directional rotation of the motor and emergency motor turn off in case of current overload. The Hall-sensor provides current measuring. If current is more than maximum value, the Hall-sensor transmits the high-level logic signal to the emergency shutdown input of the transistor driver.

Sensors (block 9 in Fig. 4) are used for the low level control board to transmit the information about environment to the single board computer.

For the spatial orientation robot is equipped with infrared depth sensor. Depth sensor allow to obtain an ambient map (disparity map) in real time and calculate the distance to the obstacles. An ambient map sample image is shown in Fig. 5, A. The distance to the obstacle codes with color: closer the object the darker its color.

For pattern recognition an ordinary web camera could be applied. In particular case pattern consists of two colors and two shapes – red rectangle with blue circle inside. Web camera signal proceeding is realized with open source library OpenCV for QtCreator. The search result of the color pattern is shown in Fig 5, B.



A B

Fig. 5. Computer vision algorithms.

It is possible to combine depth sensor and web camera in one single device - stereo camera. However, when using a stereo camera it is necessary to transform two images from the left and right cameras into one single 3D map. The two methods were chosen – Block Matching (BM) and Semi-Global Block Matching (SGBM). The principle of its functioning lies in searching the blocks of pixels from the left image on the epipolar line on the right image and calculating the distance based on the coordinates difference of the blocks of pixels on the two images.

IV. Conclusions

Two mobile robots equipped with omni-wheels and autonomous control systems were designed. One of the robots has two different control modes: either with camera based tracking system or via operator`s remote control. When the operator control the robot`s motion the human machine interface provides the camera image forwarding to the operators control station.

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