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DESIGN AND CONSTRUCTION OF A ROBOTIC VEHICLE WITH OMNI-DIRECTIONAL MECANUM WHEELS

NÁVRH A STAVBA MOBILNÉHO ROBOTA S VYUŽITÍM VŠESMEROVÝCH MECANUM KOLIES

Abstract

The paper deals with the design and construction of a universal robotic vehicle prototype, used for laboratory and educational purposes. The main goal is its use as a technology demonstrator for the needs of students, therefore it is equipped with several kinds of sensors and universal advanced control technologies and design solutions. Its basis is a control system and construction concept using mobile battery gear and omnidirectional Mecanum wheels. A manipulating arm and advanced tracking and spatial navigation systems are also components of the design. Since the problem of a customized design and construction of such a robotic vehicle is very complex and solved in various scientific fields, in this paper we will mainly focus on the detailed description of the control systems and subsystems of the vehicle.

Abstrakt

Príspevok sa zaoberá návrhom a stavbou prototypu univerzálneho robotického vozidla, slúžiacieho pre laboratórne a študijné účely. Účelom je jeho využitie ako technologického demonštrátora pre potreby študentov, z tohto dôvodu je osadený univerzálne všetkými dostupnými druhmi snímačov a univerzálnymi pokrokovými riadiacimi technológiami a konštrukčnými riešeniami. Základom je jeho riadiaci system a konštrukčné prevedenie s batériovým pohonom pre všesmerové Mecanum kolesá. Súčasťou konštrukcie je aj manipulačné rameno a pokrokové systémy lokalizácie a navigácie v priestore. Nakoľko problematika vlastného návrhu a stavby takéhoto mechatronického robotického vozidla je veľmi obsiahla a riešená v rôznym vedných oblastiach, budeme sa v tomto príspevku konkrétne venovať jeho riadiacim systémom a podsystémom, ktoré si podrobnejšie rozpíšeme.

Keywords

robot, robotic vehicles, omni-directional, mecanum wheels.

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1 INTRODUCTION

The mobile robot (Fig. l), used in our experiments, is a unique prototype fully developed and engineered at the Slovak University of Technology [1], [2]. This was the first robot with this kind of drive in Slovakia. The robot obtained the prize at the Engineering Fair - Nitra (2012) expo and it was used in a joint project with Vienna University, titled: „Biologically motivated algorithms for robot navigation".

The main robotic platform consists of a massive duraluminum construction weighing over 90 kg, and capable of a maximum speed[1] of 0.73 m/s. The robot is equipped with Mecanum wheels, which provide good maneuvering properties and are quite popular in modern robotic designs [3]. Unlike a simple differential drive, a Mecanum wheeled drive has three degrees of freedom. It allows movement in all directions, therefore it can move sideways or rotate around its own axis. A robot with this type of drive was the first of its kind in Slovakia. Inside the robot, there is a standard PC (Intel Core i5, 4 GB RAM, WiFi module, with 10 inch display). It is able to communicate with its environment via a 5 GHz wireless connection, thus it is capable of establishing connections over a range of several kilometers. The robotic system contains multiple core subsystems controlled by microprocessors that serve to control the robot's engines, to collect the sensor data, and to facilitate the power management of the robot, etc. The robot is powered by eight LiFePO4 batteries with peak capacity of 1.2 kWh, sufficient for sustaining the robot for several hours of movement and navigation in complex terrains. Moreover, it is equipped with 3 types of sensors: 8 infrared sensors with an analogue output used for long range obstacle detection, 8 ultrasonic sensors with an analogue output and 8 tactile sensors that can be used for feedback control. Anti-collision sensors (tactile sensors), or obstacle sensors detect obstacles which can block the robot's movement. In each corner of the robot's rectangular base there are two infrared, two ultrasound, and two tactile sensors. Several components will be added to the robot in the near future - a localization system (same as in [4]) and a laser scanner. These components communicate via a serial connection.

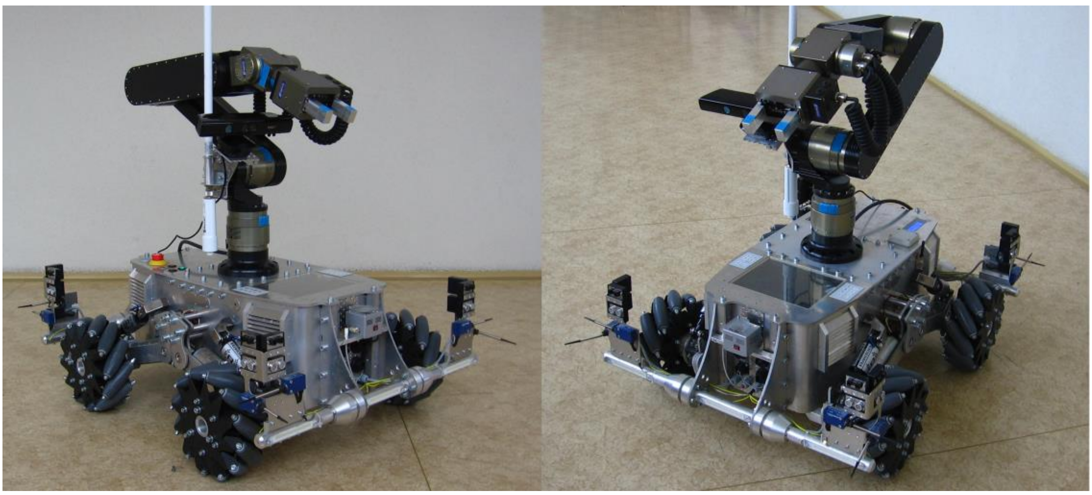

Fig. 1 Mobile robot with Mecanum wheels

The robot itself contains many intelligent subsystems which need to be controlled and communicated with. Similar control structures are discussed in [5], [6] and [7]. The following text contains a short description of the robot's mechanics, followed by an extended description of the main control and the lower level control systems.

[1] You can see robot in action on web page: http://goo.gl/q128u

2 CONSTRUCTION

The chassis of the robot is designed with 6 mm and 2 mm thick duraluminium plates. The perimeter of the chassis of the robot is made up of two symmetrical pieces welded together in the front and rear parts. The upper part is divided into three removable blocks - the front section, the middle section and the rear section. The front section is used mainly by a membrane keyboard and the display. The middle piece can either be used to support a robotic arm or can be left empty. The rear section is intended for various control and signalization elements and power connectors. The construction also includes bumpers made from cylindrical duraluminium, on which sensors and an array of high powered LEDs are placed. At first sight the construction of the robot may seem too rugged and massive, but this is necessary due to the design, as the whole body of the robot was designed to support a robotic arm weighing 18 kg. The dimensions of the robot are 93 x 73 x 35 cm (length x width x height), it has a total weight of 90 kg, and can carry an additional 90 kg. As a result of placing most of the construction on the sides of the robot, a lot of space is available inside. The chassis is made of four identical parts, with each one being connected to a motor gearbox output and a damper. Therefore the robot has four fully independent wheels.

Unlike a classical differential chassis, a Mecanum wheeled chassis has three degrees of freedom. It allows movement in a straight line in all directions - therefore the robot can move sideways as well as rotate around its own vertical axis. The Mecanum wheels can be quickly replaced with conventional ones with an inner tube, which effectively converts the chassis into a differential driven one.

3 MASTER CONTROL SYSTEM

The robot contains a powerful on-board computer that can handle more complicated computational tasks. It consists of standard desktop PC components with an integrated communication interface that can communicate with all the sensors and modules. It is composed of an ITX mainboard, an Intel Core i5 660 3.3GHz, 64 GB SSD disk, 4 GB of DDR3 RAM and a 10 inch LCD. A detailed scheme of the master control system is shown in Fig. 2. The computer can be controlled either via a wireless keyboard/mouse through the network or even via the Internet. The robot has a small local LAN network with all of its network components. Communication with the outer environment is provided by a wireless connection at 2.4 GHz and 5 GHz. For greater distances, the robot has an active network component - the Bullet M5 HP, using the 5 GHz range that can connect over several kilometers while retaining the transmission speed of more than 100 Mbps.

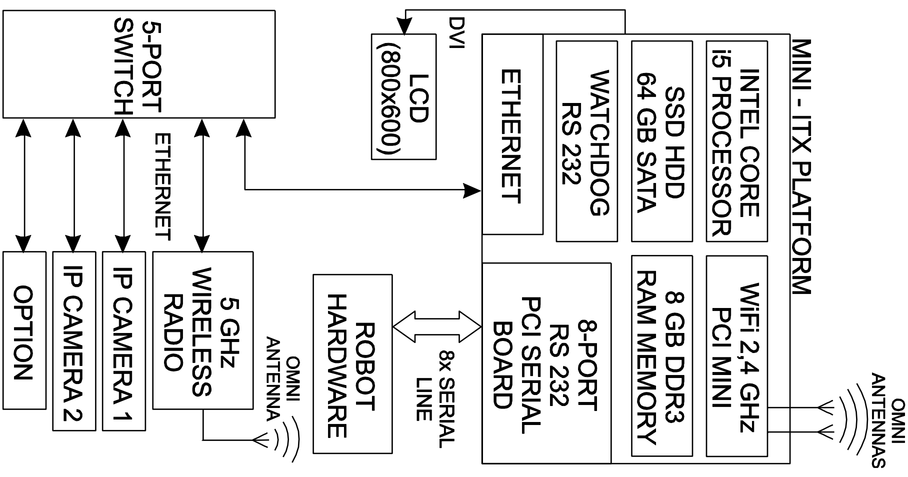

Fig. 2 Block diagram of master control system

To allow usage of multiple RS232 connected devices, an additional communication card was installed. It is a Moxa low profile PCIE card that offers eight extra COM ports. It works well with all operating systems and is an industrial card, thus is well protected.

4 LOW-LEVEL CONTROL SYSTEMS

All the electronic subsystems are either used to control a process or acquire data from the outside. They communicate with the master control system described in Section 3 using serial communication. A complete block scheme of the subsystems is shown in Fig. 3. The following text describes the motor control (drive subsystem) in a more detailed way. This subsystem is the most complex. Later on, other subsystems, such as power management, auto switch, LED driver, or the watchdog will be described.

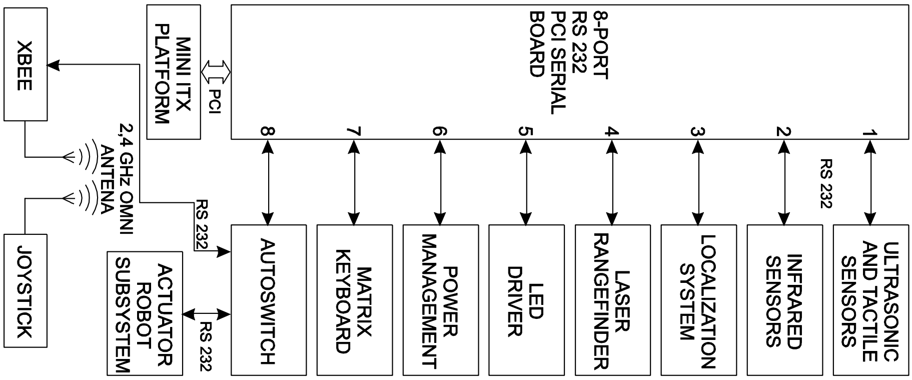

Fig. 3 Block diagram of low control system

4.1 Drive subsystem

The drive subsystem uses four DC motors, each geared down using epicyclic gearing and equipped with an IRC encoder for rotational speed measurement. A complete block scheme of the drive subsystem is shown in Fig. 4. Similar control structures are discussed in [8]. The output torque of the gearbox is 10 Nm. Each motor is controlled by a dedicated microcontroller unit, where a proportional-sum-derivative (PSD) control algorithm is applied for speed control and a PS regulator for absolute position control. These controllers enable control of the motors with great precision and a smooth movement of every wheel without jerking when accelerating or slowing down. The robot's maximum speed is 0.73 m/s.

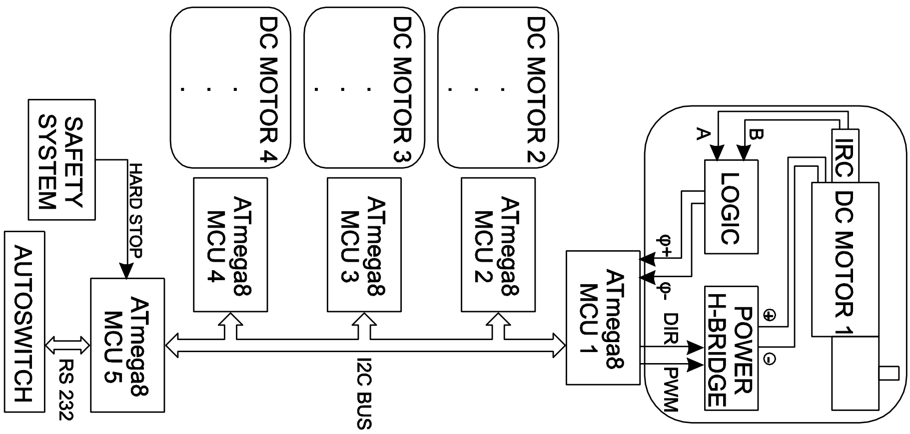

Fig. 4 Block diagram of drive subsystem

Each motor has its own power driver which was designed from scratch for this purpose. It is made of four MOSFET transistors combined together into an H-bridge and allowing for a maximum current of up to 75 A. The microcontroller units for all of the motors are located on one board. All four motor drivers are connected to it. It uses the IRC encoders (HEDS-5500 A13) as inputs. The controller board also contains a serial communication RS232 connection, used for receiving the setpoint values for the motors. Internally, the board is divided into five parts - the first four parts are identical microcontroller blocks and perform the actual control. The last part is the communication controller, which manages the communication with the master system and also distributes the data among the four slave controllers. The heart of all the parts is an Atmel AVR ATMega8 RISC microcontroller. Each of the four controllers has electronic implementation of step and direction detection based on the φ+ and φ- pulses. The block contains discrete logic elements (invertors, ANDs and monostable flip flops) and a zero order hold. Using the monostable flip flop it is possible to set the pulse duration in such a way that the controller can detect them. The φ+ and φ- signals are used as inputs for the MCU. Based on these signals the speed can be determined and the algorithms implemented inside the MCU send the control signals to the motor driver H-bridge. The desired values are received by an I2C bus. The motor controller MCUs are set up to a SLAVE position and the communication controller is set up as a MASTER. The master provides the desired values of each of the slaves. The desired values are received via the RS232 from a higher controller. The described controller uses discrete PSD based algorithms implemented on an ATMega8. The controllers can control speed and position. Generally, when controlling servosystems, three control loops are used. The first one (the innermost one) is the momentum generator - it controls the current flow into the motor, thus controlling its momentum. This loop has the fastest dynamics. The input of this controller is the output of the second controller loop, which controls the rotational speed of the motor - effectively it receives feedback of the actual value of the wheel speed. It has slower dynamics. The last loop is the slowest one, and it controls the position of the robot. Only two controllers are used in the case of our robot - the speed and the position controller. In a classical DC motor control approach, a momentum generator is integrated in the control loop of the speed controller. In this case, the speed controller has the dynamics fast enough to not consider the momentum generator. A PSD algorithm is used to control the speed and a PS algorithm is used for the position control.

The same feedback sensor is used both for rotational speed and position. One revolution of the Mecanum wheel equals to 30,000 pulses from the IRC encoder. Therefore, the control process can be very precise. The control action is stopped once the real value is within the range of ± 5 pulses. This solution increased the convergence speed of the controller and decreased the necessary control time. At low speeds a DC motor can behave quite non-linearly and therefore a simple PSD controller might be not adequate enough. Since the motor is geared down (1:60) and is relatively fast, it mostly operates at higher speeds. Therefore a PSD+PS algorithm is sufficient for our kind of system.

4.2 Power management

An intelligent power module was created to distribute and control power, and to monitor and measure the state of the batteries. This module is ATmega8 controlled and continually determines the current power consumption of the robot as well as the state of the batteries. If the state of charge reaches a critical level, this system determines which system to turn off. The measured data is shown on a small LCD. The power management module connects to the batteries, the external power, the main control elements (START, STOP, RESET, TOTAL STOP, KEY) and a signalization display. The main power for the robot's power devices is selected either from an external source or from the batteries. The main power supply control utilizes the main control elements - START, STOP, TOTAL STOP and KEY. The power supply is divided among all the robot's subsystems by the power elements, which are functioning in a bistable mode. The above mentioned microcontroller is used for control, measurement and communication, and is located on the PCB along with the LCD.

The power module uses a hall probe for current measurement and also a circuitry for voltage measurement. The microcontroller can interpret these values and display them and their outcomes (the total energy used, total power used, current and voltage). They can also be transferred to a master system, which can subsequently send commands to turn various blocks of the robot on or off. It can also turn off the whole robot. Turning the robot on can only be performed manually as none of the digital parts has access to its controls - this choice is mostly due to the safety. When the charge in a battery drops below a critical value, the robot is shut down automatically.

4.3 Auto switch

The robot can be controlled either via the computer or a wireless joystick. During real world experiments it is often desirable to switch from one controller to another using a control button on the main panel of the robot. An Auto switch feature enables the robot to automatically switch between computer control and manual control - when the joystick is not being used, the robot is controlled by the computer, when it is used, the switch activates the manual control of the robot, while deactivating the computer (master) control. This is achieved by using a module based on the ATMega8 processor, which reads the data on the bus from joystick. The individual RS232 connections are converted to TTL and switched using 4066 multiplexers.

4.4 LED driver and Watchdog

The robot is equipped with LED lights and a warning piezo buzzer. The objective of this combination is to enable the robot to make itself visible or to announce its internal state. The power LEDs are placed inside milled grooves on the bumpers. There are three power LEDs per bumper - one on each side and one in the middle, which makes a total of 6 modules. Each module has an output power of maximum 15 W. The goal was to create electronics for a continuous control of light intensity for each of the LED modules with an option to control each of them individually. The LED driver connects to an RS232 interface. An ATMega8 is used as the controller unit that controls several power transistors.

The watchdog system is a hardware element designed to check if the computer is running correctly. It is connected to the computer and its outputs are connected directly to the RESET and POWER controls of the mainboard. Once the power supply is connected, the device delays the start a few seconds. Using a serial line (RS232) the watchdog checks if the system is operating properly, and if not, the watchdog module resets it. This behaviour can be disabled when it is not needed, e.g. in situations such as installing an operating system. The device is based on an ATMega8 processor, which communicates via a serial line and affects the running of the system. Using a terminal it is possible to give it a command to hard shut down or restart the system. This can be useful because the user can not always have a physical access to any of the robot controls. The whole solution is very reliable and allows remote control of even more features of the robot. An Autostart function can be enabled in the BIOS, but it is not always 100 % reliable, and an actual watchdog is integrated only into industrial computers.

5 OTHER SUBSYSTEMS

Data acquisition from the ultrasonic and infrared sensors is performed by an ATMega8 microcontroller. Two types of PCBs were developed, one for data acquisition from the ultrasonic sensors (these use an I^2C bus, similar as in [9]) and tactile sensors via a standard GPIO. Data acquisition from the IR distance sensors is achieved by using of the AD converter of the processor which is placed on a separate PCB. These components communicate with their master using an RS232 connection, running at 9600 bps. Control algorithms are developed in Matlab/Simulink, which is more described in the following subsections 5.1.

The last part is a waterproof matrix keyboard for fast interaction with the robot. It is controlled by a microcontroller, which sends the data to the master system.

5.1 Control algorithms in Matlab Simulink

Robot control algorithms are developed in Matlab/Simulink, providing a fast and simple way of designing algorithms and experiments. Communication with the robot runs in the background, so the user may focus on developing the algorithms and experiments. The background communication consists of several layers. The first layer represents the communication with sensors and actuators, containing only microcontrollers (AT-Mega8). The microcontroller processes data from sensors (IR sensors, ultrasonic sensors and limit switches) and sends them through the UART bus to the second layer. A microcontroller receives data through the UART bus, which is then are processed and sent to the actuators (motors, lights). The second layer contains the master computer (Intel i5), which stores all the data, creates commands and watches the operations of all slave microcontrollers. The second layer is also a main communication centre accessible through the Ethernet / WiFi connection. The first advantage of this layer is its capability of interconnecting high speed Ethernet with the slow speed UART bus, the second advantage is the capability to communicate with any device with Ethernet connectivity i.e. PC's, smart phones, tablets, microcontrollers. A special software was developed to communicate with this layer, that is the third layer in communicating with the robot. The software exchanges data with the robot several thousand times per second, generates the commands for the robot, it is parsing data from received commands and exchanging data with upper layer through pipes (A pipe is a software technology used to exchange data between processes on a local computer). The upper, fourth layer is the final layer in the robotic communication. It is a Matlab S-function written in C language, that outputs data from sensors respectively inputs to the S-function are the data for actuators.

8 Conclusions

This mobile platform has already been in use for experiments in the field of robotics for two years, and has been improved for over four years. Very complex algorithms run on external computers connected to the robot via the high speed 5 GHz wireless link.

The described mobile robotic system is continuously being updated with new control systems, which are designed from scratch at our department. The open control architecture of the mobile robot allows changing the low level systems that would not be possible with a commercial robotic device. The present work is aimed at integrating a "submaster" control system for processing large amounts of noisy data originating from the inertial measurement system. Further work will deal with the implementation of the control of a robotic arm via a CAN BUS, combined with the use Microsoft Kinect 3D sensor for complex robot navigation and control.

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