A ROBOTIC SOCCER PLAYER CONTROLLED BY A TELEOPERATOR

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The article deals with the design of a two-wheeled mobile robot with differential wheel control to achieve higher maneuverability. The speed and direction of movement are controlled using the difference in speed of both wheels. The robots are designed as game robots for educational purposes for students and future students in training and experiments oriented to control and navigation methods in mobile robotics.

KEYWORDS

robot, wheeled locomotion, kinematics, teleoperation

1 INTRODUCTION

Technical education is necessarily associated with practical demonstrations and experiments. Students who study and are educated in this area must, in addition to theoretical knowledge, also gain practical experience and skills in order to be able and competent to design and solve applications in the field of automation, mechatronics and robotics. The subject of this article are didactic models of mobile robots, which are intended for education but also for gaming purposes to promote technical education and initiate interest in studying and working in this area.

It would seem that these robots are just toys, but these robots provide an excellent starting point for experiments, especially in the development of navigation methods and mapping of the environment and methods and algorithms for controlling the movement of the robot. In the development of such robots, therefore, advanced navigation and control methods are also developed. In many cases, it is also necessary to address the development of sensor systems and machine vision systems, image processing and object recognition, and the avoidance of static and dynamic obstacles. A typical example is robot soccer competitions, which are a driving factor in the research and development of new methods and technologies that can also be used in industrial practice and other sectors with the potential for the use of automated systems, mechatronic systems and robotic systems [Bellas 2017, Hajduk 2014, Hajduk 2016, Fetso 2024, Hroncova 2023, Kelemen 2012 & 2018, Lestach 2022, Liptak 2018, Lopez-Rodriguez 2016, Malik 2025, Mikova 2013 & 2014, Pivarciova 2016, Solis 2009].

The FIRA MIROSOT robotsoccer competition (Fig. 1) has been organized for several decades and is a space for research teams that develop such multi-agent robotic systems. The demanding rules of the competition create quite complicated conditions and the competitors - researchers must design a suitable solution to meet the conditions and win [FIRA 2024, Sukop 2013].

Currently, the FIRA RoboWorld Cup and World Summit are being organized simultaneously, where the robot competition is held, but also the results of the scientific research work of individual teams are presented. For example, the following are organized:

FIRA Air – Autonomous Race competition is encouraging research teams to design an agile and autonomous navigation system for the drones which can compete against human pilots in a 3D racetrack [FIRA].

FIRA Air – Outdoor Emergency Service competition is encouraging research teams to develop a robust and autonomous drone for commercial and industrial applications.

FIRA Air competition is to encourage research teams for solving current problems of developing a smart and efficient drone in both commercial and industrial fields [FIRA].

FIRA Autonomous Cars Race Challenge is to encourage researchers designing and implementing an autonomous car and finally build this long-lived human imagination [FIRA].

HuroCup encourages research into the many areas of humanoid robotics, especially walking and balancing, complex motion planning, and human robot interaction. In addition to the single events (e.g., archery, sprint, marathon, united soccer, obstacle run, long jump, spartan race, marathon, weightlifting, and basketball), there is an all-round competition for the single robot that performs best over all events [FIRA].

AndroSot Challenge - The Challenge games aim to promote the abilities of attack and defense in androids and also consist of several tasks such as dribbling, obstacle avoidance, shooting, trajectory detection, goalkeeping, role arrangement, and positioning control [FIRA].

RoboSot - the RoboSot Soccer Competition will consist of a series of challenges as well as the traditional soccer competition.

These robots are fully autonomous, which poses a huge number of challenges in their research and development in the areas of hardware design, software, communication technologies, intelligence, and sensors [FIRA 2024].

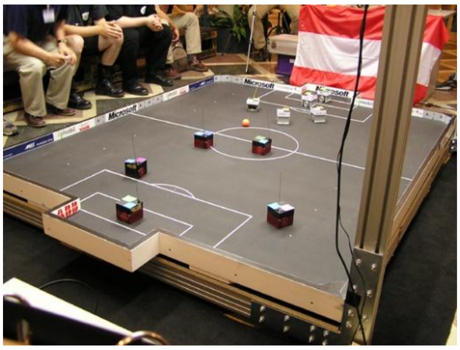
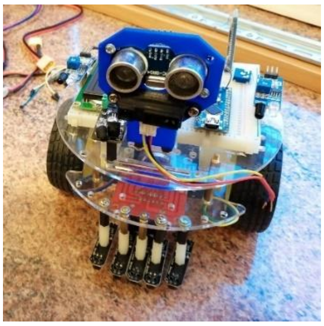


Figure 1. Team SjF TUKE Robotics - FIRA - MIROSOT category [Sukop 2013]

For the educational process, open platforms of two-wheeled mobile robots were created, which have adjustable mechanics, freely reconfigurable electronics and a reprogrammable microcontroller (Fig. 2).



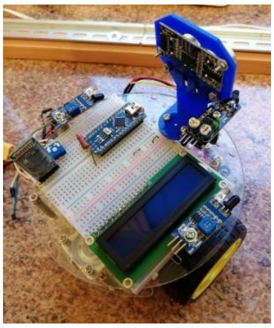


Figure 2. Open robotic platform for educational purposes

Students thus have room for innovative and creative ideas and thoughts, which they can also experimentally implement and test on these robots. Then they can verify their results in a fun way through a competition. This form of education has proven itself to us and brings many creative graduates who are able to solve challenging problems in industrial practice and other areas where these graduates will be employed.

2 ROBOT DESIGN

Robots created for the educational process (Fig. 2) are relatively large precisely because of the open platform system. However, these robots are also used for the presentation of studies at technical universities and technical high schools. These robots very often had failures that were related to rough and careless handling.

Much smaller and more robust robots that are easier to transport and do not have to have an open platform would be more suitable for this purpose.

N20 Metal Gear Motor DC 6V motors with an encoder using two Hall effect sensors were selected to drive the robot. The motors are all-metal with metal gearboxes and bearings. The direction and speed of movement of the mobile robot is given by the difference in speeds of the left v_L and right wheel v_R (Fig. 3).

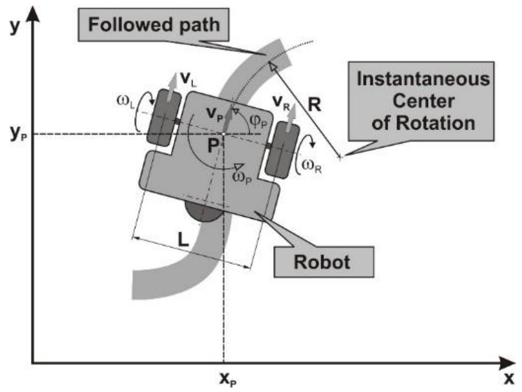


Figure 3. Robot control in a coordinate system

The instantaneous radius of rotation of the mobile robot can then be determined from the relationship:

$$R = \frac{L}{2} \cdot \frac{v_R + v_L}{v_R - v_L} \qquad (1)$$

The instantaneous translational velocity of the midpoint P of the robot chassis can also be determined as a dependence on the angular velocities of the wheels ω_R and ω_L from the relationship:

$$v_P = \frac{v_R + v_L}{2} = R \cdot \frac{\omega_R + \omega_L}{2} \qquad (2)$$

The position of the robot can be described using the coordinates x_P and y_P and the direction angle φ_P:

$$\dot{x}_P = v_P \cdot \cos\varphi_P \,;\; \dot{y}_P = v_P \cdot \sin\varphi_P \,;\; \dot{\varphi}_P = \omega_P \qquad (3)$$

The use of DC motors with encoders brought an advantage over the previous robot in the form of feedback control of the robot's movement speed. The H-bridge L298N with peripheral circuits in modular form was used as a power element. A two-wheel differential arrangement of driven wheels with two castor undriven ball wheels was designed (Fig. 4)

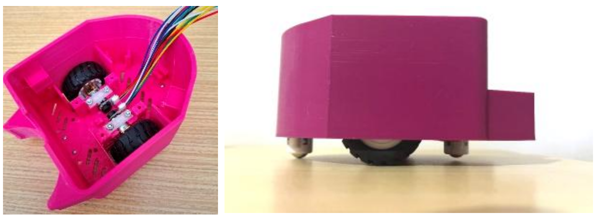


Figure 4. Two-wheel differential arrangement of driven wheels with two castor undriven ball wheels

The driven wheels are located in the middle of the chassis, so one castor wheel is not enough. The robot chassis could tip over when moving, so two castor wheels are used in this concept. They are adjusted in height to ensure clearance so that the robot has only one castor wheel in contact with the floor. This arrangement is especially necessary if there are uneven floors, because then the traction of the robot wheels would be impaired.

3 ROBOT CONTROL SYSTEM

To control the robot, the Arduino Nano microcontroller was chosen for its miniature dimensions, which required smaller design dimensions of the robot (Fig. 5). For communication, the frequently used Bluetooth communication module HC05 was chosen in the Slave connection. The connection was supplemented with a LiPol accumulator voltage monitor and when its voltage is low, the robot is programmatically stopped to prevent permanent damage to the accumulator.

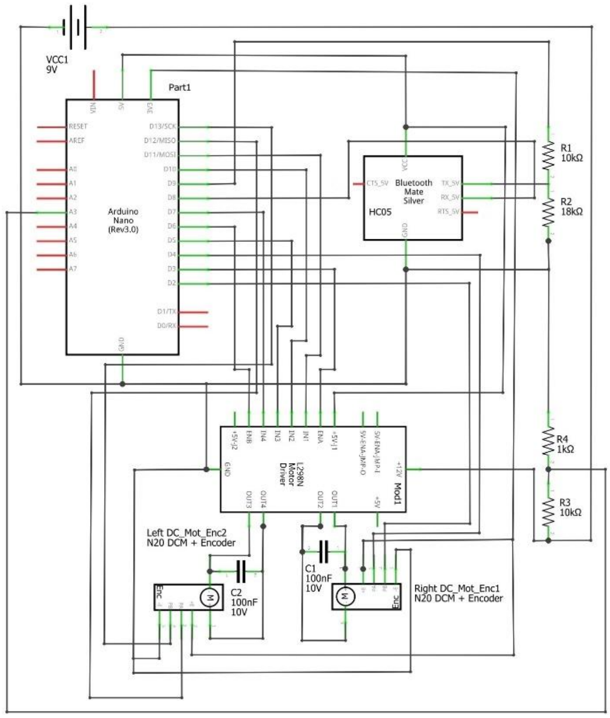


Figure 5. Robot control system

In such mobile robots using commutated DC motors, a common problem is the noise caused by the DC motor. An oscilloscope view of the signal from the rotary encoder shows that the signal is within the speed range without significant interference and this signal does not need to be modified or filtered. Nevertheless, a filter capacitor 100 nF was connected to the DC motors terminals mainly for precautionary reasons, as this noise and voltage spikes could be a problem for the microcontroller and communication circuits (Fig. 5).

For the correct functioning of the robot, it is necessary to regulate the motor speed in order to be able to follow the set trajectory. For this purpose, it will be necessary to process the signal from the motor speed encoder (Fig. 6). The motor that was used is relatively cheap and there were concerns that the signal from the encoder could be affected by noise and problems would arise in its processing and subsequent control of the motor speed. However, during the robot's load tests, the signals from the motor encoders were also monitored and they confirmed that the signal is of very good quality. Upon closer analysis, the noise was at a level of less than 25 mV, which will not affect the processing of this signal and the control of the motors. Since small voltage peaks occasionally occurred during inrush currents, low-pass filters were applied to these signal terminals.

When using robots as soccer players, the robot is often in extreme conditions. This means that the robot is constrained by another robot or an obstacle and the motors with wheels slip in place. The motors are under extreme load and can overheat and subsequently be destroyed. For this purpose, a load test of the motors was performed, where the robot was placed on a pad made of the same material as the field and the motors were powered with maximum supply voltage to achieve maximum speed (Fig. 7).

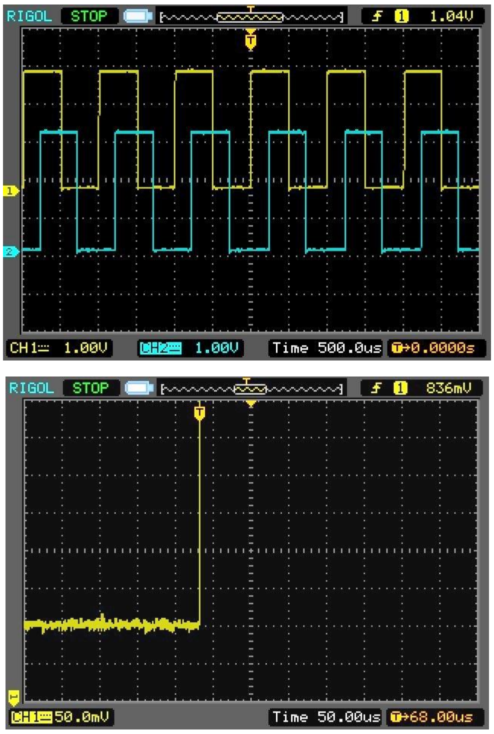


Figure 6. Oscilloscope view on signal from rotation encoder

Figure 7. Extreme load test of DC motors

When using robots as soccer players, the robot is often in extreme conditions. This means that the robot is limited by another robot or an obstacle and the motors with wheels slip in place. The motors are under extreme load and can overheat and be destroyed. For this purpose, a load test of the motors was performed, where the robot was placed in front of an obstacle on a pad made of the same material as the pitch and the motors were powered by the maximum supply voltage to achieve maximum speed (Fig. 7). This simulated extreme load test lasted 5 minutes at an ambient temperature of 25°C. The test results (Fig. 8) show that the robot motors had a maximum temperature of 44°C at the end of the test, which should not have an adverse effect on their operation.

Figure 8. Temperature distribution during extreme load test of DC motors

Previous extreme stress tests were performed with a robot without electronic parts in order to be able to measure the temperature of the motors and tires. However, under such stress conditions, overheating and destruction of the power elements of the electronics can also occur. Another extreme stress test was therefore performed with a finished robot, which is already used for educational and presentation purposes (Fig. 9). The experimental test also lasted 5 minutes and was performed under the same conditions as the previous test. The results of this second stress test showed that the H-bridge has the greatest heating, which after 5 minutes of the test reached a maximum temperature of 44.3°C (Fig. 10), which should not have a significant impact on its function. It must be said that this test is only a simulation and in practice these conditions should not occur and the operation of this robot should not be endangered.

Figure 9. Extreme electronics load test

Figure 10. Temperature distribution during electronics extreme load test

The entire designed control system was completed and integrated into the robot frame. There is space in the robot chassis for storing the battery and the entire robot is covered with a removable cover using magnetic fasteners.

In order to control the robot via Bluetooth using a mobile phone, it was necessary to create an application for the Android OS that would send signals to the Arduino via Bluetooth and the robot would move accordingly. MIT App Inventor, which is an online editor and is used to create full-fledged applications, came in handy for this task. It is intuitive and involves block programming (Fig. 11).

The Arduino microcontroller was programmed using the Arduino IDE, which uses the Wiring programming language, which is very similar to C++.

The Arduino program is described using simplified pseudocode, where the main loop of the program checks the battery status and cyclically reads the code transmitted from the mobile phone via the Bluetooth communication interface. A specific program is assigned to each button in the mobile phone application with the initial setting of the DC motor speed and subsequent correction if the motor speed does not correspond to the desired values.

The battery voltage is measured using a voltage divider connected to the analogue input. The following is a simplified pseudocode for the Arduino microcontroller. Some functions have been omitted for simplicity and were not included in the pseudocode.

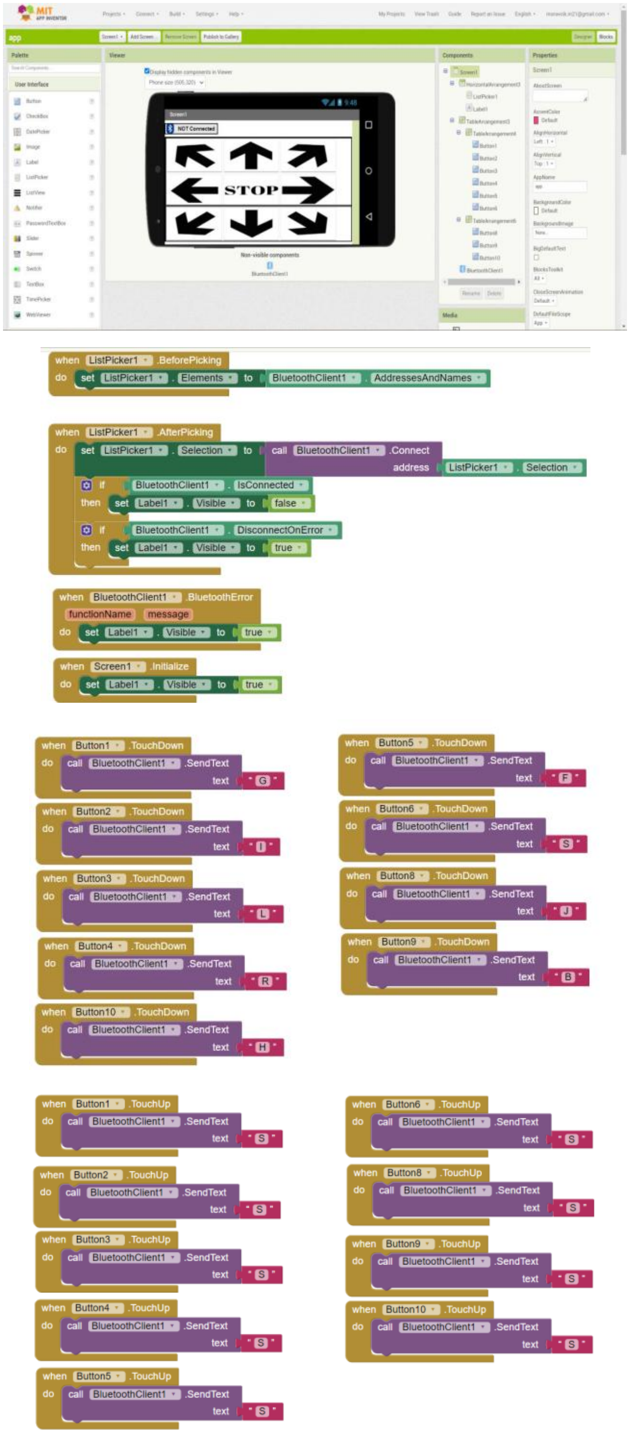


Figure 11. Design of application for robot control system

Pseudocode for Arduino microcontroller:

```
1: Start
2: Read accumulator voltage
3: If accumulator voltage < 7.6V then STOP
4: Receive BTooth signal
5:      If Forward_command then goto Forward_program
6:      If Backward_command then goto Backward_program
7:      If TurnRight_command then goto TurnRight_program
8:      If TurnLeft_command then goto TurnLeft_program
9:      If FrontRight_command then goto FrontRight_program
10:     If FrontLeft_command then goto FrontLeft_program
11:     If BackRight_command then goto BackRight_program
12:     If BacktLeft_command then goto BackLeft_program
13:     If Stop_command then goto STOP
14: Motor_program: {Forward_program; Backward_program;
     TurnRight_program; TurnLeft_program; FrontRight_program;
     FrontLeft_program; BackRight_program; BackLeft_program}
15:     Set rotation on H-bridge
16:     send PWM pulse X% LeftDCmotor
17:     send PWM pulse X% RightDCmotor
18:     Read rotation motor encoder on Left DC motor
19:     Read rotation motor encoder on Right DC motor
20:     Compute and send new PWM pulse for LeftDCmotor
21:     Compute and send new PWM pulse for RightDCmotor
22: Goto Start
23: STOP:
24:     Total stop of program and Sleep mode for MCU
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The source code is still under development and additional sensor modules and program functions are being added to the robot. Students then have further opportunities to improve this robot and create optimized source codes.

4 FINAL REALIZATION

The final implementation is in the form of a compact robot with a protective cover, which is mechanically resistant even to rough handling. The electronic components are no longer placed on a solderless breadboard but are connected using screw terminals or soldering technology. The entire robot is therefore also resistant to vibrations. An information LED display is also placed on the top cover, which shows the current value of the battery voltage (Fig. 12).

Figure 12. Final realization of the robot

Currently, eight pieces of this robot are implemented, each robot has a name and an associated MAC address of the communication module for Bluetooth communication pairing. Two teams of robots have been created and have already been used for robosoccer matches (Fig. 13).

Figure 13. Robosoccer match

5 CONCLUSIONS

Although the proposed robotic multi-agent teams are didactic models and at first glance seem completely simple, their development was quite demanding and during the development it was necessary to solve several technical problems and unclear situations. Even though the device is complex and closed, it still provides space for students for further innovative and creative creation. The microcontroller has another several free pins for connecting additional sensors or actuators. Therefore, further expansion of the functionality of these robots is expected in the future.

The development of similar devices brings students space for their education through practical applications and thus improves their knowledge, skills and experience [Brada 2023, Bratan 2023, Koniar 2014, Kuric 2021, Mikova 2023, Oscadal 2020, Pavlasek 2018, Romancik 2024, Saga 2020, Tlach 2019, Trojanova 2021, Vagas 2024 & 2025, Virgala 2012 & 2014a,b, Zidek 2018].

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