

THE REMOTE CONTROL OF AUTONOMOUS MOTIONS MINIROBOTS

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Articolul prezintă o modalitate de comanda de la distanță a unui minirobot cu deplasări autonome. Fiind realizat în întregime în cadrul catedrei, sunt prezentate toate etapele realizării proiectului. Sunt menționate modul de calcul și proiectare al principalelor elemente mecanice și electronice, însă accentul este pus pe soluția hard-soft pentru controlul de la distanță al minirobotului. Această soluție se încadrează în tendințele moderne de comandă de la distanță prin utilizarea Ethernetului ca suport de transmisie a datelor. Aceasta soluție, oferă minirobotului posibilitatea de a fi controlat și monitorizat din orice locație ce are acces la Internet.

This study presents a remote control method for a minirobot with autonomous motions. Because it was made entirely in our department, all the development stages of the project are presented here. The procedures of calculation and design of the important mechanical and electrical elements are mentioned, but we have emphasized the hardware-software solution for the minirobot's remote control. This solution is included in the modern trends of the remote control using the Ethernet as support for the data transmission. This solution allows the minirobot to be controlled and monitored from any location with Internet acces.

Key words: minirobot, crawler drive, remote control, wireless

1. Introduction

This paper presents a remote control application which can be included among those operations which are generally called teleoperation. Mainly, it is about to transmit commands from distance to a piece of equipment, using the Ethernet protocol; these commands can be provided directly by an operator or by a preset sequence. Generally, the remote command transmission to a remote equipment is called teleoperation, no matter if the one who decides the commands is an operator or an automated drive system.

The goal of this application is the remote control which can be found in one of the following situations:

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- The equipment (a mobile minirobot) operates in a hostile environment, dangerous for the human operator, such as: bombs deactivation, nuclear reactors, etc.;
- The equipment must get the information from areas which are inaccessible for the operator (the extra-terrestrial space, the narrow spaces);
- Few models of such equipment are available and the equipment must be used by many users, placed in different geographical areas (the case of e-learning) [1].

The version presented in this article has the purpose to find a solution in achieving an application for an e-learning laboratory environment. In our country, this modality is not yet used currently, because the laboratories were not conceived from the outset for such a kind of applications. The adaptation of the extant ones requires sometimes complex changes and a collaboration between specialists from different domains (the base one, automation and programming) and, also, a certain minimum level of the access speed at Internet for the users. Together with the general access speed increasing, premises will be created for the development of these solutions that will be more often met in the Romanian universities.

In order to design this type of applications, a remote control system of an autonomous minirobot with crawler moving is presented. The structure is a functional model upon which new experimental researches can be developed, having as objective the validation of the theoretical approaches and the functional performances optimization.

The presented solution is intended to be used, particularly, to study the various remote control programming strategies of the minirobot in order to avoid obstacles in a known area, which can have several types of surfaces. Another type of laboratory that can be made starting from this solution could be the study of the adherence on various types of inclined surfaces knowing the mass of the minirobot or varying its load. It should be mentioned that to be performed such a kind of laboratory, is also necessary the video access of the user, but this is not developed in this article because standardized solutions that are on the market, like IP webcams, can be used without problems.

Because e-learning, until recently, provided support only for the theoretical domains and not for the technical ones, the presented model can be included in the researches finding the solutions for the practical areas of technical e-learning.

2. Robot description and operation

For the mechanical structure of the minirobot with autonomous motion, the design using the 3D CAD Design Software – SolidWorks was made.

2.1 The general presentation of the minirobot

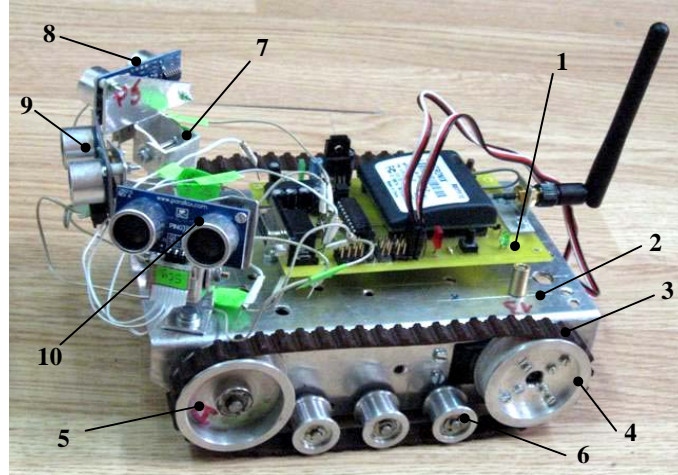


Fig. 1. View of the crawler minirobot:

1- electronic module; 2- mechanical structure; 3- crawler belt; 4- active wheel; 5- passive wheel; 6- crawler idler belt; 7- the support for the ultrasonic Ping sensor; 8- right side ultrasonic sensor; 9- central side ultrasonic sensor; 10- left side ultrasonic sensor;

The designed minirobot moves on crawlers, a better choice than movement on wheels in difficult environments. Even though the movement speed is smaller on crawlers than on wheels, this is an insignificant drawback.



Fig. 2. Bottom elements of the crawler minirobot:

1-batteries holder; 2-batteries; 3-left side servomotor; 4-right side servomotor;

The minirobot (Fig. 1) is made up of a mechanical structure which comprises: the chassis (2), active wheels (4) actuated by electrical servomotors, passive wheels (5) and wheels to reel out the crawlers. On the chassis, the

electronic module (1), as well as a number of three ultrasonic proximity sensors (8,9,10) are mounted. Even if the robot is equipped with these sensors from the very beginning, they are not used in the tests developed for this research, but they will be used in other future applications.

In Fig. 2, the two servomotors can be observed (3,4) as well as the four accumulators that generate the electric power needed to supply the whole robot - both for driving and the module of command and control.

2.2 The geometric elements of the minirobot drive system

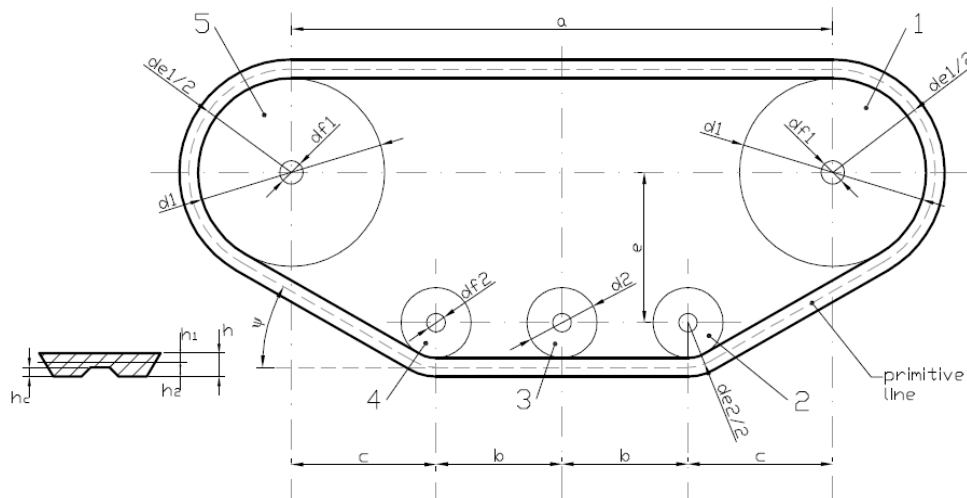


Fig. 3. The geometric elements of the minirobot's drive system

The values of the geometric elements of the minirobot drive system presented in Fig. 3, are the following: $d_1 = 40$ mm, $d_2 = 15$ mm, $df_1 = 5$ mm, $df_2 = 4$ mm, $b = 27$ mm, $c = 31$ mm, $e = 17$ mm, $h = 3.4$ mm, $h_1 = 0.5$ mm, $h_2 = 2.9$ mm, $hc = 1.4$ mm

$h_1 = h/2$ represents the primitive line position, at the insertion level of the motion transmitting belt.

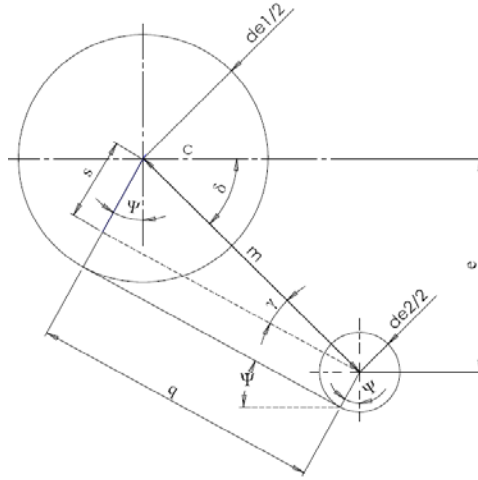
The equivalent diameters for calculation are:

$$d_{e1} = d_1 + 2h_1 = 40 + 1 = 41 \text{ mm} \quad (1)$$

$$d_{e2} = d_2 + 2h_1 = 15 + 1 = 16 \text{ mm} \quad (2)$$

The determination of the ψ angle

$$m = \sqrt{c^2 + e^2} = 35.355 \text{ mm} \quad (3)$$

Fig. 4. The geometrical elements for the determination of the ψ angle

$$s = \frac{d_{e1} - d_{e2}}{2} = \frac{40 - 15}{2} = 12.5 \text{ mm} \quad (4)$$

$$q = \sqrt{m^2 - s^2} = \sqrt{35.355^2 - 12.5^2} \Rightarrow q = 33.072 \text{ mm} \quad (5)$$

$$\gamma = \arcsin\left(\frac{s}{m}\right) = \arcsin\left(\frac{12.5}{35.355}\right) = 20.705 \text{ deg} \quad (6)$$

$$\delta = \arctg\left(\frac{e}{c}\right) = 28.74 \text{ deg} \quad (7)$$

$$\psi = \delta - \gamma = 8.035 \text{ deg} \quad (8)$$

The determination of the distance “a” between axes

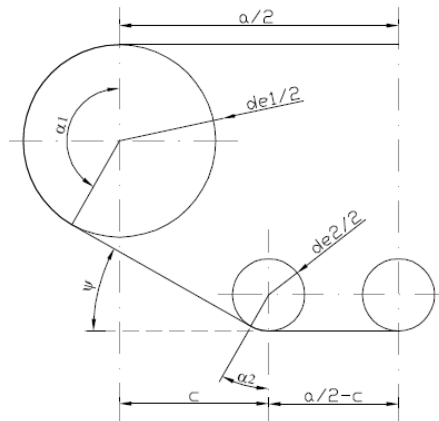


Fig. 5. The geometrical elements for the determination of the distance “a”

It is known that the length of primitive line of the belt is: $L_p = 362mm$

$$\alpha_1 = 180 - \psi = 171.965 \text{ deg} \quad (9)$$

$$\alpha_2 = \psi = 8.035 \text{ deg} \quad (10)$$

$$L_p = 2 \cdot \left(\frac{a}{2} + \frac{d_{e1}}{2} \alpha_1 + q + \frac{d_{e2}}{2} \alpha_2 + \frac{a}{2} - c \right) = 2 \cdot \left(a - c + q + \frac{d_{e1}}{2} \alpha_1 + \frac{d_{e2}}{2} \alpha_2 \right) \quad (11)$$

$$L_p = 2a - 2c + d_{e1}\alpha_1 + d_{e2}\alpha_2 + 2q \text{ at the end "a" will be: } a = 0.118 m$$

2.3 Servomotor Selection

In order to determine the necessary power, the following elements were taken into consideration:

$$P_m(\alpha, a_c, v) = M_m(\alpha, a_c) \cdot \omega(v) \quad (12)$$

where the following parameters represent: $\alpha = \pi/20$ - slope of the surface; $a_c = 0.2m/s^2$ - movement acceleration; $v = 0.25m/s$ - movement speed

The result is:

$$P_m\left(\frac{\pi}{20}, 0.2, 0.25\right) = 1.692W \quad (13)$$

Considering that:

- the movement speed of the minirobot is 0.25 m/s ,
- the active wheel has a diameter of 0.04 m,

according to the formula $v = \omega r$, where $r = d/2$, ω (angular speed in rad/s) is found $\omega = 12.5 \text{ rad/s}$, and rotation speed is deduced $\omega = \frac{\pi n}{30}$, hence the result is .

Considering that the consumed power calculated for the movement of the mobile robot is of 1.692W and estimating the efficiency of the reduction gear $\eta = 0.6$, the result is a useful power at the exit from the reduction gear of 2.82W.

Considering an overcharge coefficient $c = 1.3$ (possibly for movement speeds that are higher than the established one of 0.25 m/s), the result is an useful output power from the servomotor of $P_e = 3.7W$.

The electromotor was chosen according to these parameters, at the output level of the motor reduction gear (n , P_e).

The chosen servomotor was one without charge, the couple of motor superior to the determined ones, respectively.

$$M_{t_e} = \frac{9549.3 P_e}{n_e} = 292.85 Nmm \quad (14)$$

When the servomotor was chosen, the catalogues of the main specialized companies were consulted:

- Maxon Motor produces servomotors of constant current in a diverse range of supply powers and voltages, with motor diameters starting from 12mm, gear reducers and electronic command blocks.

- Portescap is specialized in micromotors of constant current of watts order and it also produces gear reducers gears which are compatible with the micromotors.

- Futaba is specialized in servomotors manufacturing of constant current of relatively small voltages with applications in robotics and it collaborates with the company Parallax-U.S.A, which produces electronic command modules in the same domain for a higher compatibility between the servomotor and the electronic command module.

Given all the advantages mentioned above, Futaba was chosen.

The choice of the Futaba servomotor, [4]



Fig.5. The elements of a Futaba servomotor

In the first stage, we considered two servomotors with characteristics that fulfill the requirements, respectively:

- the servomotor 1: $M_1 = 422.9 \text{ Nmm}$, $n_1 = 166 \text{ rot/min}$ - type BLS251 (FUTM0521)

- the servomotor 2: $M_1 = 494.7 \text{ Nmm}$, $n_1 = 111.1 \text{ rot/min}$ - type BLS253 (FUTM0523)

Conclusion: Servomotor no. 2 does not meet the necessary technical requirements relative to the angular speed $n_2 = 111.1 \text{ rot/min} < 119 \text{ rot/min}$ and also the technical data specified in Futaba catalogue are without load. The servomotor type BLS251 has been chosen, presenting the main technical data mentioned above and considering that the gradient (rot/min) ensures the optimal actuation of the minirobot for the imposed superior parameters (slope of surface, acceleration, speed).

1 block -contains a microcontroller type PIC16F87, made by the company Microchip [5], which is the main element of the whole electronic module. The microcontroller is gives the command of servomotors, the processing of data received from sensors, as well as the serial communication with the computer. Communication is possible with the help of the cabled version or of the wireless version. The choice of the communication is made with jumpers JP1 and JP2, respectively. Several connectors for the link with various sensors are attached to the microcontroller.

2 block-makes possible the conversion of the voltage levels necessary for the communication with the PC. So, one can make a cabled communication link which will use protocol RS232. The integrated circuit of type MAX232 produced by the company Maxim is used [6].

3 block-the communication WiFi module, type MatchPortBG produced by the company Lantronix [7]. This one, together with the driver installed on the computer emulates a serial wireless connection.

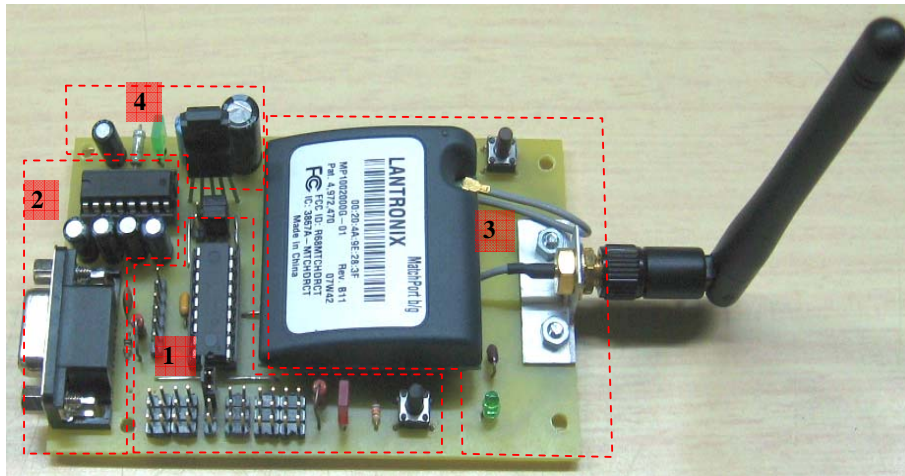


Fig. 7. View of the electronic command and control module

For such a communication type to be possible, it is necessary that an Access Point is available somewhere nearby, so that the module of the robot is allowed to enter into the WiFi network and thus to be accessed through Ethernet. This module can be set up from a browser web. Due to the driver installed on the PC, a virtual serial port is created. Thus, the access becomes very simple, just as in the case of any computer serial hardware port.

The assemblage gives the possibility to program the microcontroller within the circuit through connector J1. This is very important in the testing stage. Hence, when the microcontroller is re-programmed very frequently, it is not

necessary to take it out of the circuit every time the program is written, which could deteriorate it physically.

Microcontroller Programming

The program for the microcontroller of type PIC16F87 was written in C and compiled with the help of mikroC produced by mikroElektronika [8]. Thus, we used the principles of high level programming, which is much easier to be understood and used by any user familiarized with general programming. The interface of the used compiler is presented in Fig. 8.

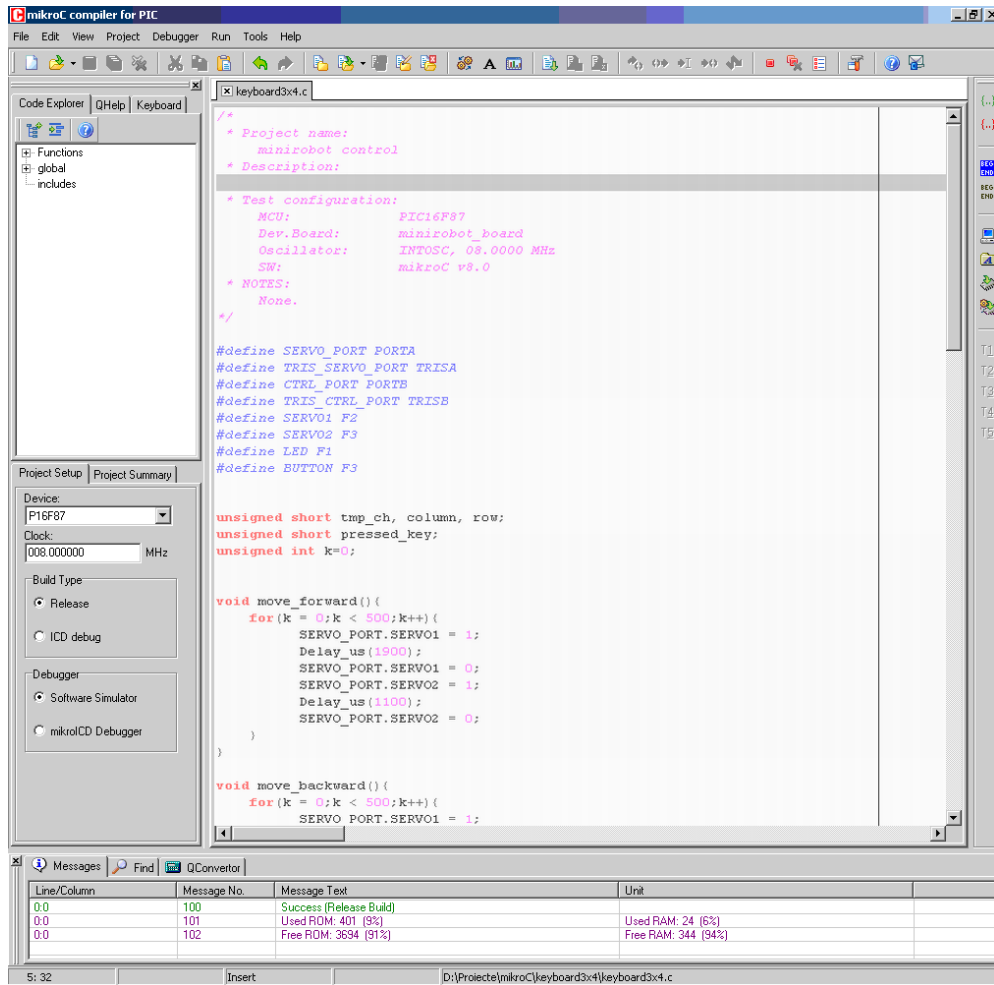


Fig. 8. Graphical interface of compiler mikroC

The basic structure of the C software program for the microcontroller is the following:

```

void move_forward();
void move_backward();
void rotate_right();
void rotate_left();
void move_stop();
void move_fw_ri();
void move_fw_le();
void move_bw_ri();
void move_bw_le();
void main() {
// uC settings & ports settings (in/out)
while(1) {
while(!USART_Data_Ready()){ // wait for USART data
move_stop(); } // if no data is received
rec_ch = USART_Read(); // read the received data
switch(rec_ch){ // received command identification
case 'a': move_forward();break;
case 'b': move_fw_ri();break;
case 'c': rotate_right();break;
case 'd': move_bw_ri();break;
case 'e': move_backward();break;
case 'f': move_bw_le();break;
case 'g': rotate_left();break;
case 'h': move_fw_le();break;
default: {for(k = 0;k < 10;k++){ //LED blinking for wrong command
CTRL_PORT.LED = ~CTRL_PORT.LED;
Delay_ms(50);}}//for
}
} //switch
} //while
} //main

```

As it can be seen, the created code contains one function for each command. The main function contains the settings of the microcontroller and the infinite loop for program execution. Stages of this function are: as long as nothing is received on serial port (USART), the stop command is transmitted to servomotors. When a command is received, the microcontroller executes the instruction "switch" that will identify the command to be performed. Correct commands are related to the receiving of one of the eight ASCII characters from "a" to "f". If a wrong command is received, the microcontroller will indicate it by flashing of a LED.

The .hex file resulted after the code compilation with mikroC, was downloaded to the microcontroller with the Microchip development tools:

- software programmer – MPLAB v8.10
- hardware programmer – ICD2

4. The software application of interface with the user

The PC application of command transmitting to the minirobot was made in the visual programming language - LabView since it allows an easy development of applications as well as its ulterior modification, if is necessary.

It is made up of two sections:

- the manual command of the minirobot by the operator (Fig. 9 and Fig. 10)
- the automatic application of a pre-established set of instructions (Fig. 10 and Fig. 11)

In Fig. 9, one can notice that, in the case of this section, the operator has the control over every type of commands by pushing the corresponding button. One should mention that, for a correct functioning of the minirobot, the communication port must be chosen from the beginning of the application. In case of a wrong serial port, data can be lost and, consequently, the minirobot will not proceed to any movement.

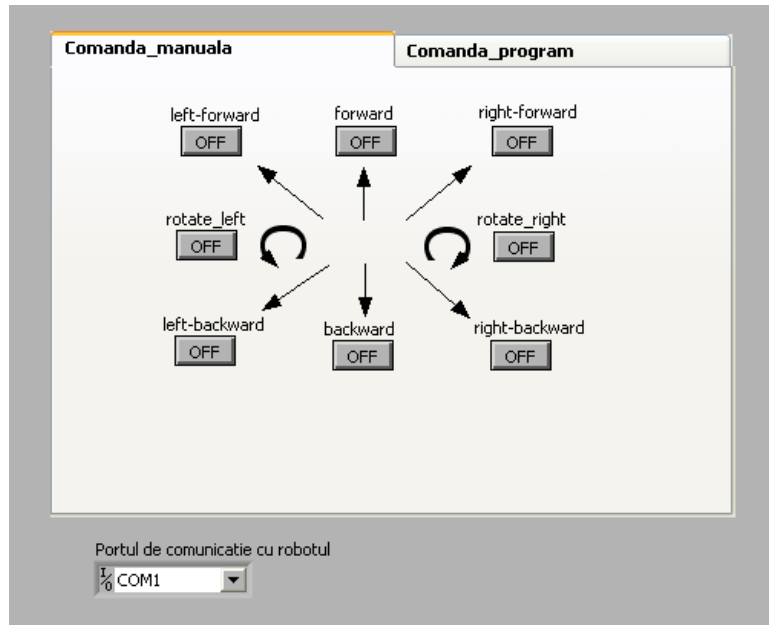


Fig. 9. Graphic interface for manual command

In the diagram corresponding to the manual commands (Fig. 10), one can identify the functioning algorithm of the application. Thus, after the application starts, it reads the port corresponding to the communication; afterwards, it enters a “while” loop in which all the buttons of the interface are monitored.

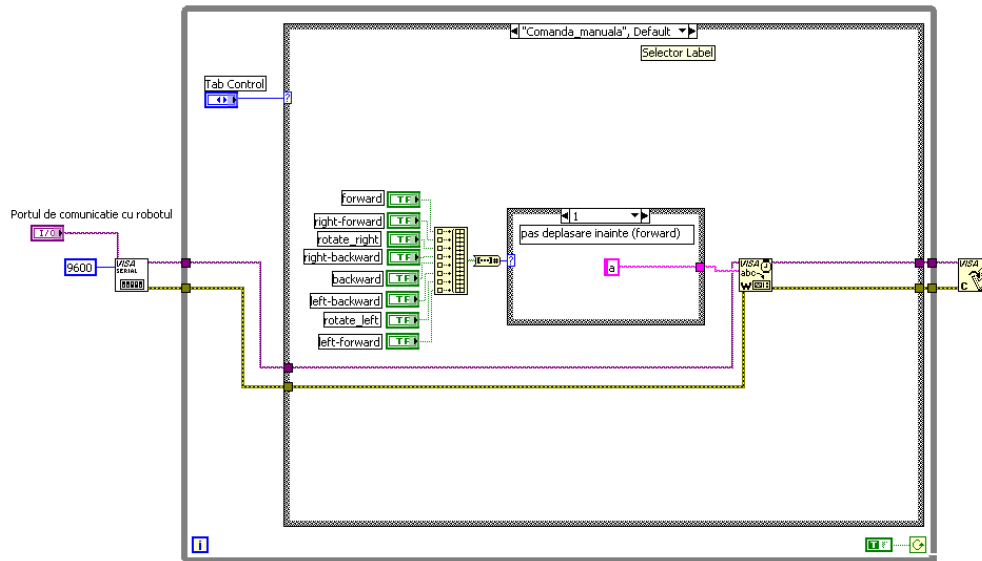


Fig. 10. The diagram corresponding to the manual command

The moment when a button is pushed, the application selects, in a “case” structure type the character corresponding to the pushed button and writes it on the serial port selected from the very beginning. The robot receives the character, it interprets it and carries out the next command.

In case of the section of commands corresponding to the program (Fig. 11) the user can write a series of commands the left-hand side. The syntax of these commands is made up of the numbers of execution cycles followed by the type of the command. The types of commands are written on the right-hand side as well so that the user should not be forced to memorize them. Finally, in order to launch the set of commands, the user must push the OK button.

Once the commands are carried out, on the top part the application indicates the actual command and its position in the set of commands, as well as the correction of the syntax. Thus, if the syntax of the actual command is not correct, the color of the indicator “The Status of the Command” becomes red, indicating an error. The program signals the error for five seconds and then goes on to carry out the next command on the list.

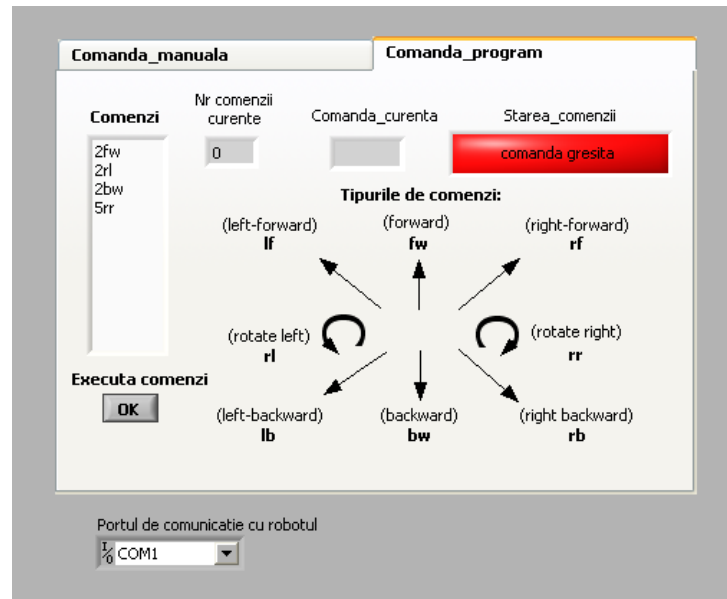


Fig. 11. The graphical interface for commands according to the program

The diagram which corresponds to the commands according to the program (Fig. 12) is more complex than the anterior one. It contains a command interpreter which analyses the syntax of each command. After the command was validated and the content was extracted under the form of number of cycles and of command type, data corresponding to every command are sent to the minirobot on the serial port. Just like in the previous case, the minirobot processes the data and carries out the command which corresponds to the received data. Thus, for the minirobot, it does not matter from what section of the application the data were sent. In this situation, the only problem is to maintain a permanent connection with the computer. From this point of view, the wireless transmission can be unreliable in certain circumstances, especially those related to the distance between the minirobot and the WiFi network access point or related to certain interferences that can appear in the case of some transmission channels. Thus, we can consider that the price paid for mobility would be an unreliable data connection. However, these problems can be solved after some tests. A working area can be established for the minirobot to be able to move safely, as well as the channels of communication in which there are no interferences in the respective area or wherever the interferences are weaker.

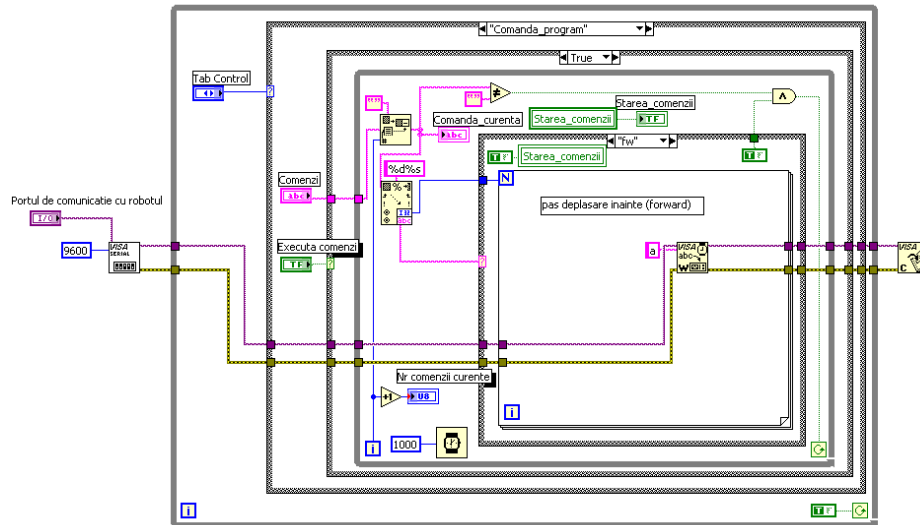


Fig. 12. The diagram which corresponds to the command section according to the program

For the accuracy check of the commands execution, an optoelectronic transducer which is part of an optoelectronic family of transducers developed in our department was used, [9]. This transducer uses the triangulation principle to get the location of the minirobot. The identification element is represented by a lighting source attached to the minirobot for this purpose. The use of this transducer has permitted to appreciate with a very good accuracy the position and the moving speed of the minirobot.

5. Conclusions

The principle presented in this paper can be applied to laboratory work via Internet with minor modifications, in the context of the concept of laboratory open for multiple users, as well as in Intranet, when lab works have to be carried out individually, without needing or allowing the access of the student in the proximity.

This dissertation opens up new possibilities for the study of problems generated in applications of telepresence and teleoperation. Experimental research validated the functioning and highlighted the difficulties related to communication speed and the chosen software solution. For further developments, the following will be taken into consideration: the command directly from the web browser and the coupling of other input/output devices (web camera, joystick).

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