A RADIO FREQUENCY COMMUNICATION PROTOCOL APPLIED ON MOBILE ROBOT CONTROL SYSTEM

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Abstract. *This paper presents the application of a radio frequency communication system to enable the bidirectional transmission of data between a robot and a personal computer. In order to get effective communication the work proposes a protocol that ensures the wireless serial transfer of information with quality and immune to errors and interferences. The system results in a simple, flexible and low cost solution that allows to make detection of obstacles and map the enviroment, presenting a graphical user interface developed in a computer.*

Keywords*: robotic, wireless communication, radio frequency, odometry*

1. INTRODUCTION

There are many applications of robotics which use a computer interface of remote control to send control signals to one or more robots. The wireless data transfer is usually developed using radio frequency (RF) modules that transmit data to the robots in order to control their movements. We can list as examples: exploration of hostile environments where there is high temperature or exposure to radiation (Monkman and Taylor, 1993) (Russel, 1997); transport of military equipment or detection of bombs in war zones; in robot soccer competitions or others challenges of robots (Vieira *et al.*, 2001) (Assis *et al.*, 2006). In others applications the robots use sensors to make measurements in specific regions and transmit this information in any way to a computer or human-machine interface (HMI) (Ottoni and Lages, 2003) (Dinnout *et al.*, 2003). We can list as example: the exploration of environments aimed at detecting leaks and measurement of gases concentration (Lilienthal and Duckett, 2003); surface of mars exploration in aerospace research, among others. Regardless of application, one of the main difficulties is the data transmission with quality ensuring that the robot performs the desired action and the measurements sent by the robot can be received with precision in the system receiver.

The transmission of information by radio waves has the advantage of the spread in all directions and far-reaching, but is susceptible to interferences and noises. One of the main concerns for to achieve good performance is the development of a communication protocol which makes precision and is relatively fast, immune of interference and without loss of data. The communication protocol should consider: the number of packets of data that make up the message being sent; the use of standards to identify each package which can be decoded in robot, as for example, the identifying the destination of the information in the case of application with more than one robot getting the same message; the maximum permissible speed of transmission for RF modules, the use of standards and filters to ensure the quality of transmission and to minimize errors. Actually, there are at market a lot of solutions available, some of them including an efficient communication protocol. This is the case, for example, of the modules with ZigBee® technology. However, these solutions are generally relatively expensive and needs didactic kits for programming. Furthermore, the communication protocol proposed in this paper presents a customized solution, incorporating in data package several information essentials for the proper functioning of a control system for autonomous robot.

2. THE SYSTEM

The system designed is constituted by two parts. The first part is related to the module to interface with the user, the human-machine interface (HMI), consisting of a personal computer (PC) and electronic circuit connected to the serial port that receives and sends the information to the robot. The module includes microcontroller, voltage source, voltage regulator, converter RS232/TTL, buffer of three states (selector-way of data transfer) and transmission and reception RF modules (RT4 and RR3 modules by Telecontrolli). These modules allow efficient communication with range from 20 to 30 m, without obstacles.

The second part is related to the circuit of robot. The module contains microcontroller, transmission and reception RF modules (either RT4 e RR3), three states buffer, bidirectional power drive, two rechargeable batteries, voltage regulator, DC minimotors with reduction, ultrasonic sensor and two speed sensors (encoders) used for mapping the route travelled by the robot.

The robot constructed at work, as illustrated in Fig. 1, is a small vehicle with dimensions 170mm x 120mm x 100mm characterized by the use of two-wheeled driven by two independent motors. The robot includes ultrasonic sensor in order to mapping the environment, detect obstacles ahead and sent the information obtained to a PC. In addition, the robot also use two sensors on wheels that detect magnetic pulses produced by references in order to estimate the speed of motors and also send this information to a computer. In the computer, with the data obtained by RF, an algorithm allows to developing a graphical interface that shows the mapping of the trajectory, i.e. the route traveled by the robot from a reference point, and indicates the position of the obstacles identified. The interface developed at computer allows, moreover, send signals to remotely control the movement of the robot, making therefore necessary to develop the bidirectional RF communication between robot and computer.

Figure 1. Structure of the robot used in the application

3. RF COMMUNICATION MODULES

Several items were considered important for the choice of RF modules, among them include: high frequency (allowing a good immunity to noise and interference); need for some way of regulation; levels of voltage and current; type of data in the transmission; size and weight; scope, power and sensitivity; reliability; speed of transmission and reception rate; and the main, the cost. Was evaluated using a *full-duplex* communication with transceivers, however, the modules available at market were very expensive. So, it was used pairs of independent transmission / reception modules developing a system *half-duplex*.

The scope of RF communication is variable and widely dependent on the type of antenna used, as well the environment in which the system is operating. The three styles of low-power antennas most commonly used in compact projects of radio frequency are: *loop*, *helical* and *whip*. Tab. 1 illustrates a comparison between these three styles; this comparison is important to determine the best solution for each specific project. At this case we used a *whip* antenna with 433.92 MHz. The Fig. 2 shows the scheme up to the antenna where the parameters used are A = 90.17 mm, B = 15.24 mm, C = 13.97 mm, D = 60.96 mm, E = 2.54 mm, F = 15 turns e G is #22AWG.

Table 1. Comparative between the main types of antennas used in compact projects

Parameter	 Loop	 Helical	 Whip
Performance	●	●●	●●●
Ease of installation	●	●●	●●●
Size	●●	●●●	●
Immunity to proximity effects	●●●	●●	●

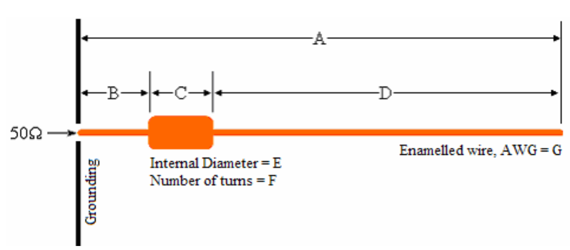


Figure 2. Design of antenna

4. SERIAL COMMUNICATION

The communication system developed can be divided into two parts: serial communication between the computer and electronic circuit of HMI, and bidirectional RF communication between the circuit of HMI and the robot. At this section we describe details about the serial communication.

As mentioned earlier, a microcontroller was used in the HMI circuit and another in the robot. The transfer of data between the microcontroller and the computer and between the microcontroller and RF modules of the robot, are performed using serial communication. In microcontrollers the serial data can be received and transmitted through the function UART (Universal Asynchronous Receiver Transmitter) full-duplex, using different registers for transmission and reception. Interruptions at programming were used to detect the reception of data and enable data transmission. The rate of transmission is also programmable in microcontroller using a splitter in the frequency generator that defines the rate of transmission.

4.1. Communication Protocol (PC → HMI Circuit)

The transmission of information from computer to the HMI circuit can use three standards. The standard # 01 is the main consisting of seven bytes. The first two bytes, CCh, are used to identify the beginning of communication between the personal computer and HMI. The least significant nibble of the third byte is used for defining the direction of rotation of the motors, more precisely, the bits 0 and 1 define the direction of rotation of the motor 1 (left) and the bits 2 and 3 define the direction of rotation of motor 2 (right). The motors may have three possible states: stopped, turning clockwise or counter-clockwise. Adjusting the four bits it is possible to control the motors rotate direction and define the movement of robot. For example, the Fig. 3 illustrates one of the movements. The fourth and fifth bytes define the speed of rotation of the motors 1 and 2. The sixth and seventh bytes define the quantity of pulses measured by the speed sensors fixed on the wheels of robot.

After started the reception (bytes CCh identified), the microcontroller will store the next five bytes and sent by computer. The Fig. 4 illustrates the package transmitted between the PC and the HMI circuit. Besides the main package (standard #01) others packages can be sent from PC to HMI circuit:

- standard #02 – used when the computer asks a new reading of ultrasonic sensor for to confirm the detection of obstacles and inform the distance from robot; the protocol used is illustrated in Fig. 5 which can be observed that the standard consists of a sequence of 5 bytes equal to FF in hex, or 255 in decimal;
- standard #03 – used when the computer asks the robot to send back the last data transmitted for to confirm or correct them when for some reason, the standardized format in the protocol was not detected by the reception circuit; the protocol used is illustrated at Fig. 6 and consists of 5 bytes equal to 00 in hex, or 0 in decimal.

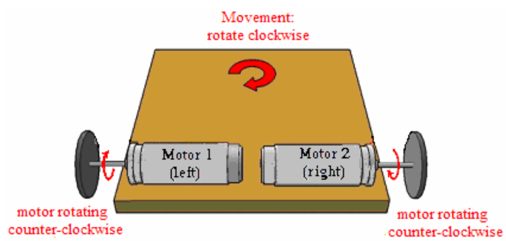


Figure 3. Movement of clockwise rotation of robot

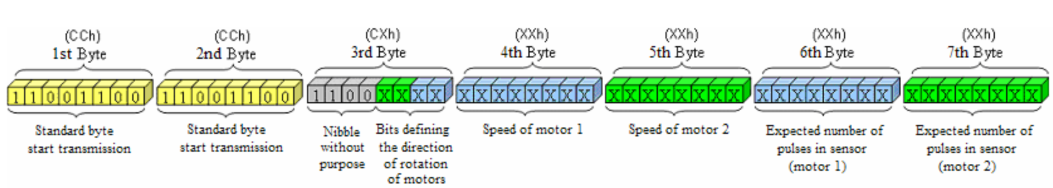


Figure 4. Package of data transmitted from the PC to HMI circuit (Standard #01)

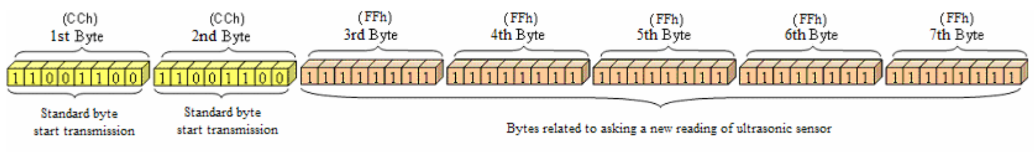


Figure 5. Package of data transmitted from the PC to HMI circuit (Standard #02)

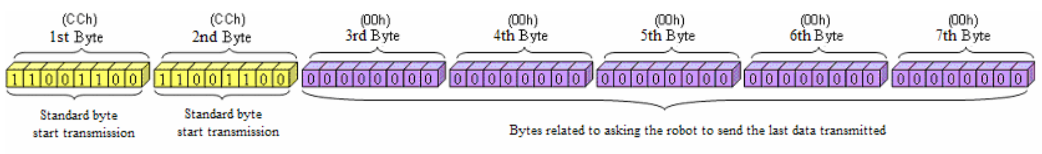


Figure 6. Package of data transmitted from the PC to HMI circuit (Standard #03)

4.2. Communication Protocol (HMI Circuit → PC)

During the development of work, it was noted some errors when the data was sent between the circuit of HMI and PC. When there is error of format at the package the last two values received are used as reference to identify the type of error found and thus correct it before to use these information at computer. To identify the data received in the middle of errors, when it happens, was introduced into the protocol a numerical sequence of 1 to 4 as shown in Fig. 7. Knowing that data sequence is equivalent to the pattern is possible to identify the exact moment when the data is being received by serial port and if one of the errors occurred. The standard used in communication consists of nine bytes. The first byte is used to identify the start of transmission. The second, fourth, sixth and eighth bytes are the numbers 1, 2, 3 and 4 respectively. The third and fifth bytes are related to the quantity of pulses read by the speed sensors. The seventh and ninth bytes represent the most and the least significant byte of the 16-bit register concerning the detection of obstacle by ultrasonic sensor.

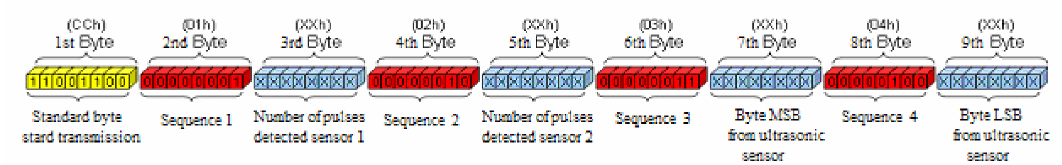


Figure 7. Package transmitted from HMI circuit to PC

5. BIDIRECTIONAL RF COMMUNICATION PROTOCOL

In this communication, in despite of using high frequency of work (433.93 MHz) that provides good immunity to noise, it was verified that the transmission of data with sequences 1 or 0, more than 4-bit produces a lot of errors in receiving data. In order to minimize these errors were used a technique for encoding data. The technique consists to substitute one bit 0 by two bits 10 and one bit 1 by two bits 01, once you can see that the number of bits being sent is doubled. This type of encryption is quite similar to the method of encoding data known by “Manchester”, widely used in telecommunication. The main advantage of this technique is that the largest possible sequence of bits 0’s and 1’s is equal to 2, thus minimizing the risk of errors in RF communication.

5.1. Communication Protocol (HMI Circuit → Robot)

Basically, we can say that only two types of information between are transferred between the personal computer and robot, they are: commands sent by the personal computer to drive the robot or measurement of sensors at robot. Besides the process of encrypting applied to data transmitted by RF communication, was added to the logic of programming in robot a "checksum." The concept is: the circuit of HMI sends the command to the robot at least twice; after the first package of data is received by the robot, the values are added and stored in a variable; after the second set of data is received by the robot, in the same way as before the values are added and then compared with the sum result of the first package, if the comparison results in a same value the robot executes the command received, otherwise, await a new sequence of data from HMI circuit.

In the flow of data from the HMI circuit for the robot, a total of twelve coded bytes are sent to robot. The first two bytes (CCh) are used to identify the beginning of communication. The third and fourth bytes are used for defining the direction of rotation of the motors, more precisely, the least significant nibble of the third byte defines the direction of rotation of the motor 1 (right) and the most significant nibble defines the direction of rotation of the motor 2 (left). The fifth and sixth bytes define the speed of rotation of the motor 1 while the seventh and eighth bytes define the speed of rotation of the motor 2. The ninth and tenth bytes define the value of the number of pulses produced by the sensor mounted on the wheel right of the robot. The last two bytes define the value of the number of pulses produced by the sensor mounted on the left wheel robot.

After the start of reception (recognized byte CCh) and the process of checksum, the data received will be decoded. The Fig. 8 illustrates the flow of data in the system of communication. At this figure we can see the package of information sent from HMI for the robot in response to the dispatch of standard # 01 (Fig. 4) from computer to HMI, but entering the encryption described above. Just as in the transmission of data between the PC and HMI, also the circuit of HMI can to send the standards # 02 and # 03 to robot, but in such cases also including the encrypting to minimize the errors.

5.2. Communication Protocol (Robot → HMI Circuit)

A total of ten bytes coded are sent from robot to HMI circuit as illustrated in Fig. 8. The first two bytes CCh are used to identify the beginning of communication between the HMI and the robot. The third and fourth bytes are related to the quantity of pulses produced by the speed sensor on the right side and the fifth and sixth bytes are related to the sensor on the left. The seventh and eighth bytes include the value of the most significant byte of the 16-bit register with information produced by ultrasonic sensor, as well as the ninth and tenth bytes include the value of the least significant byte of the same register. It is important to clarify that the byte CCh, is being used for the recognition of the package of data, because there is not the possibility of having a character encrypted equal to CCh character, and that the sequence maximum of bits 0's and 1's that byte is equal to 2. Finally, it is important to remember the HMI module can receive or transmit data and transfer data both to PC and RF communication module. So, it was necessary to establish a kind of key to selection a single communication. So we used a buffer of three states to enable the direction of data flow.

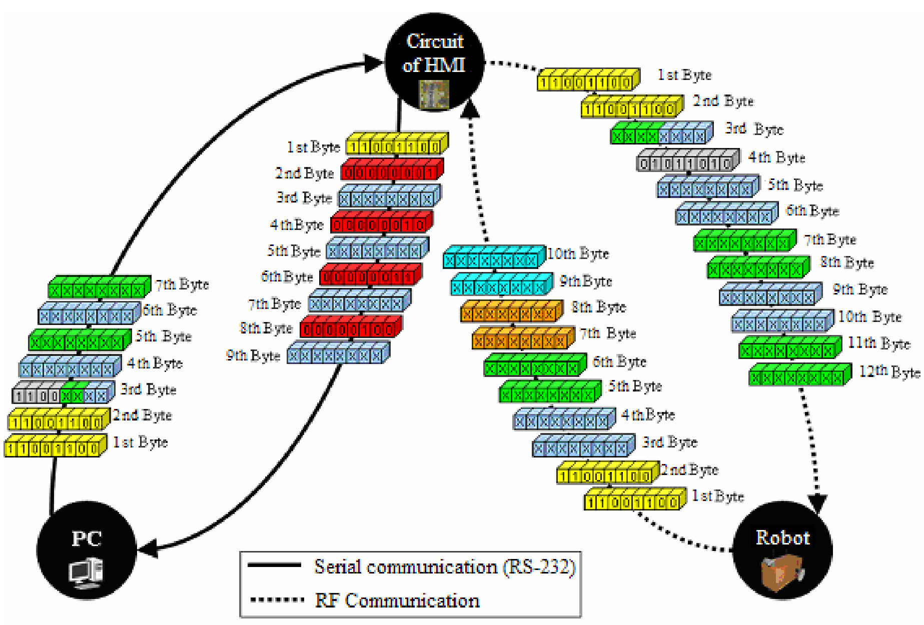


Figure 8. Flow of data in the system communication (using Standard #01)

6. OBSTACLE DETECTION AND ODOMETRY

The obstacle detection is obtained by means of ultrasonic sensor properly positioned on the front of robot. The sensor sends a pulse acoustic and awaits the return of an echo for certain period of time. Once the echo is detected by microcontroller is possible to estimate the distance between the sensor and the obstacle, simply multiplying the speed of sound in half of time measured. Some interference were not considered in measuring distances: speed of propagation of sound waves that are strongly influenced by changes in temperature and smoothly by changes in atmospheric moisture;

uncertainty in the detection due to the influence of the material to be detected; angle of issue and its interaction with the surface can result in effects of absorption, refraction or diffraction.

The logic of programming developed for measuring the pulse time of ultrasonic sensor is based on the used of 16-bit of the microcontroller and can be summarized thus: the ultrasonic sensor send a sound wave; this pulse is reflected by any barrier in front of the robot; the time that this wave takes to return to the sensor is measured; the value stored in 16-bit register is sent to PC through a serial communication; the process is repeated four times and the average is considered in calculating the "time of flight" (*Tf*).

Tests performed with the sensor and using obstacle at distances ranging from 2.5 cm and 150 cm resulted in *Tf* between 0.29 ms and 8.89 ms and calculated distances between 4.93 cm and 152.70 cm. The inaccuracies in the calculations were verified and the error obtained was always positive values as illustrated at Fig. 9. Therefore, it may be performed a calibration. Thus, provided the average difference between the measured and calculated distances (2.92cm) and subtracted this value of calculated distance. The result is also shown in Fig. 9. It can be seen clearly that difference is reduced considerably, showing a measurement system much more precise.

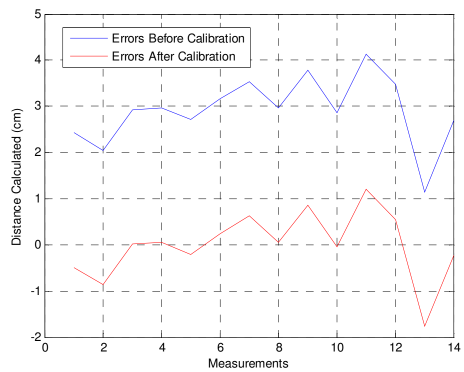


Figure 9. Errors between the distances measured and real (before and after calibration)

One of the main tasks into a navigation system is to determine the location of the robot, or its position and angle of direction which may be determined by a method of odometry. As illustrated in Fig. 10, the robot has two-wheeled placed on the sides of which are individually driven by two independent motors (differential drive) (Bezerra, 2004). To determine the location it is necessary to obtain the position of its central point (x, y) and reference angle θ, knowing that: L is the length of the shaft, r_e, r_d are the radius of the left and right wheels, ω_e, ω_d are the angular velocity of left and right wheels, υ_e, υ_d are the linear velocity of the wheels, υ is the linear velocity of the robot and ω is the angular velocity of the robot.

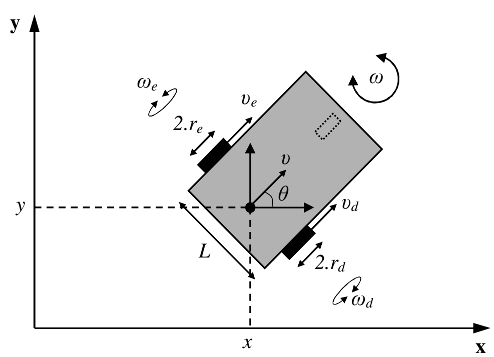


Figure 10. Robot with differential motor drive

For the robotic platform presented, the odometry system consists by speed sensors installed in each of the motors, which can measure the corresponding rotations of the wheel. The sensors used in the project detect magnetic fixed points on the wheels producing pulses. Basically, the frequency of the voltage of the output signal is proportional to rotational velocity of the wheel. So, using kinematic parameters of the robot and its original position is possible to determine the equations that will determine its position and orientation in a given moment (Bezerra, 2004).

The speed control of motors are adjusted by parameters of PWM ("*Pulse Width Modulation*") used at microcontroller programming, by means of an 8-bit register where 0 (100%) mean maximum velocity and 255 (0%) means that the motor is stopped. The PWM is basically a DC square wave with fixed amplitude and high frequency. The average voltage obtained is proportional to the time that the wave is at high level (Vcc).

To improve the performance of the system and ensure a speed control with accuracy, one better solution is to control the speed of motors using a closed loop PID (Assis *et al.*, 2007). However, due the limitations of the system is proposed a simpler but less efficient solution using an algorithm for the compensation of speed where the parameters of adjustment and calibration were scaled through the tests made in the system.

7. RESULTS OBTAINED

The operation of the system including RF communication, obstacles detection and odometry can be summarized as explained below.

After started system, the PC receives the data sensors transmitted by robot. The information received is presented on HMI interface in PC. So, the system awaits a new decision from the user, as for example, an order for the robot performs a movement. After this order, the data are transmitted by microcontroller on HMI circuit where they are encrypted and transmitted to robot. On the robot, the microcontroller processes and decodes the information received, triggering the sensors to speed and obstacle measurement, as well as the power circuit, so that it can provide enough energy to drive the motors. And so, this cycle is repeated continuously.

The Fig. 11 shows the screen of the software developed to make the remote control of robot and show the results. The software presents the following modules: serial communication setup, parameters set of robot, control of motors, reading of ultrasonic sensor and graphical interface for representation of the path travelled by the robot. Furthermore it is possible to observe the time elapsed between the command sent and the equivalent response in the robot.

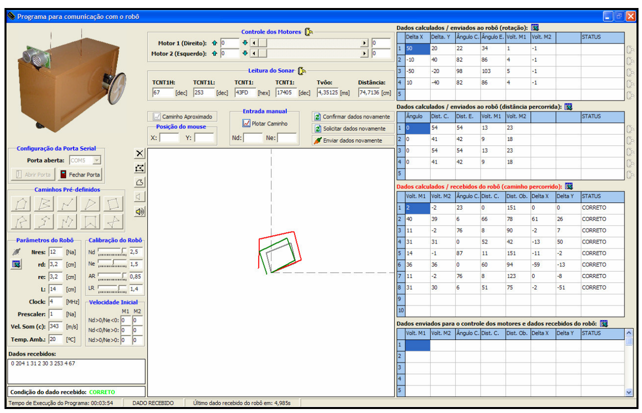
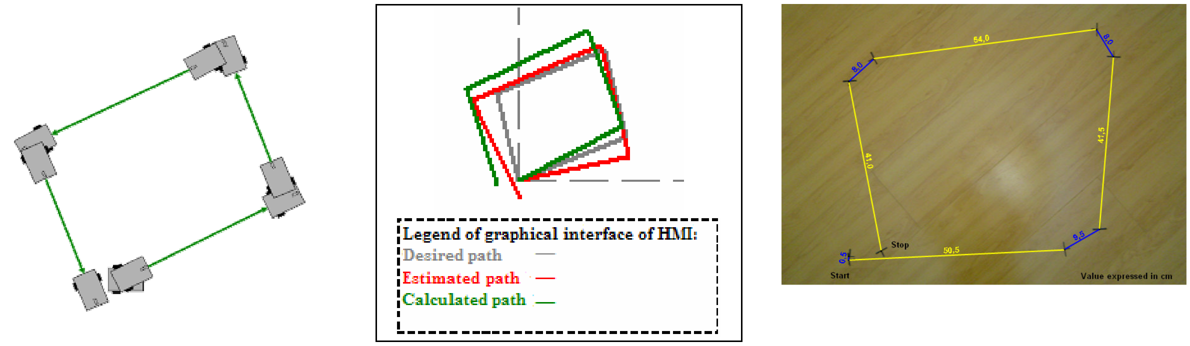


Figure 11. Screen of human-machine interface (HMI) program

To evaluate the efficiency of mapping system were used the graphic interface designed in PC to show the path travelled by the robot. For this, were conducted several testes and the results of one of them are shown in Tab. 2 and Fig. 12. The Fig. 12(a) illustrates an image of the desired path. The Fig. 12(b) presents the graphical interface of HMI showing the desired path, estimated and real path traveled by the robot. The Fig. 12(c) illustrates the real route of robot (lines in yellow and blue).

Table 1. Trajectory of robot – Results of tests of the mapping system

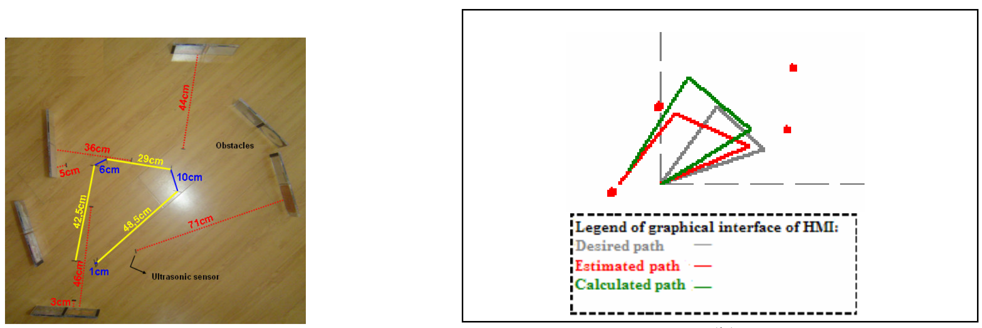
Step	Distance and angle desired and transmitted by PC (Desired path)	Distance and angle calculated on PC using data transmitted by sensors (Estimated path)	Distance and angle actual measured (Real path)
1	0 cm / 22°	0 cm / 12°	0,5 cm / 23°
2	54 cm / 0°	52 cm / 0°	50,5 cm / 0°
3	0 cm / 82°	9 cm / 93°	9,5 cm / 89°
4	40cm / 0°	44 cm / 12°	41,5 cm / 0°
5	0 cm / 98°	8 cm / 86°	8 cm / 89°
6	54 cm / 0°	55 cm / 25°	54 cm / 28°
7	0 cm / 82°	8 cm / 68°	8 cm / 60°
8	40cm / 0°	42 cm / 25°	41 cm / 29°



(a) (b) (c)

Figure 12. Trajectory of robot (a) Desired path (b) Trajectory estimated by HMI (c) Real trajectory

The Fig. 13(a) illustrates a image of the path traveled by the robot (lines in yellow and blue) and the distances of obstacles in front of robot referred to the point of ultrasonic sensor (lines in red). The Fig. 12(b) illustrates the route estimated in the HMI. The points in red indicate obstacles identified.



(a) (b)

Figure 13. Trajectory of robot with detection of obstacles
(a) Measurements of robot positions and obstacle detection at trajectory (b) Graphical interface of HMI

7. RESULTS AND FINAL COMMENTS

This work presented a radio frequency communication protocol used to allow the communication between a robot and a human-machine interface. To evaluate the performance of robotic system were developed several tests analyzing separately the operation of each stage in the communication process. There was a considerable improvement in the quality of data transmitted resulting in a much better performance than the obtained without the use of the protocol proposed.

The main features of protocol developed are: use of data encrypting technique primarily responsible for the minimization of errors and interference produced during the RF communication; detection of error of format produced during the communication process using the computer's serial port, and development of methodology for correction of these errors; logic of programming with "checksum" in communication between the circuit and interface that allows to robot detect failures in communication; logic of computer programming that allows ask to robot send back the last data transmitted for to confirm or correct them when for some reason, the standardized format in the protocol was not detected. The performance of system was evaluated in an environment free of interference, with distance of 3m between the robot and computer resulting in effective communication and remote control of robot by computer, detection of obstacles and measurements of real trajectory.

The structure of the robot and the system of communication with computer implemented resulted in a simple, flexible and low cost solution, but allowing data transfer with quality using sensors installed in the robot, as well directly to control the movement of the robot through commands made at computer.

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