WIRELESS CONTROL OF MOBILE ROBOTS

Dragos Mihai POSTELNICESCU[1], Constantin NEGRESCU[2]

Articolul prezintă o soluţie de control wireless a vehiculelor autonome realizată experimental. Particularitatea soluţiei constă în utilizarea unui Access Point îmbarcat pe vehicul care asigură transmiterea comenzilor date de utilizator de la tastatura unui calculator personal prin intermediul unui API, precum si recepţia informaţiilor furnizate de senzorii amplasati pe robotul mobil. Setul de senzori ofera informaţii proprioceptive (referitoare la poziţia, orientarea si viteza vehiculului la care se adaugă si informaţia de bună funcţionare) si exteroceptive (referitoare la mediul înconjurător) de o manieră avantajoasă oferind perspective pentru realizarea fuziunii senzoriale.

The article presents an experimental realized solution for the wireless control of the autonomous vehicles. The specific feature of the solution consists in using an access point embarked on the vehicle, which provides the transmission of the commands given by the user from a keyboard connected to a personal computer, using API, as well as the reception of the information supplied by the sensors placed on the mobile robot. The set of sensors offers proprioceptive information (reference to the position, orientation and the speed of the vehicle, to which it is also added the information relative to the good functioning) and exteroceptive information (reference to the environment) in an advantageous manner, giving the perspectives for the realization of the sensorial fusion.

Keywords: mobile robots, wireless cards, remote control

1. Introduction

This article endeavors a presentation of a relatively new concept in the mobile radio communications ([1], [3]). The efforts were targeted to create a cross-breed in wireless mobile communications consisting in the implementation of a type 802.11g wireless communication on a mobile robot.

[1] Eng., PhD Student, Dept.of Control Engineering Industrial Informatics, University Politehnica of Bucharest, Romania, E-mail:daragoshi@yahoo.com
[2] Eng., PhD Student, Dept.of Control Engineering Industrial Informatics, University Politehnica of Bucharest, Romania, E-mail:negrescu55@yahoo.com

WLAN (Wireless Local Area Network), standard 802.11g in our case, (see Table 1) represents a rather original method in average range radio communications. The use of this radio digital transmission is more or less assigned to computers in LAN (Local Area Network), WAN (Wide Area Network) or MAN (Metropolitan Area Network) data transmissions.

The implementation on the mobile robot consists in a TrendNET access point, model TEW-431BRP shown in Fig.1, easy to implement and to adapt to the robot existing power sources. The functions required for this application can also be easily programmed.

A wireless card (any type) is installed in the PC and is assigned a static IP from the same subnet as the access point IP on the mobile robot. An additional programme emulating a virtual serial port is installed, so that the data transmitted and received by the software installed on the PC (as graphic interface with the user) and being sent / received on this virtual serial port are automatically sealed through a tunnel into the existing TCP/IP connection between PC and the mobile robot.

The implementation of this technology onto a mobile robot is somehow difficult. Our mobile robot, for instance, includes two microcontrollers which secure its operation. The first is used as a controller for the movement motor, direction servomotor, debug display LEDs, while the second is used as controller for reading the telemetry data from the sensors located on the mobile robot, as control master for the first microcontroller. The most significant function of the second controller is the interface PC – mobile robot, used to send the data collected from the sensors on the robot while on the receiver side, it receives all controls coming from the PC.

The interface on the robot between the microcontroller serial port and the access point (meaning between the serial communication RS232 and WLAN) is obtained through the converter module EM100, which includes an ethernet port with static IP address and a programmable serial port. This EM100 module operates in tandem with the serial port software installed on the PC.

2. Mobile Radio Networks and WLAN Standards

The market offers a large number of radio digital communication standards at this moment, as shown in the table below, however in our opinion the standard 802.11 g offers the most significant advantages combined with a relatively easy implementation.

Comparative table between different wireless standards

Table 1

Criterion	802.11b	802.11g	802.11a	802.11n draft	802.16 (WIMAX)	GSM (GPRS,UMTS)	Bluetooth
Maximum Operation Area (theoretical)	550 m/ 55m	300m/ 30m	500m / 50m	800m / 80m	5Km - 100Km according to standard	20Km-30Km	100m / 10m
Transfer Rate (maximum / real)	11 Mbps / 4-6 Mbps	54 Mbps / 25-30 Mbps	54 Mbps / 25-30 Mbps	300 Mbps / 30 Mbps	According to implementation 15-150Mbps	According to operator and coverage: 6-144 Kbps	According to manufacturer and standard 115-1000 Kbps
Frequency Band	2.4 GHz	2.4 GHz	5 GHz	2.4 GHz	0.7-66 GHz	0.8, 0.9,1.8, 1.9, 2 GHz	2.4 GHz
Mobility	Low up to 10Km/h					Higher	Low up to 10Km/ h
Advantages	Easy adaptability to hardware, easy programming				Large communication distance	Almost global coverage, low energy consumption	Low energy consumption, relatively high communication speed
Disadvantages	Low communi cation speed	---------		High energy consumption		High costs /minute, or for sent data when used frequently	Small distance, high interference

Standard 802.11a, working on a frequency of 5 GHz, where the radio spectrum is also considerably free, has similar advantages with standard 802.11g. The major disadvantage of standard 802.11a, as well as of standard 802.11n draft, is that the energy consumption of the access point is almost twice as high as that of standard 802.11g. As for GSM and BlueTooth technologies, their disadvantages clearly consist in the transfer speed and costs, radio coverage respectively, not to mention the implementation of certain software transmission protocols on the microcontrollers and the software on the PC.

Future implementation of WiMAX 802.16 equipments might stand as a good idea if the energy consumption would compare positively to 802.11g (on implementation on the mobile robot).

3. WLAN Structure

As already mentioned, digital radio communication between the mobile robot and PC is made, in this application, through the standard 802.11g. The hardware components, used on the PC, consist of a radio card (any type), operational on the 2.4 GHz range of the standard 802.11g, in tandem with an access point model TEW-431BRP from TrendNET, also operational in the 2.4 GHz range of standard 802.11g.

In Fig. 1 is shown the board of the access point:

Fig.1 - TEW-431BRP – Very good coverage, stable signal, low energy consumption

The AP is programmed only once, using the PC, the subsequent radio connection and the communication between the network card installed on the PC and the AP on the mobile robot running automatically, without any interference of the operator, as long as both are located in the same coverage area.

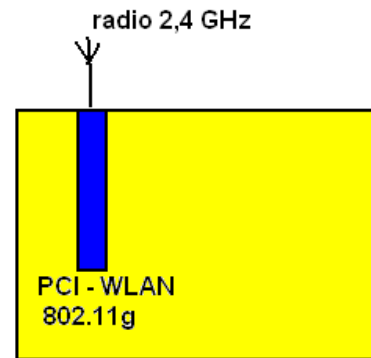## 4. Communication Diagram between PC – Mobile Robot (ROV)

In Fig. 2 is shown the radio communication diagram between the PC and the mobile robot:
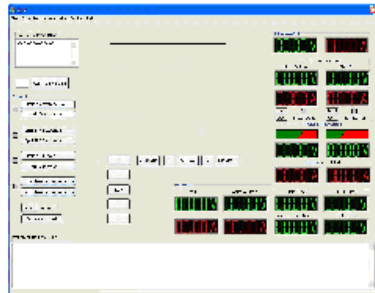
Fig. 2 - Software + PC Hardware

Above diagram presents the PC which includes the radio network card on the standard 802.11g, together with the graphic interface with the user. Given the radio solution adopted, the communication between the PC and the mobile robot is full duplex.

In Fig.3, the following operational modules can be identified on the mobile robot:
- Access Point TEW-431BRP
- Module EM100
- IP Video Camera
- Power sources and battery chargers
- Microcontrollers and relative circuits
- Control part for motor and servomotor drives
- LEDs and debug displays

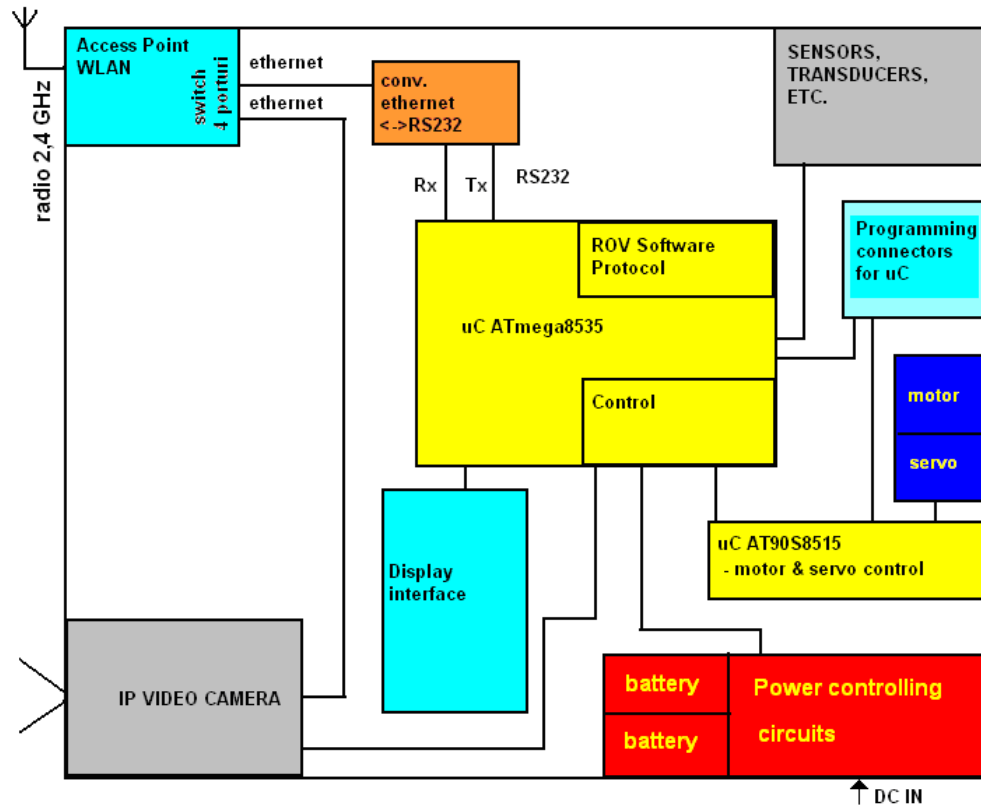Remark: Drives and power supply part to be presented in a future article.

Fig. 3 - Mobil Robot Diagram - ROV

The interconnection between the IP Video Camera and the EM100 module is made through the Ethernet ports of the Access Point. Therefore, the transfer of TCP/IP packets between the 802.11g radio interface, IP Video Camera and the EM100 module is transparent.

According to TCP/IP standard, the following IP addresses from the same network segment have been selected for:
-   IP for the Access Point: 192.168.200.189
-   IP for the Video Camera: 192.168.200.188
-   IP for the EM100 module: 192.168.200.187
-   IP address for the PC: 192.168.200.1 to 192.168.200.254 can be selected. It can alternatively be adopted a DHCP solution which allows automatic assignment of IP by the Access Point.

Images taken by the video camera at 25 fps and at a resolution of 352x288 pixels are transparently sent to the user through the radio connection to the software installed on the PC. This transmission does not require a band larger than 500Kbps, which fits very well into the band limits of the 802.11g standard.

The module EM100 does not require a complicated programming. It simply requires an IP assignment and a minimal and intuitive programming with the help of the PC software (accompanying the module), the connection to one of the AP ethernet ports and the connection to the microcontroller serial port. The traffic generated by this component does not exceed 200 Kbps.

5. Functions Available by the Adopted Solution

The primary advantage is the possibility to use an IP camera. The solution eliminates the requirement for additional video digital - analogue converter or analogue video transmitter. Advantages do not end here, as the solution allows use of 2, 3 or 4 video cameras until full use of the AP bandwidth. The only disadvantage presented is the slightly larger overall size of an IP video camera and the rather high power consumption: 5 Vcc / 1.5 A.

Speaking of the data transmission from the mobile robot, it is also worth noting the significant quantity of information which can be sent from the robot sensors:
- Voltage
- Currents
- US sensors
- IR sensors
- Transducers, etc.

Following example illustrates our statements:
Most of the sensors implemented on this robot are voltage and current sensors. There are 24 measuring points for voltage and current which contribute to the good operation of the robot, avoiding occurrence of over currents, short-circuits and assisting in sampling the telemetry data which are then sent to the computer, for subsequent display and information of the user.

Measuring of the 24 voltage points is made automatically, by means of 3 analogical multiplexers type 74HC(T)4051,[6] the microcontroller Atmega8535, outfitted with 10 bits analogue-digital converter. The microcontroller cannot read analogue voltages higher than 5 Vcc, his internal construction not allowing its supply at voltages higher than 5 Vc.c.

Use has been therefore made of voltage dividers (see Fig.4) with two serial connected resistances which can divide voltages higher than 5 Vcc by 3, 4, 5 or 10 times. The resistances should be top quality, having a metal film with errors of maximum 1% so as to give accurate voltage readings, with minimum errors, unaffected by more than 1% by the ambient temperature variations or the heat delivered by the other circuits.
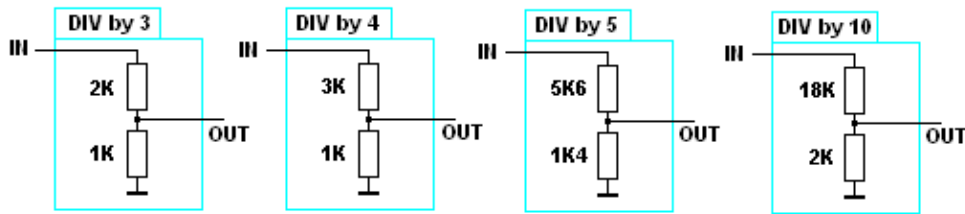
Fig. 4 – Voltage divisors

Multiplexing of readings is made automatically by the microcontroller. The analogue channel from 0 to 7 of a multiplexer 74HC(T)4051 is first selected by means of a 3 bits word, the selection of one of the three multiplexers 74HC(T)4051 being subsequently made by validating one of three analogue reading inputs of the microcontroller.

As this integrated circuit is supplied at 5 Vcc the voltage, the dividers mentioned above are fitted on the diagram before this integrated circuit.

In Fig.5 is shown the block diagram of the communication and main control circuit:
- Interface with analogue multiplexers
- Interface with voltage control card
- uC programming connector
- Interface with module EM100 – which is responsible for the conversion TTL / 802.11, programmable with IP address and which can be contacted from the PC, via the user interface installed on the PC, by means of Access Point on the ROV.
- Control LEDs
- Two digit display interface for debug
- uC AT90S8515 interface – responsible for traction and servo-direction control
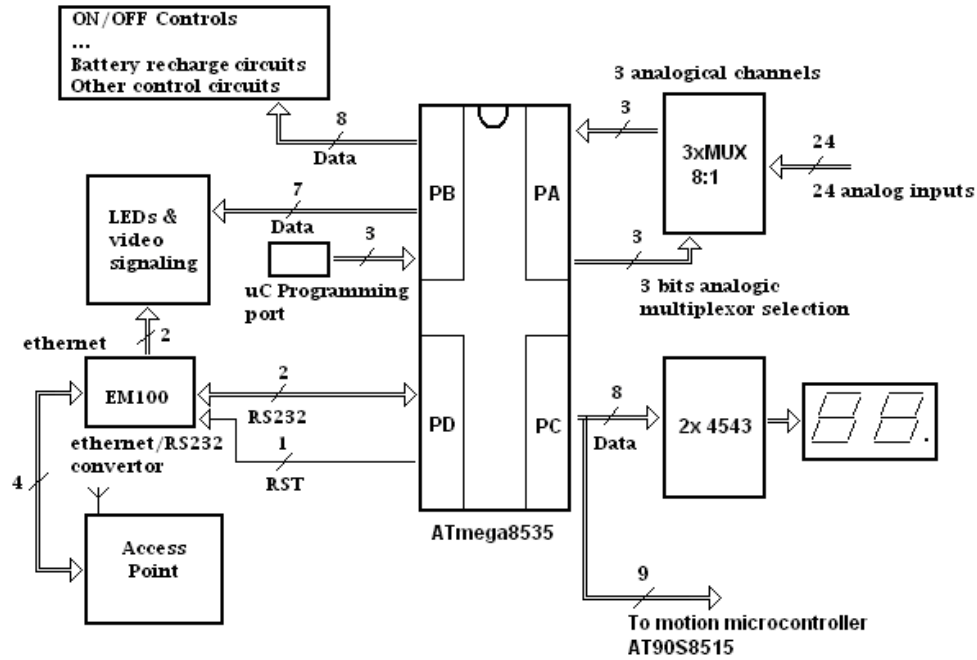- Independent, stable 5 Vcc source for the analogue/digital conversion

Fig. 5 – Block diagram for main controller on ROV

Below is detailed the analogue part of the microcontroller which includes the analogue-digital conversion:

- The resolution of the analogue-digital conversion is on 10 bits
- Nonlinearity error 0.5 LSB
- Conversion error ±2 LSB
- Conversion time 65 – 260 μs
- 6 multiplexed analogue inputs with common ground
- Input analogue voltages 0 – 5Vcc
- Continuous or ordered analogue-digital conversion
- Internal interrupt on completion of conversion

ATmega8535 [2] uses an analogue-digital conversion with successive approximations. Input pins are located on port A. Memory and sampling circuits are used inside to maintain analogical voltage constant during the conversion. Present application uses for analogue inputs only pins 0, 1 and 2 of port A, remaining pins 5, 6 and 7 being used for the control of multiplexers.

The conversion minimum value is a voltage equal to GND, while the maximum value is the voltage on pin AREF (5 Vcc in our case) minus 1 LSB. The voltage reference on pin AREF should be externally disconnected with a

condenser of minimum 100nF in order to increase immunity to noise. The internal selection of the analogue channel read (PAO, PA1 or PA2) is made by means of an internal multiplexer by writing a 3 bits word in the ADMUX register. The converter is started by writing a logical 1 in the register ADEN. The 10 bits result is present in two register ADCH and ADCL.

Data thus obtained from the analogue sensors are encapsulated by means of a software protocol in the microcontroller and then sent for further analysis and display on the PC display.

6. Programming of uC Atmega8535 Ports

Port PA

Port PA is entirely assigned to the A/D conversion of analyzed voltages. The configuration of PA0-PA2 port pins, as inputs to three distinct converters of A/D analogue voltages supplied by three analogue multiplexers 8:1, as well as the configuration of PA5-PA7 port pins as selection outputs of the 8 multiplexer channels create the possibility of conversion of 24 analogue voltages.

S2	S1	S0	---	-----	An-C	An-B	An-A
PA7	PA6	PA5	PA4	PA3	PA2	PA1	PA0

An-A, An-B, An-C – analogue inputs supplied by Multiplexers (Mux) A, B and C.
S0, S1, S3 – selection bits for the 8 voltage inputs channels

The system converts 19 analogue voltages which are balanced. Significance, value range and remarks are entered in the paragraph concerning the voltage sources.

Port PB

SCK	MISO	MOSI	IRF P/O	RELEU	IRF P/O	RELEU	IRF P/O
PB7	PB6	PB5	PB4	PB3	PB2	PB1	PB0

SCK, MISO, MOSI – uC Atmega8535 programming inputs / outputs
IRF P/O – IRF on / off controls (drives)
RELEU – RELAYS on / off controls (drives)

Port PC

D7	D6	D5	D4	D3	D2	D1	D0
PC7	PC6	PC5	PC4	PC3	PC2	PC1	PC0

D0...D7 – 8 bits Parallel Data Transfer to uC drives and debug display

Port D

/INT	IRF P/O	TTL ShutDown	CONV ADC	RST-EM	Com. Source	TXD	RXD
PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0

/INT - /Strobe for uC AT90S8515 drives

IRF P/O – IRF on / off controls (drives)

TTL Shutdown – Emergency shutdown of movement motor power supply (drives)

CONV ADC – Control of Blue LED signaling Analogue / Digital conversion (debug)

RST-EM – Automatic RESET of module EM100

Com. Source – P/O Commutation Source for IP Video Camera and Access Point supply

TXD – RS232 data transmission from uC to PC

RXD – RS232 data reception from PC

7. Securing Power Autonomy of Communication Devices

One of the greatest issues the mobile robots are confronted with is the autonomy. Our robot is fitted with two chargeable batteries, the first supplying the sensor part, the modem, the EM100 module, access point and the video camera and the second supplying the robot driving part.

In Fig.6 is shown the control circuit for recharging the batteries, the disconnection of the batteries from the modules they supply during recharging process and the voltage sensors which constantly monitor the smooth operation of the circuit.

NiMh rechargeable batteries with capacity between 2500mAh and 3500mAh have been selected. These rechargeable batteries offer life duration of 45-60 minutes under an extensive use of the robot. The PC warns the user when the batteries are almost completely discharged. The batteries are recharged from the external source which secures three separate voltages for the mobile robot:

- Recharging of drives supply batteries
- Recharging of electronic part batteries
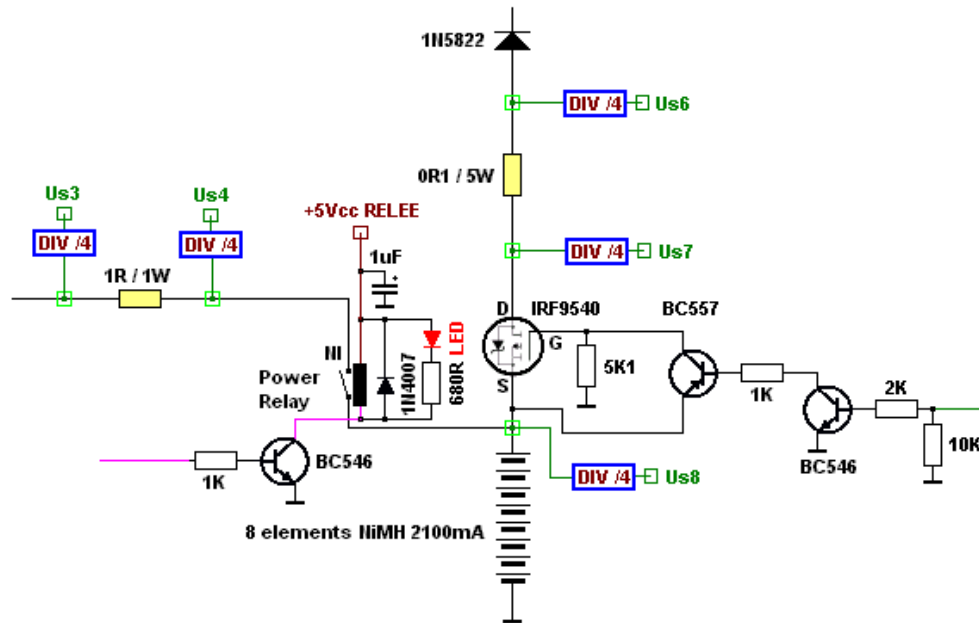- Back-up source for the further operation of the robot, with space movement restrictions

Fig. 6 – Recharging & control circuit

8. Conclusions

For the completion of this mobile robot, it was necessarily to test the individual circuits, sensors, radio etc. before assembling them into the final project. The serial connections between the two microcontrollers was first simulated on PC, and then tested by connecting them.

The robot is very useful in didactic purposes, in the lab for showing students the different circuits that can interoperate inside a robot and also the possibility of remote controlling a robot.

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