http://dx.doi.org/10.15202/25254146.2017v2n1p36

A PROTOTYPE OF A ROBOTIC RESEARCH FACILITY FOR NUCLEAR APPLICATIONS

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ABSTRACT

This work presents the development of the prototype of a robotic nuclear monitoring facility aimed to support technological and scientific research. It is a terrestrial robot in which nuclear and conventional instrumentation are available and easy-to-use through a user-friendly library for Python programming. The facility may be teleoperated (by mobile devices, notebook or desktop) or operate in autonomous mode, in which a user-defined program run on robot CPU.

Keywords: Autonomous robot; Nuclear; Python programming

1 Introduction

Currently, robotics has been successfully used in unsanitary and inhospitable environments exploration, such as: space (Katz & Some, 2003), volcanic (Muscato et al, 2003), submarine [Bingham et al, 2010), caves (Morris et al, 2006), etc. Other not less important use of robots is to substitute humans in risky situations that may affect their physical integrity, such as environment subject to chemical or nuclear exposure.

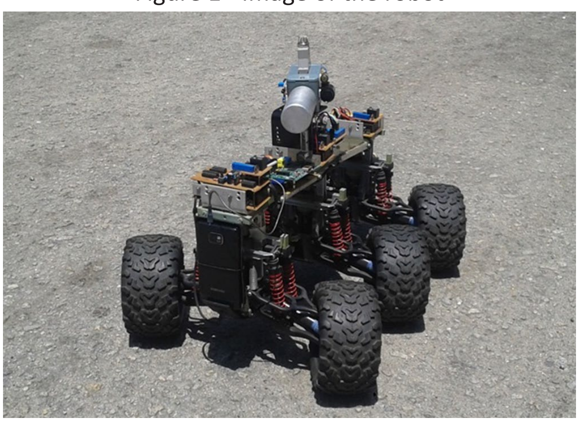
Despite the great diversity of robots available, there are few nuclear plants using them on tasks which present great risk to their professionals, as detections of leaks, inspections and routine measurements of radioactive environments and nuclear waste deposits.

Even during normal operation, a nuclear power plant (NPP) requires some repairs and regular maintenance that involve risks of irradiation and contamination of workers. In order to protect workers in NPP, all countries have laws and regulations that establish the dose limits per year. This situation requires specialized professionals in constant training, a wide range of personal protective equipment, various systems and equipment involving the collective safety of the working environment. The use of robot inspection and detection, not only decrease costs (specialized professionals, equipments and systems), it would also increase individual protection, avoiding human exposure to unnecessary or prolonged irradiation.

Currently there are several robotic prototypes being applied in the nuclear field, such as: wall climber inspection robots (Briones L.; Bustamante P.; and Serna M. A., 1994), the Robug IIS (Luk B. L. et al, 2005), which is a robotic vehicle on legs to overcome obstacles in more complex terrain, Robot Snake (Buckingham R., Graham A., 2005), used to make repairs on nuclear pipes, Korean robots Kaerot (Kim S., et al, 2010), used for inspection and detection in nuclear plants, underwater robots (Nawaz S. et al, 2009) to inspection and detection of nuclear waste, and the robotic vehicle called EQUIPA NIPPON (Ohno K. et al, 2011), designed to measure radiation at the Fukushima Daiichi Nuclear Power Plant, developed by the Japan Atomic Energy Agency (JAEA), Tohoku University, and Tokyo Electric Power Company (TEPCO).

This paper presents the development of the prototype of a robotic facility aimed to support technological and scientific research related to application of robots in nuclear field. The facility is a terrestrial vehicle designed to make inspection, nuclear detection and monitoring in industrial environments subject to radiation, such as NPP and nuclear waste deposits. The robot presents nuclear (detector) and conventional (temperature, infra-red and some gases) instrumentation and can be teleoperated by mobile devices (cell phones, smartphones, tablets, notebooks) and desktop computers, or may be programmed to operate in autonomous mode. In this case, a user-friendly Python library is available to user. An image of the developed prototype is shown in Figure 1.

Figure 1 - Image of the robot

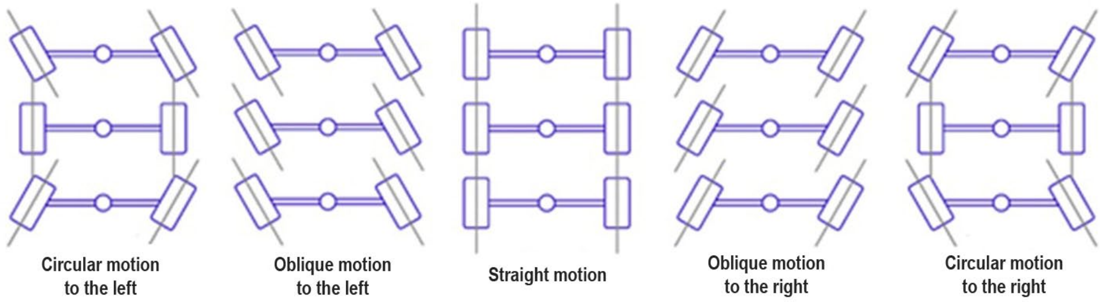


2 HARDWARE

2.1 Robots moving system

The need for transposing obstacles such as stairs, steps and construction debris driven to the choice of a 6x6 wheels platform, which uses a triple double suspension system “A” in order to increase the points of support to the ground, optimize traction and add more balance to the system. Each pair of wheels is designed to develop independent directional movements. So the fact that it has six wheels generates a huge diversity of movements, providing a key resource in the degree of maneuverability of the robotic system. Figure 2 shows the types of movements performed by the robot.

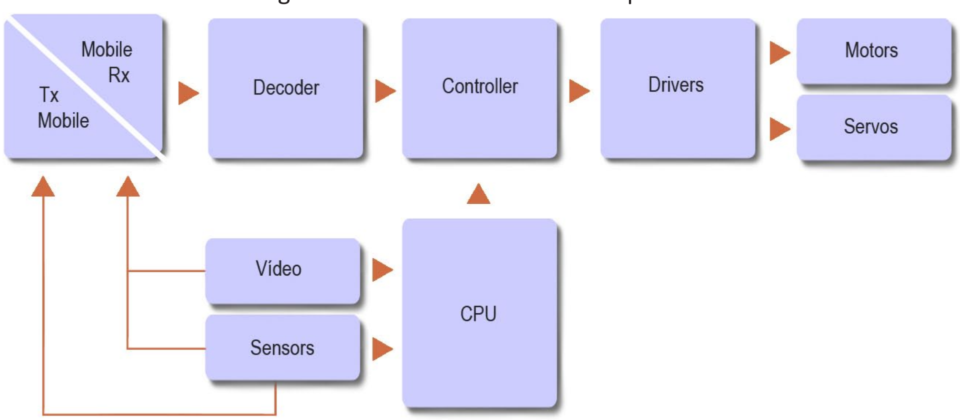
Figure 2 - Wheel movements



2.2 Data Transmission and Reception

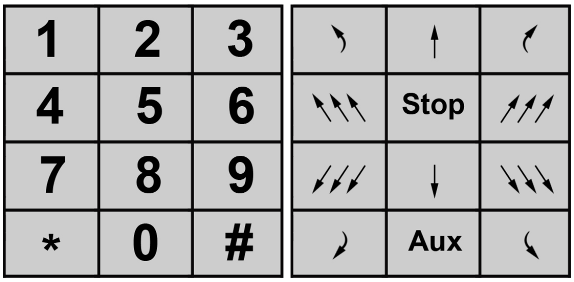
In order to allow teleoperation from extremely long distances, providing a secure control, as well as the advantages of interchangeability, modularity, small size and low power consumption, a mobile phone has been chosen as the communication device. The block diagram in Figure 3 shows an overview of the robot operation and data communication.

Figure 3 - overview of the Robot operation



All communication robot is performed by DTMF commands, whether to transmit data or to receive control information. The DTMF standard was chosen to be available on all mobile devices and computers. Figure 4 shows the correlation of function keys for each teleoperated robot motion mode.

Figure 4 - functions of the keys

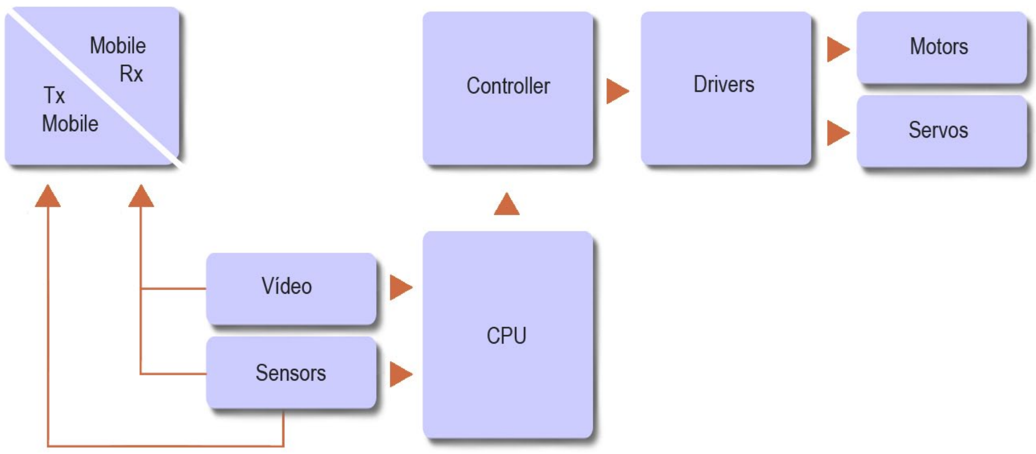


Once received the DTMF control signal, it is decoded and control driver activates the traction motors and wheel control servomotors according to the requested function. The diagram in Figure 5 shows the pathway taken by the signal reception.

Figure 5 - Data reception robot control

In autonomous mode, the robot receives control information from the CPU, which selects which motors and servomotors should be triggered due to its internal programming, which is based on sensor readings. This CPU is also responsible for handling and sending sensor information to the remote supervisory system (operator) Figure 6 shows the pathway followed by the transmission signal.

Figure 6 - Data transmission



2.3 Correction of center of gravity

Stability while moving is very desirable in any robotic systems. In order to improve the assistance to the robot navigation, a smart suspension system based on fuzzy logic, which allows a constant correction of the center of gravity was developed. The diagram in Figure 7 shows the smart suspension control system.

Figure 7 - Smart Suspension Control System

2.4 Sensors

The robot has a pod of sensors located at the top, which has a rotational movement that provides a 360-degree sweep. This pod has a metallic structure where the flame sensors, IR radiation and hydrogen detectors are fixed. At their base there is a stepper motor with a reduction gearbox which provides the rotational movement of the entire structure. Tables 1 to 7 show basic specifications of the available sensors.

Table 1 - Temperature sensor

Type	Infrared thermometer
Range	-32 a 350ºC
Precision	±1,5ºC
Resolution	0,1ºC
Response time	500mseg

Table 2 - Gas sensor

Type	Semiconductor Sensor
Detection Gas	CO and combustible gas
Concentration	10-1000ppm CO / 100-10000 ppm combustible gas
Sensitivity	Rs(in air)/Rs(100ppm CO)≥5
Slope	≤0.6(R300ppm/R100ppm CO)
Tem. Humidity	20℃±2℃; 65%±5%RH

Table 3 - Proximity sensor

Type	Retroreflective
Voltage min / max	2.7V - 6.2V
Range	2-10cm
Output	Digital
Size	21.6 mm × 10.4 mm × 8.9 mm
Weight	1.5 g

Table 4 - Luminosity sensor

Type	LDR - Light Dependent Resistor
Light Resistance at 10Lux (at 25°C)	8～20KΩ
Dark Resistance at 0 Lux	1.0MΩ(min)
Gamma value at 100-10 Lux	0.7
Power Dissipation (at 25°C)	100mW
Max Voltage (at 25°C)	150V
Spectral Response peak (at 25°C)	540nm
Ambient Temperature Range	-30～+70℃

Table 5 - Flame sensor

Type	Plastic silicon infrared phototransistor
Range	760 nm to 1100 nm
Angle of detection	60 graus
Derate power dissipation linearly (25°C)	1.33 mW/°C
Peak Sensitivity Wavelength	880 nm
Operating Temperature	-40 to +100 °C
Power Dissipation	100

Table 6 - Rotation sensor

Type	Encoder incremental
Operating voltage	4.5V to 5.5V
Digital outputs	2 channels (quadrature)
Current consumption at 5.0V	14 mA
Resolution	48 counts per revolution
Weight	1.6 g

Table 7 - Radiation sensor

Type	Scintillation counter
Operating voltage (discriminator/counter)	5.0V to 15V
Operating voltage (photomultiplier)	1000V
Digital outputs	square wave
Current consumption at 5.0V	250mA
Operating Range	0.01 to 1000 µSv/hr 0 to 5000 CPS
Weight	110g

3 Software

3.1 Basic Control Software

The robot basic control software runs on a PIC16F628A microcontroller and was developed using the MPLAB IDE 8.36 (Microchip) with MPASMWIN compiler assembler. The following routines are implemented:

- Decoding DTMF (Dual Tone Multi Frequency) for strings controller;
- Check the positions of the drive and servomotors wheel positioning motors;
- Check the positions of the suspension servomotors;
- Fuzzy control of intelligent correction of the center of gravity system.

3.2 A Simple Aplication Program Interface

In order to support the development of customized autonomous applications, a simple application program interface (ROBOT_LIB.PY) providing driver to all robots functionalities (control, communication, data acquisition, etc) have been developed using Python 2.7.12. The users program runs on a Raspberry processor PI B (the CPU represented in Figure 3). Table 8 presents a brief description of the available functions.

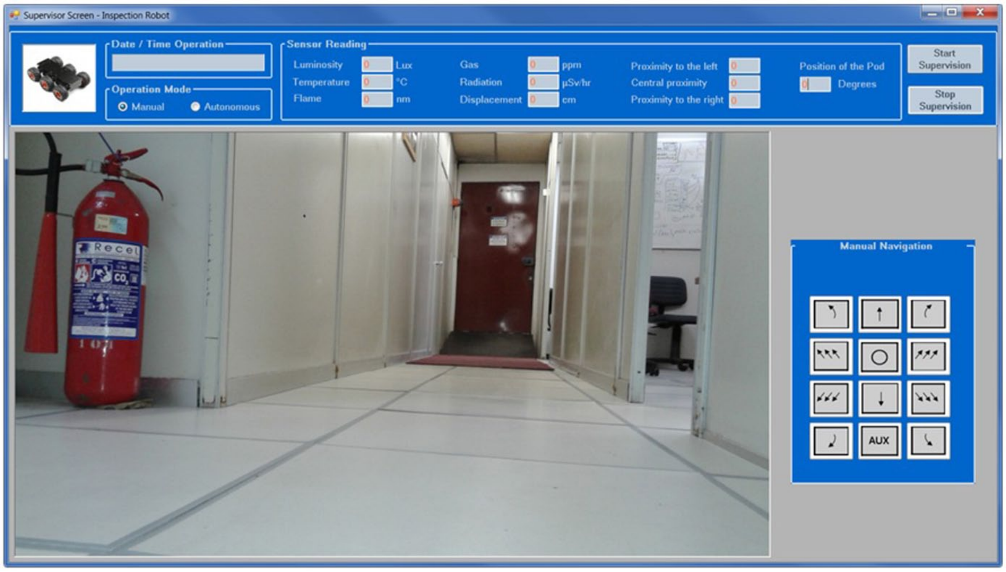
Table 8 - Robot_Lib Functions

Function Name	Description
move_forward	Move the robot forward continuously.
move_backward	Move the robot back continuously.
move_right_side_forward	Move the robot forward continuously and turning to the right.
move_left_side_forward	Move the robot forward continuously and turning left.
move_right_side_backward	Move the robot back continuously and turning to the right.
move_left_side_backward	Move the robot back continuously and turning left.
stop_move	Stop all movements of the robot.
move_right_oblique_forward	Move the robot forward obliquely right.
move_left_oblique_forward	Move the robot forward obliquely left.
move_right_oblique_backward	Move the robot back obliquely right way.
move_left_oblique_backward	Move the robot back obliquely to the left.
read_luminosity	Read luminosity sensor.
read_temperature	Read temperature sensor.
read_flame	Read flame sensor.
read_encoder	Read encoder.
read_gas	Read gas sensor.
read_radiation	Read radiation sensor.
read_ proximity	Read proximity sensors.
rotation_pod	Rotate the Pod.
transmission_data	Transmit data to the supervisory system.

3.3 Monitoring Software

In order to perform remote monitoring of the robot, it has been developed a monitoring software in Visual Basic.Net language, which is a simple supervisory system that provides visualization of reading values of embedded sensors, control and navigation of the robot. Figure 8 illustrate the monitoring software.

Figure 8 - Monitoring Software



4 Testing the Facility

4.1 Teleoperation

The robot has been successfully used to make some measurements in a nuclear waste deposit at Instituto de Engenharia Nuclear (Brasil). It has been teleoperated with aid of its frontal camera. Figure 9 illustrates the operators screen, showing the robot's sight and the monitored variables.

Figure 9 - Robot teleOperation

4.2 Overcoming obstacles

The ability of the robot in overcoming obstacles have been tested. Its 6x6 independent smart suspension allowed it to overcome obstacles with approximately the height of their wheels, as illustrated in Figure 10.

Figure 10 - ROBOT OVERCOMMING OBSTACLES

4.3 Programming for autonomous operation

A simple Python program has been written to automate the search for radiation sources. The robot is going to move forward until detecting some radiation level or to find an obstacle. If it find obstacle it will change direction according to the combination of proximity sensors. If it detects some radiation, it will measure directional dose rates and turn to the direction with greater intensity. Figure 11 shows the Python code using Robot_Lib.

Figure 11 - uSER PROGRAM FOR AUTONOMOUS OPERATION

```
import Robot_Lib
import time
PI = 3.14159
RADIATION_LIMIT = 100

def move_robot(robot):
   object_found = False
   robot_angle = measure_angle(robot)
   proximity = robot.read_proximity()
   radiation,maximal_radiation_direction = get_radiation_data(robot,robot_angle)
```

```
    if radiation > RADIATION_LIMIT:
        object_found = True
    while not object_found:
        if proximity in [3,6,7,2]:
            if proximity == 3:
                robot.move_left_side_forward()
            elif proximity == 6:
                robot.move_right_side_forward()
            elif proximity == 7 or proximity == 2:
                if robot_angle < maximal_radiation_direction:
                    robot.move_right_side_forward()
                else:
                    robot.move_left_side_forward()
            time.sleep(5.)
        else:
            if proximity == 5:
                pass
            elif proximity == 0:
                if robot_angle < maximal_radiation_direction:
                    robot.move_right_side_forward()
                    time.sleep(5.)
                else:
                    robot.move_left_side_forward()
                    time.sleep(5.)
            elif proximity == 1:
                if robot_angle < maximal_radiation_direction:
                    robot.move_left_side_forward()
                    time.sleep(5.)
                else:
                    pass
            elif proximity == 4:
                if robot_angle > maximal_radiation_direction:
                    robot.move_right_side_forward()
                    time.sleep(5.)
                else:
                    pass
            robot.move_forward()
            time.sleep(5.)
        robot.stop_move()
        proximity = robot.read_proximity()
        radiation,maximal_radiation_direction = get_radiation_data(robot,robot_angle)
        robot_angle = measure_angle(robot)
        if radiation > RADIATION_LIMIT:
            object_found = True

def get_radiation_data(robot,robot_angle):
    radiation = robot.read_radiation()
    angle = 0.
    for n in range(1,21):
        robot.rotation_pod(2*PI/20)
        new_radiation = robot.read_radiation()
        if new_radiation > radiation:
            radiation = new_radiation
            angle = 2*PI/20*n
    return (radiation,angle + robot_angle)
```

5 CONCLUSIONS

In this paper we describe the development and test of the prototype of a nuclear robotic system, aimed to be used as a research facility to investigate customized applications of robots in radioactive environments.

As the project is very recent and some details are yet to be finalized, until now, the robot has been tested in simple tasks.

In the first test, the robot was successfully teleoperated for radiation monitoring in a nuclear waste deposit. Another test verified the ability of its smart suspension using fuzzy control in aiding overcome some obstacles. And finally, a user program was developed to automate the search for radioactive source.

Tests have been motivating and the prototype is been continuously improved in order to support increasingly kinds of applications.

Future work includes: i) improve some electronic systems in order to achieve better robustness; ii) include some new feature, such as manipulators and other kinds of sensors; iii) development of a full scope simulator of the robot with a simple environment builder in order to test programs in a virtual manner before using the robot itself in autonomous tasks.

ACKNOWLEDGMENT

Cláudio M. N. A. Pereira and Roberto Schirru are sponsored by Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq.

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