

# Development of an in pipe inspection minirobot

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**Abstract.** In the first part of the paper, authors present a new in pipe inspection minirobot with wheeled adaptable structure for pipe diameters ranging from 220 to 380 mm. The mechanical structure is composed of three adaptable mechanisms placed at 120 degrees around the central axes. For adapting to the interior surface of the pipe, a passive method is used which utilizes elastic elements. In the second part of the paper, authors present the simulation of in pipe minirobot locomotion, components of driving and control systems, user interface, conclusions and future development areas.

## 1. Introduction

Rapid development of modern society accelerates the evolution of pipe transport systems such as drinkable water, gas, petrol, etc. This evolution led to the creation of many pipe networks and maintaining them is expensive due to their underground placement.

The difficulty in maintaining these pipes has led to beginning research finding alternative solutions for pipe inspection and maintenance. An attractive solution to this problem is represented by mobile robots adaptable to the work environment inside pipes that can inspect pipes with a minimum of effort and resources.

In this domain of mobile pipe inspection robots are a variety of constructive solutions [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]. These robots can perform different tasks in a variety of situations specific to the inspected environment. The ability to perform these tasks depends on information initially known about the work environment and information obtained during the task is performed.

Robots from this category usually have a flexible structure, are adapted to the work environment in which they perform, have high dexterity and high utility, being capable to work in difficult/hostile environments.

Depending on their relative position to the pipe, these pipe inspection robots can be classified in two categories: robots that inspect the outside of the pipes and robots that can inspect the inside of the pipes.

The in pipe inspection robots can be classified according to several criteria: locomotion system, mechanical structure adaptability, adapting method to the inner surface of pipes, structure arrangement, autonomy [2], [3], [7].

In previous papers [5], [6], [7] different constructive solutions of robots adaptable to the inside pipe diameter, have been presented. The proposed minirobot (named *IPMR-3* after the abbreviation for *In Pipe Inspection Mini Robot*) uses three new, identic mechanisms for adaption, six wheels for locomotion and three continuous current motors for driving. The adaptability to the pipe interior ranges between 220 and 380 millimeters.



The paper is structured as follows: in the first part the proposed in pipe inspection minirobot's structure is presented and the range of pipe diameters to which the robot can adapt is determined. In the second part of the paper is presented as follows: simulation of the in pipe minirobot, driving, transmission and control of the minirobot, user interface, conclusion and future development areas.

## 2. The minirobot structure

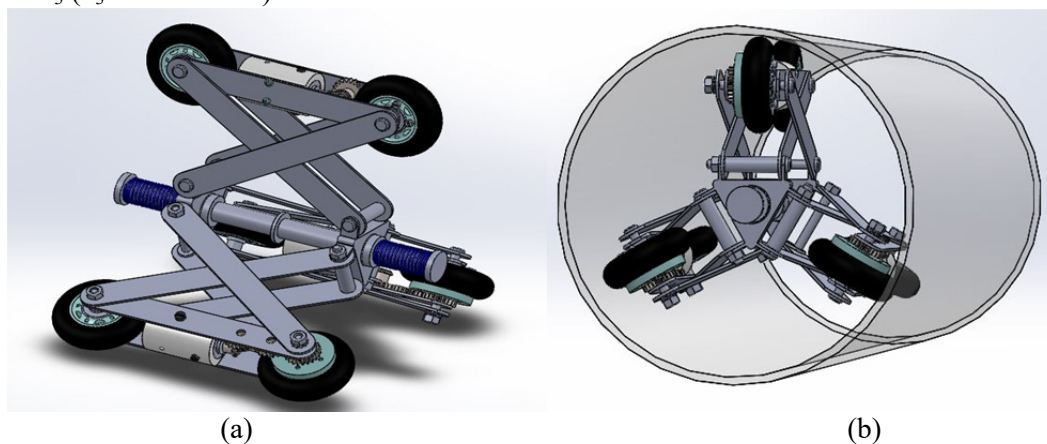
In [11] are shown diverse in pipe inspection robots with hybrid locomotion systems. These hybrid locomotion systems can be classified in three categories: caterpillar wall-pressed type, wheeled wall-pressed type and wheeled wall-pressing screw type [11].

IPMR-3 is an in pipe inspection minirobot which can be framed in the hybrid locomotion category of wheeled wall-pressed.

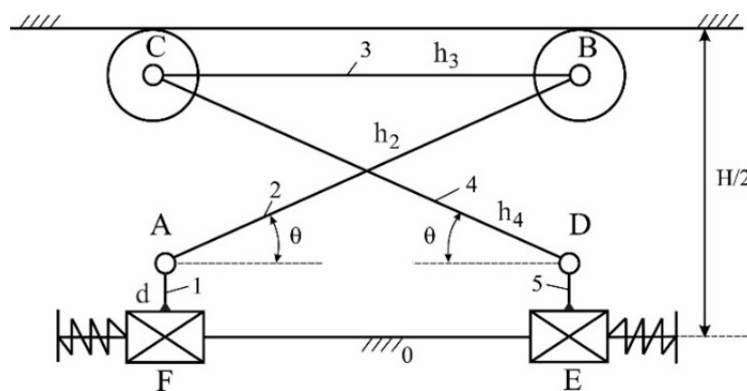
IPMR-3 is composed of three adaptable mechanisms, placed at 120 degrees around the central axes. Adapting to the interior surface of the pipe, a passive method is used which utilizes two preloaded elastic elements.

The minirobot's elements have lengths of:  $h_2 = h_4 = 160\text{mm}$ ,  $h_3 = 150\text{mm}$ , widths of  $20\text{mm}$ , thicknesses of  $2\text{mm}$  and the distance from A and D to the central axis is  $d = 26\text{mm}$ . The wheels are  $63\text{mm}$  in diameter and  $18\text{mm}$  in thickness (figure 2). The elements and the central shaft are fabricated out of stainless steel. The shaft is  $h_0 = 222\text{mm}$  long and  $15\text{mm}$  in diameter.

IPMR-3 is driven with the help of three continuous current motors placed on the elements with the length of  $h_3$  ( $h_3 = CB = C'B'$ ).



**Figure 1.** IPMR-3 modeled in SolidWorks: (a) outside and (b) inside the pipe.



**Figure 2.** Adaption mechanism from a plane of the IPMR-3.

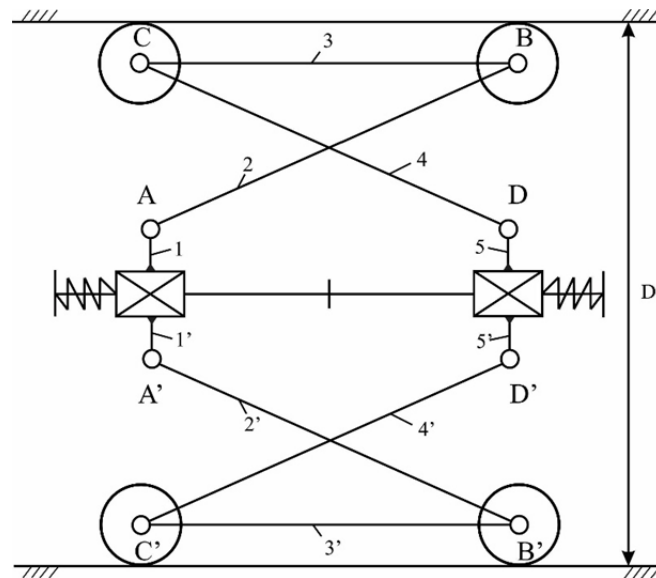
On the same element (which connects the drive wheel and the passive wheel (not driven) in a

minirobot's plane) the transmission from the c.c. motor to the drive wheel is placed.

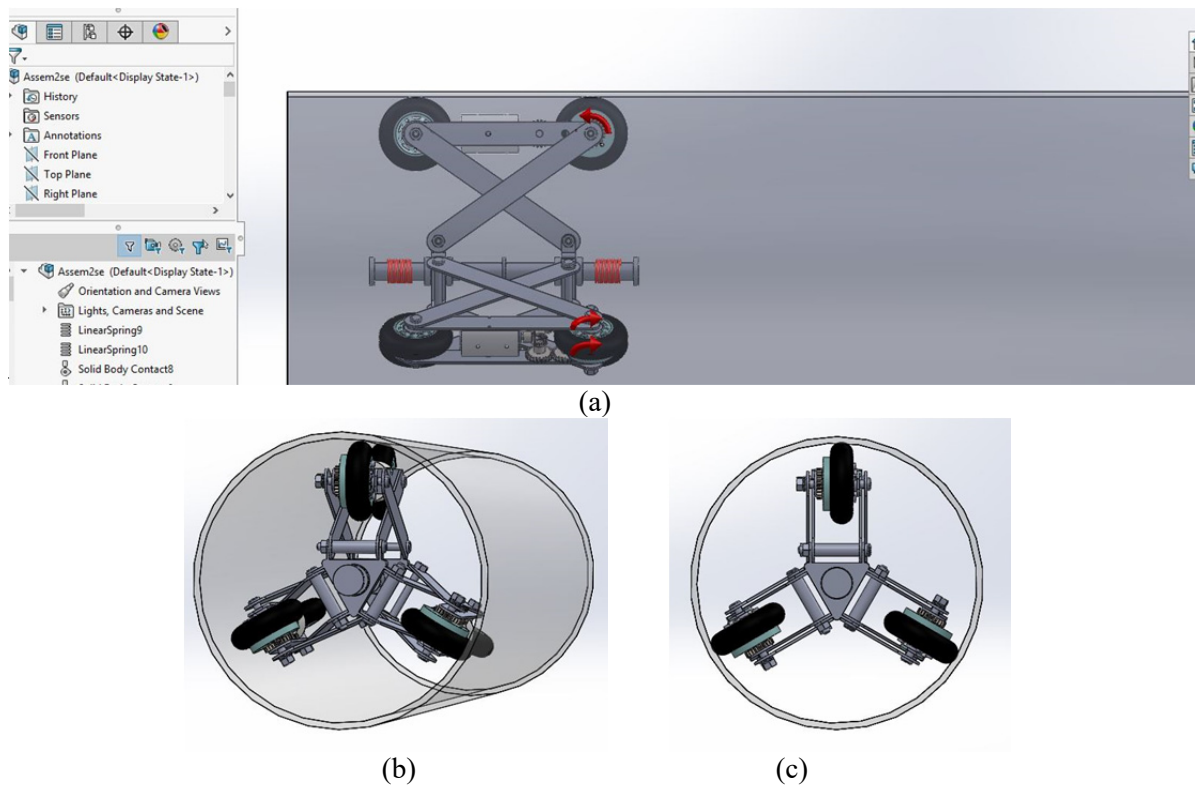
The proposed structure ensures the necessary pressure between wheels and pipe wall maintaining the minirobot's position in pipes. It can be used for inspecting pipes with diameters ranging between 220 and 380mm.

In figure 2 is presented the adaption mechanism from a plane of the IPMR-3.

IPMR - 3 in pipe simulation for 300 mm diameter is presented in the figure 4.



**Figure 3.** Adaption mechanism from a plane of the IPMR-3 in pipe.



**Figure 4.** Locomotion simulation in horizontal pipe with 300 mm diameter.

An important condition is that the two elastic elements used to have the same elastic constant and the movement of the two prismatic joint E and F to occur simultaneous with the same stroke and the minirobot vertical structure adaption.

Simultaneous movement of the two translation joint E and F can be accomplished through active adaption methods. In this regard the authors propose in the future to combine the two adaption methods (passive and active). Using active method, the normal force between wheels and pipe wall can be controlled.

The rotation of the IPMR-3 structure around the central shaft is not possible.

### 3. Minirobot height variation

The minirobot's height ( $H$ ) equal with the diameter of inspected pipes ( $D$ ) can be determined with the relation:

$$H(\theta) = 2r + 2d + 2h_2 \sin(\theta) \quad (1)$$

where  $r$  is the radius of the wheels and  $d = AF = 26$  mm.

The maximum and minimum height of the minirobot can be determined based on the angle  $\theta$ , ( $\theta \in 19^\circ \div 56^\circ$ ) and on the lengths of the elements  $h_2$ , with the relation:

$$H_{\min/\max} = 2r + 2d + h_2 \sin(\theta_{\max/\min}) \quad (2)$$

where  $\theta_{\min}$  and  $\theta_{\max}$  are the maximum and minimum limits of the angle  $\theta$ .

IPMR-3 height variation ( $H$ ) depending on the angle  $\theta$  is presented in figure 5.

IPMR-3 in 2 pipe diameters ( $D_{\min}$  and  $D_{\max}$ ) are shown in figure 6.

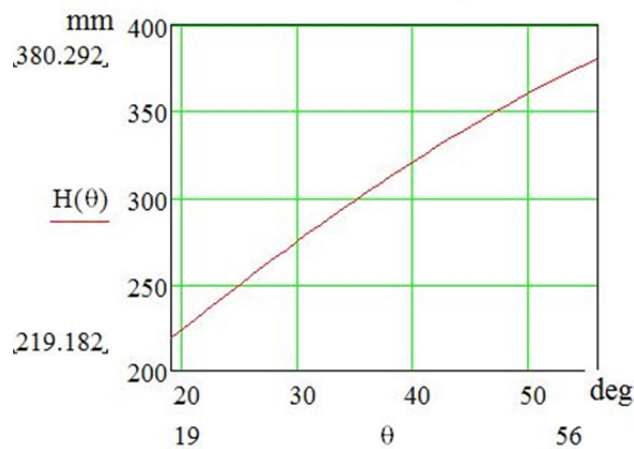


Figure 5. Minirobot height variation.

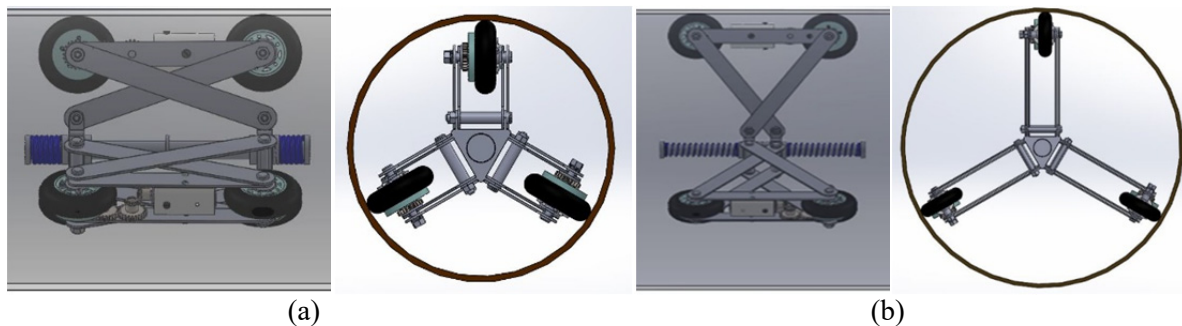


Figure 6. The IPMR-3 in pipes with  $D_{\min} = 220$  mm and  $D_{\max} = 380$  mm.

#### 4. Actuation and transmission system

Actuation of IPMR-3 is done through using three motors IG-22 with gear reduction (reduction 19:1).

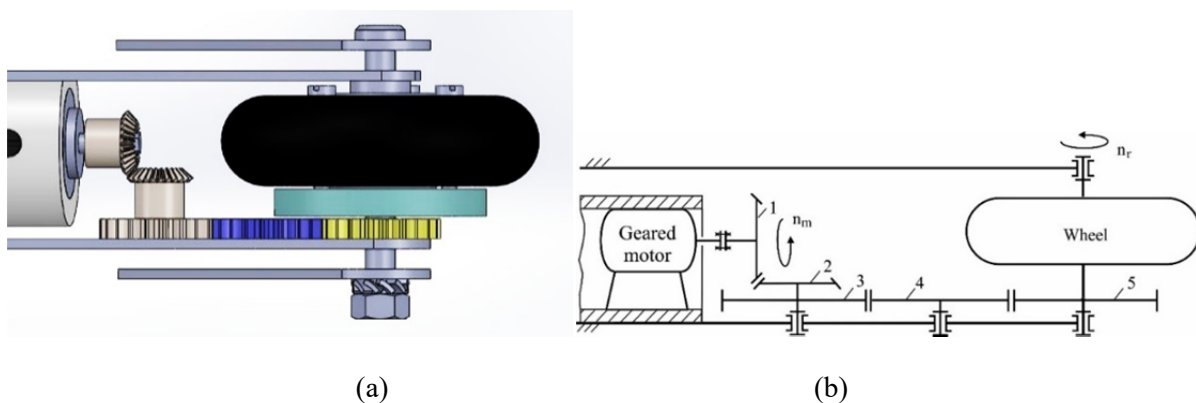
Table 1 presents specifications of the three geared motors [14].

**Table 1** Specifications of three geared motors

	<i>Driving motors</i>
<i>Diameter</i>	12,5 mm
<i>Rated voltage</i>	12VDC
<i>No-load speed</i>	789 rpm +15%
<i>Max continuous torque</i>	0.11 N/m
<i>Max continuous current</i>	1.36 A
<i>Reduction ration</i>	19:1

The transmission used from the motor with reduction to the IPMR-3 drive wheel is composed of conic gears and cylindrical gears with the module  $m = 1$  mm.

Motor transmission – drive wheel assembly is shown in figure 7.



**Figure 7.** 3D model and structural diagram of the motor - transmission – drive wheel assembly.

Transmission ratio from motor to drive wheel is:

$$i = \frac{n_m}{n_r} = i_{12} \cdot i_{34} \cdot i_{45} = \left(\frac{z_2}{z_1}\right) \cdot \left(-\frac{z_4}{z_3}\right) \cdot \left(-\frac{z_5}{z_4}\right) = \frac{z_2 \cdot z_5}{z_1 \cdot z_3} \quad (3)$$

results:

$$n_r = n_m \cdot \frac{z_1 \cdot z_3}{z_2 \cdot z_5} \quad (4)$$

where:

$i$  – the total transmission ratio

$n_m$  – the rotation speed of the actuator

$n_r$  – the rotation speed of the active wheel.

$i_{12}, i_{34}, i_{45}$  – transmission ratio of the gears

$z_1, z_2, z_3, z_4, z_5$  — number of teeth on gears

Because in the minirobot's proposed case the driving motor's rotation speed is limited the following number of teeth have been chosen for the gears  $z_1=z_2=25$ ,  $z_3=z_4=z_5=22$  resulting in the rotation speed of the drive wheel  $n_m=n_r=348$  rpm.

IPMR-3 is not energetically autonomous being supplied by a power supply through mobile conductors.



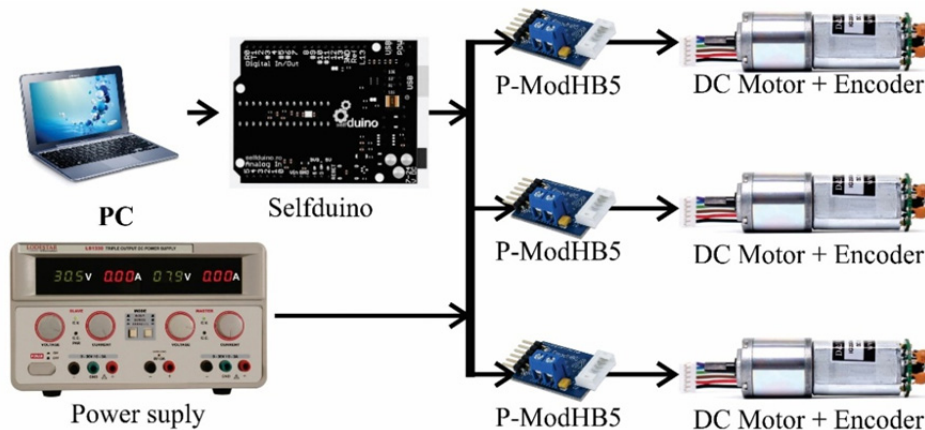
## 5. Control systems

For the command of IPMR-3 the structure shown in figure 8 was implemented and tested. The control system contains an electronic board with microcontroller. This board has the architecture of an Arduino Duemilanove, thus an Arduino program can be implemented on the microcontroller.

For driving the three motors with reduction, we require the use of three H bridges, in this regard there are three electronic components P-ModHB5 [14].

These bridges receive the command transmitted from the electronic board, limit and directs electrical power supplied by the power supply.

Through these bridges we can ensure proper supply for the driving motors.



**Figure 8.** The flow chart for controlling the *IPMR-3*.

The command of IPMR-3 is carried out by a human operator. In this regard a program that permits interaction between operator and minirobot has been developed.

The program is composed in two parts, one part is implemented in Matlab and the other part is implemented in Arduino. With the first part of the program the user interface has been created. The resulting interface facilitates the transmission of commands to the second part of the program located on the electronic board.

The second part of the program executed in Arduino, facilitates the connection and communication between the language used in Matlab and the language used in Arduino.

This part of the program receives the command transmitted and interprets it as PWM signals to command the motors.

Communication between the two parts is serial.

## 6. The user interface

The implemented interface is presented in figure 9. This contains five buttons, four slide bars and a window to show the image captured by the camera. The buttons “Open Connection” and “Close Connection” are used to open and close the serial communication link and the buttons “Forward”, “Stop” and “Backward” we can control the motors direction of rotation and stop them if the need arises.

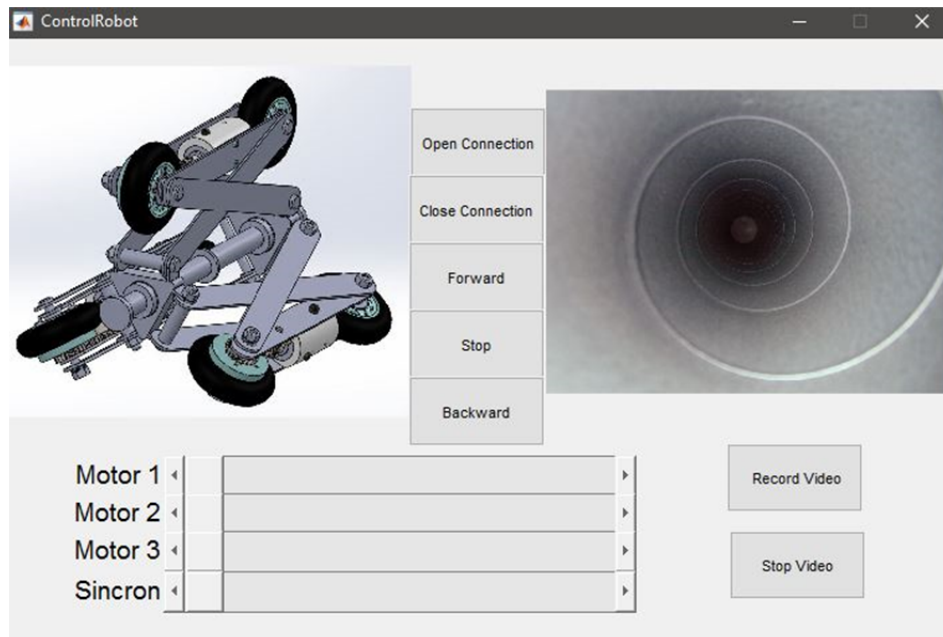
The motor’s rotational speed can be controlled separately through their specific slide bars for each of the three motors (Motor 1, Motor 2, Motor 3). The slide bar named “Sincron” allows the user to simultaneously control the rotational speed of all three motors.

After starting the program, pressing the “Open Connection” button will establish communication between program and controller. The “Close Connection” button will close that connection and all opened instances in Matlab.

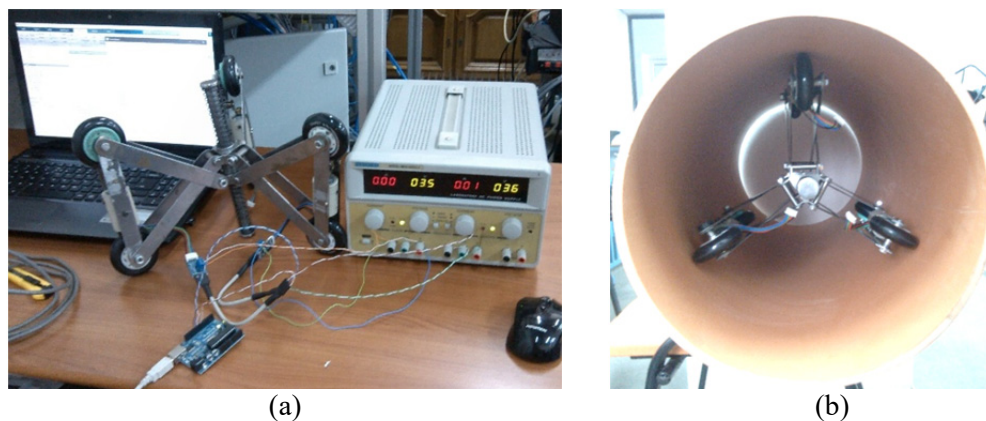
The “Forward” and “Backwards” buttons dictates the minirobot’s direction of travel, and the “Stop” button stops all motors regardless of previous commands.

To avoid errors, at the start of the program only the “Open Connection” button is visible, after the connection is established the “Open” Connection” button disappears and the other buttons appear.

In the same manner a direction of travel is selected through the “Forward” or “Backward” button, when pressing one of them the other will disappear preventing the user from issuing an unsuitable command for the correct functioning of the robot. By pressing the “Stop” button the motors stop allowing the safe change in direction of travel and the “Forward” and “Backward” buttons become visible.



**Figure 9.** Minirobot's command interface.



**Figure 10.** Photos of the developed minirobot.

Photos of the developed minirobot are presented in the figure 10.

In the proposed configuration of IPMR-3 it can access horizontal and vertical sections of pipes or sections which have a certain incline. For different configurations of pipes that include curves in scientific literature [4], [12], [13] are presented limitations for the robot's width and length ( $w$  and  $h$ ).

According to these relations, the dimensions a pipe inspection robot (width  $w$  and length  $h$ ) are limited depending on the pipe diameter  $D$  and its curve radius  $R$ .

In this case to answer these requests the minirobot's central shaft and springs can easily be replaced.

## 7. Conclusion and Future work

In the paper authors propose an in pipe inspection minirobot, IPMR - 3 which is composed of three adaptable mechanisms, placed at an angle of 120° degrees around the central shaft. Adapting to the interior surface of the pipe, a passive method is used which utilizes two preloaded elastic elements. Further the authors aim for improving the visual inspection system which uses a wireless video camera. The wireless video camera is mounted on the central shaft of the minirobot. IPMR -3 will be fitted with temperature sensors and sensors to indicate the tilt of the pipe. The interface will also be changed to display the temperature and tilt of the pipe. Another component to consider is testing the minirobot in real life conditions in the pipe and experimental determination of the traction force.

## 8. References

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