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PIPELINE INSPECTION ROBOT

*Rafael R. Marangoni** *Raphael Baron***

*Institute for Design and Precision Engineering, Ilmenau University of Technology, Germany
**Department of Computing Engineering and Digital Systems, University of São Paulo, Brazil

ABSTRACT

The design and construction of a remote-operated pipeline video inspection robot and the development of a software for its remote control were addressed in this work. Based on the analysis of existent solutions, a robot with the following characteristics was built: wheel based movement mechanism, energy supply through embedded batteries and communication through a category 5 Ethernet cable. The embedded controller is a Raspberry Pi board (32 bit ARM processor), coupled with an Arduino (ATmega328 microcontroller) and a driver circuit to power the motors. An USB video camera and its pan and tilt control systems are connected to the Raspberry Pi and driver circuit respectively. The camera images are digitally sent to the operator, and are encapsulated in IP-packets, in such a way that it is possible to take advantage of the reliability and efficiency of the preexisting protocols and infrastructure. Through the developed remote control software, it is possible to visualize the captured images and the batteries' state, as well as control the robot's speed, camera orientation and illumination. The operational capabilities of the robot were evaluated by means of field tests. The robot is capable of inspecting dry pipelines with a minimal diameter of 400 mm and with up to 25 m of length. The maximal operating time is 4 hours.

Index Terms **–** PIG, video inspection, robotics, Raspberry Pi

1. INTRODUCTION

Pipeline inspection is a common problem in the industry. There is a diversity of solutions available on the literature, whose characteristics depend on the particular restrictions and requirements of each situation. Kawaguchi et al. [3] have built a robot with magnetic wheels in order to inspect pipelines with a diameter between 150 mm and 600 mm. Their robot is controlled by a remote station and its communication is done through a fiber optic cable. Hirose et al. [1] developed a system called "Whole Stem Drive", for operation on pipelines with a big number of bends. In their system, the contact forces between the communication cable and the pipeline's wall are reduced by using a queue of robots. In this work it was also performed an analysis involving three forms of robots: robots which have a drive system on its body (wheel type, crawler type, legged type and inchworm type), robots which use the fluid pressure in the pipeline as motion system and robots that are moved through an elastic rod (like an industrial endoscope). Suzuki et al. [8] have built a robot for the external pipeline-surface inspection. Their prototype is equipped with a serial RS-232 communication interface, and has a body divided in three parts which can be moved in order to overcome obstacles. Magnetic wheels were also applied to their project. Nassiraei et al. [5, 6] covered the mobility problems of inspection robots in Japanese pipelines. In their work it was developed an autonomous robot that doesn't require the use communication cables. Its motion system is based on horizontal wheels and it is powered from lithium polymer batteries. Images acquired by a fisheye camera and data collected from a laser sensor are saved in an embedded hard drive disk. At the end of the inspection task the data can be retrieved and processed. The robot is also equipped with a set of LEDs, which can be used with a fiber-optic cable as a communication system. In that case the robot can be remotely controlled. Li et al. [4] proposed a more generalist approach, developing a multifunctional platform to be used in different situations (MMU - Multifunctional Mobile Units). The authors have built three prototypes using the same developed platform. The robots are equipped with a system driven by two motors, which generate a spiral motion centered in pipeline's axis. Saenz et al. [7] have built a robot for both inspection and cleaning of concrete pipelines. In their work were considered pipelines with relatively big diameters, between 1600 mm and 2600 mm. Their robot is equipped with an inspection system composed of nine cameras, one ultrasonic scanner, one patented sensor for infiltration detection and seven light-section sensors. This system is highly sophisticated, with a 3D interface that allows the observation of flaws on pipeline's intern surface with min. 0.1 mm. An umbilical cable, with metallic wires for energy supply and a fiber-optic cable for communication, connects the vehicle to the control station. This cable is strengthened in a way that is possible to pull the robot out of the pipeline in case of failure. Ismael et al. [2] performed a study involving the different types of robots for pipeline inspection. The authors assemble the characteristics of each type of robot and compare its advantages and drawbacks.

Taking into account the many existent solutions for the pipeline inspection problem, and considering the project requirements, a remote-operated pipeline inspection robot was designed and a prototype was built.

2. PROJECT REQUIREMENTS

Geometry and length of the pipeline are constraints for the size and form factor of the robot, as well as for the type of communication employed. The material of the pipeline may also affect other project specifications, such as the motion system. In this project, horizontal pipelines made of any material, with a diameter equal or greater than 400 mm, are considered. Tests are performed on straight pipelines with up to 25 m length.

The dimensions of the robot should be compatible with the pipeline's size. Therefore, the maximum dimensions of the robot are defined as 200x250x200 mm (WxLxH). The weight of the robot affects the traction generated by the motion system, which must overcome the friction forces between the communication cable and the pipeline. It is specified that the robot should weigh between 2 kg and 3 kg.

The operational conditions are related to the presence of residues in the pipeline. In this project dry pipelines with high humidity (90-99%) are considered, as well as with small obstacles and residues.

3. PROJECT

A decision matrix was used involving different types of robots available on literature, and regarding the following criteria:

- Project cost;
- Project complexity;
- Possibility to damage the pipeline's surface;
- Maneuverability;

- Grip to the pipeline's surface;

It was chosen the robot with wheel based motion system as the most suitable for the project. From this point, the mechanical components, electronic hardware and control software were designed.

3.1 Mechanical Components

The pipeline inspection robot was designed using a pre-existing chassis with a four-wheel drive motion system. Based on this chassis, the camera's motion system and the supports for the embedded electronics and batteries were designed and built. The CAD project of the vehicle and the built prototype, which is discussed in Section 4, are presented in Figure 1.

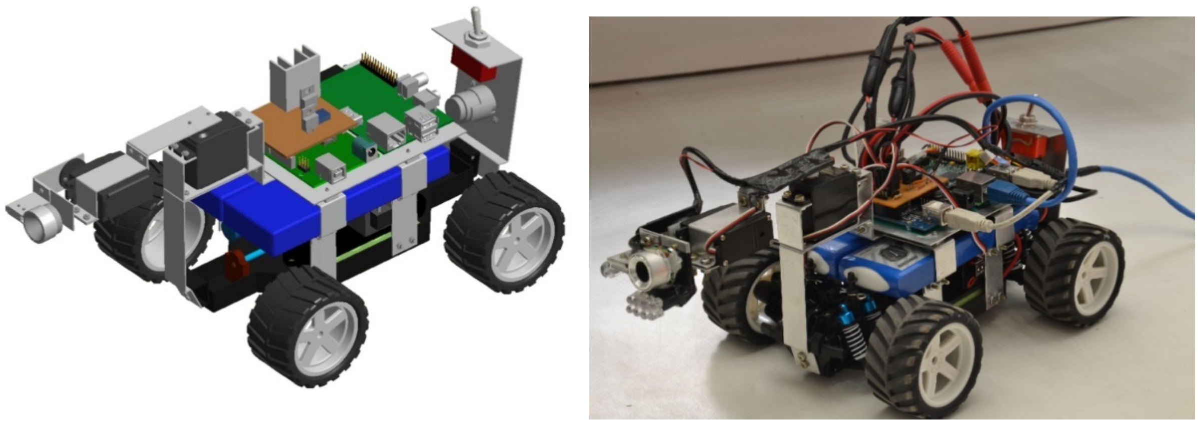

Figure 1: CAD project of the vehicle and built prototype

3.2 Electronic Hardware

As the main microcontroller, the Raspberry Pi model B board was employed, which has 512 MB of RAM memory. This board is equipped with a System-on-a-chip Broadcom BCM2835, with an ARM1176JZFS processor, whose nominal clock rate is 700 Mhz. In addition, this processor has a graphic processing unit VideoCore 4 and eight digital general purpose inputs/outputs (GPIO). The Raspberry Pi board runs the GNU/Linux operating system, allowing the employment of a big number of software developed for that platform. Through this board it is performed the communication between the inspection robot and the control station. An USB video camera and an Arduino Duemilanove board, whose tasks are controlling the vehicle's motors, controlling the illumination system and sampling the voltage on the system's batteries, are also connected to this board. The vehicle is powered by two parallel-connected lithium polymer batteries, constituting a 7.4V/10 Ah power source. The motion system is driven by a DC motor, which is powered by a driver controlled through a PWM signal. The steering system and the camera's motion system are driven by one and two servos respectively, which are also controlled through PWM signals. The whole electronic system is shown on Figure 2a.

With the objective to interconnect the electronic components of the vehicle, it was developed an additional board for the Arduino (shield), which accomplishes the following tasks:

- Ensure a power source of 5V and 1.5 A for the Raspberry Pi board;
- Ensure a power source of 5V and 3A for the three servo motors;
- Perform the connection between the three servos and the main DC motor with four PWM ports of the Arduino board;

- Provide a power switch for the robot;
- Provide one solid-state relay to control the servos power system;
- Provide the illumination control system;
- Provide a system capable of sampling the voltage on batteries.

The developed shield is presented in Figure 2b. As observable, this board is directly connected to the Arduino board. From left to right it is possible to observe the cables, which are:

- Power cable for the DC motor driver;
- Cables to connect the batteries (one pair);
- Power switch;
- Power cable for the Raspberry Pi.

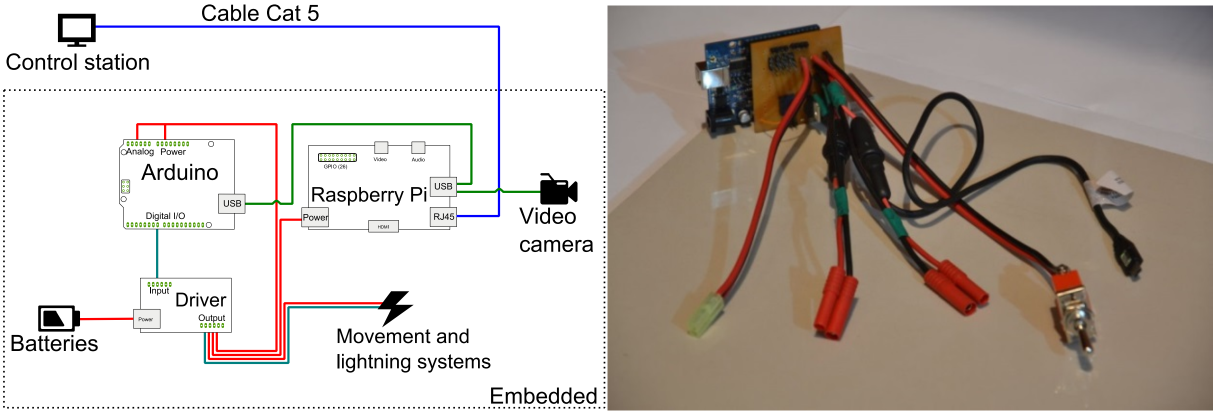

Figure 2: Electronic system (a) and shield for the Arduino board (b)

3.3 Control Software

Given the robot's operational requirements, software components for controlling the robot and interacting with the operator were designed and implemented using a client-server architecture. In this section, the decisions and their impacts regarding the software components will be discussed.

The server application, which is run on the robot's embedded hardware, consists of a program written in Python and is responsible for the following tasks:

- Capturing images and sending them to the client software;
- Reading remote commands - such as for controlling the robot's position, querying the batteries' state or controlling the robot's lights - and answering accordingly.

The choice of Python as the programming language is justified by the fact that it provides higher level control mechanisms for the management of multiple threads, network communication and image capture, which sped up considerably the development process of the prototype.

The client side application, in its turn, consists of a Java application that is responsible to perform the following tasks:

- Capturing commands from the operator and send them to the server application (on the robot);
- Querying for and displaying the images captured by the robot, as well as the batteries' and lights states.

The Java programming language was chosen for its portability. It provides a higher level interface for network communication, threads and graphical user interface (UI) management, while abstracting the lower level details of the underlying operating system, which means the client application is capable of running on a variety of systems out of the box. Figure 3 provides an architecture overview of the system.

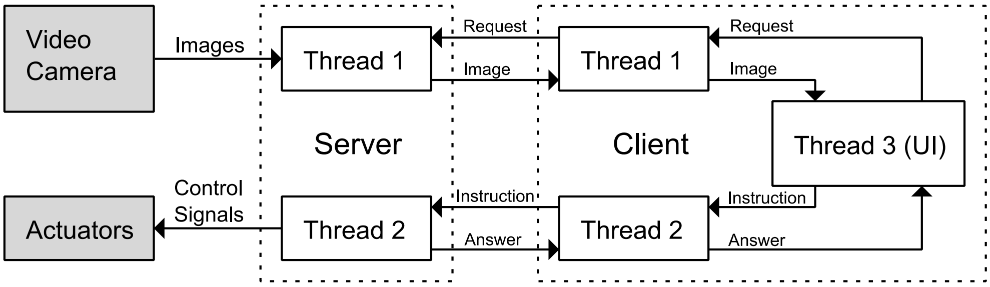

Figure 3: Architecture of the control software

4. PROTOTYPE AND RESULTS

The mechanical components of the robot were built following the project specifications and the final prototype with its control interface is presented in Figure 4. Field tests were conducted with the robot in order to verify the fulfillment of its operational requirements. The characteristics of the built prototype are presented in Table 1.

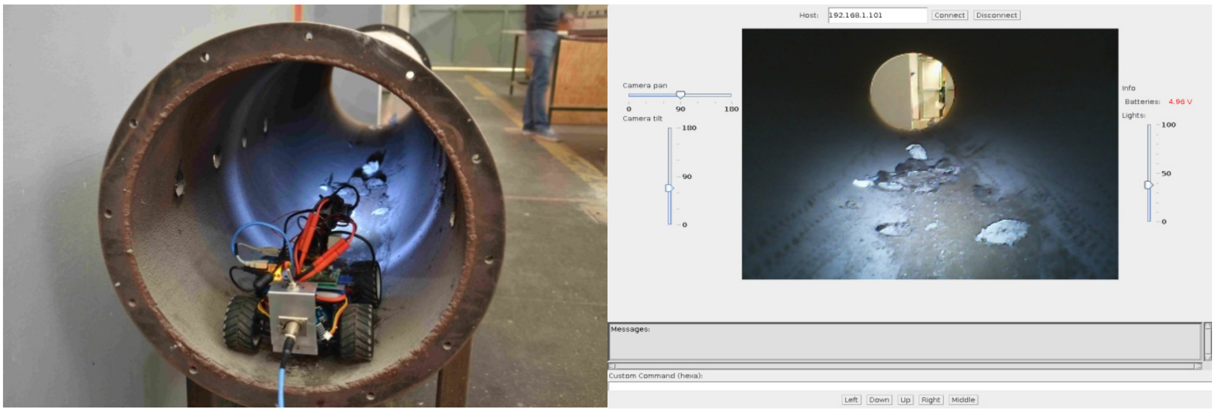

Figure 4: Robot under operation and its control interface

Table 1: Characteristics of the prototype

Characteristic	Attribute
Max. operation time	4 hours
Dimensions (WxLxH)	190x250x200 mm
Min. pipeline diameter	400 mm
Pipeline material	indifferent
Max. pipeline length	25 m
Voltage on batteries	7.4 V
Camera's PAN movement amplitude	180°
Camera's TILT movement amplitude	180°
Max. camera resolution	1.3 MP

5. CONCLUSION

Different solutions for the pipeline inspection problem were analyzed. The conception of a robot for this purpose comprises a big number of project variables, and there is a diversity of solutions for this problem available on literature. Considering the multiple design possibilities, and regarding the project requirements, a remote-controlled robot with wheel-based motion mechanism was build. Visual inspection tasks are possible through a camera equipped with panning, tilting and illumination control mechanisms. The maximum operation time is limited by the embedded batteries and comprises four hours. The accordance with the project requirements was verified by means of field tests executed with the prototype.

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CONTACTS

M.Sc. Rafael Ramos Marangoni rafael.marangoni@tu-ilmenau.de
M.Sc. Raphael Baron rbaron@rbaron.net