ROBOTIZED SYSTEM FOR IN-PIPE INSPECTION USING PRESSURE TOLERANT ELECTRONICS TECHNIQUE

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Resumo – Este artigo descreve o desenvolvimento e a avaliação experimental de um sistema robotizado para executar dois tipos de medidas no interior de um duto: a espessura da camada de tinta do revestimento interno e o raio interno. A medida da camada de tinta permite a inspeção da qualidade da pintura e pelas medidas de vários raios é possível estimar o formato da seção transversal do duto. O sistema proposto obteve resultados bastante satisfatórios em testes de campo em um duto de 14" (polegadas).

Palavras-chave – inspeção de duto, instrumentação de duto, pintura interna de duto, robô de duto, eletrônica tolerante à pressão.

Abstract – This paper reports the development and experimental evaluation of a robotized system devised to perform two kinds of measurements inside a pipeline: the thickness of the internal wall painting layer and the internal radius. The thickness measurement allows the inspection of the painting layer quality and by measuring several radii it is possible to estimate the pipeline transversal section shape. The proposed scheme is shown to yield very satisfactory results on an actual 14" (inches) pipeline in a real site.

Keywords – pipeline inspection, pipeline instrumentation, pipeline internal painting, pipeline robot, pressure tolerant electronics.

1.Introduction

In the beginning of the year 2002, Petrobras has begun a maintenance program which consists of cleaning and painting the inside surface of a underground pipeline (42 km of total extension, 26.1 miles). A problem issued from this program was how to monitor the quality of the painting service provided by a contracted servicing company.

There are several commercially available instruments designed for measuring the painting thickness by manual operation at a given wall point. The measure is obtained by pressing the sensor normally against the painted surface at the given point. Since manual operation with such instruments is precluded for measuring in-pipe painting thickness for long pipelines, the Petrobras Research Center (CENPES) has proposed the development of a dedicated device to appropriately manipulate the sensor along the interior of the dry and clean pipeline, as a first experiment for the inspection and maintenance device.

The development was carried out with GSCAR (Group of Simulation and Control for Automation and Robotics), a research group of COPPE / Federal University of Rio de Janeiro. The device, now named SIMCRODUTO, should operate coupled to GIRINO, an in-pipe hydraulic actuated crawling robot for visual inspection purpose, under development by CENPES, (Reis, 2001).

As part of the same project, we also made some experimental tests using the concept of **P**ressure **T**olerant **E**lectronics (PTE). It consists of electronic components and circuits submitted to the full environment pressure by packaging them with a light thin-walled housing filled with oil, discarding the need of a pressure housing. This technology makes it possible to develop electronic devices for high pressure environments applications that result in low-cost and small-size systems. The literature on this subject in scarce and not easily available, (see Barnes and Gennari, 1976). Since there is no such thing as a qualified parts list for PTE, (see Sutton, 1979), experimental results on PTE would be very important and useful.

The objectives of this work are to develop SIMCRODUTO to make two kinds of inspections: to measure the in-pipe painting thickness and, in addition, to estimate the shape of the pipeline with a given desired precision; and to evaluate the feasibility of using current commercially available electronics components, including microprocessors units, on high pressure environments applications using the PTE technology.

2.System Description

SIMCRODUTO is an electromechanical device controlled by a microcontroller via RS-485 serial interface. The acquired data are sent to the computer, where they are logged for immediate or subsequent analysis. The data is acquired from two sensors (see figure 1):

- The painting thickness is measured by a commercially available sensor (Mitutoyo model Digi-Derm, 979 series).
- The radius measurement (with respect to the central axis of the SIMCRODUTO) is made by a highly sensitive mechanical micro-switch, which is actuated when a needle touches the pipe wall.

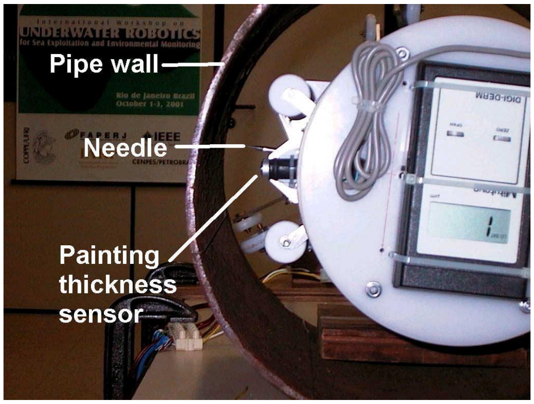

Figure 1. SIMCRODUTO: Detail of the painting thickness sensor and the tactile sensor (needle).

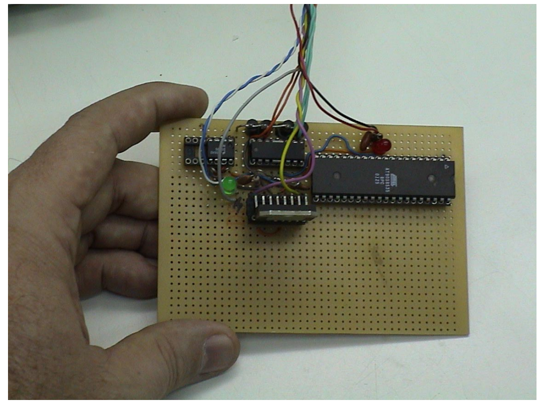

Figure 2. Electronic circuit for PTE experiment.

2.1 Mechanical Characteristics

SIMCRODUTO was designed as a two degrees-of-freedom robot. It consists of a revolute joint required to turn the sensors to a desired angular position along a transversal section of the pipe, and a prismatic joint to move the sensors forward and backward, with respect to the in-pipe wall, so that the desired data can be acquired. Figure 3 shows a typical measuring being made with the sensors touching the pipe wall.

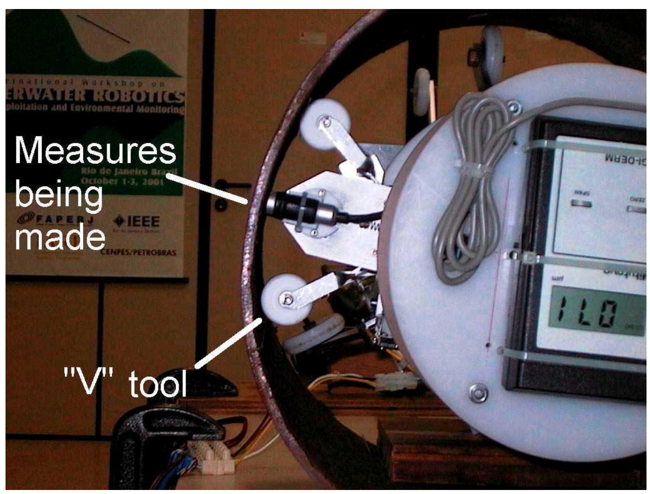

Figure 3. SIMCRODUTO operation and the "V" tool (with two side-wheels).

The mechanical structure must be compliant in order to correctly position the sensors. Ideally, the painting thickness sensor must be aligned with the normal axis of the pipe wall. A "V" tool was build to make sure that this sensor is correctly aligned. Figure 3 shows this tool which can be identified by the device supported by the two small side-wheels touching the inner pipe wall.

2.2 Actuators

Both robot joints are actuated by d.c. motors. One d.c. motor is coupled to the revolute joint with a reduction rate of 161.25:1. The other motor is connected to a spindle (reduction rate of 15.7:1). The prismatic joint moves the sensors forward and backward with respect to the pipe wall. The spindle step size is 0.125 cm (0.04921 inches), so that every 15.7 turns of the motor yields a linear displacement of 0.125 cm (0.04921 inches).

The sensors support is connected to the spindle through a solenoid. In case of power failure, the solenoid releases the sensors from the spindle and a spring pulls the system back to the rest position. This guarantees that SIMCRODUTO can be removed from the inside of the pipeline without damaging the sensors.

2.3 Electronics

All the control functions of SIMCRODUTO are implemented with an AVR family microcontroller AT90S8535, Atmel manufacturer (AVR AT90S8535 datasheet), through serial RS-485 communication, (DS485 datasheet).

The robot d.c. motors are controlled by the AVR microcontroller using PWM (*P*ulse *W*idth *M*odulation) drivers (National's LMD18245 datasheet). A conventional PI control law was used for motor positioning.

For the position control of the revolute joint and the measurement of the radius, through the prismatic joint, two incremental optical encoders were attached to the motor rotors. The HCTL2020 (HP HCTL2020 datasheet) decoder chip, HP manufacturer, is used to count the encoders pulses (total resolution of 2000 CPR).

The painting thickness sensor has an analog output which is connected to the Analog-Digital Converter (ADC) of the AVR microcontroller.

2.4 PTE Electronics

In parallel with the development of the SIMCRODUTO, we also made some experimental tests using the concept of **P**ressure **T**olerant **E**lectronics (PTE).

The objective of having this technology is twofold:

- To reduce the size of the volume of the electronics by removing the pressure housing. In fact, volume is one of the main limitations for devices working inside pipelines.
- To reduce the cost of the electronics.

In order to evaluate the effects of hyperbaric pressure over an electronic circuit, we designed a prototype circuit (see figure 2) with all the functionality of the SIMCRODUTO's circuit with an additional step motor driver.

The microcontroller uses a ceramic ressonator as the clock source. Usually, a metallic encapsulated crystal is employed on microcontrolled circuits, but its implosion is possible due to spaces filled with air inside the package. In contrast a ceramic ressonator has no empty spaces and thus more appropriate for PTE circuits.

The d.c. motor is driven by a LMD18245 driver from National. Polyester and ceramic capacitors have been used for the peripherical circuitry required by this driver. Carbon composition resistors (solid construction) were used for this circuit and for the termination of the communication twisted pair.

The driver for the step motor is the 5804 from Allegro (BiMOS II Unipolar Stepper-Motor Translator/Driver datasheet). The diodes used to short-circuit the reverse currents from the motor are epoxy encapsulated.

The RS-485 communication interface was selected in view of its relative long range specification (4000 feet). A DS485, from National, was used as the RS-485 transceiver.

Both motor drivers, the communication transceiver and the microcontroller are integrated circuits with **P**lastic **D**ual **I**nline **P**ackage (PDIP), except the LMD18245 driver, that has a TO-220 packaging. The others components, above mentioned, are carbon resistors, epoxy diodes and polyester and ceramic capacitors.

The circuit was immersed in silicon oil inside a plastic recipient, see figures 4 and 5.

Figure 4. Electronic circuit inside the empty plastic housing.

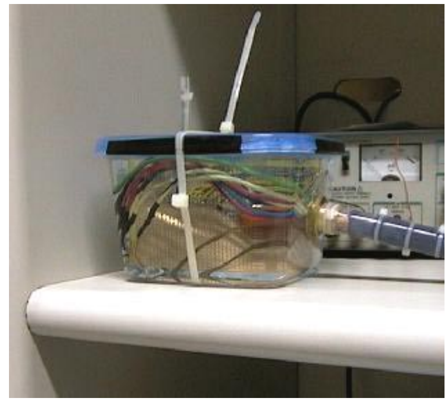

Figure 5. Circuit inside thin-wall plastic housing filled with silicon oil.

2.5 Software

The control algorithm was coded in C language, compiled and linked using the AVR's software tools. By using the development AVR board, the executable code was downloaded to the AVR flash memory.

The user interface, see figure 6, was coded in C++ language and the data transfer was handled by the serial communication port under Windows operational system running on a PC.

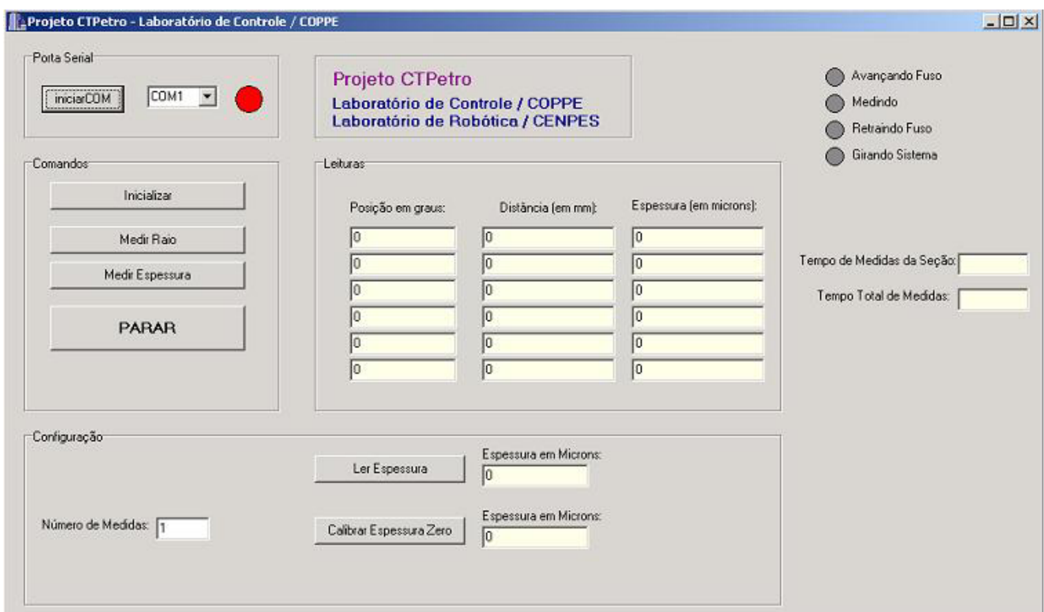

Figure 6. Software interface.

Using the interface the user can:

- define the number of measures in the same pipeline transversal section.
- initialize the system (retract the sensors, turn on the solenoid and moves the revolute joint to the initial position).
- start and stop the measurements.
- vizualize the measurements (painting thickness in µm, radius in mm and angles in degree), the total measurement time (in seconds) and the actual system status.

3.PTE Experimental Results

A hyperbaric chamber with pressure capacity up to 5000 psi (≈ 3400 m of depth) was used for the test. The connector to the hyperbaric chamber did not have the required number of contacts, so that both motors could not be used. The step motor was selected for the test. However, the d.c. motor electronics was also submitted to high pressure.

The test was carried out in three parts. In the first part the pressurization was made by 200 psi increments at a time until the 5000 psi limit was reached. After each increment, the signals, voltage and frequency, from a step motor coil were measured via an oscilloscope.

The circuit responded satisfactorily in the course of the entire test. When the chamber reached 5000 psi, after all increments, it remained under this pressure for about five minutes before it was depressurized.

In the second part of the test, another pressurization method was used: the chamber received the total pressure (5000 psi) in one single shot. In both pressurization methods, the circuit presented no changes.

Finally, in the last part of the test, the circuit was cleaned from the oil and tested again outside the high pressure chamber, this time with both motors. The circuit behaved equally well. The communication and circuits operated with no noticeable changes.

4.Conclusion

The results collected during our PTE experiments allows us to develop electronic circuits to work under high pressure environments without a pressure housing.

However, some limitations on encoders, motors, power electronics and painting thickness sensors must be acknowledged as there are no conclusive tests in this issues.

We conclude from the experimental tests that SIMCRODUTO achieves good performance for both inside painting layer thickness measurement and pipeline transversal section shape estimation. The system exhibited a remarkable performance on *in-situ* experimental tests in a 14" (inches) pipeline located at Madre de Deus, district of Salvador, Bahia, Brazil.

Considering that the pipeline was previously well cleaned, the data acquired revealed that the paint had drained to the bottom of the pipe. As a consequence, on the pipe top, the painting thickness was considerably smaller than on the bottom. Earlier, this possibility was only a speculation that hitherto had not been confirmed by direct *in-situ* measurement. The results so far have been very satisfactory.

One first application of the SIMCRODUTO is to monitor the quality of the painting made by some service company.

5.References

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