Telerobot: Failure Detection Using Imaging Technique for Piping Internal Surfaces

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Abstract. Pipelines are the energy lifelines of almost every activity of everyday life. It is a safe way of transporting water, gas and oil over long distances. It is also the most practical way to deliver oil and gas across countries as being an extremely safe and economically viable solution to transport energy. Cracking and corrosion on the external and/or internal surfaces of in-service pipes, reduces the integrity of the material and potentially reduces the service life of the transportation system and equipment. Defects in pipelines may have various forms and may be initiated by one or more mechanisms potentially resulting in corrosion and/or cracking. In this paper we propose a system that detects the internal cracks in pipelines through a telerobot which can be inserted into the pipelines and detects the internal Failures (cracks) through a special modern high resolution digital camera and image processing techniques. The telerobot is a programmable and can be controlled as per the requirements such as speed and direction of the telerobot and sensors using mobile application and can be connected to a computer and smart phone. The telerobot captures a high definition images and also captures the precise location. These images are transferred to a computing facility for the analyses and to detect cracks.

Keywords. Fault Detection; Inspection; Pipelines; Telerobot.

1. Introduction
Failure detection using robot and imaging technique for piping internal surfaces were the robot is inserted into pipes to check for failure or damage has many advantages. These robots differ from totally machine-controlled robots in the sense that the advantage of presence of man is taken in situations where it is not possible to expect all the motion and handling requirements in such details as to render them programmable for machine control. Telerobot are human controlled robots that take routine, dangerous or long-duration tasks out of human hands. Most telerobots are multi-functional for example a medical robot has arms to grab, cut, and move skin. Telerobotics is the area of robotics concerned with the control of semi-autonomous robots from a distance, using Wireless network (like Wi-Fi, Bluetooth, and similar).

The technique is designed to remove the human factor from labor intensive or dangerous work and also to act in inaccessible environment. The use of such devices is more common today than ever before and it is no longer exclusively used by the heavy production industries. The inspection of pipes may be
relevant for improving security and efficiency in industrial plants. These specific operations as inspection, maintenance, cleaning etc. are expensive, thus the application of the robots appears to be one of the most attractive solutions. Inspection devices are used in many fields of industry. One application is monitoring the inside of the pipes and channels, recognizing and solving problems through the interior of pipes or channels. In October 2013, it has been discussed to presents an autonomous robotic system to perform pipeline inspection for early detection and prevention of leakages in thermal power plants, based on the work developed within the MAINBOT [1] European project. The formally reported work on design and fabrication of in pipe inspection robots is presented by Prasad et al., [2], Yousef et al., [3] and Barane and Mujibaile [4].

In this paper we propose a system that detects the internal cracks of pipelines through a Telerobot which can be inserted into the pipe and detects the internal failures (cracks) through a special modern high resolution digital camera. The Telerobot captures a very clear and high definition images which are analyzed as per the requirements. The remaining paper is organized as, the proposed Telerobot: failure detection using imaging technique for piping internal surfaces long with its design and fabrication is presented in Sec 2; discussion on usages and limitations are presented in Sec 3; final conclusion and further enhances are described in Sec 4.

2. Telerobot: Failure detection Using Imaging Technique for Piping Internal Surfaces

The main objective for developing Telerobot is to provide non-destructive testing inspection solution by inserting the robot into pipes to check for obstructions and damages and distant controlling the same. Controlling mechanisms for in pipe inspection robots are presented in papers [5,6]. A specially designed rotating probe for the inspection is suggested by Sun et al., [7]. The proposed solution is to inspect the interior of pipelines through a Telerobot which can be inserted into the pipe and detects the internal failures (cracks) through a special modern high resolution digital camera. The Telerobot captures a very clear and high definition images which are analyzed to find the interior information of the pipelines. One application is monitoring the inside of pipes and channels, recognizing and solving problems through the interior of the pipes or channels. In this work, Failure detection using imaging technique for piping internal surfaces with ability to move inside horizontal pipes has been designed and fabricated.

2.1. Design of Telerobot

We identified the need, dissatisfaction, improved existing products, determined specifications and requirements & collected relevant design information feasibility study. Then we designed mechanical parts by using SolidWorks applying stress analysis and mode of failures of each part of the mechanism. After that we designed control system by determining the required applications of the Telerobot which contains DC motors, ultrasonic sensor, temperature sensors & LED lights and we can control it by using specially designed mobile application.

The Telerobot is collapsible in-order to fit in different sizes of pipe lines. Sensors and controlling mechanism used are concealed in the central pipe (body). All legs (Links) dimensions are equal for execution of uniform motion. The angle at the maximum diameter must not exceed 80 degree and not go below (15-20) degree for minimum diameter for proper functioning as shown in Fig. 1. The wheels of the Telerobot is chosen such that they should be capable of moving without slipping in the vertical direction and should not wear out easily with the use. Stress analysis is performed on all the components in the Telerobot to validate and optimize the material used and dimensions. The feasibility analysis is also performed. The overall dimensions of the Telerobot can be increased or decreased based on the requirements. The challenge is to make this robot adaptable to vary its diameter by adding one sliding mechanisms.
The developed Telerobot is shown in Fig. 2. The Telerobot consists of one sliding mechanisms fitted onto a PVC central tube, referred as body. Sliding mechanism has six legs work as a driver and another six legs work as a driven, each two legs fixed together by a part (Collector, component 4 in Fig. 2) between them. To slide, a nut connected to power screw (component 5 in Fig. 2) makes the linear movement possible, if the nut move outside legs are moved away from each other, the telerobot's diameter decreases. Once the nut return to its position or reverse its direction, the telerobot extends automatically. Inside the PVC tube, there is a holder of the electronic components. Each two legs are controlled by two geared DC motors that make them powerful enough to drive the whole mechanism. The components of the Telerobot are presented in Table 1.
Table 1. Components of the Telerobot

| Component No. as in Fig. 2 | Name          | Material | Number of components |
|---------------------------|---------------|----------|---------------------|
| 1                         | Body          | PVC      | 1                   |
| 2                         | Arm1          | Acrylic  | 6                   |
| 3                         | Arm2          | Acrylic  | 6                   |
| 4                         | Arm Collector | Acrylic  | 3                   |
| 5                         | Power Screw   | Steel 37 | 1                   |
| 7                         | The Core      | Acrylic  | 2                   |
| 8                         | Washer        | Acrylic  | 1                   |

The Telerobot is fitted with Mini Panoramic 360 Degree Fisheye WiFi Wireless Camera for capturing images and see through the pipe which is inspected. This camera facilitates discovering the insides obstacles and inner cracks inside the inspected pipe so that these can be rectified.

2.2. Control system of Telerobot

A programmable microcontroller is used in the Telerobot as a self-contained system with peripherals, memory and a processor that is used as an embedded system. 10 steps procedure (starting from hardware requirements and interfaces to actual experiments through software architecture, cost and power constraints) is followed to ensure that the right choice is made.

The selected Arduino (an open-source prototyping platform based on easy-to-use hardware and software) board is able to read inputs - light on a sensor or a finger on a button, and turn it into an output - activating a motor, turning on an LED, publishing something online or send required information to mobile application. The mobile application interacts with the Arduino board what to do by sending a set of instructions to the microcontroller on the board. To do so the Arduino programming language and the Arduino Software integrated development environment (IDE) are used. The important hardware components used in the Telerobot are described in the following paragraphs.

Mini DC gearbox motors, selected based on the requirements (size, torque, inertia and expected motion profile), are used as actuator of the Telerobot and connected directly to the tires without any couplings. This elements the assembly complications and ensures the compactness. Motor driver kit, dual H-bridge DC motor drive controller board module for Arduino L298 is used to control motion of the Telerobot.

Temperature sensors (LM35) are fitted in the Telerobot to measuring temperature of a particular environment, providing thermal shut down for a circuit/component and monitoring battery temperature. Ultrasonic sensor (HC-SR04) is used to avoid and detect obstacles, measure the distance and depth of pits, walls, obstacles. Mini Panoramic 360 Degree Fisheye WiFi Wireless Camera is fitted to capture images and see through the pipe and also to discover the obstacles and inner cracks inside the inspected pipe.

Li-ion Battery 18650 3.7v 1100mAh as in-built power supply is fitted. HC-05 Bluetooth module is used for communication between the mobile application and Arduino board.

The programing is done to control the motion, speed, camera, sensors and lights inside the inspected pipe using a mobile application which permit us to control it completely with no external wires (remote control).

2.3. Telerobot Fabrication and Testing

The fabricated model for inspection of pipes is shown in Fig. 4. Materials used for the Telerobot are light and rigid. Different materials can be used for different parts of the robot. Table 1 shows the materials used for different components. The fabricated components are shown in Fig. 3. It has been tested in empty horizontal pipelines. The Telerobot is working fine and controlled remotely. Pictures are taken the transferred to the personal computer. Two images taken by the Telerobot are represented in Fig. 5.
Limitations are identified as restriction in turning in T-shaped pipe and moving in a plug valve. It did not work in water-filled pipes. In order to work in water-filled pipes and T-shaped pipe and plug valve, the Telerobot design and controlling mechanism need to be modified.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig3.png}
\caption{Components in Telerobot.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig4.png}
\caption{Fabricated Telerobot for piping inspection.}
\end{figure}
3. Discussion

The inspection of pipes may be relevant for improving security and efficiency in industrial plants. These specific operations as inspection, maintenance, cleaning etc. are expensive, thus the application of the robots appears to be one of the most attractive solutions. It reduces the frequency of entering human into the testing environment. Operating cost related to other method is low. Save comprehensive investment, improve work efficiency, more accurate detection. The pipe inspection robot inspects situation inside the pipe which will be recorded and displayed on the monitor screen, it also facilitates working personnel for effective observation, detection, quick analysis and diagnosis operating cost related to other method is low. The robot has great application in accessing the regions of pipe in which human doesn’t have reach. It is mounted with a camera to take pictures of inside and help in complete inspection.

By taking advantage of the non-destructive testing inspection methods, the proposed robot offers to identify faults in order to avoid increasing the 'up and running' operational time of all kinds of pipe systems. It has wide application including power plants, chemical and petrochemical plants, gas pipelines, communal waste water pipe systems. Leakages in long distance heat conduits, cause through external corrosion, cause energy and water losses resulting in damage to, among others, subterranean constructions. Minimizing energy loss during the transport of heat from source to end user is one of the most important requirements in order to exclude danger to people and the environment. The proposed Telerobot can help in distant inspection in such kind of conditions. The hygiene standard in the food and drinks industries can be maintained by inspection of the individual pipe networks using the proposed Telerobotic solution.

4. Conclusion

Telerobot for complete inspection, detecting internal cracks of pipelines is developed. The Telerobot is inserted into a pipe, takes pictures and detects internal failures (cracks). The components of the Telerobot are designed in Solidworks by applying stress analysis and mode of failures of each component of the mechanism. The mechanism consists of DC motors to move forward and backward, Ultrasonic sensor, Temperature sensor, and LED lights. The movement, speed, direction and all the sensors of the Telerobot are controlled by mobile application which can be connected to other computing devices (i.e. computer or other mobile device) for further analysis and visualization. It offers many advantages over conventional methods.

In order to work in water-filled pipes and T-shaped pipe and plug valve, the Telerobot design and controlling mechanism need to be modified which is consider as future work.

References

[1] Ibarguren A, Molina J, Susperregi and Maurtua I, 2013. Thermal Tracking in Mobile Robots for...
Leak Inspection Activities. Sensors, vol. 13, pp. 13560-13574, Oct. 2013. (http://www.mainbot.eu)

[2] Prasad EN, Kannan M, Azarudeen A and Karuppasamy N, 2012. Defect identification in pipe lines using pipe inspection robot. IJMERR, vol. 1, pp. 1-14, July 2012.

[3] Yousef BF and Bastaki N, 2014. Worm Robot with Dynamic Adaptation to Pipe Diameter for In-Pipe Inspection. IJEIT, vol. 3, pp. 286-292, April 2014.

[4] Bakane PP and Mujbaile P. 2015. Pipe inspection system: a review. IRJET, vol. 02, pp. 1865-1868, May 2015.

[5] Kuber KH, Kumar P, Patil A, Yadav U, Nair J, 2016. Review of Design and Fabrication of in Pipe Inspection Robots. IJRRCME, vol. 2, pp. 81-84, Oct. 2015 – Mar. 2016.

[6] Cuong NC, Phuong NT and Van DV. 2013. Design and Control of In pipe Inspection Robot. International Journal of Engineering and Science, vol. 3, pp. 38-46, Nov. 2013.

[7] Sun KNY, Srivastava RK, Ogai H and Bishakh. 2010. Advanced pipe inspection robot using rotating probe. ISAROBAROB, pp. 573-576, Oita, Japan, Feb. 2010.