Design and Development of In-Pipe Inspection Robot

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Abstract: An in-pipe inspection robots are designed to remove the labour force and to act in inaccessible environment. Recently many troubles are occurring in the pipelines because of natural calamities and mechanical damages from third parties and defects are occurring in the pipelines. So after some period every pipeline requires inspection and maintenance to ensure their safety and integrity. In-pipe inspection robots are used to inspect vary pipes elements such as straight pipelines, elbow and branches internally. In-pipe inspection robot inspect the pipes of various size and find the defects and obstacles in the pipes. There are many in-pipe inspection robots which are differ by their power source, steering mechanism and application. This paper shows the comparative study of different in-pipe inspection robots. Section VI shows the new developed steering mechanism for improvising working style of in-pipe inspection robot. Still the applications of in-pipe inspection robots are limited according to pipeline material, pipe size and working environment.

Keywords: in-pipe robot, defects, inspection, maintenance, elbow, branches, steering mechanism.

I. Introduction

Pipeline is the major tool of transportation. It has been proven that the pipeline is the safest way to transport and distribute Gases and Liquids. Many kinds of pipes are being used for water and gas supply in our contemporary society. Also pipelines are widely used in chemical industries and in gulf countries for carrying petrol, diesel, oil etc. But recently many troubles are occurring in the pipelines because of natural calamities and mechanical damages from third parties and defects are occurring in the pipelines. If the defects in the pipe are caused by aging, corrosion, rust and nature calamity then it is difficult to find out the defects and the place of the defects, and also there is great amount of loss. So we require to schedule the inspection. If we decide to do this inspection manually then large amount of time, effort and labour is necessary to grub up the pipes that are buried in the ground. If the robot can inspect inside the pipes, fast and accurate examination is able to do at low cost.

With a considerable history behind the development of robotics, in-pipe inspection robots can be coarsely classified into seven different sub-categories based on their movement pattern and applications. Fig. 1(a) shows Pig type robot which is one of the most popular commercial robot. Generally this robot don’t use additional driving utilities to move along the pipeline. This type of robot is usually used when there is a sufficient flow in the pipeline. Practically this type of robot is used in pipelines with large diameters. Fig. 1(b) shows Wheel type robot. This robot is only applicable in horizontal pipelines. As shown in Fig. 1(c), Caterpillar type robot is usually used in such conditions where more grip is demanded on the wall of the pipeline.

Figure 1: Classification of in-pipe robots. (a) Pig type. (b) Wheel type. (c) Caterpillar type. (d) Wall-press type. (e) Walking type. (f) Inchworm type. (g) Screw type. [1]
Fig. 1(d) shows Wall-press type robot. This is another type of in-pipe inspection robot finding its prime usage in vertical pipelines. This robot needs some adequate force to exerted on the wall of the pipeline that will prevent the robot from falling down. Walking type robot depicted in Fig.1(e) is a robot with articulated legs that will help the robot in movements that are highly sophisticated. Inchworm type robot is shown in Fig. 1(f), does in a way mimic the movement of a worm. Apparently this kind of motion is slow so prefers smaller length and diameter pipelines. Screw type robot as shown in Fig. 1(g) is also called as helical drive type robot.

This paper is organized as follows. Section II describes the power sources of pipe inspection robot. Section III describes review of in-pipe inspection robot. Section IV describes the comparative analysis of existing in-pipe inspection robot. Section V describes the need of different mechanisms. Section VI describes development of steering mechanism for improvising working style of in-pipe inspection robot. Section VII provides summary and section VIII provides the conclusion and future scope.

II. Power Source of In-Pipe Inspection Robot

A. DC motor
DC motor is mainly used to control the moving speed of the robot. Also DC motor can be used to change the contact angles of the legs and to twist the robot body around 360 degree at a pipe branch.

B. Air pressure system
The air pressure system is composed of air compressor, solenoid valves and air hoses. A solenoid valve is an electromechanical valve for use with liquid or gas controlled by running or stopping an electric current. Compressed air that comes out from air compressor is supplied to solenoid valve and solenoid valve delivers compressed air to air cylinder of robot.

III. Review of In-Pipe Inspection Robots

A. In-Pipe Inspection Robot 1
In this robot mechanism movement is copied from both the inchworm and the wall press type in nature. For the structure of robot, the proposed mechanism mimicked structure of a folding umbrella. The structure of robot is based on 4-bar-link. Size of whole structure can be changed according to change of length of link. Link of the top portion has motion that goes up and down vertically by sliding. Using this, robot gives pressure to pipe and is endured through the friction between the link of the top portion and the pipe.

![Figure 2 Mechanism of robot [17]](image)

As Fig. 11. Shows the in-pipe robot is composed of one expansion device, two clamping devices, and two universal joints. The expansion device uses a standard cylinder, while the clamping device uses a magnetic rodless cylinder. Using 4-bar-link on front and back side of robot, size of whole structure can be changed according to change of length of link. When pipe was established horizontally or vertically, enough bearing power of robot is required in order to move in pipe. Robot must be able to pass bent pipe to move smoothly in the pipe. Expansive leg mechanism is connected with universal joint to give flexibility to robot. Universal joint is a joint in a rigid rod that allows the rod to 'bend' in any direction, and is commonly used in shafts that transmit rotary motion. It consists of a pair of ordinary hinges located close together, but oriented at 90° relative to each other.

B. In-pipe Inspection Robot 2
Fig. 3 shows in-pipe inspection robot which consist of a fore leg system, a rear leg system and a body. The fore and rear leg system are designed as linkage mechanism.
The fore and rear leg system consist of three legs respectively. Each leg has two wheels. Three legs of the each leg system have only a DC motor that controls the moving speed of the legs. Moreover, the fore and rear leg system has another motor, respectively to change the contact angle of the legs.

Three legs of the each leg system are arranged 120 degrees to each other by using worm gear system. The worm gear system is constructed by two helical gear sets. The front and back part of the robot body have a joint respectively. Each joint has a RC servo motor. Also, a DC motor is installed in the body so that the body can be twisted to around 360 degree at a pipe branch.

C. LS-01

LS-01 model is as shown in Fig.13. LS-01 uses a simple 4-wheeled type robot with foldable top platform acts as the camera holder, called holder for fibre optic camera (HFOC). LS-01 uses a standard differential drive system based on the caterpillar type robot that demand much more grip on the walls of the pipeline. This system allows the robot motion to be controlled smoothly. The rectangular-shape structure is used to house all the components. The robot will enter the boiler header and traverse along the pipe. While moving, the camera captures the view inside the boiler header and transmits the visual through the feed cable to outside viewer.

D. MRINSPECT I

Fig. 5 (a) and (b) shows the prototype and the kinematic scheme of the in-pipe inspection robot called MRINSPECT I (Multifunctional Robotic crawler for INpipe inSPECTion). It has six slider-crank mechanisms, arranged at 120˚ one from each other, each of these having a driving wheel. The wheels are actuated by DC motors and belt transmission. The robot is designed as the springs to actuate the mechanisms with equal forces. This mechanism allows the robot to move within pipes with horizontal, vertical, and elbow-typed portions. The movement of the robot within T junctions is not possible.
E. MRINSPECT II

Fig. 6 shows another type of mechanism known as modified pantograph which can assure the adaptability of robots to different pipe diameters used in the structure of the MRINSPECT II robot. This mechanism allows the movement of the wheels along the radial direction. This aspect is very important, because distortion forces no longer appear, as the robot passes over the obstacles. For the control of the pushing force over the inner surface of the pipe, a linear actuator and two position sensors are used.

Figure 6 (a) MRINSPECT II (b) its mechanism [15]

(a)  
(b)

F. MRINSPECT IV

Steering mechanism of MRINSPECT IV is shown in Fig. 7. MRINSPECT IV composed of 1) a body frame that mounts a CCD camera assembly and driving modules with foldable linkages 2) a camera assembly which is for the navigation and the visual inspection of the pipelines and 3) three modularized driving modules which are located circumferentially with 120° apart.

Figure 7 MRINSPECT IV [16]

Front wheel set  Rear wheel set
Driving module

A driving module consists of a DC motor with an encoder and a reducer, several wheels and casings. The driving units can be controlled independently and thus they amplify the tractive forces as well as provide steering capability.

To provide the sufficient tracting forces and flexibility in navigation, a body frame designed. At the end of the legs on the body frame three driving modules are fixed 120° apart circumferentially.

IV. Comparative Analysis Of Existing In-Pipe Inspection Robots

Table 1 Comparison of Existing IPIR

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Robot</th>
<th>Author, University &amp; year</th>
<th>Mechanism</th>
<th>Remark</th>
</tr>
</thead>
</table>
| 1.      | In-pipe Inspection Robot 1 | Yun-Jong Kim, Kyung-Hyun Yoon et al., 2009 | Four bar link mechanism | - Movement through T junction is not possible  
- Compressed air as energy source |
| 2.      | In-pipe Inspection Robot 2 | Hun-ok Lim & Taku Ohki, Kanagawa, 2009 | worm & worm wheel mechanism | - Difficult to construct  
- More power consumption |
| 3.      | LS 01         | Mohd Zafri Baharuddin, Juniza Md Saad et al., Tenaga Nasional Jalan, 2012 | Simple 4-wheeled type Mechanism | - Movement through only straight pipes |
V. Need of Different Mechanisms

Following are the needs of in-pipe inspection robot:

- Simple mechanism
- Higher expansion range of legs
- Low power consumption
- Faster speed
- Accuracy in movement
- Low weight
- Should pass through various pipe elements
- User friendly

VI. Developed Steering Mechanism For Improvising Working Style Of In-Pipe Inspection Robot

Figure 8 and 9 shows the modified steering mechanism of an in-pipe inspection robot. The robot mainly employs aluminium as structural material. This robot composed of body, fore leg system, rear leg system and springs. Robot body is hollow rectangular. Four brackets are welded on the faces so as to support the robot leg. Each leg system consists of a DC motor, belt, pulley, wheel and spring. DC motor is prime mover for this robot which is used to drive the robot. Motion is transmitted from motor shaft to robot wheel by using belt drive.

![Figure 8 Top view of robot](image)

Coiled spring is attached to each leg and a robot body. By using springs robot is able to move freely inside the pipes of 9 inch to 19 inch (250mm to 500mm) diameter range. Expansion range of leg is from $40^\circ$ to $90^\circ$

![Figure 9 Side view of robot](image)

Advantages of developed in-pipe inspection robot are as follows:
Differential inspection robot is able to pass through straight pipes freely inside the straight pipe, elbow and T joints of different diameter pipes. IEEE This developed in a system with active steering [19] [18] [17] [16] [15] [14] [13] [12] [11] [10] [9] [8] [7] [6] [5] [4] [3] [2] [1] crack detection and visual inspection of various diameter pipelines. Proper configuration of mechanical and electronic parts we can use this developed in-pipe inspection robot to detect crack and visualize inspection of various diameter pipelines.

VII. Summary

After doing comparative study of all above robots it is clear that some of the existing robots can freely pass through only straight pipes some of them passes through straight pipes and elbows and some robots pass through T-joints also. But somewhere these robots have complex steering mechanism. New developed in-pipe inspection robot can freely pass through straight pipes, elbows and reducer of various diameter pipes. Also, its driving mechanism is simple as compared to existing one.

VIII. Conclusion

In this paper mechanical construction and steering mechanism of in-pipe inspection robot is discussed. In-pipe inspection robots are mainly differ by power source, steering mechanism and their application. Existing in-pipe inspection robots are able to move freely inside the straight pipe, elbow and T joints of different diameter pipes. But driving mechanism of all the pipe inspection robots is complex. So, new and simple driving mechanism of in-pipe inspection robot has been developed. Developed in-pipe inspection robot is able to pass through straight pipelines, elbows and reducer.

In future, driving mechanism of developed robot can be modified to pass through T-joint. Also, by doing the proper configuration of mechanical and electronic parts we can use this developed in-pipe inspection robot for crack detection and visual inspection of various diameter pipelines.

References