A Critical Review on Development of Robots for Inspection and Cleaning Operations

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***Abstract*—** Nowadays, the vast majority of the tunnel inspection processes are performed manually by qualified operators. The process is subjective and the operators need to face very uncomfortable and even dangerous conditions such as dust environments, absence of light, or toxic substance exposition. Robotic technology can overcome many of these disadvantages and provide quality inspections collecting different types of data. This paper presents the key aspects of tunnel inspection and a survey of the developed robotic tunnel inspection systems up to date. Additionally, two projects regarding automation of the processes involved and future trends will be discussed.

***Index Terms*— Magnetic wheel, in-pipe inspection, climbing, obstacle passing.**

1. INTRODUCTION

Lot of work has been done on the pipe cleaning robot up to now. Many types of robots had been invented. In this a lot of literature study is done to understand the mechanism of various types of in-pipe robots. Literature work is also done on various sensors that are used for inspection of in-pipe environment for detecting the flaws in the pipe.

Classification of In-Pipe Robots

Generally, in-pipe robots configured into the following six types:

i. Wheeled type
ii. Caterpillar type
iii. Wall-pressed type
iv. Walking type
v. Inchworm type
vi. PIG type(Pipe Inspection Gauges)

Wheeled type in-pipe robots are very simple in design. They will appear just like a regular robot. They can only use for pipes with horizontal sections. The main problem with this type of robots is that they can't give enough support to the robot structure while the robot is in motion inside the pipe line. Enough support can be provided to the body by maintaining more wheel track [1]. Fig.1 represents a typical wheeled type in-pipe robot for inspection purpose.

Fig 1 A typical wheeled type in-pipe robot [1]

Caterpillar type in-pipe robots will provide more gripping nature to the interior of the as compared to that of a standard wheeled type in-pipe robots. They are used in places where we require large grip with the pipe walls. Moreover, these robots are suitable for varying diameter pipes [1]. Fig.2 represents a typical caterpillar type in-pipe robot for inspection purpose.

Fig. 2 A typical caterpillar type robot [1]

Wall pressed type of pipe cleaning and inspection robots were very useful for the locomotion in the vertical pipes. This type of robot contains flexible links that can provide sufficient amount of force which will help the body to move in vertical pipes without slipping [2]. Fig.3 represents a typical wall pressed type in-pipe robot for inspection & cleaning purpose.

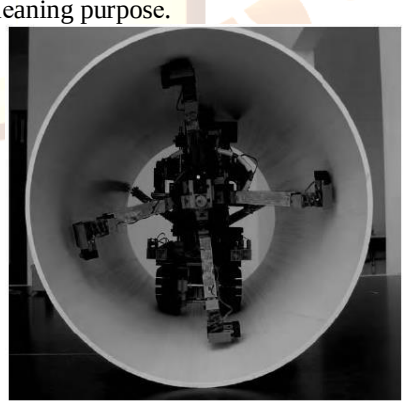

Fig.3 A typical wall pressed type robot [2]

Walking type in-pipe robots are rarely used in the industries due to its mechanical complexity. Its design is very sophisticated so it can't be used in all the time unless the situation demands [3].Fig.4 represents a typical walking type in-pipe robot for inspection & cleaning purpose.

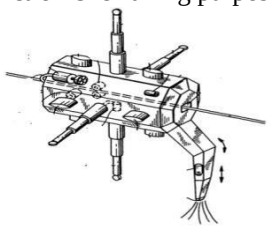

Fig 4 A typical walking type robot [3]

Inchworm type in-pipe robots are very rarely used for pipes with long distances. They are preferred using the pipes with small diameters of range in millimetres. Fig.5 represents a typical inchworm type in-pipe robot for inspection & cleaning purpose.

Fig.5 A typical inchworm type robot [4]

PIG type in-pipe robots are very famous for inspecting pipes with large diameters. It is one of the most commonly used pipe cleaning robot when there is a good amount of flow in the pipeline. By making small changes like adding a propeller, the motion of the robot can be controlled [38] as shown in Fig.6.

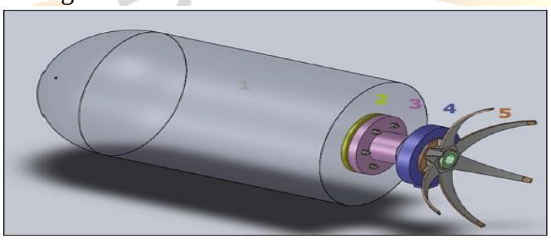

Fig.6 A typical PIG type robot [5]

This investigation has been focussed on the implemented methodologies on the categorised in-pipe robots for performing in-pipe cleaning and inspection tasks. Moreover, this work has been concentrated on review of various sensors used in robots to perform in-pipes inspection operation for determining flaws/cracks, corrosion affected areas, blocks and coated paint thickness. Various actuators like dc motors, servo motors, pneumatic operated and hydraulic operated are discussed in this review analysis to control the motion of various mechanical components of the robot.

2. REVIEW ON SENSORS USED FOR INSPECTION

There are several sensors are equipped to the robot for the inspection purpose. Inspection task includes detection of corrosion, blocks, flaws, cracks, tracing, locating, etc. in the pipe. Some of the sensors used for this purpose are:

a. Ultrasonic sensor

b. Magnetic sensor

c. Infrared sensor

d. Vision sensor(camera)

e. Tactile sensor

f. LASER (Light Amplification by Stimulated Emission of Radiation).

Most of the above mentioned sensors are range sensors and are used to measure the distance a point to the objects. The several range sensing techniques are

Triangulation This is the simplest method for measuring range. The light is emitted from the source to the object at an unknown distance 'D'. The object reflects the light back to the detector at an angle 'β' as shown in Fig.7. The distance between the source and the detector is already known and it is B.
Therefore the unknown distance D = B * tan β

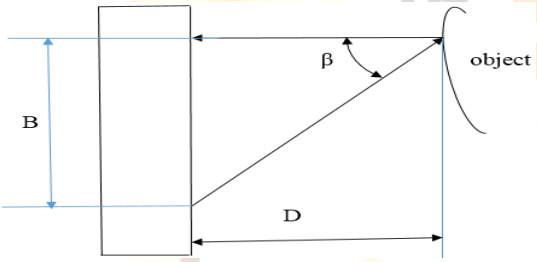

Fig.7 Representation of triangulation for measuring distance

Structured Lighting Approach This method uses light for calculating the range. In this method a light pattern is projected on to a set of objects as shown in Fig.8. Then according to the distortion caused by objects, the range is calculated from Eq. (2).

$D = \tan \lambda \beta$

Where λ is the focal length of the lens

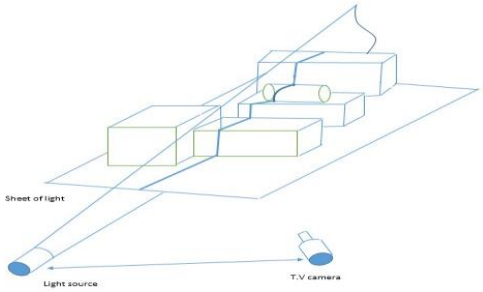

Fig.8 Representation of Structured Lighting Approach for measuring distance

Time-of-Flight Laser Range Finders A laser rangefinder which uses a laser beam to determine the distance to an object as shown in Fig.9.It operates on the time of flight principle by sending a laser pulse towards the object. It also measures the time taken by the pulse to be reflected off the target and returned to the sender.

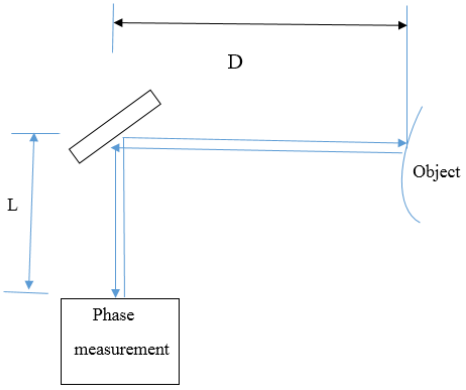

Fig.9 Representation of triangulation for measuring distance

In-pipe inspection using ultrasonic sensor

Ultrasonic sensor is one of the commonly used sensors that is being used for the distance measurement and can also be used for the inspection of the pipe. The sensor uses the ultrasonic waves for finding the obstacles in the pipe. The working principle of a typical ultrasonic sensor is represented in Fig.10. In order to inspect the in-pipe environment and detect the flaws in the pipe, ultrasonic sensor has been used inpast research work [1],[6],[7], [8], [9], [10], [11].

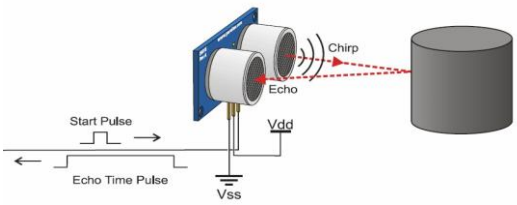

Fig.10Working principle ultrasonic sensor

In-pipe inspection using magnetic sensors

Magnetic sensors are commonly used to communication (between the user & robot) in the pipe. These sensors reduce the shielding effect in the metallic pipes. Many experimental results gave useful output in communication when magnetic sensors are used in the robot. The working principle of a typical magnetic sensor is represented in Fig.11. A magnetic sensor has been used by Choi et al. [9], Qi et al. [10] for tracing and locating the robot in the underground pipes.

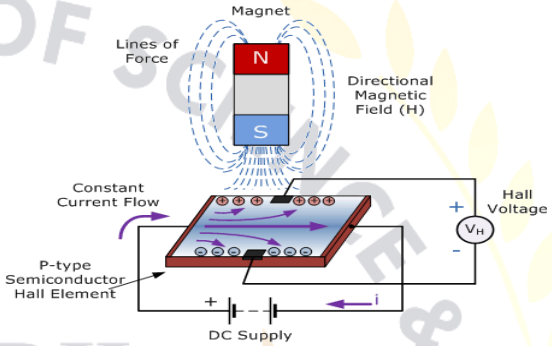

Fig.11Working principle magnetic sensor

In-pipe inspection using infrared sensors

Infrared sensors are just like the ultrasonic sensors. They use infrared waves for detecting motion of robot inside the pipe on the basis of temperature. This kind of sensors can be used for detecting the path of robot in the pipeline. The working principle of a typical infrared sensor is represented in Fig.12. In order to inspect the inside area of the pipe infrared sensors have been used in [8]

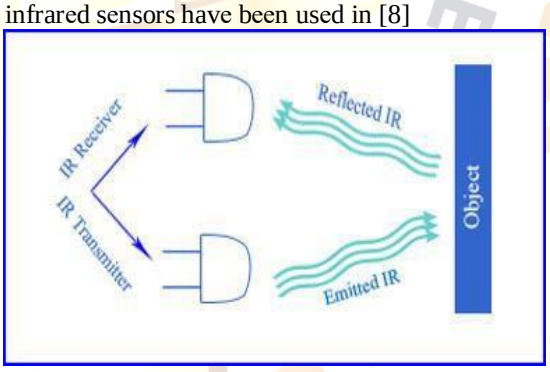

Fig.12Working principle infrared sensor

In-pipe inspection using vision sensors

Vision sensors (cameras) are very useful for performing inspection tasks in pipe lines. The vision sensor is a charged coupled device. This sensor gives the most accurate information about the interior of pipes. It is very useful for monitoring the pipe with the help of a display device. In order to inspect the inside pipe environment [1], [7], [8], [11], [12], [13], [14], [15], [16], [17], [18], visual

sensor (camera) has been.

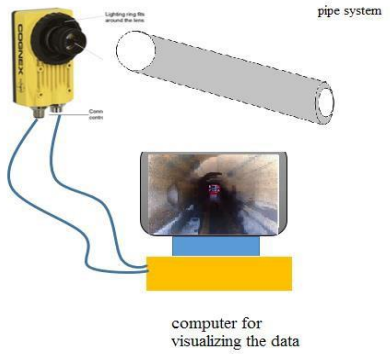

Fig.13 A typical vision sensor [8]

In-pipe inspection using tactile sensors

Tactile sensors give information about the inside environment of the pipe by staying in continuous contact with the pipe. This sensor can be very helpful in detecting the pipe structure and roughness caused by the corrosion and wastes accumulated in the pipe. The working principle of a typical tactile sensor is represented in Fig.11. There are different types of touch sensors those uses principle of capacitance, inductance, resistance etc. In order to detect paint thickness and flaws the pipe capacitive sensor has been used [2], [19].

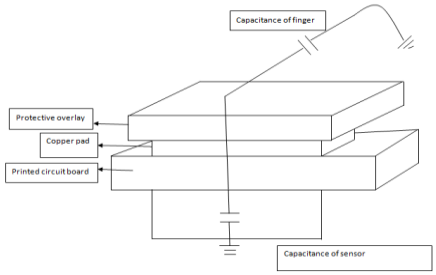

Fig. 14Working principle touch sensor

In-pipe inspection using LASER sensors

LASER (Light Amplification by Stimulated Emission of Radiation) is an electronic device that produces electromagnetic radiations. The working principle of a typical laser sensor is represented in Fig.12. It produces light by the method of optical amplification. For the purpose of inspection LASER has been used in [1], [8], [18].

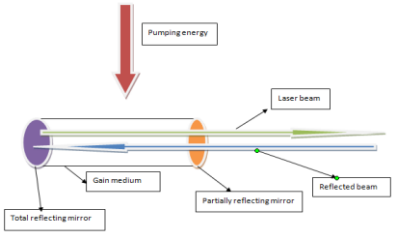

Fig.15 Working principle of ruby laser

Table 1 Sensors used by robots for performing inspection operation

SI. No	Type of sensor used	Reference number	Application
1.	Ultrasonic sensor	[1], [6], [7], [8], [9], [10], [11].	Detecting flaws in the pipe.
2.	Magnetic sensor	[9], [10]	Tracing and locating the robot in the underground pipes.
3.	Infrared sensor	[8]	Inspection of pipe environment.
4.	Vision sensor	[1], [5], [7], [8], [9] [11], [12], [13], [14], [15], [16], [17], [18]	Visual inspection of the pipe.
5.	Touch /capacitive sensor	[2], [19]	To detect paint thickness and flaws the pipe
6.	LASER	[1], [8], [18].	For the purpose of detecting flaws

3. Review on Actuators used for Motion Control

Actuators are the devices used for causing relative motion between the adjacent links. The may be of linear of rotary. Robots will perform their tasks (may be of inspection or cleaning) in the pipeline according to the energy/power supplied to the joints. The following three many types of actuators are generally used for imparting motion to the mechanical parts of in-pipe robots.

Electrical actuator takes the electrical energy as the input and converts it into a mechanical form. Some of the electrical actuators used in-pipe robots are DC motors, and servo motors (Fig.13). In order to do move the robot inside the pipe, servo motor has been used in [18] and dc motor has been used in [13], [15].

CONCLUSION AND FUTURE WORK

After having presented an overview of the existing locomo- tion concepts for in-pipe inspection, this paper first describes an application that requires a compact system that can deal with high abrupt diameter changes and vertical climbing. It shows that magnetic wheels are the best concept for this ferromagnetic environment. It is then shown why an adapted magnetic wheel is necessary in order to negotiate the complex obstacles of the considered application. A promising solution to this locomotion problem is then pre- sented: an innovative active magnetic wheel unit incorporating an active lifter-stabilizer mechanism. It is shown how this locomotion concept can be used in order to negotiate complex shaped structures. The paper finally presents its advantages towards robot downsizing and simplification, by explaining that a 2 aligned wheels structure is sufficient.

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