



## DEVELOPMENTS IN INPIPE INSPECTION ROBOT: A REVIEW

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### Abstract

*Pipeline inspection robots are gaining importance and have seen several developments throughout the past decade. Developing a pipeline inspection robot can specifically overcome the issues of humans in labor and their intervention in an inconvenient condition during repair and maintenance inside the pipeline. This survey shows the advancements made in the field of pipeline inspection robots by classifying them according to their type of locomotion. The locomotion's are divided into seven basic types and prototypes are developed based on these motions. Each prototype has its benefits and drawbacks based on their purpose of inspection. Different models are designed and validated for ensuring their functionality and performance. This review attempts to present the capabilities of various inspection robot models and compares their performance. This will provide insights into selection, developments and research gaps in this domain.*

**Keywords:** In-pipe robot, Pipelines, Mobile robots, Inspection, Shape adaptability, IPIR

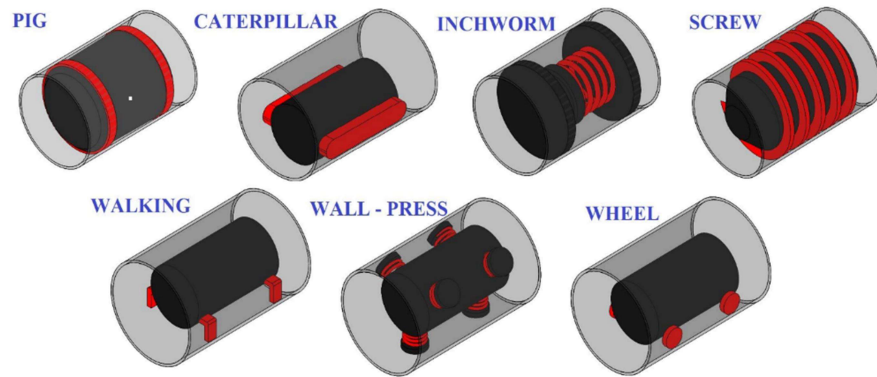
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### I. Introduction

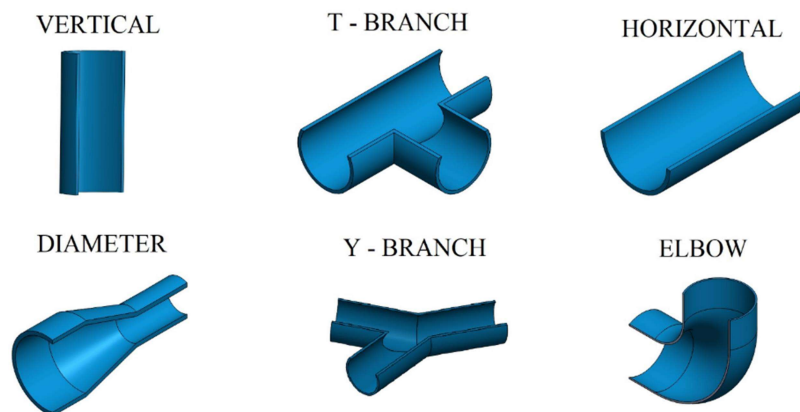
Pipelines are used for transporting fluids and gases that are monitored for efficient functioning to avoid issues like cracks, corrosion, ageing and mechanical damages. The pipeline inspection, maintenance and cleanup are expensive; therefore during these situations robots play a vital role by becoming a valuable asset. In this survey the pipeline inspection robots are categorized by their locomotion namely Pipeline Inspection Gauge (PIG), caterpillar-type locomotion, wheel-type locomotion, screw-type locomotion, inchworm-type locomotion, wall press-type locomotion and walking-type locomotion [IV] (Fig 1). Every class has its benefits and downsides based on its ability to resolve a selected drawback. The robots

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irrespective of its locomotion face difficulties in moving through the horizontal, vertical, t-branch, y-branch, elbow and varying diameter pipelines [I] (Fig 2).



**Fig. 1:** Different in-pipe inspection robots [IV]



**Fig. 2:** Commonly used pipeline bends and joints [I]

## II. Developed in-Pipe Inspection Robot

Many research papers based on recent developments in pipeline inspection robots are collected and reviewed. The pipeline robots are categorized based on their mode of locomotion. A concise description of their mechanism, navigation and inspection techniques for each of these different types are given below.

### Pipeline Inspection Gauge (PIG)

PIG is an inspection robot used for inspecting the pipelines and this works using the flowing pressure of water. The PIG is launched into the pipe using a PIG launcher and it is received at the other end of the pipe using the PIG receiver. PIG was developed to clean and scrape pipes to eliminate rust along with other contaminants inside the pipe. Smart PIG is developed for pipeline inspection by shell development in 1961 using electromagnetic methods to collect information. Smart PIG is used for cleaning and inspection purposes they don't have to stop the flow of

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product in pipeline to clean or inspect. Their main goal is to clean the pipelines without leaving any debris behind that can reduce the performance of the pipelines which results in increased cost and cause corrosion.

In the past few years many PIG type pipeline inspection robots were developed and they all used different sensors for inspecting the pipelines. The existing problems of PIG are travelling for a long distance with wired connection, due to changes in pipe diameter, passing through acute bends and branches due to the lack of flexibility and the unavoidable effect of fluid hammer due to the rapid opening and closing of valves. Such drawbacks were overcome using a wireless communication for long distance control, adjustable structure for passing through variable pipe diameter, improved flexibility and maneuverability for passing through bends and branches and water can flow through the PIG which reduces the effect of fluid hammer [I].

Even after these developments there were still problems in the PIG system like the sudden change in diameter of the pipeline increases the speed of the fluid which generates a pressure inside the pipelines that reduces the efficiency of the process. This problem was solved by developing a PIG that does not influence the velocity and pressure of the fluid inside the pipeline. This PIG not only detects cracks on the pipe but also detects the corrosion or metal losses [XII].

PIG have a very hard passing through bends and to improve this Ramirez-Martinez A et al., [XV] developed a geometric adjustment PIG that can pass through concave and convex pipelines by carrying an ultrasonic sensor that improves the ultrasound technique. This PIG reduces the risk of PIG being stuck inside the pipeline and also has a UN actuated system that reduces the energy consumed by the system.

### **Screw Type**

Screw type pipeline inspection robot generally use helical motion to move inside the pipeline and they are very easy to control and handle due to its simple structure. This type of locomotion doesn't drag the body of the robot inside the pipeline so they won't infect the internal surface of the pipe. The screw type robot is very flexible as it can adapt to pipelines with varying diameter and the structure of the robot allows the water to pass by without blocking them. The major ability of the screw type robot is to climb vertical pipelines without any difficulty this is due to their inability to back drive because of their angled wheels.

The problems faced by screw type pipeline inspection robots are moving through bends, branches and vertical pipes and these are solved by a screw type robot developed by Kakogawa A et al., [V] that uses a helical type of motion to move inside the pipelines. Even after many developments the screw type robots confronted many problems like facing obstacle inside the pipes, inability to steer at bends and branches. Li P et al., [X] designed a pipeline inspection robot that can pass through obstacles and steer through branches furthermore they can also adapt to change in structure of the pipeline like moving in circular and square pipelines.

Li T et al., [XI] mentioned that there is an increase in cost during the stages of developing and testing a robot. To overcome this problem, they designed and

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simulated a screw type pipeline inspection robot using CMD language of ADAMS software. This process not only eliminated the cost but also reduced the time by identifying the problems faced by this design.

### **Inchworm Type**

The inchworm pipeline robot moves like a worm by expanding and contracting the robot's body. The main problem with the robots is their traction ability and compared with other types of locomotion this has a very less traction ability. Qiao J et al., [XIV] developed an inchworm robot using the self-locking mechanism and proposed two flexible joints to increase the traction capability of the robot. The first is the screw linkage and second is the spring linkage these two helped in the process of increasing the traction between the robot and the pipe. Compared to the traditional method which has a static force of 0.35N the static force when measured experimentally was 15.2 N.

Few years along the line Fang D et al., [III] developed an inchworm robot using the self-locking and telescopic mechanism for continuous propulsion which guaranteed a locking force of 586 N with a moving speed of 0.11 m/s. Takagi M et al., [XXI] developed an inchworm robot using soft materials and Double Network hydrogel (DN gel) to control the friction between the pipe that helps in moving through narrow or closed spaces which eliminates the traditional method of making robots using hard materials.

### **Wall Press Type**

Wall press pipeline inspection robot uses spring tension for establishing contact within the robot and the internal wall of the surface to move inside the pipeline. Caterpillar type pipeline inspection robot also comes under wall press because it uses the traction force for shape adaptability and generates friction to move inside pipelines. This is due to their large area of contact that they cover when compared to other types and hence this system is more stable among them. Caterpillar type inspection robots are tested for different pipeline diameters like 80 – 100 mm [VI] and 150 mm [VII]. Kwon YS et al., [VI] developed a caterpillar type robot using a differential drive for steering and four-bar mechanism for gripping the walls of the pipe during varying pipeline diameters. Kim JH et al., [VII] developed "FAMPER" a caterpillar type pipeline inspection robot that uses 4 tracked modules which functions using 2 motors each and to offer steering capability each caterpillar wheel is controlled independently to access 45° elbows, 90° elbows, t-branch and y-branches. "FAMPER" showed that the caterpillar type configuration is superior in all types of pipeline network. Venkateswaran S et al., [XXII] developed a robot to eliminate the difficulty to maneuver through curves and intersections a design for the passive configuration with a tensegrity structure that practices 3 tension springs and universal joint is offered. The analyzed results are useful for forming the digital prototype of the whole robot.

The problems faced by wall press robot are to move inside unknown pipelines, controlling them through remote and climbing a slope. Wahed MA et al., [XXIII] developed a robot using wall press mechanism to move through a pipeline of

varying diameter of 150mm to 230 mm and can climb a 30° slope furthermore the whole robot operation is remotely controlled.

Kim HM et al., [VIII] developed a wall press robot for a gas pipeline with a diameter of 150 mm and the mechanism consists of a multi-axial differential gear driven by a single motor. The major advantage of this design is that it can adapt to different geometries like elbows with any additional control. Brown L et al., [II] developed an autonomous robot that can determine the parameters of the elbow inside unknown oil, gas and water pipelines this is attainable by utilizing three bespoke feeler sensors and an algorithm for detecting the corners with a mean deviation of 4.69°.

### **Wheel Type**

The wheel type internal pipeline inspection robot is a normal mobile robot which works on a basic mechanism by rotating the wheels by using various actuators for the driving force [IV]. These robots are mounted with some inspection sensors and they are sent into the pipelines for examination. Even though so many researches are done on wheel type inspection robots there is still a great difficulty in moving through bent pipes (or) vertical pipes.

To effectively observe, detect and diagnose a problem occurring in a pipeline a wheel type pipeline inspection robot was developed by Mohammed MN et al., [XIII] that carries a camera and displays the atmosphere inside the pipeline. This robot is fully autonomous and carries an ultrasonic sensor for detecting the problems occurring inside the pipelines.

Hidemasa Sawabe et al., [XVI] proposed a controller mode by which a mobile wheeled robot transits within a tank. For each unit, the robot used two distinct forms anti-slip and regular. Traction control modules stop the robot from sliding through a vertical tube. Normal mode modules provide a bent pipe to travel. Through changing modules within the two modes, the robot can toggle between straight and curved tubes. The switching module method was based on a simplified form. Experiments have shown the efficacy of the control method. It is assumed that if the operator takes a curve from several pre-planned curves to match a bent or branched pipe, the robot will travel in a pipeline using the proposed form.

Atsushi Kakogawa and Shugen Ma [IX] developed a wheel type pipeline inspection robot with a shadow-based activity system. The purpose of designing this robot is for simplifying the functional complex. The approach used for this function includes differential mechanism, multiple DOF arrangement on common axis. The camera is used for inspection as well as for operation assistance. They also developed many prototypes of wheel type pipeline inspection robot to overcome problems like pipeline diameter variation, ability to turn automatically at branches and to reduce the distance travelled by the robot due to friction caused by communication & power cables that increases the cost of the process.



**Walking / Legged Type**

The walking type pipeline inspection robots are used for their mobility that is achieved by adapting to the changing geometry of the pipelines. A six-legged walking pipeline robot is developed using footstep algorithm that can move in curved pipes. These robots use mapping of pipes and plans a footstep on the surface of the pipe [XVII]. These kinds of robots require information which is available using the data gathered by the sensors. Single legged motion robot shows an improvement in system control during the existence of data quantization and noise sensor. The reaction force of the robot should be attached to the observer design that uses an observer in the finished robot mode and shows better results during the presence of noise [XVIII].

The linearization of the rotation matrix is used to signify the inverse kinematics like a quadratic program that allows it to solve using a numeric method. The solution uses small angle rotation which reduces the limitations of the orthogonal group and makes the solution drift by violating the orthogonal limitations. It showed that the violation of the orthogonal limitation will not depend on approximation parameter [XIX]. A motion planning algorithm is introduced for the pipeline robot and this algorithm is built on RRT (Rapidly exploring Random Trees) which assists the robot in a bent pipe with branches and obstacles. The algorithm behavior affects the computation time and value of the solutions. The algorithm works better in smaller pipes with simple structure and it shows a bad performance when the number of bends is increased [XX].

**III. Summary**

Table 1 shows the comparison on Inpipe robots. This table shows the advantages and disadvantages between different types of locomotion in Inpipe inspection robots.

Table 2 shows the performance table. Here, the type of pipelines are denoted as H (Horizontal Pipe), V (Vertical pipe), T (T – Joint), E (Elbow), VPD (Variable Pipe Diameter) and when the robot meets the expectations it will be denoted as ✓ (yes) and if it doesn't meet the expectations it is denoted as ✗ (no).

**Table 1: Comparison on Inpipe robots**

Types of Locomotion	Advantages	Disadvantages
PIG	Does not stop the flow of fluid. Moves due to the pressure of fluid. Can travel through long distance. Time taken to complete the process is less.	Difficult to move in varying diameter pipelines. Sharp turns are not possible.
Screw	Reduces the damage caused in the inner wall of the pipeline. Does not stop the flow of fluid. Moves through curved, horizontal, vertical and varying diameter pipes.	Inability to back drive. Complexity in steering.

Inchworm	Gripping force is high when compared to other types. Moves through curved, horizontal, vertical and varying diameter pipes.	Less traction force when compared to other types.
Wall-press	Lighter and smaller in structure. High friction in the line of motion between the robot and the interior surface of the pipe. Large Contact area. Moves through curved, horizontal, vertical and varying diameter pipes.	High friction damages the inner wall of the pipe. Complexity in steering.
Wheel	Simple mechanism. Less friction between robot and pipes inner wall. High mobility. Moves through curved, horizontal, vertical and varying diameter pipes.	Slippage is high.
Walking / Legged	Causes only minor damage to the walls of the pipe. Slippage is minimum. Climbs vertical pipe easily. Moves through curved, horizontal, vertical and varying diameter pipes.	Complicated mechanism. Gets stuck inside pipe when the mechanism fails.

**Table 2:Performance table**

Authors / year [reference]	Type of Study	Type of Locomotion	Type of control	H	V	T	E	VPD
Brown L et al.,(2019) Ref [II]	Experimental Theoretical	WALL PRESS	Autonomous	✓	✓	✓	✓	✓
Fang D et al., (2018) Ref [III]	Experimental Theoretical	INCHWORM	Manual	✓	✗	✗	✗	✓
Kakogawa A et al., (2010) Ref [V]	Experimental Theoretical	SCREW	Manual	✓	✓	✓	✓	✗
Kwon Y S et al., (2012) Ref [VI]	Experimental Theoretical	CATERPILLAR	Manual	✓	✓	✓	✓	✓
Kim J H et al., (2010) Ref [VII]	Experimental Theoretical	CATERPILLAR	Autonomous	✓	✓	✓	✓	✓
Kim HM et al., (2013) Ref [VIII]	Experimental Theoretical	WALL PRESS	Manual	✓	✓	✗	✓	✗

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Kakogawa A et al., (2019) Ref [IX]	Experimental Theoretical	WHEEL	Manual	✓	✓	✓	✓	✓
Li P et al., (2018) Ref [X]	Theoretical	SCREW	-	✓	*	*	✓	*
Li T et al., (2019) Ref [XI]	Theoretical	SCREW	-	✓	✓	*	✓	*
Mohammed MN et al., (2018) Ref [XIII]	Experimental	WHEEL	Autonomous	✓	*	*	*	*
Qiao J et al., (2012) Ref [XIV]	Experimental Theoretical	INCHWORM	Manual	✓	*	*	*	*
Sawabe H et al., (2019) Ref [XVI]	Experimental Theoretical	WHEEL	Manual	✓	✓	✓	✓	✓
Takagi M et al., (2019) Ref [XXI]	Experimental Theoretical	INCHWORM	Manual	✓	*	*	*	*
Venkateswaran S et al., (2019) Ref [XXII]	Experimental Theoretical	CATERPILLAR	Manual	✓	✓	✓	✓	✓
WahedM A et al., (2017) Ref [XXIII]	Experimental Theoretical	WALL PRESS	Manual	✓	✓	*	*	*

#### IV. Conclusion

This paper presents a concise review of Inpipe inspection robots that are improving safety and plant reliability. Numerous researches and developments are done on Inpipe inspection robots to assist the maintenance and operation issues economically. Every Inpipe inspection robots are created for a specific purpose and therefore the robots developed completes the objective by fulfilling their purpose by inspecting the pipelines. These robots facilitate in solving the maintenance and operation issues economically. This paper categorized the Inpipe inspection robots according to their locomotion and reviewed them.

Different types of pipeline inspection robots have their own advantages and disadvantage. The PIG robot still finds it difficult to pass through varying diameter pipelines and to take sharp turns inside pipes. The screw type pipeline inspection robot still needs to improve its steering and back drive capability. The inchworm type inspection robot must develop its traction ability and on the other hand the wall press type inspection robot must find a way to not damage the inner wall of the pipes by reducing the traction to a required amount in the middle of robot and the pipes wall.

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The wheel pipeline inspection robot still needs to improve its steering capability and reduce slipping. The walking type inspection robot has a room for development and many researches needs to be done on walking type pipeline inspection robot. This study provides you with the Up-to-date developments done on pipeline inspection robots conclude by expressing that there's a desire to optimize the design of the robot to scale back its complex mechanism that permits the robot to examine pipelines of various diameter. The development of micro internal pipeline inspection robots reduces the traction force created by certain types of pipeline locomotion's (caterpillar type, wall press type) by permitting them to pass through small and large diameter pipelines this proves that robots play a serious role in automation, observation and inspection that helps in rising the speed, exactness and accuracy. Thus, internal pipeline inspection robot still plays an active role certain the pipeline system healthy and operational. In the near future we can see many developments on pipeline inspection robots as long as we have pipes.

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