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Research Article

Design and Development of Internal Pipe Inspection Robot

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ABSTRACT

In this modern era, the robotics has become the most significant key in almost all working fields of engineering where work is done without or with minimal physical interference of humans. In the field of engineering the robots are being used to reduce the work effort, to ease the work, to do the work in the areas where humans are inaccessible, to give precision in work, etc. In essence, robots are utilized to boost performance and efficiency while reducing manufacturing costs. The most reliable and secure method of transferring liquid and gas is through a pipeline. Robots have already taken over the production sector in the pipeline industries, they are also utilized in the inspection sector. Since the majority of the fluids that are delivered from pipes are toxic and hazardous, direct human contact is prohibited in this inspection area. The defects occurs external areas of pipe can be easily noticeable and fixable, but those that arise inside the pipe are more difficult to detect and more challenging to fix. So the internal pipe inspection robots are designed to ease the inspection for internal area of pipeline. These robots are designed to move inside the narrow area of pipe to detect, locate and fix the defect. The main objective of current work is to reduce the human effort and provide safety in pipeline inspection sector. This robot can move along the various diameters pipes within its prescribed range. With the help of DC motor the forward and reverse movement is obtained, while IR sensors and camera used to detect the defects like blockage, holes or cracks, dents, leakages, etc.

Keywords: Inspection, Pipeline, Robot, Defect Detection, Design, Manufacturing

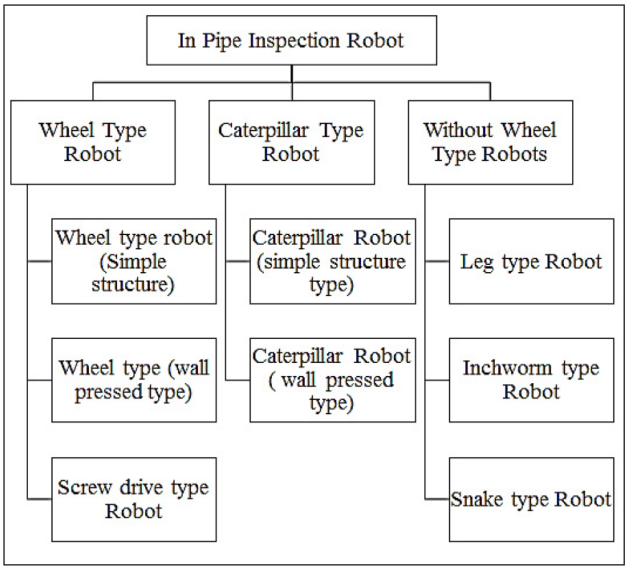
Introduction

Robotics is the most advanced and constantly emerging sector in the field of engineering. Robots are being used in nearly every sector to reduce human effort and most importantly to improve productivity and efficiency. Robots are designed to reach out and do tasks efficiently in Hazardous/ Dangerous work locations that are often inaccessible by humans while many industries have hazardous work environments that make it difficult for humans to operate. Pipelines have been proven to be the safest way of transferring liquid and gas. Pipelines could be used to convey hazardous chemicals and gases, hence regular inspection must be done from external and internal area of the pipeline to maintain safety. It is not difficult task to inspect external surface of pipeline, but it may be a challenging for human to inspect internal area of pipeline. It is a fact that only direct contact or access to the pipe wall will result in reliable and accurate test results. Consequently, several different types are robots are being used in the pipeline industry for the inspection purpose to inspect precisely in the inaccessible areas of pipe.The regular and precise inspection is necessary to ensure the safety in pipeline industry. It is possible for piping networks to develop a variety of problems such as ageing, corrosion, cracks, mechanical damage that result in the loss of the transported medium and can also have an impact on the environment. As a result, it is increasingly important to inspect pipes because failing to do so could result in serious industrial accidents that cause environmental contamination and the loss of human lives.[1] To inspect internal area of pipeline, the requirement for robot is to detect blockage, cracks, blow holes, dents, material loss, etc.

In this research work designing and development of internal pipe inspection robot is carried out. The robot is designed with four bar mechanisms that can alter its diameter with testing pipe within a specified range, accompanied with an electronic system that can identify defects and allow it to move along the pipeline within a predetermined range. A survey has been done for the types of robots which is currently used in the industries for the inspection purpose. All possible designs are considered for the inspection application and taking into all considerations, selected a wall pressed type design. The robot is initially designed using the Fusion 360 software, then the 3D model is brought into the 2D drafting by dissecting each component. After taking into consideration all design parameters, the model is successfully fabricated and tested.

Research

Inspection is necessary in almost all fields of pipeline sector for ensuring safety. To prevent further damage or flaws such cracks, holes, corrosion, material loss, blockage, etc., periodic inspection is necessary. These kinds of defects typically occurs in the chemical pipeline industry. The inner surface of pipelines is affected by toxic chemicals, leading to corrosion, metal loss, blow holes, cracks. Numerous companies are offering inspection services to the pipeline industry in a variety of packages, such as inspection and cleaning or inspection, cleaning, repairs. Research found that numerous studies have been conductedfor enhancing its control, range, mechanism, vision, inspection capability. In-pipe inspection robots available in a multitude of varieties that are categorized based on their movement patterns. Each robot's design is dependent on its particular application.[2] There are several types of robots are available in the market having three categories and eight sub categories depicted as below in Figure 1 and 2, depicts a few of the several robot kinds that are employed for various tasks in accordance with their particular designs.



Figuer 1.Classification of Robots Used For Inspection Purpose[1]

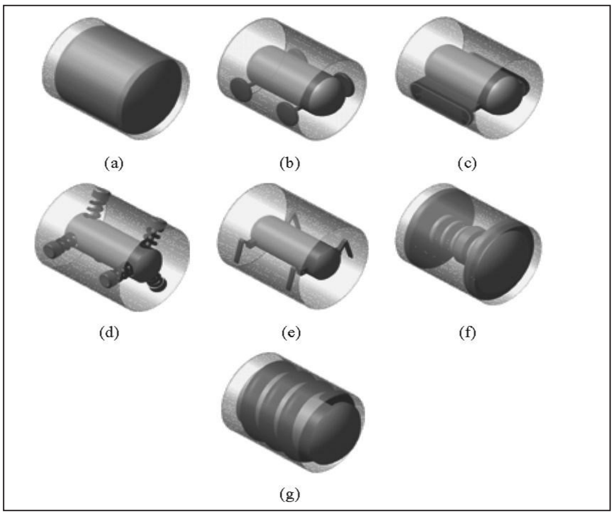
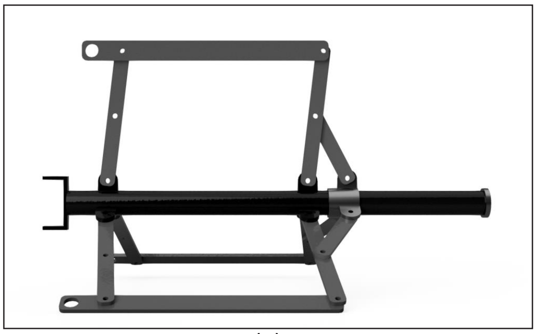


Figure 2.(a) Pig type robot (b) Wheel type robot (c) Caterpillar type robot (d) Wall-press type robot (e) Walking type robot (f) Inchworm type robot (g) Screw type robot[2]

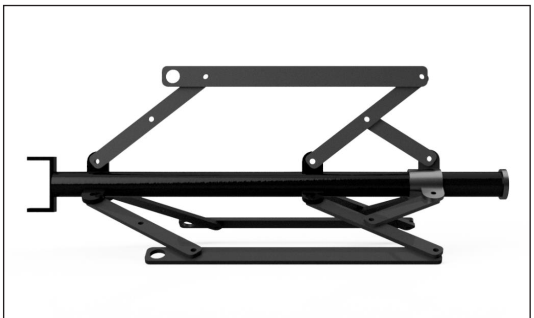
Design and Fabrication

To determine the best robot motion mechanism according to its operational conditions, many types of in-pipe inspection robots have been compared using various performance indicators like its horizontal and vertical mobility, Size and shape adaptability, Stability of robot, Motion efficiency. On the basis of factors considered we concluded that the Wall pressed type is a better choice as compared to other. Thus, a wheel type robot (Wall pressed type) makes more sense for our specified application.

In this robot four bar chain mechanism is used considering with three revolute pairs and one single prismatic pair, as shown in the Figure 3. The robot is having three legs are each equipped with a separate four-bar mechanism as shown in Figure 3. All three legs are attached to the main tubular bodycircumferentially with 120^0 apart. Total 6 wheels are mounted on the linkages and due to connection considerations and interactions between the elastic force at the body frame's main spring and the reaction forces of the wall, two wheels of the driving module move independently in the radial direction.[2] The major parts of the pipe inspection robot is fabricated by drilling and shearing operations. Rivets are used to connect the links to one another. Each of the four links in a single four-bar linkage is fastened with a rivet. The center body is riveted at a 120-degree angle to three connections. Therefore, drilling operations are required to make it easier for these rivets to be inserted. Here, 5 mm rivets are being used. Therefore, the drilled hole must be 5 mm or larger. From an MS sheet, the links themselves are severed. The MS sheet is approximately 4 mm thick. The single MS is divided into sheets with the necessary length and width. Additionally, welding is required to connect the joints that a rivet uses to keep the links in place. The robot's circuit box must also be attached, which requires welding a short C channel to the robot's rear side. The circuit box is attached on the back side which is made by PLA material with the 3D printing process. The 3D modelling of the robot is done on the fusion 360 software. Each part of the robot is designed according to its dimensional constraints. Initially the model is driven on the software simulation then after successful working results, it been taken to the next stage as manufacturing.



(a)



(b)

(c)

Figure 3.Four bar Mechanism used in PIR

The distance between the main body and the wheels is changed by the movement of links and a compression spring attached to the main body, which varies its diameter range according to compression and retraction of the spring. The robot is equipped with an electronic circuit that includes IR sensors and gas sensor on the rear to check for hole defects and hazardous or harmful gas which presents inside the pipeline. A camera is also mounted on the front to provide a view of the internal area of pipeline. The gas sensor we have used is MQ 135. A servo motor is also used to inspect the whole 360 degree inner area of pipeline. Two IR sensors are mounted in opposite position on the servo motor which is given 180 degree rotation which means it covers the whole 360 degree area of pipeline. The robot is driven by the DC motors having 30 rpm of speedwith both forward and reverse motion. The gripping wheels are used to avoid slipping in slurry or mud if present in the pipeline. Total 3 DC motors are used to give enough power to the robot and 6 wheels are used to give stability during inspection. The robot is made for the pipe of diameter ranges from 250 to 350 mm. It can go inside the pipeline according to the wire length. The operator can able to monitor all the visual view of inner pipeline and also with the help of IR sensors and gas sensor it gives the feedback to the operator on the display as hole or hazardous gas is detected.

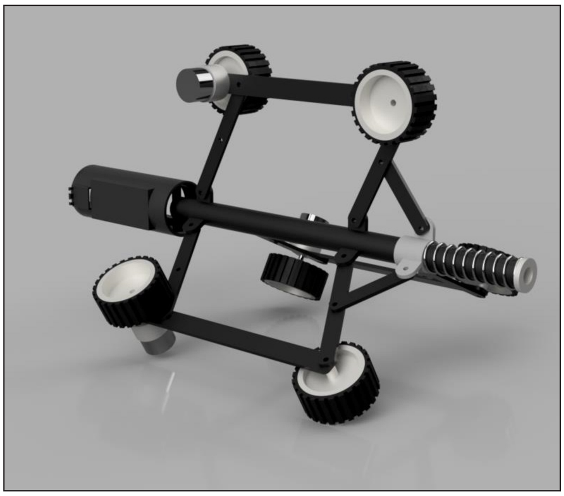


Figure 4.Front view of CAD design of Internal Pipe Inspection Robot

Figure 5.Rear view of CAD design of Internal Pipe Inspection Robot

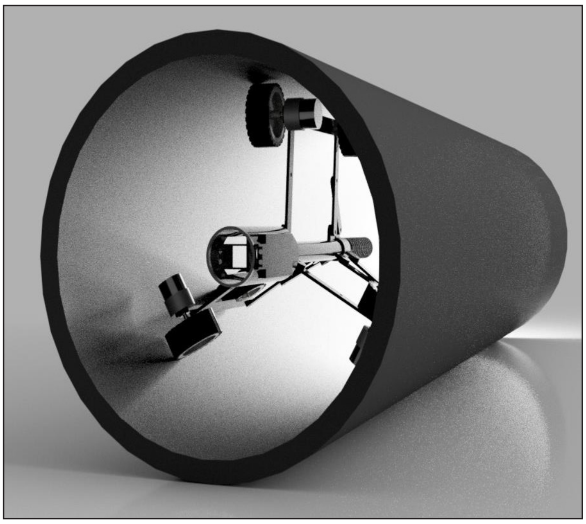


Figure 6.Working CAD design of Internal Pipe Inspection Robot

Working Methodology

Internal pipe inspection robot has three arms for better grip and crawl inside the pipe. To make it cost friendly and less in weight used only three arms. IPIR is loaded with three driving wheels of 10 rpm, 12 V DC motors. The speed of this motor is 30 rpm. The power given to these motors by 12 adapters. Because of three arms the load on each motor is equally distributed. The range of IPIR is moving in pipe diameter of 130mm to 170mm. Because of the spring used in it this adjustment of range is possible. The stiffness of spring is taken suitable for the sufficient grip inside the pipe. The arms of IPIR align with the wall of pipe using spring power. The spring is neither too stiff nor too loose, it is perfectly tuned. If the pipe inner wall is smooth or slippery IPIR can move easily. According to the traction force and for flexibility a body frame is designed. At the end of legs the supporting wheels are fixed 120^0 apart circumferentially. The distance between main shaft of body frame and link construction, it helps effective contact with wall of pipe line whatever diameter changes. Three legs of IPIR 120 degree apart from each other. The main body frame structure of IPIR is based on 4-Bar mechanism. This mechanism is similar to folding umbrella links. The size of IPIR is changed according to change of link length. The sliding sleeve is used to slide on mainframe of IPIR; this sleeve holds the spring to give pressure to pipe and wheel of IPIR. The IPIR moves inside the pipe forward and backward motion using driving wheels of speed 30 rpm. The speed is purposefully kept low to inspect properly, in high speed there may be possibility to miss any defect. To detect any hole inside the pipeline we are used IR sensors that can able to detect the hole which is min diameter of 5 mm within the 360 degree inside area of pipeline. Whenever the robot moves inside the pipeline, ir sensors mounted on the servo motor likely opposite to each other that means we have used 2 IR sensors to detect holes inside the pipeline. Each of the IR sensor covers 180 degree internal area of pipeline. Another thing we have implemented in the robot is that to detect hazardous gases which are harmful for human being such as carbon monoxide, chlorine, nitrogen dioxide and phosgene, etc. In this robot a Gas sensor is implemented to detect such type of hazardous gases. As IR sensor and Gas sensor, we also have integrated a visual inspection which can be done by a camera sensor. The camera is operated by the another controlling button on the remote. The viewing angle of camera is 70-80 degree. The image captured by camera is shown on screen devices. The pictures are sent through the cable.

The operator of IPIR can control it as well as see the images coming from inside on the screen, this helps to find any defect or any other damage. The location of any damage is judge by the distance of cable. The results of inspection are extracted using image processing display.

Actual model of Internal Pipe Inspection Robot is provided below:

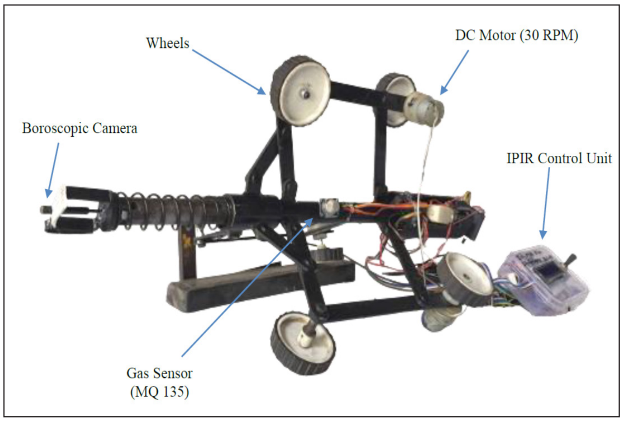


Figure 7.Actual developed Internal Pipe Inspection Robot with components used

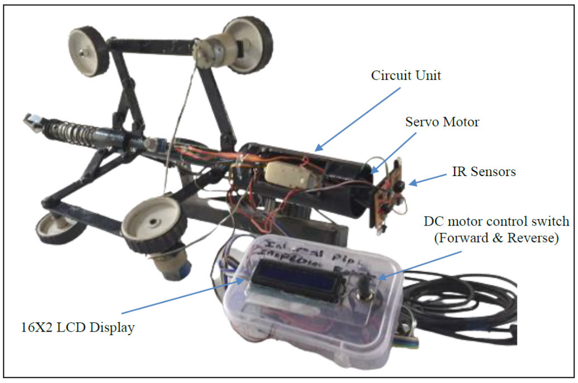


Figure 8.Electronic components used in the robot

The main purpose of designing any robot is to reduce the human effort and provide safety in the hazardous work areas. The IPIR is divided into major parts are robot, IR crack detector, a hazards gas detector and a visual camera inspection device. The hardware components are camera, IR sensor, gas sensor, display, Arduino, etc. In IPIR is mainly used in pipes and tunnels for crack detecting. The all actions of IPIR are determined through sensor unit and then given to the processing unit, after that the feedback is given to output devices. The movements of IPIR are controlled by a unit which consists of Arduino, sensor unit which is collaborated with computer program. The unit of IR sensor that emits radiation to find the damage in pipes.

The sign of hole detection is processed and then a message is sent on screen "HOLE DETECTED". The message is displayed on the 16X2 LCD Display. Another thing the Gas Sensor MQ 135 is used to detect the hazardous gas such as NH3, smoke, C6H6, sulfurwhenever any of the hazardous gas is detected inside the pipeline then it send the signal in terms of gas value which is displayed on the LCD Display. On the display there are two terms are shows as defect detected inside pipe in that first is hole detection and gas detection as shown in Figure 10. The camera is used to view detected defect and also to view obstacle inside the pipe that you can see in the Figure 11.

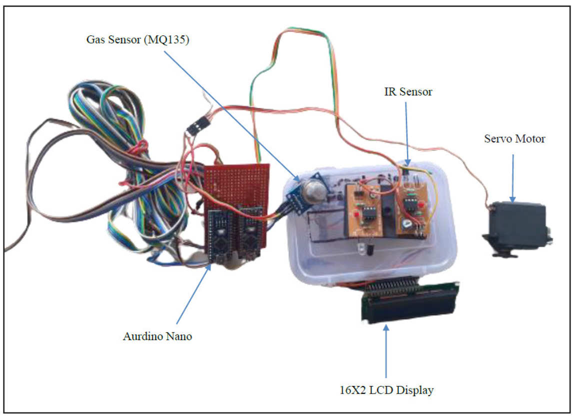
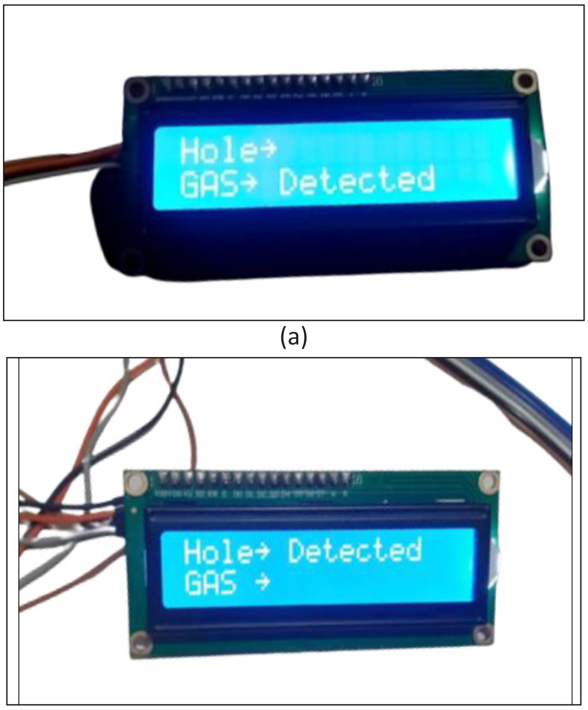


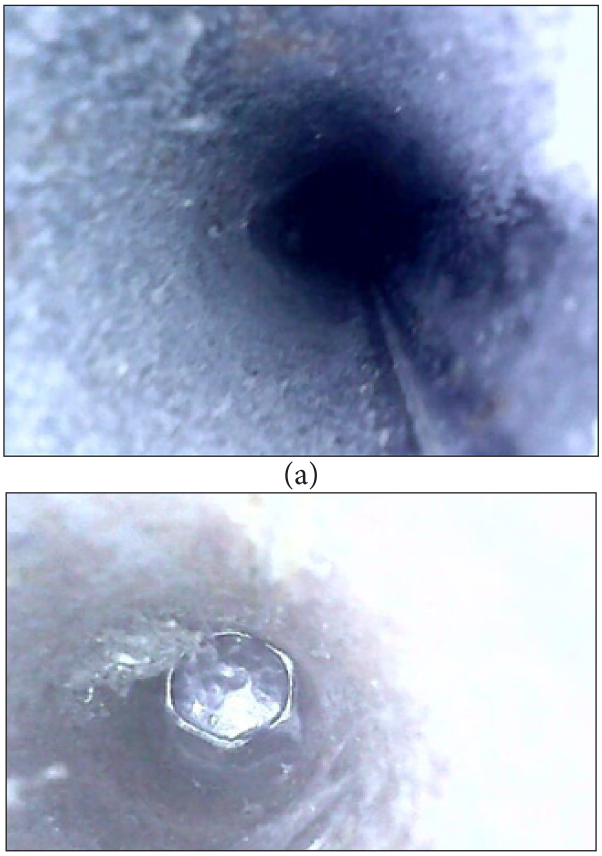
Figure 9.Electronic Circuit used in Internal Pipe Inspection Robot



(a)

(b)

Figure10.Result of Hole (a) Gas (b) Detected Shown on Display



(a)

(b)

Figure 11.Boroscopic Camera View of Inspected Internal Area of Pipe

Conclusion

Robots are essential for internal pipe network inspection and repair. Some individuals might adjust to the shape and functionality of the modification of the pipe under scrutiny. Some of them were created to carry out specialized jobs for pipelines with constant diameters. The proposed inner pipe modular robotic system in this project. The flexibility to the inner diameters of the pipes is a key design objective for these robotic systems. The specified prototype type allows the use of a micro allowing viewing in-pipe inspections or other equipment required for detecting failures in the interior of pipes (measurement systems with laser, sensor systems, etc.). The main benefit is that the straightforward mechanism can be employed even when the pipe diameter varies.

We designed a pipe inspection robot that will be utilised in the field with pipeline measuring diameter of 250 mm to 350 mm. To examine the viability of this robot for internal pipeline inspection, an actual prototype was created. There are many distinct kinds of inspection tasks. For quick adaptation to new contexts with little adjustments, a modular design was taken into consideration. A challenging problem is the existence of obstructions inside the pipelines. A spring actuation and increased flexibility in the proposed system fix the issue. Vertical and horizontal pipes can be navigated by the robot. The Pipe inspection robot's key goals have indeed been met. All of the project's following objectives are consequently accomplished.

The objectives are:

- The pipeline industry's safety must be guaranteed
- To develop an internal pipeline inspection robot that is semi-autonomous
- To quickly manoeuvre the robot within the pipe and investigate the area
- It must be able to move through pipes of different diameters between its specified range (250mm to 350mm)
- To detect hazardous/ toxic gases
- To locate defects such as obstruction, blowholes, dent marks, damage at joints or welds, cracks

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