IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 4 Ver. VII (Jul- Aug. 2014), PP 01-08
www.iosrjournals.org

"Development and Adaptability of In-Pipe Inspection Robots"

Nur Afiqah Binti Haji Yahya, Negin Ashrafi, Ali Hussein Humod,
Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Putra Malaysia, Malaysia

Abstract: *Robotics application has slowly increasing for the past 13 years. Much increase was seen in 2011. This review paper was written to study the robotics application in various industries mainly in pipeline inspection. This review paper was to fulfil the requirement of Automation and Robotics module assessment. The objectives of this review paper are; to observe different robotics applications in pipelines inspection, to learn the different design of robots in pipeline inspection, to outline the problems and adaptability improvements in the robotics application that was applied. The major problem of in-pipe inspection robots found is the different in diameter of pipes in any plant. And other problem relative to the inspection ways for different types of pipe applications.At the end of this review paper, it was concluded that improvements were seen in few designs of the robot example like the Parallelogram wheel leg.*

Keywords: *Robotic; Robot; In-Pipe Inspection, Adaptability, Non-destructive Testing, Image processing.*

I. Introduction

Robot is as a programmed mechanical device which execute activities usually controlled automatically [12]. It is considered to be used in tasks that requires high efficiency, large productivity and high precision, depending on which criteria the type of robots is required for. Robotics is meant for the whole production system with robots utilization. Robotics are now used widely in many industries such as automotive, oil and gas, railway, food & beverage, mining solution, chemical solutions, power generation and more [13]. In Fig. 1, shows the usage of robots from the year 1994 to 2011 where it can be seen that the supply of industrial robots gradually increases to 38% just from 2010 to 2011 [14]. These studies were taken from a press conference in Taipei conducted by the International Federation of Robotics Statistical Department in 2012. From this it shows that the growth and usage of robots have been increasing. For this review paper, the focus is majorly into robotics use in pipeline inspections in those industries that use pipes.

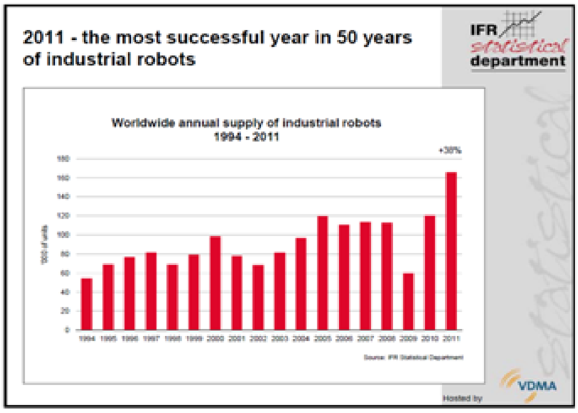


Fig. 1: Worldwide annual supply of industrial robots [14].

With different applications of robotics, the design of robots varies to be equipped for the desired task. Some robots are designed for high productivity such as in car manufacturing, the robotic arms can be design for the same task, example for spot welding which can be used in different types of cars to be weld on using the same robot. The task programmed is also repeatable for each car in the production. But in some other complex robotics applications like pipeline inspections, usually the robots are specially designed for a particular task and a targeted diameter of pipes with high precision and limited degree of freedom and fixtures. For this application, the specific design enhancements on the robots are required to carry out inspection and repair activities. To some extent, the complexity goes to extreme of producing a micro-robot with a diameter of 10 mm [4].

II. Background

Pipelines have the purposed for the movement in transferring liquids and gases from one point to another point such as to transport water, oil, sewage and natural gas. With these daily activities, pipes are prone to defects like corrosion, stress and aging which causes the pipes to leak, crack or break. Some defects are caused by moisture and chemical substances in soil for underground pipelines. Another problem usually faced is when sediments and corrosion accumulate can decrease the pipeline transfer volumes which result inconsistency. The effect can be seen in increase time of complete volume transportation and thus can slow down the business activities, a high impact can be observed in oil and gas industries [5, 15, 16].

There are many types of activities in pipe inspection, the common activities are such as visual inspection by using camera and non-destructive testing (NDT) such as ultrasonic testing or using eddy-current testing. After which type of in-pipe inspection activities are selected then the next concern is in the design of the robot and the configuration of the robotic system. Usually, the crucial aspects in designing the robot is the shape and size which affect the movement of the robot in the pipe. This is also depends on the layout of the entire pipeline structure [15].

The other detailed features of the robots depends also on the pipe geometry like pipe branch, different diameters, pipe elbows and pipe length which is to be inspect. Then, with those details the other specifications can be determined such as the required torque, wheel type, power, steering mechanism, width, height, length of robot, overall weight and material used. These specifications and the inspection testing equipment will make up the characteristics and behaviour to be programmed into the robot [5]. The problems which are discussed further in this review paper is for the design development of the in-pipe inspection robot in the adaptability in different diameter of pipes, with the help of the correct amount of tractive force for long distance range [1]. Most of the reviewed papers have basis of supporting design calculations in order to justify the produced design.

III. Application of In-Pipe Inspection Robot

Because of the defects in different types of pipes like cracks, internal corrosion and leakage, in-pipe inspection robot is one of the important robotic applications during these years, especially in gas pipelines, water pipes, sewage system and oil pipes. Most of the pipes for different purposes burn under the ground, then become the necessity to develop the in-pipe inspection robot to be adapt with all types of pipes with different applications and different diameters.

3.1 Current Trend of In-Pipe Inspection Applications

Many researchers are going to develop the in- pipe inspection robot to improve its adaptability for different pipes diameters. Improve Traction force for it to be able to pull its self with its peripherals in horizontal and vertical pipes. Improve the signal transmission system to be able to move for long distance. They are some programs software are using to designing, modelling, assembling and developing on pipe with diameter 750mm, in the future are going to implement this model on the ground also increase the strength and the size of robot component to run for long distance [8].

3.2 construction and Working of In-Pipe Inspection Robot

"Numerous in-pipe inspection robots have been built for the last two decades based on wheeled type, caterpillar type, snake type, legged type, inchworm type, screw type, PIG type and helical-drive type" [2]. The construction for any robot based on the purpose which manufactured for it or in other term various working condition adaptability. Knowing the surrounding conditions for the pipes like the diameter, pipes material, the inspection distance and the direction, all these parameters it should be known before design stage. For example wheeled type robot can use with T conjunctions in pipe network and elbow. Also for caterpillar type can move and face the obstacles inside the pipe. Snack and legs type use for T conjunction and pipes network with high adaptability for mobile system. The last type, inchworm type has advantage to move in elbow pipes. In Fig. 2, show some types for in-pipe inspection [8].

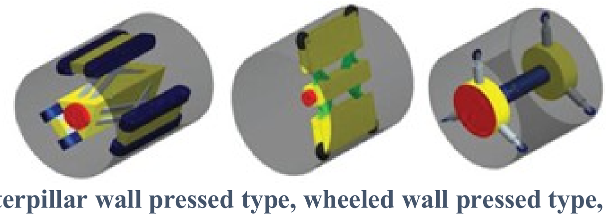


Fig. 2: (from the left) caterpillar wall pressed type, wheeled wall pressed type, and wheel wall pressing screw type [8].

The attempt for any robot design is trying to reduce the electromechanical complexity. This goal achieve by using a single actuator. The two main parts for the robot are: stator and rotor both of are connected by active joint. The content for these are two parts are D.C. motor with reducer, and universal joint. This universal joint will make easy moving through the curve pipes.

In other term the robot is designed for the size of pipe diameter. The studies on in-pipe still continues and some of developed base on different motion mechanism. The new design for in-pipe inspection robot that is working to inspect the gas purification apparatus has the ability to change automatically depend on the pipe diameter and also adjust its tractive force automatically to be stable during its moving inside gas purification apparatus. This type can vary from diameter 400mm to 650mm and its can move until 1km to check and observe the block, corrosion, crack, defect and wall thickness of the gas pipelines. [1, 8]

In general the in-pipe inspection robot consist of [1, 8]:

- Running mechanism.
- Pipes diameter adaptive mechanism.
- Sensing system.
- Lighting system.

Many things can be mounted on the in-pipe inspection robot like the lighting source and the CCD camera, transformer, switching power supply, step motor driver and embedded computer system [1].

As it mentioned before this robot move to 1000m then the power supply and the information data transferred by optical fibre cable that it is avoid the interfacing between the signal and the power. The efficiency of the in-pipe inspection robot based on adjusting the pressure between the robot wheel legs and the pipe inner wall. That means there is proportionality exponential between the additional pressure with the tractive force and diameter adaptability. [1]

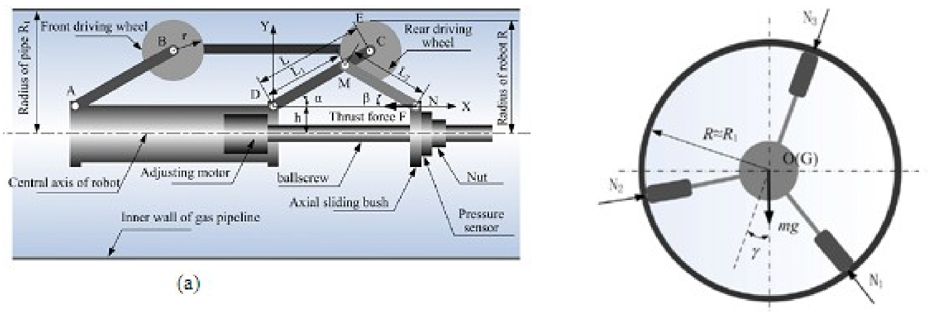


Fig. 3: (a) A parallelogram wheel leg of pipe diameter adaptive mechanism, (b) supporting force distribution [1].

When considering the design of the robot used in pipe diameter 80 mm has been focusing on the ability of the robot to the appropriate diameter with a weight-bearing and additional forces anywhere inside the pipe. Motor appropriate for this size is a servo motor due to its small size with high torque capability [5]. It is very important in these types of small-sized robot into account the slippage inside the pipe. One of the techniques used in this field, magnetic force that is placed inside the robot rim to bear the weight of the robot. As well as the solutions used during the design process to avoid the process of sliding the robot inside the pipe, covering the rim with rubber material. [5]

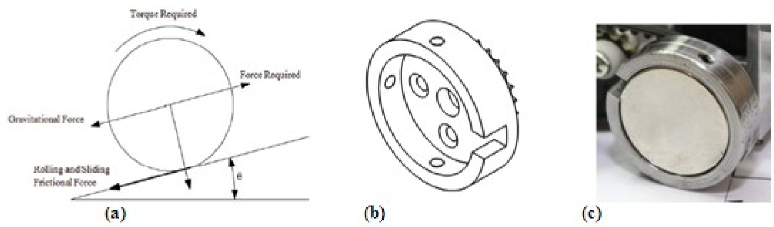


Fig. 4: (a) Free-body diagram of acting on the wheel, (b) Designed of an empty wheel rim, (c) Completed prototype of wheel rim with magnet disc slotted in [5].

Mobile mini-robots, it has the flexibility to environmental in the pipe with it is suitable structure that make it easy adapt with pipe diameter. There are several types of mobile mini-robot based on its structure and functions: MRINSPECT I, MRINSPECT II, MRINSPECT IV. MRINSPECT I: has six slider-crank mechanism each one has driven wheel actuated by DC motor and belt transmission. This one can work with horizontal pipe, vertical pipe and elbow typed portion but it is not working with T junction. MRINSPECT II: is moving radial direction and this movement will reduce the distortion forces. MRINSPECT IV: this type can work with elbow and T-junctions pipelines. The components for the mini-robot are: helical spring, translation element, actuator support, worm wheel, worm gear, actuator, central axis, link, and wheel as shown in Fig. 5, Fig. 6 and Fig. 7. [11]

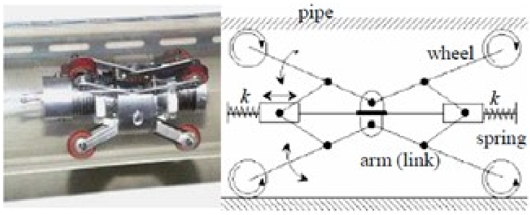


Fig. 5: MRINSPECT I in-pipe robot and its basic mechanism [11].

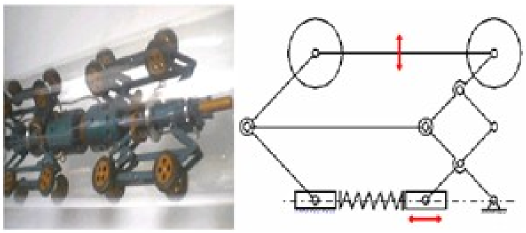


Fig. 6: MRINSPECT II and its corresponding mechanism [11].

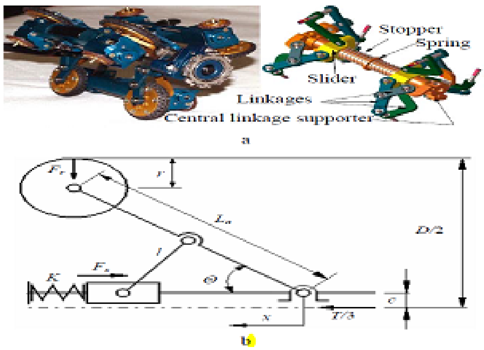


Fig. 7: MRINSPECT IV and its corresponding mechanism [11].

Pneumatic and vacuum pressure is one the methods used in the development of the robot used in pipe inspection. The upper limit for the distance of 20 meters at 33 mm per second and the traction force of 7.8 N in pipe with diameter 44 mm. One of the difficulties which faced this type of robot is to pull a feeding air tube and electric cable for long distance. This problem was solved in the design by generating large traction force this apply by increasing the number of friction rings. This type of robot provided with CCD camera and light emitting diodes. The function for this robot to inspect crack and corrosion in the pipe Fig. 8 show Pneumatic and vacuum pressure [6].

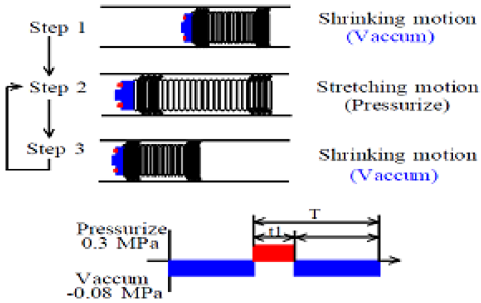


Fig. 8: Time-chart of the pneumatic pressure [6]

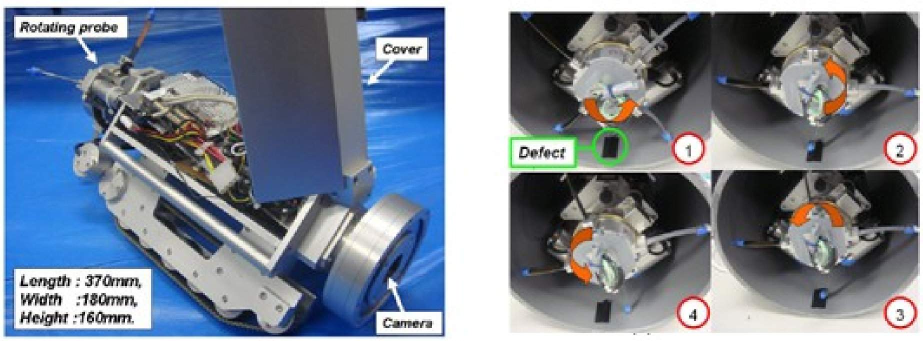
There are several software programs are using to design and test the model for in pipe inspection robot. SolidWorks11 are using to design, modelling and assembly. Stress analysis for all major components are doing by SolidWorks11. Static stress analysis and assembly are using Ansys 13.

3.3 Control of In-Pipe Inspection Robot and Information Transmission

Most the robot types that it used in pipe inspection are using the cable to control the robot and to transfer the information data to detect the defects inside the robot. As mentioned before for in-pipe inspection robot in gas purification apparatus, it is controlled by wired remote. One photoelectric hybrid cable using to transfer the power and information data. The inspection robot can establish a real-time communication with the ground workstation based on TCP/IP protocol, and transfer video information, environmental parameters, running status of the robot, control instructions, and detecting data. [1]

Another types of robot like drian pipe inspection robot are using practical wireless radio communication system. "The robot was developed based on drain pipe inspection robot 'Mogurinko250' by Ishikawa Tekkousyo."[7]. and it can be used the same wireless radio communication system to transmit image information of the inside pipe. "The Indian Institute of Technology Kanpur has researched a rotating probe using piezo element for inspecting the inside of pipes with a touch sensor system" [7] this touching sensor system by using rotating robe could inspect and detect the curve and the change of the stress (detect the defects). These procedures applied by is capturing the voltage changes and convert it from analogue to digital signal and move it into the microcomputer and then the main computer in the robot read the data through serial transmission.

Some in-pipe inspection robot are using ultrasonic sensor that is detect the defects in the pipe (crack or damage) and move the wireless data to the computer this way help us to detect the location and known the size for it although for using CCD camera that it responsible to give an image for the defects pathway. [8]



(a) **(b)**

Fig. 9: (a) Inspection robot (Mogurinko) and (b) Movement of rotating probe.

Some of robot like mini-robots is powered by using wire and it is controlled with aid of microcontroller ATMEL AT-mega 8535, also the defects or the malfunction are detected by using CCD camera.

3.4 The Future Techniques Trends For Detect the Defects in Pipe Inner

The Most common method of pipeline inspection is using a remote-controlled-machine equipped with a CCTV (closed circuit TV). The CCTV for in pipe inspection still in progress especially when they develop the system that it takes pictures of inner surface of the pipe and produces high quality unwrapped images.OYO-USA has developed a new type of sewer inspection system called SSET, which is equipped with a fish-eye lens to get a direct view to the pipe wall [17]. A new approach is developed to overcome the limitation of SSET.The developed system uses larger area of side view and constructs high quality stitched side view images. Side view unwrapping and stitching technology using image process technology are developed which delivers high resolution image data. Digital image scanning method is an innovative method for the pipe condition assessment High quality images would bring dependable condition assessment of the pipes as well as the convenience of digital technology.

Nowadays, there are many techniques for inspection in this paper will review nondestructive evaluation methods. Noncontact inspection techniques can be classified into optical and no optical techniques. Non-contact optical inspection techniques include machine vision system, conventional optical instruments (optical comparators and microscopes), Laser system (scanning laser device), linear array devices, and optical triangulation techniques. Non-contact non- optical inspection techniques include: electrical field techniques, radiation techniques, and ultrasonic inspection methods. In in-pipe inspection robot have used machine vision (computer vision) in most of them because of the distinction is that machine vision tends to imitate the capabilities of the human optical sensory system. Which includes not only the eyes but also the complex interpretive powers of the brain. [18]

One of the technique that will focus on it here image processing system. CCD based technique that is embedded in in-pipe inspection robot structure has some limitations that restrict their implementation like: the lack of visibility in the interior of the pipes and (2) the poor quality of the obtained images because of difficult lighting conditions. Fig.10 (a) show image acquisition test pipe (b) CCD camera and Lens system. [17]

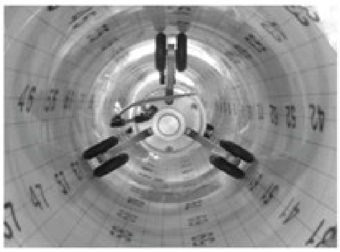


Fig 10. (a) Image Acquisition Test pipe [17] (b) CCD Camera and Lens System

Image processing technology can use in pipeline welding defect detection. In pipeline inspection robot vision system that it contain of CCD camera, lighting, image acquisition card, mechanical devices, host computer (PC), ultrasonic probe, pipes as shown in fig. 11. Where this system capture the image inside the pipe to and send it to the computer after convert it to digital image. Here in this system the experiment was to detect the location and defects for the weld position. They focus here how to provide high quality image to recognize it from the interference object. The procedures for the image starting from weld image analysis and processing then weld image segmentation that it has two methods (the largest variance comparison method and feature prominent method). In both methods, there are sometimes rough surface within the pipeline led to a lot of interference the times of identification, the uneven illumination, motion blur. It is not easy for objects edge split. Therefore the contrast between weld and other objects is too small. To solve these problems, using projection method identify object in fig.12 will show the treatment by using this method on the previous two methods. [19]. the trends here to get pretreatment image with high quality to distinguish and recognize the defects in the weld area.

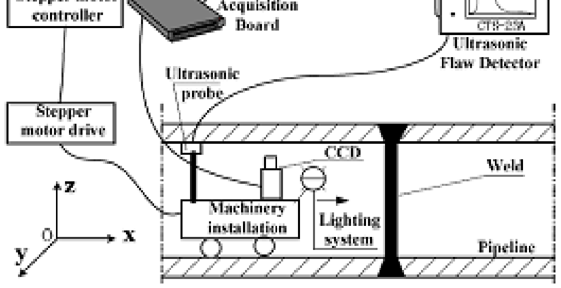


Fig. 11 Visual Inspection System for Pipe Weld Visual Inspection

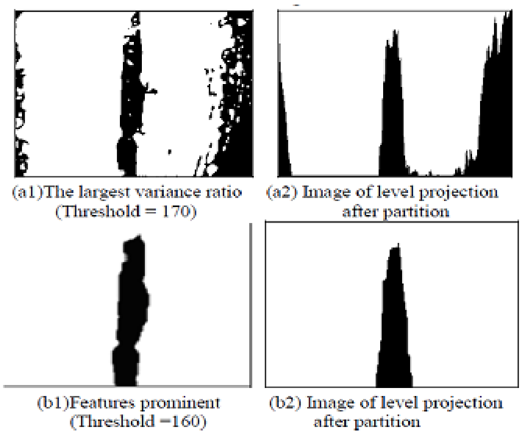


Fig. 12 Level Projection Map of the Weld [19]

The mechanism of firber grating vision sensor uses in in pipe inspection robot to recognize straight pipe, T- shaped pipe (branch), bending pipe, and T- shaped pipe (the end of straight), in this method the fiber grating vision sensor is construct by a laser equipment, fiber grating and CCD camera. A laser equipment, fiber grating and CCD camera are located horizontally [20]. Monochrome camera which takes low illumination environment because the inside of pipe is dark. Fig. 13 show the snapshot of fiber grating image. Fig. 14 show the developed fiber grating sensor.

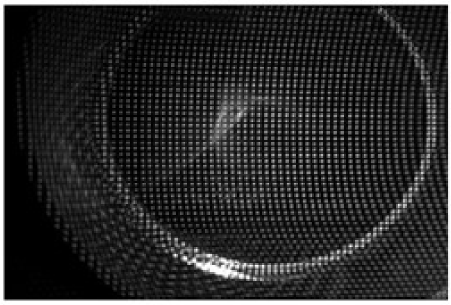


Fig. 13 The snapshot of fiber grating image

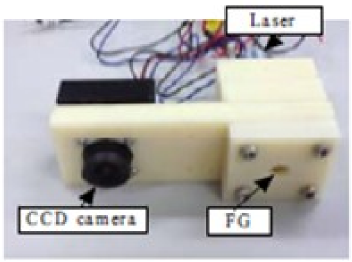


Fig. 14 The developed fiber grating sensor

IV. Discussion

The obstacles in designing and developing an in-pipe inspection robot as elaborated according to the above applications, is the design of the robot for the pipelines. Then, further challenges faced during the developments of the in-pipe inspection robot are:

1. Change in diameter pipe, Curve and energy supply is configure one of the major challenges.
2. The max adaptability for in pipe inspection robot with diameter 700 mm.
3. Increasing the diameter adaptability for the robot mean increase the size that it will lead to increase the pressure and traction forces.
4. The additional pressure lead to increase the load distributed in the robot parts.
5. Inability for using the robot include the magnetic forces inside the rim with non- ferromagnetic alloy pipelines.
6. Control the robot and transmit the information data by using wireless radio signal are affected by the shape and material of the pipes on the radio wave.
7. The vibration and small defects in the PVC pipes will not give correct voltage reading while the robot moving through the pipe. In the future the current trends to improve the probe with no vibration and to inspect the real defects while driving.
8. Image processing techniques developments will help to improve the inspection working for in pipe inspection robot because of its adaptability with pipes environment.
9. Pipe structures and materials made from them must be examined carefully to help develop the work of the robot. It is very important link between the inner surface of the pipe and the surroundings of the robot.
10. The future trends focus on nanotechnology to decrease the weight for the robot and increase the ability to move in low power inside the pipe.

"The key problem in any design and implementation consist in combining the capacity of self-moving with that of self-sustaining and the property of low weight and dimension. A very important design objective is represented by the ability of the in-pipe robot to the inner diameters of the pipes." [11]. It is now taken into consideration that the most important factors affecting in designing and developing the robot and the entire robotic system is the different diameters of pipes and other factors is how to control transmitting of data. Some of the adaptability features and enhancements are already discussed in Section 3. It was found that a few of the robots design like using the parallelogram wheel leg are able to adapt the changes in diameter of pipes and with the help of the additional tractive force from the leg the robot is able to give extra push through the pipeline. Other improvements features are also mentioned above.

V. Conclusion

In conclusion, the objectives of the review paper were met where the robotics application in in-pipe inspection was understood, reviewed and discussed. Some of the activities found in the in-pipe inspection robot are Visual Testing and Non-Destructive Testing (NDT). Visual imaging is use to capture picture images to see the condition inside the pipe. Whereas the NDT will give a clear representation of data either by graphical method of how critical the defect condition is inside the inspected pipelines. Some of the design and development we elaborated in section 3 which result in solutions for the adaptability of the in-pipe robot in different pipe diameters. With these improvements, industry plants will increase their efficiency, consistency and quality in liquid and gas transportation. Thus, reduce downtime of their whole production system before any breakdown were to happen.

Future work is highly recommended in these area of study as improvements are still vastly to be discovered such as in-pipe grinding and polishing robot for further Non-Destructive Testing (NDT).

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