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Research paper

Design and Development of an Inspection Robot for Oil and Gas Applications

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Abstract

Pipeline or mass transport line are the chief applications which are typically involved in the oil and gas industries. After various background studies, the pipeline involved in such industries comes from a high technology design and material of use. Hence, inspection and maintenance must be done frequently to ensure the pipeline can be used in an excellent working state. The inspection on pipeline must be done before and after its maintenance. However, it is difficult to inspect within the pipe to ensure it is in good condition. Currently, various new types of technology are used for inspection purposes specifically by means of the Non-Destructive Testing, but it highly costly. Thus, this project focuses on the design and development of an inspection robot to perform a pipeline inspection. Some applications that can accommodate to the designing of a robot is that the robot is able to manoeuvre inside the pipeline wirelessly and give a visual interface while proceeding it. Therefore, this project shows the development processes included in the design and development of an inspection robot for the oil and gas applications.

Keywords: *Oil and Gas; Pipe Inspection; Robotic Inspection Robots; Field Robotics; Design and Implementation*

1. Introduction

Robotics is an example of the rapidly developing industries in the engineering field nowadays. Robots are intended to decrease human element in work-intensive or unsafe jobs and to act in unreachable surroundings. Using robots as an aid has turned out to be more generic now and is not only used solely by the heavy production industries. Utilizing robotic technologies offers several benefits such as reducing continuous expenses, saving time and increased safety in the work conditions [1-2]. Besides, the usage of the robot gives various job opportunities specifically in the manufacturing fields, e.g., spot welding, painting, etc. In essence, robots are built to lessen human involvement in the work-intensive and dangerous work condition. Occasionally, robots are utilised to determine unreachable workplaces that cannot be easily accessed by people [3-5]. The complicated inner spaces and dangerous contents of pipes need robots for inspection purposes. For pipe inspection purposes, it is most excellently required to use a robot particularly to inspect the corrosion level, retrieval of usable parts, sludge sampling and scale formation on the inner surface, etc [4]. The mobile robot can be controlled as autonomous, semi-autonomous or can also be done manually with specific controller. This causes the control system distinct from every feature used [6]. The inspection of pipes could be pertinent to improve security and efficiency in the industrial plants. Special tasks such as inspection, maintenance, and cleaning are costly, thus the use of the robots seems as among the most viable answers. The pipelines are the main means of transporting drinkable water, liquid waste, fuel oils, and gas [7]. Pipeline ageing, cracks, mechanical damage, and corrosion can lead to many complications. Mobile inspection and maintenance robotics are the future of the industrial market. The ability to access places which are unreachable to people because of size limitations, temperature, and liquid immersion or safety reasons is among the chief benefits of mobile robots. An instance of such a robot is the BIKE inspection robot which possesses a new technology to operate as an inspection robot [8-12].

The BIKE robot is a magnetic wheeled robot and is efficient at checking power plant facilities and several purposes in the oil and gas industry, such as a vessel or pipe inspection.

Fig. 1: BIKE Platform 2016 robot [5]

1.1. The Challenge

Pipeline transport is the transportation of goods or materials through a pipe. Maintenance and inspection of the pipeline should be conducted frequently. Generally, congested and oxidized pipeline interior are the usual issues faced by every engineer

during the maintenance. But, inspection should be applied first prior to carrying out maintenance. Due to the inadequate space in the interior of the pipes, executing inspection becomes difficult. Using this issue, designing an in-pipe inspection robot is segregated into three scopes, which are visual inspections and actuating the components [13].
Nuclear power plant and Petrol-chemical industries hold the highest importance on safety concerns. A consistent inspection of the pipes must be conducted before any disastrous incidents occur due to inadequate inspections. With the NTD benefit of visual inspection [2], defect and default could be detected and will increase during pipeline operational times. Using the NDT technique in this study offers additional qualities to the robot capacities [14].
Anyway, it is important to persistently lessen the hazards caused by the production, transport and storage of chemical. This implies that potential threats must be assessed and the required testing and inspection need to be conducted to evade or control the probabilities of unwanted things from occurring. However, since some or a majority of pipelines are fixed underground, performing maintenance in the pipeline directly becomes tough for people. Several methods have been developed to help individuals perform pipeline maintenance [15-18].
If a pipe wall is subjected to water and impurities in the natural gas, rust or oxidisation happens on the interior wall the pipeline. The nature and degree of the corrosion are influenced by the concentration and specific mixtures of different corrosive elements inside the pipe, and the working surroundings of the pipeline. Put differently, a certain gas mixture could trigger corrosion in a certain operating situation but not others. An internal corrosion can be identified using numerous approaches, such as visual inspection of the pipe's interior, using devices to externally measure the pipe wall thickness, assessment of corrosion coupons or probes positioned within the pipeline, or pipe inspection with an in-line inspection device to detect places of pitting or metal loss. [10]

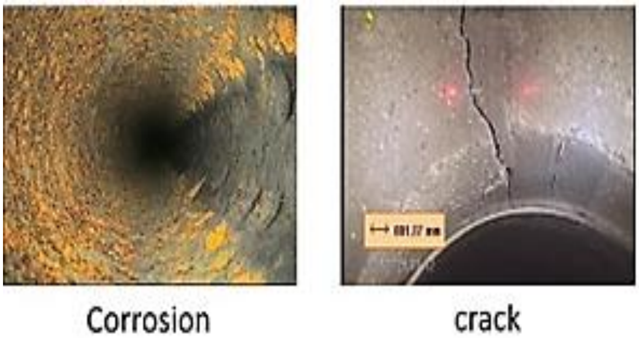

Fig 2: Problems occur inside the pipe [11]

2. Literature Review

A robot is the combination of engineering and science that includes mechanical engineering, electrical engineering, computer science, and others. Many robotics come from the design, development, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing. All robots have a mechanical structure, a frame, form or shape designed to accomplish a specific job. For instance, a robot developed to move across heavy dirt or mud may use caterpillar tracks. The mechanical feature is mainly the designer's answer to achieving the designated work and handling the physics of its surroundings. As more robots are developed for particular tasks, this approach of categorisation becomes more significant. For instance, some robots are developed for fabrication task, and so they could not be used for other purposes; they are known as "assembly robots" [19].

2.1. In-Pipe Inspection Robots

The robots with flexible structures may be the most adaptable to the surroundings, particularly to the pipe diameter, with an improved efficiency to manoeuvre in dangerous settings. Wheeled robots have highest qualities in terms of simplicity, energy efficiency, and capability for long range. When the wheels are loaded with springs, the robots also give some benefits in manoeuvrability with the capability to go through uneven surfaces in the pipe and remain steady without sliding in pipes; they are also miniature in size.
Pipe inspection robots are used extensively to operate maintenance in the pipeline. The pigging type, generally used in the oil and gas pipeline, is inertly propelled by liquid or gas going within the pipe. A different kind is the wheeled robot, which is commonly used for commercial purposes.
Wheeled robot system with active manoeuvring ability is created for internal inspection of urban gas pipelines. One other kind of pipe inspection robot is the caterpillar type robots that are applied in indoor pipe inspection. Each of these robots has benefits and drawbacks, causing a specific robot to operate only in a specific environment [20].

2.2. Robot Design Evaluation

There is also another mobile design look alike car concept. This design is simpler compared to the spring loading wheel concept and caterpillar types. Besides, to indicate this design, the closest concept is the remote-control car with some modifications on the wheels to make sure it is compatible with crawling in the pipes.

Table 1: Comparison of pipe robot [21-25]

Type	Caterpillar	Mobile robot	Wheeled type
Structure	Wall press type	Car-like robot	Wall press type
Principle of motion	Moving by pressing and walking on walls	Moving on the ground	Moving by pressing and walking on walls
Exterior diameter	Big	Small	Big
Advantages	Adaptable to changes of inner pipe diameter	Does not damage the inner surface of the pipe due to the small contact area	Moves fast as wheels provide highly efficient propulsion
Disadvantages	High friction force may damage the inner surface pipe	Unable to move in a vertical path	The wheel can be stuck in holes on the inner pipe

2.3. Robot Control System

Arduino is an open source hardware and software project. It comes in various shapes and sizes. It is used by professionals to easily design, prototype and experiment with electronics [26].
An Arduino contains a microchip that is a very small programmable computer. Sensors can be attached to it to measure various variables (like the amount of light in a room). It can control how other things respond to those variables (room gets dark. LED turns on). The Arduino platform consists of:

- Hardware design: The physical programmable circuit board, or the microcontroller, as it comes in different types
- Software development: Creating the needed program the Arduino needs to perform its tasks, created in the dedicated Integrated Development Environment (IDE).

2.4. Software

During the design stage, drawing is among the important things executed in a product development phase. The drawing will illustrate the design parameters that simplify the fabrication phase. It also includes the choices of components which can be understood by everybody. Thus, for this study, SolidWorks software is utilised in finalising the design of the Inspection Robot. The software is also utilised to program the control system for the robot which will determine its movement to achieve the objective of the study. Coding of the program is implemented using C++ language. SolidWorks is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) platform. Along with its supporting components, such as *eDrawings*, a collaboration tool, and *DraftSight*, a 2D CAD tool. [5, 10, 26]

3. Methodology

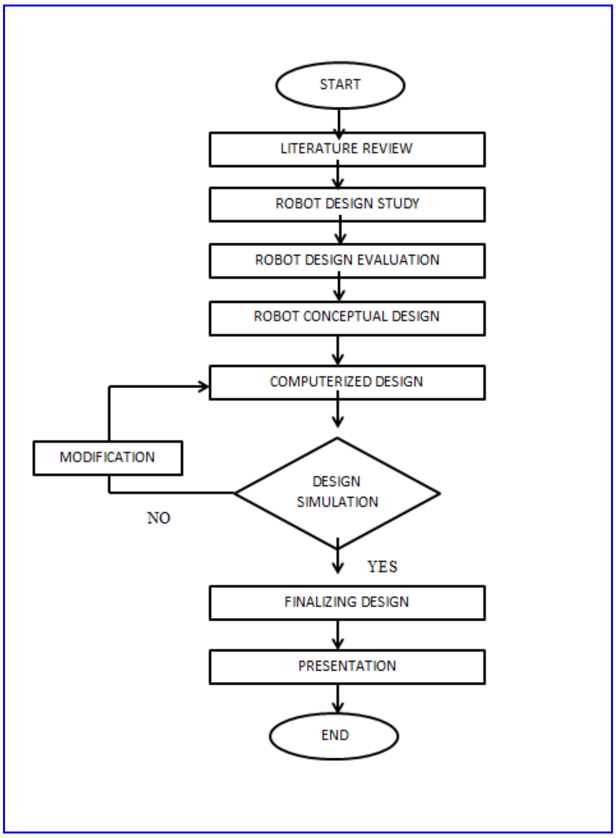

Fig 3 Methodology flowchart

3.1. Arduino

Arduino serves as the microcontroller chipboard which is used as a controlling system which offers sets of digital and analogue I/O pins that can interface with other circuits. The boards contain serial communication interfaces, including Universal Serial Bus (USB) on some models, for loading programs from personal computers. To program the microcontrollers, Arduino offers an integrated development environment (IDE) based on a programming language called Processing, that supports C and C++ languages too [8. 9, 27].

3.2. Hc-06 Bluetooth Modules

A Bluetooth module provides a straight instruction to interface and data transmission between an Arduino board and a computer. Therefore, the Bluetooth component must be integrated in this project to control the robot wirelessly. This component functions as a slave to the Arduino microcontroller chipset.
Prior to doing the hardware calibration, the hardware connection should be established. Each component of the Arduino platform – hardware, software and documentation – is an open source and available for free. The platform can be learnt as how it is made and to utilise its design as a basis for your own circuits [9, 28].

3.3 DC Motor

The motor is the key component of the actuating element to manoeuvre the robot. The Arduino chipset provides an output DC supply of 5V; if 5V becomes inadequate, then the servo module should be applied to increase the output voltage. Else, a suitable motor for the application should be selected to ensure the robot can crawl more efficiently [29].

3.4 Robot Conceptual Design

In this study, the caterpillar type is chosen as the in-pipe inspection robot. The power applied by this type of robot on the pipe's interior walls is produced with the aid of an extensible spring. The helical spring positioned on the central axis promises the repositioning of the robot, supposing there is a variation of pipe diameters. Three DC motors are used to manoeuvre the rear wheels.

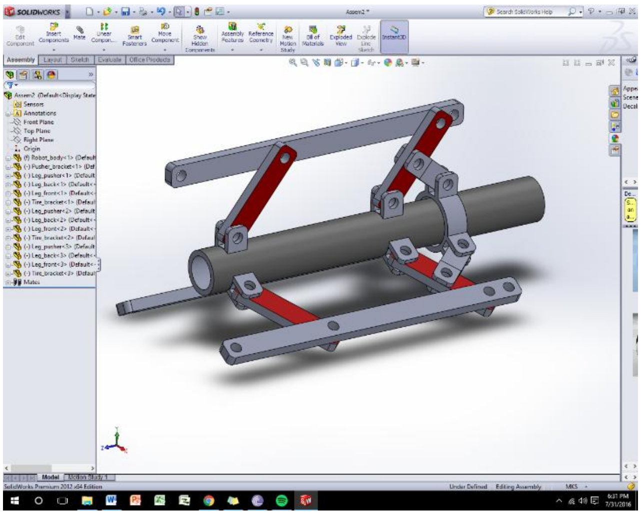

Fig 4 Conceptual design (Initial phase)

Figure 4 illustrates the preliminary stage of a computerized design developed with the SolidWorks software. The design does not show the entire concept and has several mechanisms that must be added to the robot body. For example, spring loaded and spring stopper must be added at the robot's rear section and a bracket is needed to support the motor to connect to the tire. Another feature is to develop a control box location which is attached to the body and camera bracket.

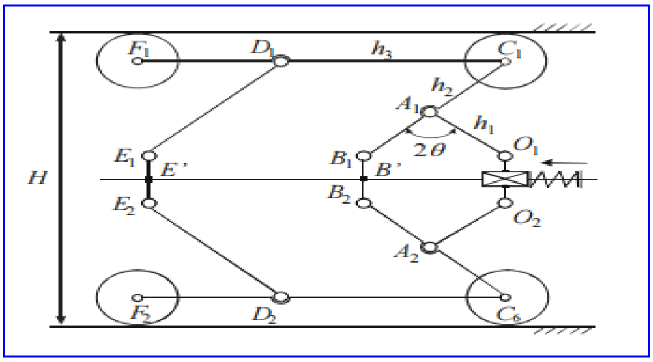

Fig 5 Structural scheme of the caterpillar robot [7]

The height of the robot is identified using this relation (h1 =OA, h2 = BC = DE, h3 = CF), found from this equation (1):

$$H = 2r + 2d + 2h_2 \cos\theta \tag{1}$$

Where r is the wheel radius, and d is the distance EE'. The maximum and minimum heights of the robot are identified based on the angle θ, (θ ∈ 15°÷ 60°) and on the lengths of the elements h1, h2 (2):

$$H_{min/max} = 2r + 2d + h_2 \cos(\theta_{max/min}) \tag{2}$$

Where θ min and θ max are the minimum and maximum limits of the angle θ, respectively.

4. Development of Inspection Robot

Figure 6 illustrates the finalised design of the robot after various stages of the design and development were completed. SolidWorks 2012 was used to create these models.

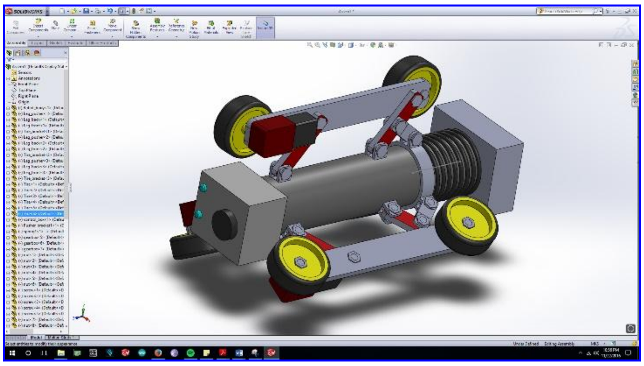

Fig 6: Adding the DC motor, gearbox, camera box, springs, and camera

4.1. Robot Structure

The robot frame or configuration is the primary element in constructing the design and developing the robot since the design must provide traction for the robot in the pipe. Essentially, the idea of this robot is like an umbrella. When the push bracket on the back advances forward, the robot's leg will expand to the largest radius. Because the pipes are cylindrical, this design will provide extra grip in the wheel to roll over, manoeuvring within the pipe. The centre cylindrical part of the body is designed to be hollow to add other controlling parts such as wiring of the motor and battery pack. next

Subsequently, DC motors with a gearbox and wheel at each leg are added to the body. A sum of 3 DC motors with the gearbox were placed at the front section of the inspection robot due to the fact that the robot is designed to pull forward whereas the front wheel moves the back wheel. The DC motor with gearbox is obtained from a current product which can be bought online. Simply put, the DC motor and gearbox are only fixed to the robot's leg. This part demonstrates the extra components attached to the design such as the Arduino chipset board casing which is fixed on the robot's hind part. Besides, the spring mechanism is fixed between the control box and the push bracket in the mid-section of the body. This spring functions as spring loaded to ensure the robot leg is at the expanded position and the wheel touches the interior of the pipe wall as it moves back and forth.

An extra piece is the casing for the camera which is attached at the robot's front part with an LED on it. The casing size follows the wireless camera size such as GoPro or SJ2000 to ensure it fits.

4.2. Controlling the robot

This subchapter of the in-pipe inspection robot controlling system describes the methods in the development of the controlling system to operate the robot. Arduino Uno, the core of the controlling system, is the microcontroller that operates the robot's actions. With the support from other devices, the microcontroller controls all the mechanisms required by the robot. HC-06 Bluetooth module is added in the controlling system to provide users with a wireless control of the robot's manoeuvre within the pipe. Likewise, the Double Dual H Bridge L298N DC Motor Driver Module Controller Board is included in the system to govern the motor speed [11]. Furthermore, Light Emitting Diode (LED), Battery Pack, different kinds of resistor and breading board are also required in the development of the control system. Fritzing Software is used to create the schematic diagram and simulator for electronic devices. It is an open source hardware initiative which guides users to create a project which contains the Arduino microcontroller. The Fritzing Software allows users to understand whether the connection of the system design is in the correct position. This software also contains a toolbox of all the electronic instruments or devices which aids in making a system efficient [12].

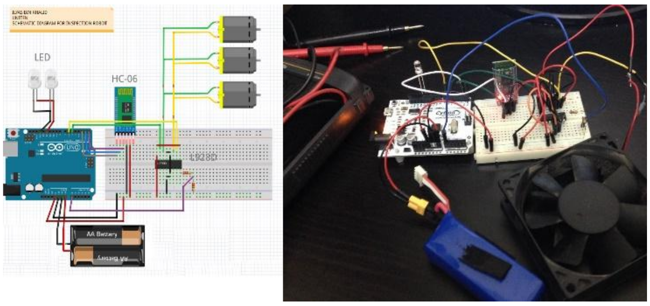

Fig 7: Setup of the developed control system

The building of the source coding developed to control all the operations that this inspection robot requires is shown below. The codes are developed with the aid of the Arduino Software which are then transferred to the Arduino Uno microcontroller chipset. These codings were done through some Internet research and assistance from a few robotic communities.

4.3. The Assembly Process

After completing the design of a control system, the assembly process commences. All the parts needed for building the prototype of the robot body were created with resources sold at a hardware store. For instance, the primary body frame is built using PVC pipe. Each piece is subjected to a few activities, such as cutting, drilling and finishing, applied to finish the robot prototype. Nevertheless, because these parts are manmade, there is a minor inaccuracy concerning the precision in developing this inspection robot.

5. Testing the Developed Robot

During the implementation phase, a number of issues arose: the spring was not suitable for the robot as a 1.5-inch spring was very hard to find in the Malaysian market unless by a customized order from other countries.

All springs more than 1 inch are industrial springs which are created specifically for heavy duty works. For this robot, a heavy-duty spring is inappropriate as the spring is only used to provide grip to the tires. So, the prototype applied a steel wire-based spring from which there is insufficient force provided.

Fig. 8 Complete assembly

Next, since the prototype is developed using a plastic-based material, there is insufficient rigidity for the robot particularly the bracket which is built using Perspex, causing the bracket to bend when the robot is in a prepared position.
To assess the robot prototype, a few setups must be complied with prior to conducting the testing. As the robot is controlled by Bluetooth through a wireless connection, a tuning need to be done foremost between the robot and computer. Plus, a 9V battery supplies power to the Arduino controller and the robot motor. This test takes place when the robot is assessed in terms of forward and backward movement through wireless control and the robot motion behaviour is observed. A Tera Term emulator is used to link the robot prototype and the computer by providing a direct command [13].
In order to perform the needed testing on the developed robot, the steps below are required:

1. Attach a 9V battery to supply power to the Arduino and Bluetooth modules.
2. Search for HC-06 Bluetooth and pair it with the computer.
3. Go to Tera Term software and switch to serial connection. Next, modify the port COM based on the COM number which the Bluetooth is paired with the computer. Distinct computers correspond to distinct values.
4. The Tera Term software is ready to be used. The connection has been established.
5. Enter a command to the Tera Term software to see the motions needed. Listed below are the commands that have been programmed into the Arduino Microcontroller.

5.1. Traction Analysis of Developed Robot

One of the biggest concerns of this paper is the success of the robot in travelling through the pipes with frictional forces and the traction formed between the robot wheels and the pipe's interior walls. Without proper traction between the robot and the pipe, the robot would slip and fail to travel properly through the pipes. This, in turn, would defeat its own purpose.
As discussed above in Figure 5 and equations 1 and 2, the developed model was successfully able to exert enough forces to cause enough traction to form smooth motions of the robot.
The change made to the robot design is its 6 tires, 3 motors and 1 spring. The idea of the change came from an integration of two benchmarks.
Plus, the design was sketched and then transformed into a CAD design using SolidWorks software. Using the resulting technical drawing, a robot prototype could be developed. In developing the prototype, all the proportions used in the drawing are carefully obeyed.
The secondary objective is completing the robot prototype design and integrating a controlling system as well as operating the robot, which comprise a main element in developing the in-pipe inspection robot.
To design the controlling system, the robot's purpose should foremost be identified. For this study, the robot is required to move forward, backward, stop and turn the LED on/off. An Arduino microcontroller and HC-06 Bluetooth module control the controlling system which enables the robot to be controlled wirelessly. Coding of the system is developed using C++ in the IDE provided by Arduino. The testing and observation phase proved that the secondary objective is accomplished, implying that the controlling system can operate the robot.

5.2. Observations

Through the testing of this prototype, some observations concerning the testing on the robot could be made. The first test was done to find out the ability of the robot in manoeuvring.
The test indicated that the robot has no issue to move forward, backward and stop according to command given. But, the movement of the robot was somewhat skewed from a straight line due to the tire orientation that was not in a parallel position in relation to the robot body.
The second test was done to know the distance of coverage between the robot and the computer. From the test, the covered distance between the robot and the computer almost reached 10 meters before the connection began to lose. The test was conducted in an open area without obstruction between the robot and the computer. In a nutshell, the prototype functions while the objective is accomplished.

6. Conclusions

One of the objectives of this study is to design and develop an inspection robot for oil and gas applications, which has the abilities to manoeuvre or crawl in the pipe's interior. Another objective is to integrate the design with a controlling system to handle the robot.
The first objective was tackled by researching about robots for inside the pipe purposes. As a result, the caterpillar type of in-pipe robot was selected. A few changes were done to the caterpillar type design compared to the benchmark of this project.

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