

ORIGINAL ARTICLES

Design and Development of Pipe Inspection Robot Meant for Resizable Pipe Lines

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ABSTRACT

Daily tasks mixed with the various applications in the robotic field. Since past, pipes have been used as the safe fluid transmitter. But gradually, these pipes affected by fatigue, cracking, leakage, sediment and breaking down. Also, sometimes humid environment and chemical products existing in the soil, causes rust and fatigue the pipes. All these problems lead to redundancy and impose high expenses for installation and maintenance. One of the recent inspection ways, is using the robot controller which leads to help and reduces the inspection time and preventive repairs activity. Besides, sometimes there are some unpleasant situation such as unfit pipes. It is obvious that in these conditions, doing inspection in toxic arena, narrow and meandering ways is impossible by human. So, designing a pipe inspection robot can be helpful in such circumstances. In this design, first, the former study, the way of operation, movement, mechanisms and advantages of each robot have studied. Then, by considering important parameters in designing, and sketching, making robot with the help of CATIA took place. This structure enjoys a regular mechanism design. It also has a proportional pipe diameter with the possibility of crossing through the slope routes. On the other hand, recording and processing of visual report, needs a camera and GUI toolbox written in Matlab. So image processing can help to exact investigation. One of the main difference of this research work over the various test on the platform, is hiring the mentioned toolbox which helps the operator to have the double investigation inside of the pipes. Moreover, the adjustable mechanism to pipe diameter, polyhedral movement and ascension power, relatively high efficiency in order to use frictional power and reducing repair and pause time are the advantages of this design. Also, observing the inner side of the pipe on the monitor, leads to reducing images. Moreover, its investigation by the introduced toolbox, causes more effective observation, more quickly diagnosis and analysis.

Key Words: Pipe inspection robot, Flexible mechanism, Image processing, Designing and fabricating pipe inspection robot

1. INTRODUCTION

The pipelines have known as the best, low cost, more secure and fast flowing transmission lines. These lines have damaged because of different reasons like erosion that makes the procrastination in transmission, waste expenses and time. Today's robotic challenges make them applicable in the var-

ious field in industries and agriculture, education, clinical, etc.^[1-4] But inspection mission hires the robot to work in different arena and applications. Requests to use the robot specially in the pipe jobs are consist of: Inspection of pipe interior, Blockage removal, Cleaning of pipe interior, Welding of pipe, Repairing of leakage, Recovery of lost parts

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from pipeline, Sample collection etc.^[5] Inspecting and preventing table repair might be applicable by sending a robot into the pipes. So, doing inspection like taking the photo, film analysis in order to distinguish defects and eliminate them seems necessary.^[6] One of the major reason for designing, making and using a pipe inspection robots with the capability of horizontal movement is their vast application in pipe inspection missions. The rest of this paper is organized as follows: Firstly, based on earlier pipe inspection review.^[7] Pons and cons of pipe inspection robot compared in designing and assembling inspector robot in section 2 and then by considering the main criteria of robot design, the system modeled in CATIA and finally made. Additionally, to have the better inspection inside of the pipe with the help of MATLAB, the GUI tools helps the operator and report the founded diffraction in Section 3. The various experiments have done with some curvature and pip ramp setup. Then some initial stages for error detection have experimented in section 4. Finally, the paper concluded with the achieved result and future work.

2. PIPE INSPECTION ROBOT CONSIDERATION

Many researchers have tried to improve and control the different aspects of pipelines inspector robot.^[8,9] Based on these investigations and last review,^[7] these robots can be divided into three basic groups and nine subgroups. To get the best results, this classification has done on the size, structure conformity, movement mechanism, stability and being autonomous.^[9,10] (see Figure 1).

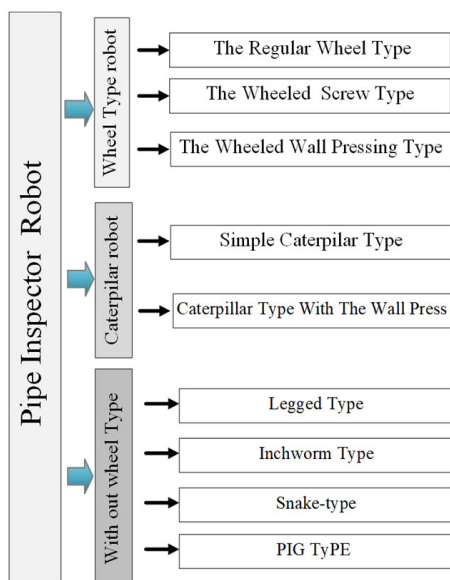


Figure 1. The Robot inspection categories^[5]

The Figure 1 shows the pipe inspection robots which can be classified into wheel type, non-wheeled and caterpillar type robots and each of them are subdivided into mentioned types in Figure 1. Each type of these categories has their own benefits and drawback.

2.1 Selecting Different Operations, Advantages, and Defects

Pipe climber robots have different structure in movement mechanism.^[11-13] This difference causes some merits and defects that have shown in Table 1. As it has shown in previous study,^[7] the wheel pressed type has more advantages in comparison with other robot types.

2.2 Effective Factors in Robot Designing

One of the researchers concern is designing quality and making the pipe climber robot proportional to inspection policy environment case study. To find and design a good structure more manoeuvre are given to the structure. So, it brings more success for the robot missions. The size selection and robot shape are the effective factors in this design which are influenced by some parameters such as pipe internal diameter, bend sand curves, condensation and expansion. Besides, kinds of sediment, obstructions, diversity in internal surface, connections and pipes length have a major impact on the robot movement in the pipes. Some of the most important mentioned parameters have shown in Figure 2.

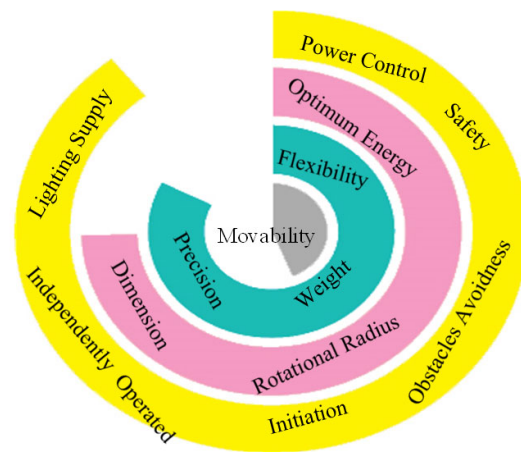


Figure 2. The main aspect and consideration in pipe inspection robots

As Figure 2 shows, over the robot design shape, power consumption control, rotational precise movement, lighting supply inside of the pipe, flexibility, collision avoidance system with obstacles, safety, stability, initiation and doing the operations independently, should be investigated. At the end, the robot propulsion system and things like type of the robot

wheel, optimum energy control system, material, weight and body dimension, will effect on the robot design platform.^[4]

3. DESIGNING AND ASSEMBLING INSPECTOR ROBOT

Many researchers have tried to improve different aspects of using a robot to control its movement inside of the pipeline. Based on studies,^[7, 13, 14] for designing of these type of robots, the robot structure, its operation and abilities should be noticed. More over some limitations such as size, shape, conformity, etc. (see Figure 2). Advantages and disadvantages of robot type are considerable. As it has shown in Table 1, with respect to defined duties and its work environment, the best strategy is selected based on prior study, constructing pipe inspector robot have considered in the following three aspects. First is robot designing mechanism, second is the components designing along simulation and last stage is im-

age visualization data report toolbox. All mentioned sections are explained in the subsequent sections.

3.1 Robot Designing Mechanism

As it mentioned before, based on merits and demerits of robot type, the robot comparisons are shown in Table 1. The wheeled robot with the method of pressing against the septum, has the good rank of reaction against changing diameter and speed of replacement, pipe shape (smooth surface, vertical, “T” shape and bend) selected. So, considering the mentioned items and using a spring in pressure mechanism against the septum, can make it simple. The high ability of conformity and reaction against changing diameter with the interest of pipe friction, robot movement in vertical surfaces improved. On the other hand, the pipe size of 8 inches nominated by its vast usage in petroleum industries. Besides, the other aspect of this research have the flexibility against changing diameter.

Table 1. Pipe Inspection Robot Pons and Cons^[5]

Axis_Type	Structure Type	ADVANTAGE	DISADVANTAGE	
Single	Simple wheel	Simple structure	No capability to climb and speed control	
		Able to climb		
Multi axis	Wheeled wall-pressed	Able to match different pipe size	Poor ability on the uneven surface.	
		Applied friction to move		
	Wheeled wall pressing screw	Multi movement direction capability to climb	Need the big radius in curvature to turn	
		Small size		
Single axis	Caterpillar	Need of small radius in curvature to turn capability to climb	Poor ability on the rugged surface	
		Able to match different pipe size		
	Caterpillar wall-pressed	Upper lift force	Big Friction Force	
		Multi movement direction		
	Caterpillar	Movement ability with the obstacles	Big size	
		Movement ability with the obstacles		
Single axis	Snake shape	No capability to climb	No capability to climb Big size	
		Ability to match different pipe size		
	Without wheel Type	Legged	Complicated structure	
		Inchworm	Complicated structure	
	Without wheel Type	Legged	Ability to match different pipe size	Extra force requirement to move
		Inchworm	Simple structure	Lack of speed mobility
Without wheel Type	PIG	Self-movement principle without actuator	Speed Control difficulty	
			Pipe adaption Inability	

3.2 Designing and Selecting Components

After geometry consideration (8 inches) next step is designing the components and fixing their size. The components design section is divided into two activities.

First section consists of some parts especially designed for a particular mechanism of this purpose. Second section consists of calculating particular components which can be readymade and accessible. Both sections are significantly important in design success. With respect to the main principle

of robot structure, pressing against septum wheeled, at the time of designing robot structure has considered. Some calculation and consideration like kinematic chain, calculating degrees of freedom mechanism, static analysis, computing force against the pipe wall and calculating and selecting components are also investigated.^[15] In both mentioned steps, first, the CATIA V5R21 software has used for geometrical modeling, design mechanism, tolerance control and making the technical plan. Finally, the robot assembled with the

length of 23.5 cm considering the camera place as shown in Figure 3 and Figure 4.

After simulation by CATIA software and doing required calculations, making and assembling components of inspector robot (see Figure 5) have considered.

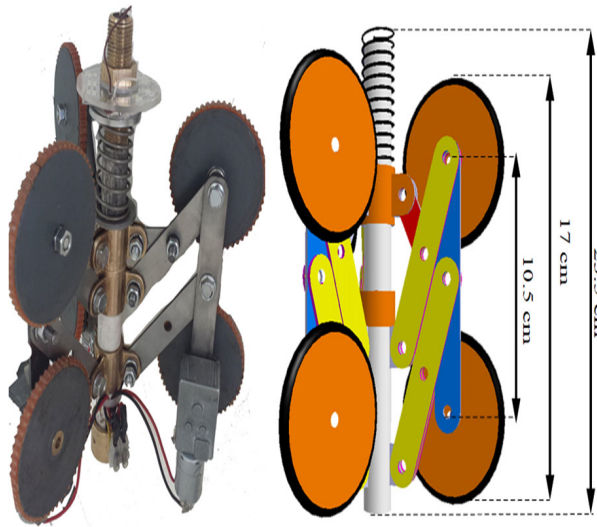


Figure 3. The Robot Catia Design and real assembled component

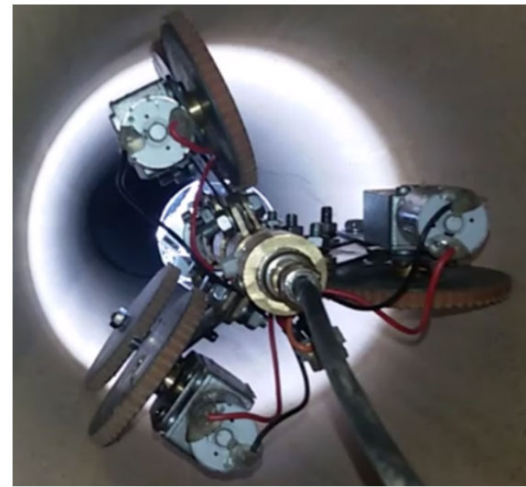


Figure 5. The assembled movement model mechanism of the robot

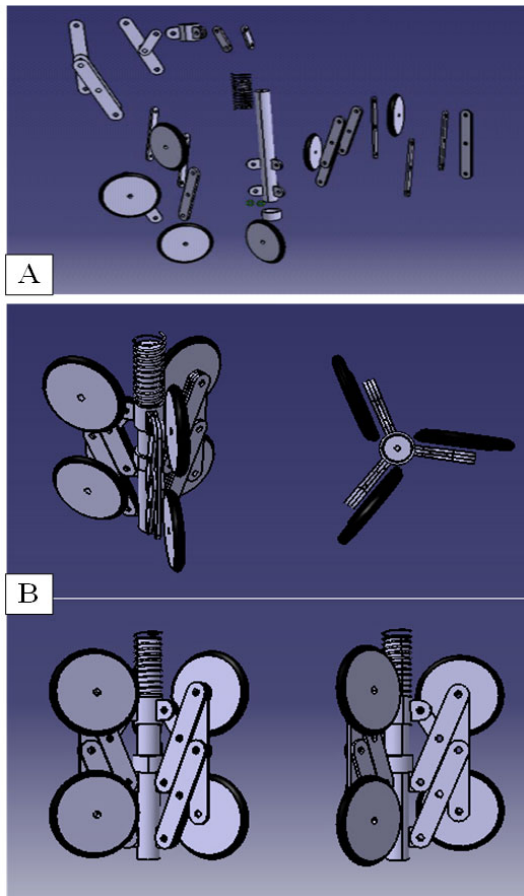


Figure 4. The Robot Catia Design. A: The robot parts and B: The Robot view from Different sides up/down, right/left

The component details such as dimensions ,specifications and parts of design have shown in Table 2. The robot assembly has shown in Figure 6 with the label section.

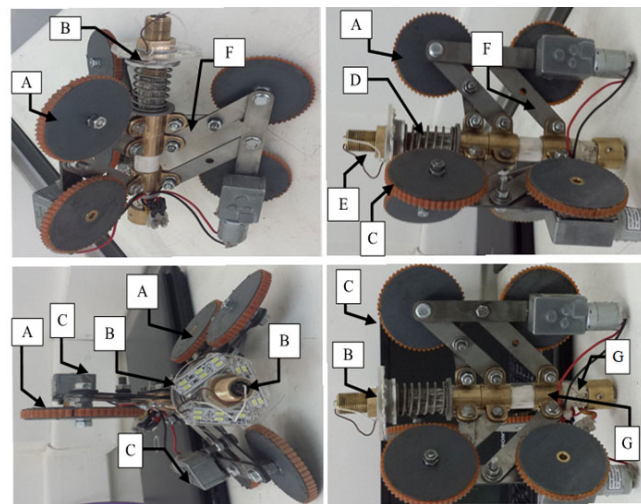




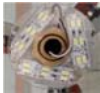



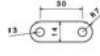
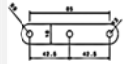
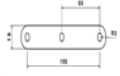

Figure 6. The Made robot parts and section A: wheel, B: Illumination Section, C: Motor, D: Spring, E: camera place, F: Link, G: Main body

3.3 Visual Data Report Toolbox

Image processing is the best tool for particular extractions, situation analysis and making correct decision, at the end. This tool is divided into two significant parts: Image improvement and machine vision. Image improvement consists

of ways such as using the fading filter and increasing contrast to make better visual images quality. Nowadays, machine vision application in inspection missions and robotic field have increased. Also, lots of applications have used these tools. The image processing stages from the first moment up to image generation have shown in Figure 7.

Table 2. The Pipe Inspection Robot Part and Specification

NO	Part Photo	Part	Specification	Quantity	Unit	
1		Wheel	Outer Diameter	72	mm	
			Inner Diameter	67		
		Section: A	Hole Diameter	6		
2		Camera: Eagle Eye	Pixels	15	Mega	
			Frame rate	30	fps	
		Section: B	Interface	2.00	USB	
3		Lighting system	9 pairs of SMD Type LED			
		Section: B				
4		Motor ZWL_FP-12V	Operating voltage	12	V-DC	
			Gear Box Ratio	500		
			Speed	10	Rpm	
			Nominal Torque	6	Kg.cm	
			Max Torque	8	Kg.cm	
			Nominal Current	1.1	A	
			Section: C	Weight	150	gram
5		Spring	Inside Diameter	23	mm	
			Outside Diameter	52		
			Distance Pitch	5		
6		Main body	Outer Diameter	20	mm	
			Section: F	Length		230
7		Small link	Length	30	mm	
			Section: F	Width		14
8		Medium Link	Length	85	mm	
			Section: F	Width		18
9		Big link	Length	105	mm	
			Section: F	Width		18
10		Moveable Section	Outer Diameter	23	mm	
				Inner Diameter		18
			Section: G	Length		25

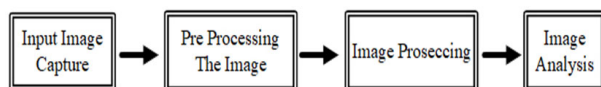


Figure 7. Image processing Steps and sequence

As it has shown in Figure 7, the first image is received from an entrance and enter to the system. The input image can be on the saving toolbox or it can be taken by a camera. In a

designed system, saved images are analyzed. Then, in the preprocessing image stage, image promoting and omitting unnecessary component take place. After it, in the process image stage, some properties like special points and curves will identify. At the end, with the help of extracted particulars, the image will be analyzed. All the mentioned boxes are performed in the Matlab GUI (Graphical User Interface) Figure 8. These tools have considered as the extra tools for

the designed robot with the aim of better image analysis and fault detection.

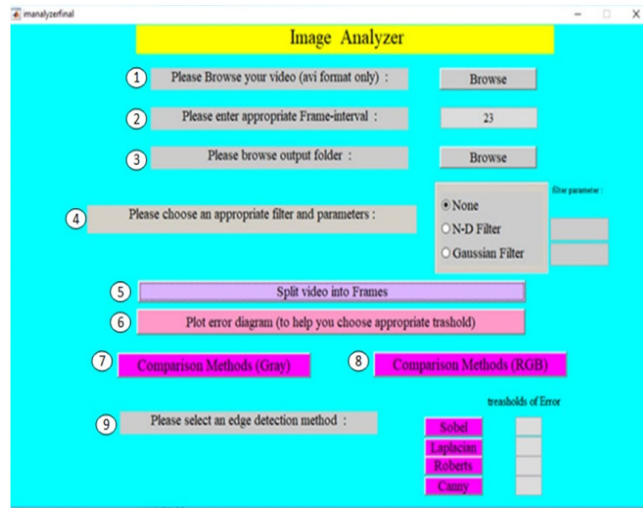


Figure 8. The image Processing toolbox

Table 3. The image analyzer sections

Section LABEL	Function	Description
1	Input Browser	Enter the captured movie file from saved location
2	Splitter frame	Splitter the movie frame based on camera limitation
3	Output Browser	To specify the output folder to save the splinted image
4	Filter was chosen	To select the N-D filter or Gaussian filter
5	Splitter button	Start to split the frame with the specified frame in Section 2
6	Plot	Plot the finding error based on a frame for algorithms
7	Gray Comparison	Select the SOBEL, Laplacian, Roberts, Canny edge detection Method with the specified threshold
8	Gray Comparison	Select the SOBEL, Laplacian, Roberts, Canny edge detection Method with the specified threshold
9	Method selection	Select the Edge detection method SOBEL, Laplacian, Roberts, canny with the specified threshold

The designed GUI works through entering the captured movie taken from robot performance inside of the pipes and inform the probable errors to the operator. The main methods for the fault identifications are edge detection based on algorithm named Sobel, Roberts, Canny, and Laplacian. All four mentioned methods applied for the image and result plotted. It shows the ratio of faulty pixels with error to all pixels. As the Figure 8 has shown, the GUI section has nine sections and provision of acquiring the image and analysis.^[16] The brief description for the GUI parts has shown in Table 3 and the GUI has the provision of draw the line for the error or any abnormal object which can be identified

inside of the pipe. To have the better performance and more accurate fault detection, the operator can select the threshold number which can hire the better results. This stage used for unknown condition which may happened by the light reflection or any other issue inside of the pipe which may causes the wrong evaluation.

The preferred video format is AVI which will be addressed in the first section by the operator. Then, in the second section the GUI needed the sampling number related to the quality and frame rate. For e.g. if the frame rate is 50 by entering the 100 samples, it will be implemented after each 2 seconds. Then, the output of the split image folder should be specified by the operator. As mentioned before, in the GUI, the four famous algorithms of edge detection of SOBEL, Laplacian, Roberts, canny are used. As the next stage, according to the operator selection, the proper filter such as N-D, Gaussian has been used. So, the proper ratio number can be hired or can be left as NONE. After passing this stages, by pressing the “split video into frames” button the image sampling process will be started and by selecting the “plot error diagram” the ratio of error pixels to all pixels will be plotted. In this plot, the X-Axis is the image number and the Y-Axis is the ratio of the identified edge pixel ratio to all pixel shown. This step needs to specify the threshold number which is different in altered algorithms. In the next step by pressing the “comparison (RGB)” for the colored images and “comparison (Gray)” for the Gray images, the results of all four algorithms for edge detection have been monitored which has shown in the same plot (see Figure 15).

4. THE ROBOT OPERATION AND RESULT

After designing, the experiments are planned into two sections. First, movement operations and robot mechanism have studied which this section also is divided into two different parts. The Figure 9 shows the summary of planned tests.

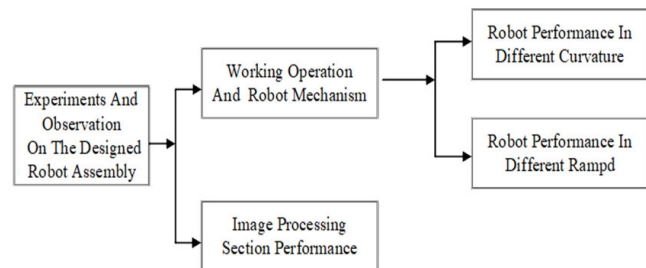


Figure 9. Robot performance test procedure

As the Figure 9 shows, the experiment splinted into two sections to observe the robot mechanism and image processing. To investigate the robot mechanism, the first experiment sec-

tion consists of 8 inches pipeline and two different joint of 45 and 90 degree in order to make the different curvature have designed. The second test is using different ramps by putting in different modes. Finally, to have the study for finding obstacles and defects, with the help of image analyzer section, some test planned as it has described in the following.

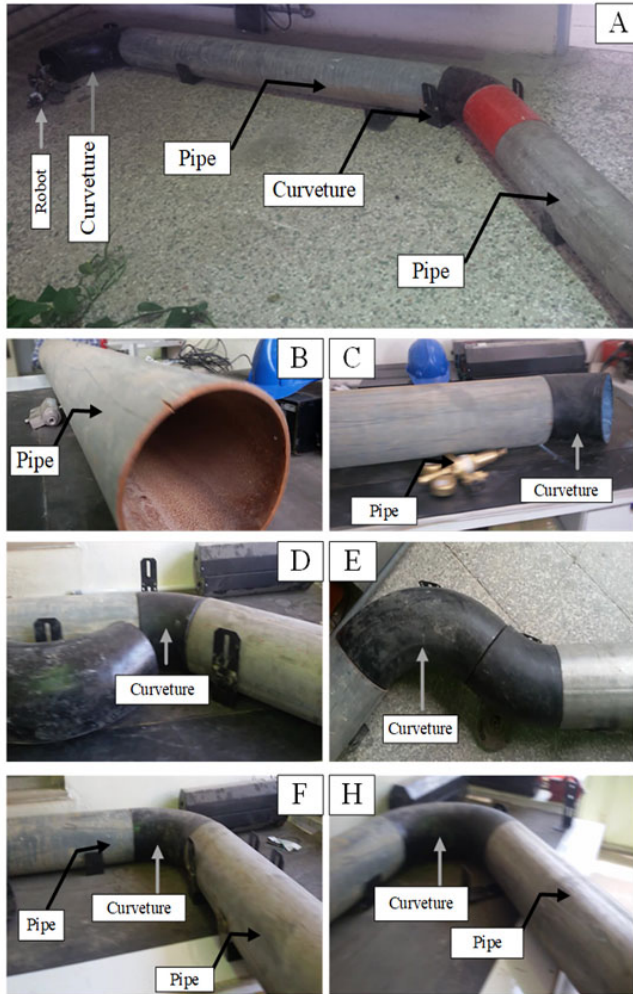


Figure 10. The robot performance in different curvature. A: the sample assembly for 45 degrees, B: straight, C: 45 degrees at the end, D: 45 degree, E: (90 – 45) degrees, F: 90 degrees, H: (90+45) degrees

4.1 The study of working operation and robot mechanism in different joint and curves

For this purpose, pieces of 8 inches diameter pipe with the length of 150 cm and 183 cm along with two joint 45 and 90 degrees as shown in Figure 10 in the workshop arena employed. The aim of this section was testing the robot movement and performance in various curvature. The Figure 10 shows the experiment arena with the different curvature shapes which used to evaluate and experiment the robot. The parameters like pipe length, number of repeated experiments, reaching time average, maximum current and success rate are investigated and shown in Table 4 and Figure 11.

As it has shown in Table 4 and Figure 11, at the first test which is considered without curve, after 4 times repetition, the same result has obtained and the success rate has been 100% each time. But in the 90+45 and 90-45 test, which it was the combination of 90 and 45 degrees joint in two types of the same and opposite direction, after 4 times repetition, the success rate has considered 90%. Although, robot passed slowly the rout successfully, observed that sometimes robot moved with difficulties in created curves.

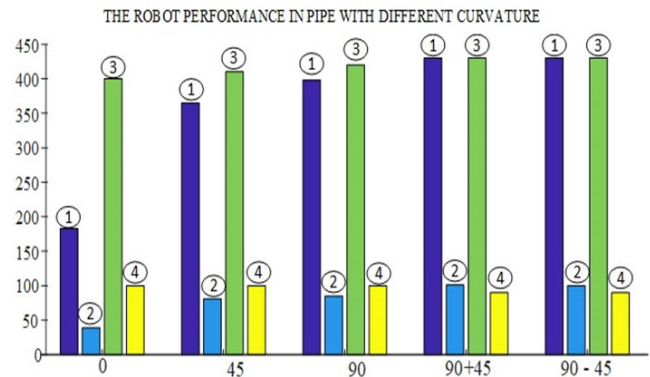


Figure 11. The robot performance in different curvature Compare with 1: Pipe length, 2: reaching average Time, 3: Maximum Current, 4: Success Rate

Table 4. The Robot Performance Evaluation in Different Curvature for The 8 Inches Pipes

No	Curvature (Degree)	Pipe Length (m)	Repeated Experiments	Reaching Time (S)	Maximum usage Current (mA)	Success Rate
1	0	183	4	39	400	100
2	45	365	3	81	410	100
3	90	398	3	85	420	100
4	45 and 90 (Same Direction)	430	4	101	430	90
5	45 and 90 (Opposite Direction)	430	4	100	430	90

4.2 Robot movement test on various slopes

In the second section, for testing and investigating robot movement in different slopes, a 183 cm pipe in different slopes from 0° to 60° with the step of 10o have used and robot movement in these slopes have studied (see Figure 12). The summary of tests and obtained results have shown in Table 5 and Figure 13. The parameters like pipe length, number of repeated experiments, average reaching time, Max current and success rate are monitored.

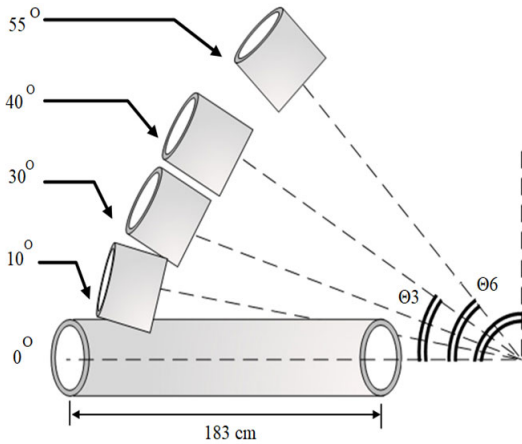


Figure 12. The robot performance in different slope from 0° to 60°

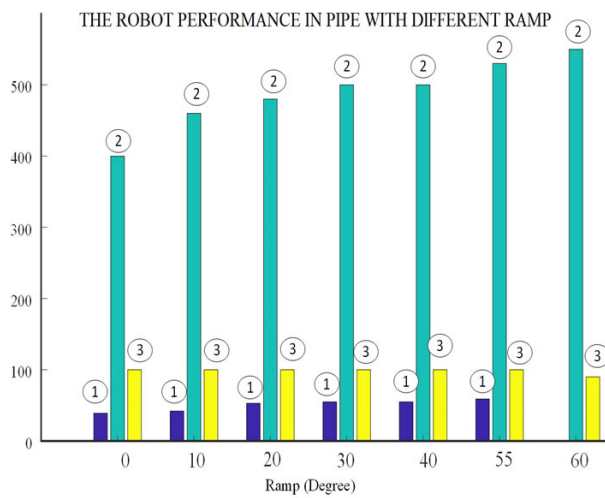


Figure 13. The robot performance in the different ramp Compare with 1: reaching average Time, 2: Maximum Current, 3: Success Rate

As it has shown in Table 5 and Figure 13, by increasing pipeline slope, the engine current intake is increasing as well. While the success rate of a tested robot with used motors is completely successful up to 55-degree slope and for more than this slope, should use more powerful motors.

Table 5. The Robot Performance in Different Ramp

No	Ramp (Degree)	Repeated Experiments	Reaching Time (S)	Maximum usage Current (mA)	Success Rate
1	0	3	39	400	100
2	10	4	42	460	100
3	20	3	53	480	100
4	30	4	55	500	100
5	40	3	55	500	100
6	55	4	59	530	100
7	60	2	--	550	90

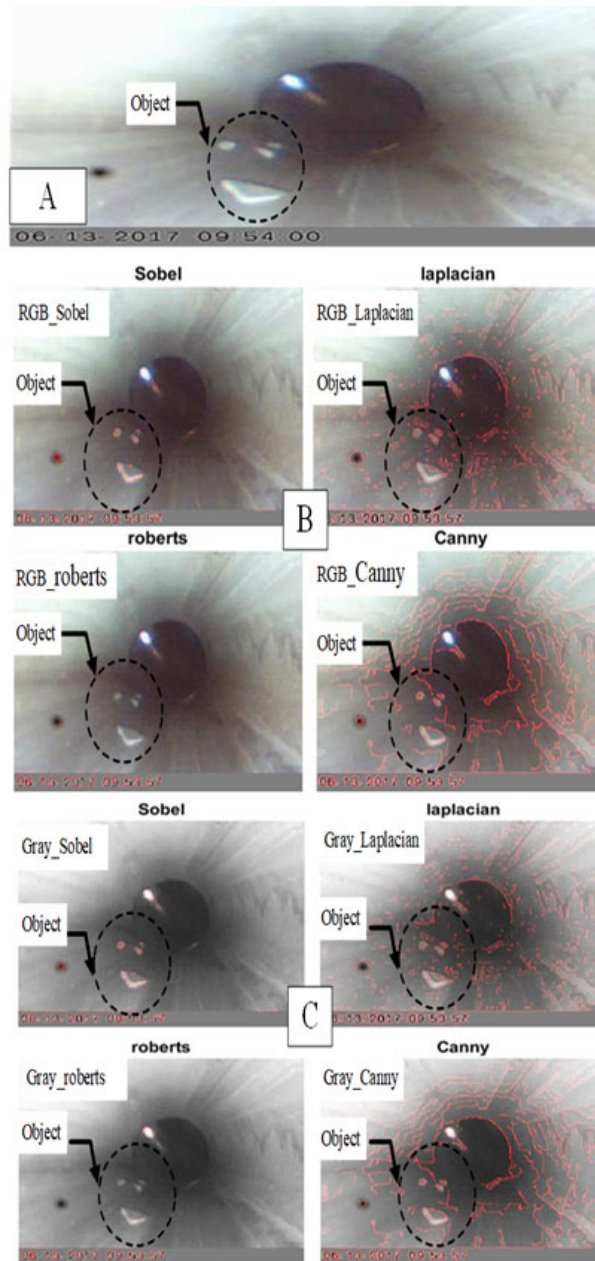


Figure 14. The robot image analysis and detection of the stone

4.3 The Study of Image Processing Tool Operation

As it mentioned before, in order to inspect any abnormal thing inside of the pipe, the GUI (Graphical User interface) has designed.

Always, there is the possibility of remaining gravel and solids in the pipes. So, to put the test in the more real condition, some stones as the extra objects have been used in the pipeline (see Figure 14). Then, via film-taking, by the robot,

it has been investigated.

As the Figure 14 shows, the red line is the error detection which identified by the image analyzer tool in RGB and Gray images with the Sobel, Laplacian, Roberts and canny edge detection methods with the help of designed GUI.^[16] Besides, to help the operator to have the perfect analysis for the images, the graph based on detected fault and image number in all four mentioned methods has plotted (see Figure 15).

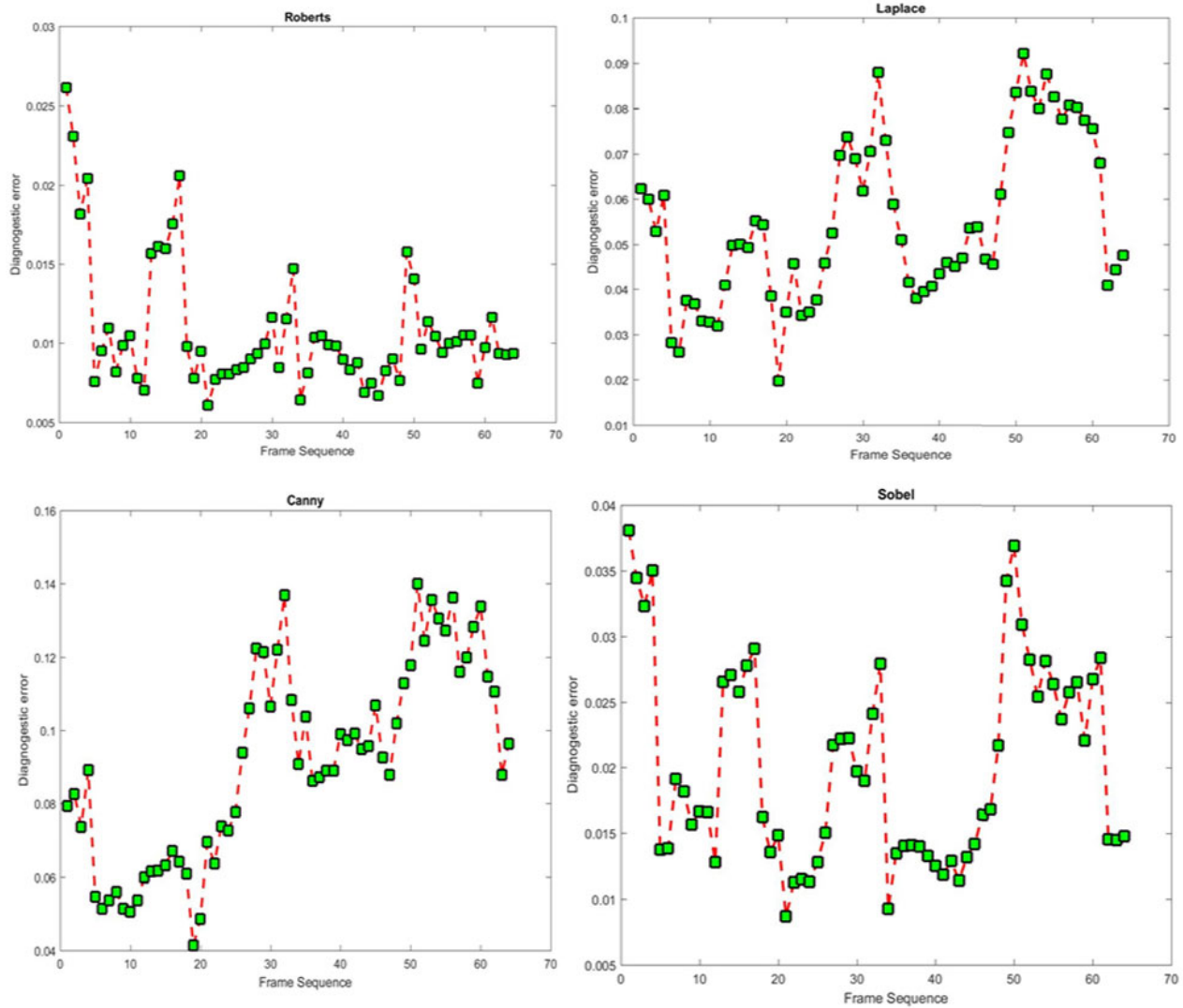


Figure 15. The error detection plot

The Figure 15 has shown the error detection in the image number 26 which is specified in Figure 14.

5. CONCLUSION AND FUTURE WORKS

The robots have a critical rule in today’s industrial activities like the inspection and repair missions in transmission pipes. Some of these robots can do their task in the fixed size and some have the resizable structure with the pipe size which

make them more popular due to the facility in precautionary inspecting input frequency to repairs phase. So, it causes to save money and time in operation. The current research, proposed the pipe inspection design with the wheeled robot and the pressing against the septum method. The main parameter of the mentioned structure is the ability to adapt itself to the pipe size.

Table 6. The Designed Robot Advantage Points

NO	ITEM	DESCRIPTION
1	Structure additivity	This robot mechanism, because of the ability to adapt with pipe diameter, is able to multi-faceted and ability to climb.
		Due to the using friction force, it enjoys relatively more efficiency.
		One of the most important advantages of this design is the adjustable mechanism to the pipe inner diameter.
2	Final Cost	By its simple design has the lowest machinery work.
3	Image analyzer	Image and movie recorder as well as the capability of throwing images on the monitor and saving those images at the time of operation.
		By a study of recorded images with the help of presented toolbox, in addition to effective observation, diagnosis and analysis can be faster.
		Obtaining experience and moving toward localization in this field, causes helping to domestic industries for inspecting fluid transfer pipes as well as preventing of outflow of currency.

Moreover, the experiments are carried out to observe the robot performance in different curvature compare with the pipe length, reaching average time, maximum current and success rate parameters. Besides, the prototype design has the provision to handle a camera along with the designed GUI to have the better inspection and help the operator to check inside of the pipe better. The mentioned design has the capability to enter the pipe with the diameter of 200 to 230 millimeter (around 8 inches). In order to have the resizable size as well as having the good performance in the pipe curvature and impedimenta the spring prepared. So, it gives the flexibility to pass them all and finish the task completely. The existence of spring caused the robot shows flexibility in

confronting physical obstacles and passing them. The result of the designed robot shows the success of its movement inside of 8 inches pipe and passes the ramp up to 60 degrees as well as 0,45,90,90+45,90-45 curvature in the same and opposite direction. According to designed robot structure (see Figure 6).^[17,18] The most difference between the proposed design and previous ones^[15] is the optimization in the size, the image analyzer tool as well as various test which carried out in different situations. Besides, the mentioned robot has some advantages which are shown in Table 6.

Although the proposed robot shows the good result in performance. It has some restrictions, which is discussed in Table 7.

Table 7. The Designed Robot Disadvantage Points

NO	Item	Description
1	Movement limitation	This robot has movement limitations such as moving in cross connections. “+” and “T” connections.
2	Motor weakness	It requires a more powerful Motor for passing the routs with the slope of more than 80 degree and long time.
3	Distance navigation	Friction against the pipe and visual connections cable and power supply leads to the limitation in distance navigation, of course by using the optical fiber or more powerful motors as well as using the cable with a wheel, this limitation can be reduced.
4	Working arena	The designed robot is usable in an empty pipe of fluid or inflammable half-filled with fluid so that its electric parts have no damage.

As the future work, the authors proposed to work on the optimized structure which can work in the cross shape “+” and “T” type junction, also capability to move in the 90° ramp in presence of fluid.

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