International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 4, October 2013

Research Paper

DESIGN AND DEVELOPMENT OF PROTOTYPE MOBILE ROBOT FOR IDENTIFICATION OF DEFECTS IN PIPELINES

Hameedah Sahib Hasan[1,2]* and Sriram Venkatesh[1]

*Corresponding Author: Hameedah Sahib Hasan, Iraq ✉ ham_sa33@yahoo.com

The development of a fully autonomous pipelines inspection system requires design of a robot equipped with the required sensors. In this paper, it is designed a robot with suitable four bar mechanism that can give two linear motions one forward and another backward and carry a camera to capture the picture of defects if any in pipe lines. This self configurable robot has six powered wheels (rollers) chains with three belts and each wheel chain is operated by a micro DC motor. The new wheel chain mechanism is foldable by using a threaded rod. Using this foldable mechanism, a small-sized robot whose external diameter is 180 mm is designed. The velocity and acceleration analysis of each link is calculated for four bar mechanism. Validity of this new foldable wheel chain mechanism is proved through dynamic simulation. Based on this, the stiffness of the torsion threaded rod and the actuator size of DC motors are decided and a prototype of the pipeline inspection robot system is developed. It consists of a main body made from aluminum material and main DC motor and 6 micro DC motors to give motion to six rollers.

Keywords: Autonomous, Pipe inspection, Microcontroller, Obstacle sensor, GSM modem

INTRODUCTION

Autonomous pipe inspection method is introduced to improve the inspection efficiency by reducing the time and manpower in the inspection process. An autonomous robot can act on their own, independent of any controller. Many pipeline inspection robot systems have been developed and have been used in many areas to replace the human efforts. Specially, pipeline maintenance is challenging area for which robots can be employed. Industrial robots are very familiar to most type of industries since their capability to provide services or perform their job that human cannot make it in such a hazardous and dangerous environment. Robots also offer some

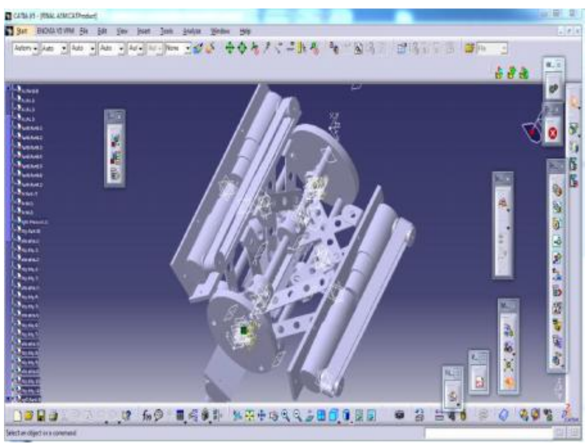
[1] Mechanical Engineering Department, College of Engineering, Osmania University, Hyderabad, India.
[2] Foundation of Technical Education, Al-Diwanyia Technical Institute, Iraq.

advantages in maneuverability with the ability to adapt in-pipe unevenness, move vertically in pipes, and stay stable with-out slipping in pipes. A very important design objective is adaptability of the in-pipe robots to the inner diameters of the pipes.

SELECTION OF MATERIAL

The materials used for prototype robot are light and rigid. Different materials are used for different parts of the robot. Aluminum is chosen for the main body, two circular plates, three rods and bush. However, other suitable materials are chosen for the motor.

Figure 1: Proposed Pipe Line Inspection Robot



THE MECHANISM

The basic mechanism involved here is a four bar mechanism consisting of three revolute joints and one prismatic joint as depicted in Figure 2 the notation and calculations are shown in successive paragraphs.

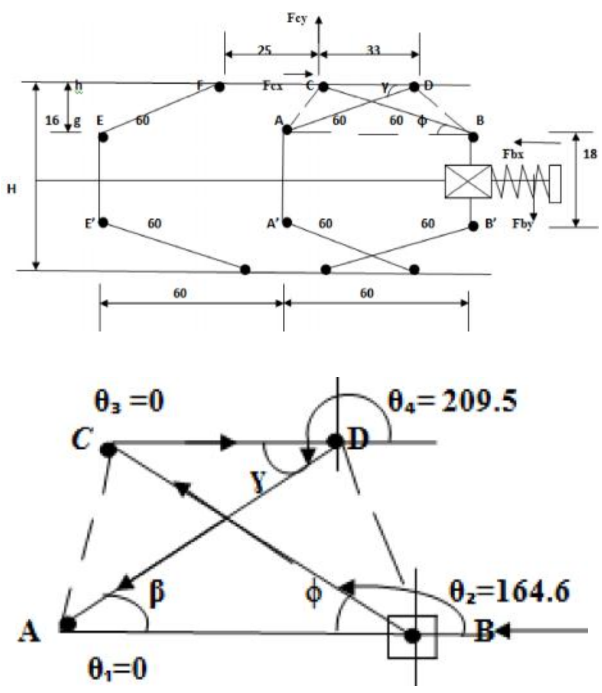
where:

$AB = r_1 = 60$ mm, $\theta_1 = 0$

$BC = r_2 = 60$ mm, $\theta_2 = 180° - \alpha$

$\alpha = \sin^{-1}(hg/BC)$

Figure 2: Mechanism of Pipe Line Robot



$\alpha = \sin^{-1}(16/60) = 15.4°$

$\theta_2 = 180° - \alpha = 164.6°$

$CD = r_3 = 33$ mm, $\theta_3 = 0$

$DA = r_4 = 60$ mm, $\theta_4 = 180° + \gamma$

The robot's height can be determined with the relation.

The maximum and minimum height of robot can be determined based on angle ~ (maximum and minimum limits) and the length of the element (L_2) as shown in Figure 3 and Table 1.

STATIC ANALYSIS

The linkage structure is represented as shown in Figure 4 is a four-bar mechanism consisting of three revolute joints and one prismatic joint.

In order to decide the actuator size, it is necessary to perform the static analysis. Noting Fcx and Fcy are the reaction force and

Table 1: Variation Between Height of Robot and Angle ¤

¤	2*r mm	2*d mm	L_2 mm	$2L_2$cos¤	H mm
15.40	25	2*16	60	115.69	172.69
22.20	25	2*23	60	111.01	182.00
28.60	25	2*28	60	105.35	186.35
35.73	25	2*36	60	97.41	194.41
40.20	25	2*41	60	91.65	198.65
48.80	25	2*48	60	79.04	200.00

Figure 3: Variation of Height of Robot Depending on the Angle ¤

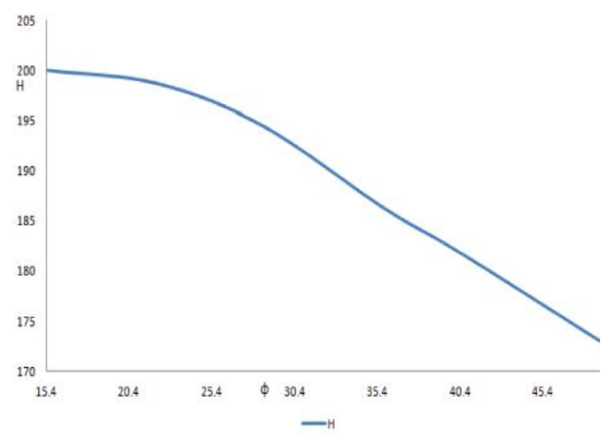
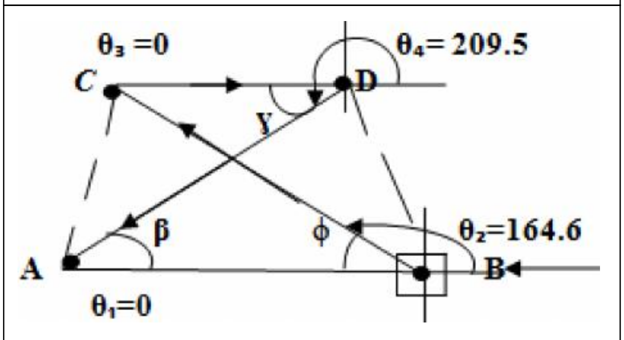


Figure 4: Linkage Structure

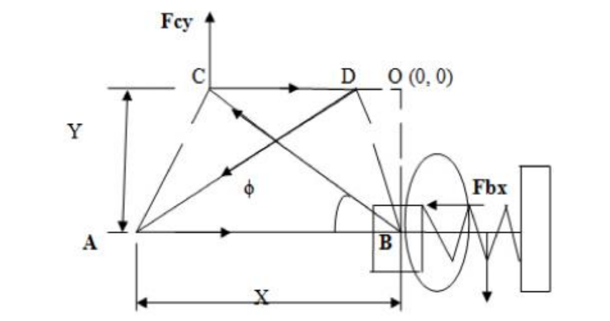


the traction force exerted on the four-bar by the driving wheel, respectively as shown Figure 5. Applying principle of virtual work to the free-body diagram in Figure 4:

¢*W* = *Fcy*¢*y* – *Fbx*¢*x* = 0

where *Fbx* is a spring force.

Figure 5: Static Analysis



This is because only *Fcy* and *Fbx* contribute to work. The corresponding coordinates of these forces relative to the coordinate located at the *O*(0, 0) are expressed as:

cos¤ = *X*/60, *X* = 60 cos¤

sin¤= *Y*/60, *Y* = 60 sin¤

¢*W* = *Fcy*¢*y* – *Fbx*¢*x*

¢*W* = *Fcy*¢(60 sin ¤) – *Fbx*¢(60 cos ¤)

= *Fcy*(60 sin ¤ ¢ ¤) – *Fbx*(60 cos ¤ ¢ ¤) = 0

Rearranging gives

Fbx = *Fcy**(sin ¤/cos ¤)

Thus, the spring force at the prismatic joint *B* is related to the normal force *Fcy* by:

Fbx = *Fcy** tan ¤

Fcy = *Fbx*/tan ¤

at the maximum efficiency Torque = 1.63 m N.m

Fbx = T/0.2**d*

d = diameter of threading rod

0.2 friction factor

Fbx = 1.63/0.2*10 = 0.815 N,

Fbx = *K**Δ *X*, *k* = Threading rod stiffness

K = 0.815/5 mm = 0.163 N/mm,

The traction force *Fcy* determined by

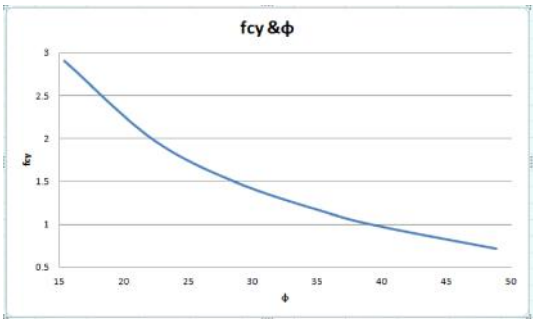
$Fcy = Fbx/\tan$ ¤

$Fcy = 0.163/\tan 15.4° = 0.815$ N

Table 2: Variation Between Traction Force (Fcy) and Angle (¤)

Fbx(*N*)	¤	tan ¤	*Fcy* = *Fbx*/tan¤(*N*)
0.815	15.4	0.275	2.9
0.815	22.2	0.4	1.99
0.815	28. 6	0.54	1.49
0.815	35.73	0.7	1.13
0.815	40. 2	0.84	0.96
0.815	48.7	1.14	0.71

Figure 6: Varition of Traction Force (Fcy) Depending Angle (¤)



The traction forces Fcx exerted on the belt. Thus, each traction force *Fcx* is one six of the whole weight of the robot structure. Thus, the size of the actuator enclosed in the wheel is calculated by $G = Fcx*R = W*R/6$.

where *R* is the radius of the wheel. From the above static analysis, it is known that the weight of the robot does not influence the foldable motion of the linkage.

PROTOTYPE DEVELOPMENT

Typical 3-D solid modeling of pipeline inspection robot components namely main body, circular plate, threaded rod, link, DC motor, PIR main component and micro DC motor are shown in Figures 7 to 13.

Figure 7: Pipe Line Inspection Robot

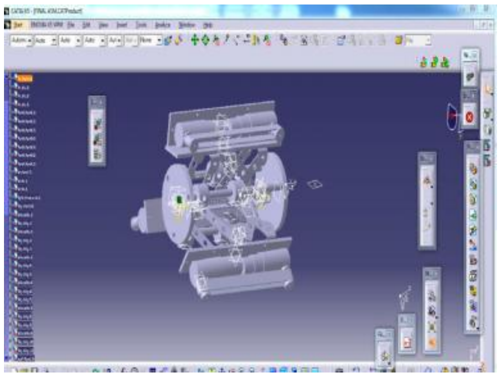
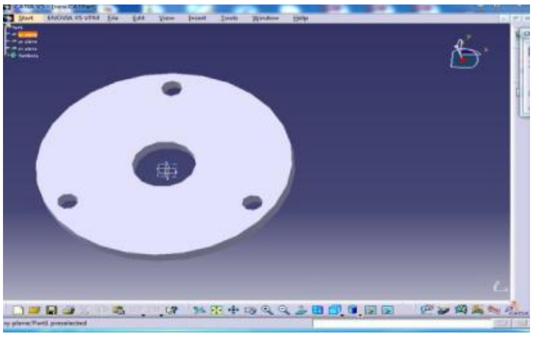


Figure 8: Aluminum Circular 1



Threaded Rod

Inner diameter 8 mm, Outer diameter 10 mm, Pitch 5 mm, Length 130 mm with diameter 10 mm, Length 10 mm with diameter 8 mm, Material – mild steel as shown as in Figure 9.

Figure 9: Threaded Rod

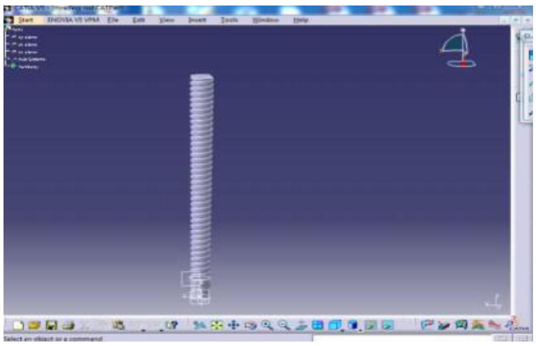
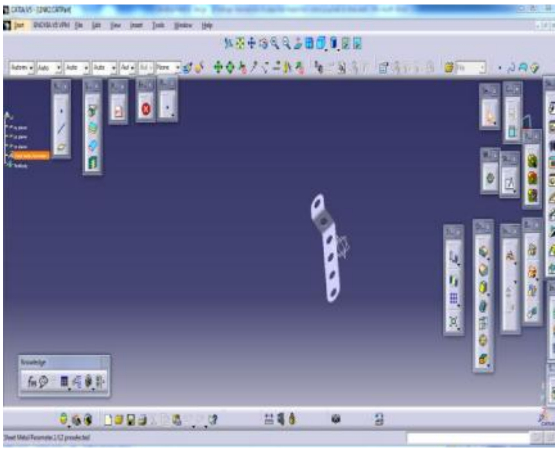


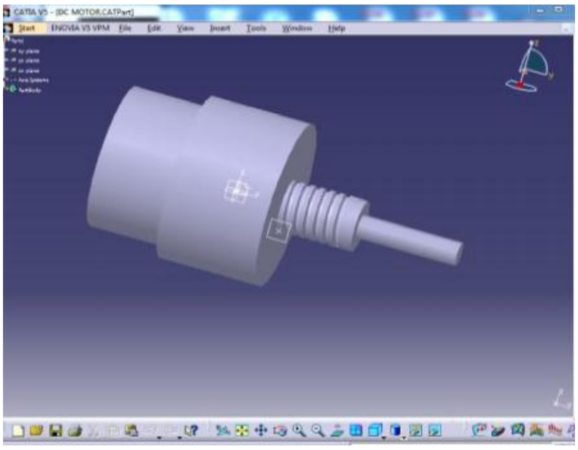
Figure 10: Link



DC Motor

The specifications of DC motor are as follows: Voltage: 12 V, torgue: 1.6 mN.m, power: 0.5 W current: 500 m amp, RPM 100 rpm, as shown in Figure 11.

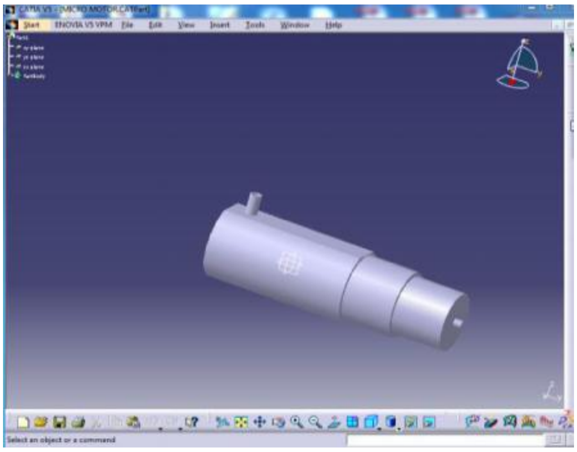
Figure 11: DC Motor



Micro DC Motor

A micro DC motor equipped with an encoder is enclosed inside the caterpillar wheel parts with following specifications: Voltage: 6V, torgue: 1.6 mN.m, power: 0.45 W, current: 0.059 amp, RPM 2620 rpm, as shown in Figure 12.

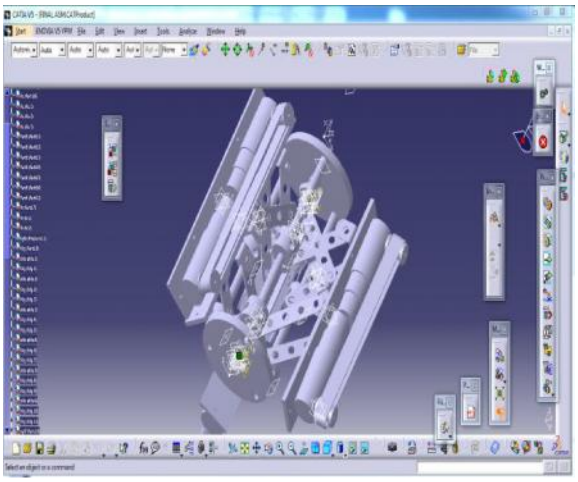
Figure 12: Micro DC Motor



Center Frame of Pipeline Robot

Central body is the frame of the robot (Figure 13). It gives two motion and Connected with other components and supports all part and holds batteries at the centre of the body. The joints (net) are brazed on the central frame with six links at 120°. The central body threading rod, main part and main component fabricated from aluminum material, which the single aluminum is cut into rectangular sheets and circular of required length and breadth.

Figure 13: PIR Main Component



DEGREE OF FREEDOM

Degree of freedom of a pair is defined as the number of independent relative motion, both translation and rotational.

Degree of freedom for planer mechanism

$DOF = 3(N–1) – 2j_1 – 2j_2$

where

N: Total number of link in a mechanism

j_1: Number of pair having one degree of freedom

j_2: Number of pair having one degree of freedom

For this pipeline inspection robot, the degree of freedom calculated as below for the shown in Figure 14.

$N = 10, j_1 = 13, j_2 = 0$

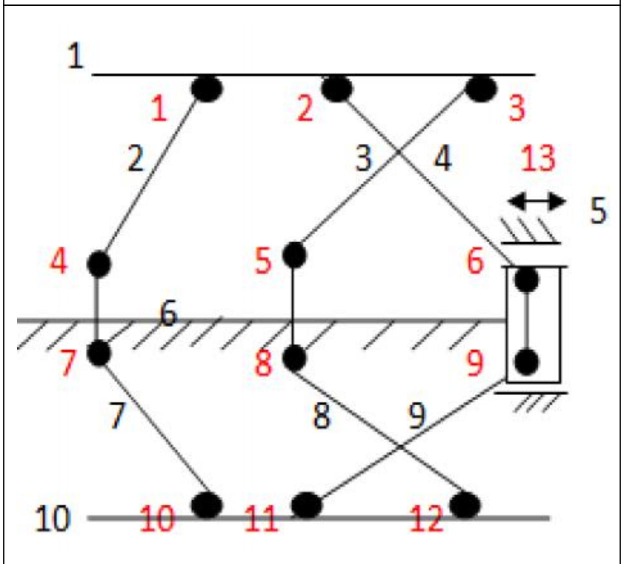
$DOF = 3(N–1) – 2j_1 – 2j_2$

= 3(10–1) – 2*13 – 2*0

= 27 – 26

= 1

Figure 14: DOF



VELOCITY ANALYSIS

Velocity analysis four bar mechanism which consisting of three revolute joints and one prismatic joint as shown in Figure 15.

where

$AB = r_1$ = 60 mm, ¯$_1$ = 0

$BC = r_2$ = 60 mm, ¯$_2$ = 180° – ¤

¤ = $\sin^{-1}$ (hg/BC) = 15.4°

¯$_2$ = 180° – ¤ = 164.6°

$CD = r_3$ = 33 mm, ¯$_3$ = 0

$DA = r_4$ = 60 mm, ¯$_4$ = 180° + ¥

where

¤ = 15.4°

$CA = [r^2_1 + r^2_2 – 2*r_1*r_2\cos 15.4°]$ ^ ½

= [60² + 60² – 2*60*60*cos15.4°] ^ ½

= 16 mm

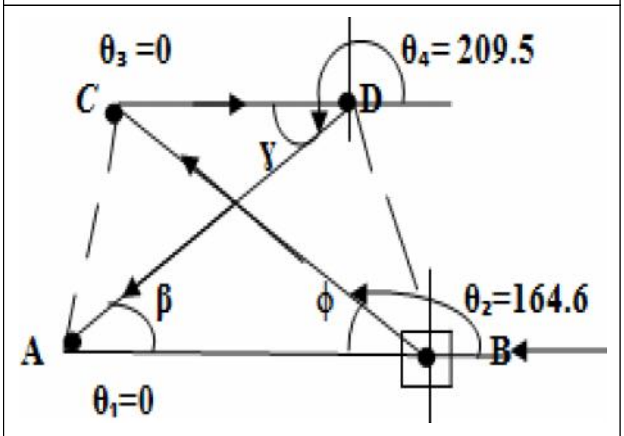
$DB = [r^2_2 + –r^2_3 – 2*r_3*r_2\cos 15.4°]$ ^ ½

= [33² + 60² – 2*33*60*cos15.4°] ^ ½

= 29.5 mm

¥= $\cos^{-1}[(r^2_1 + r^2_4 – db^2/2*r_1*r_4\cos 15.4°)]$

Figure 15: Velocity Analysis



¥ = 29.5°

$^{-}{}_{4}$ = 180° + ¥ = 209.5°

$$\bar{r}_1 = \overline{AB} = r_1 \cos{}^{-}{}_1 i + r_1 \sin{}^{-}{}_1 j$$

= 60 cos 0 *i* + 60 sin 0 *j* = 60 *i*

Velocity for link 1(V_1) = 0 fixed link

$$\bar{r}_2 = \overline{BC} = r_2 \cos{}^{-}{}_2 i + r_2 \sin{}^{-}{}_2 j$$

$$\bar{r}_2 = \overline{BC} = 60 \cos 164.6 i + 60 \sin 164.6 j$$

$$\overline{BC} = -57.8 i + 15.9 j$$

Velocity for link 2(V_2), W_2 = 10.5 rad/sec

$$\overline{V}_2 = \overline{BC} * W_2$$

$$\overline{V}_2 = \begin{vmatrix} i & j & k \\ 0 & 0 & 10.5 \\ -57.8 & 15.9 & 0 \end{vmatrix}$$

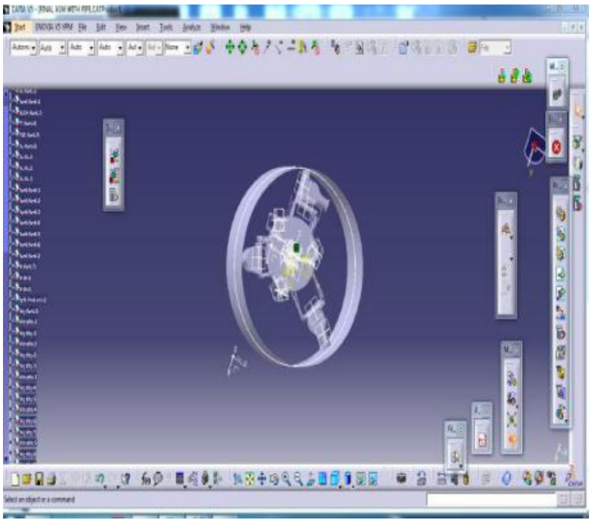
= *i*(0–(10.5*15.9)) – *j*(0–(10.5*–57.8)) + *k**(0)

$$\overline{V}_2 = -106.9\ i - 607.67\ j = 617\ \text{mm/sec}$$

PIPELINE MOBILE ROBOT TEST RESULTS

The prototype mobile robot for identification of defects in Pipelines of proposed mechanism is built. The prototype was built for a robot with the weight of 1.5 kg. The body of the robot was fabricated mostly from aluminum. The Robot was driven by one main DC motor and six micro DC motors. Pipeline inspection robot tested successfully for movement in horizontal for forward and backward motion. The robot has a good mobility and ability to detected obstacles by using IR sensor. The static analysis and kinematic analysis is carried out.

Figure 16: Modeling and Simulations of Pipeline Inspection Robot Using Catia Software



CONCLUSION

Prototype mobile robot for pipeline inspection is designed and fabricated with aluminum material. The robot is applied to 180 mm pipeline maximum diameter and it has flexibility to adjust links to another diameter less 180 mm. The kinematic and static analysis of main robot has been carried out by consideration four bar mechanism and actuator sizing of this robot have been investigated. The robot has got one degree of freedom that is translation either to or forward with total weight 1.5 kg. Finally robot is tested for functionality and found suitable for inspection of defects pipelines with camera attach to it.

REFERENCES

1. John Juicker J R, Gordon R Pennock and Joseph E Shigley (2009), "Theory of Machines and Mechanisms", 3rd Edition, Oxford International Student Edition, New Delhi.

2. Jong-Hoon Kim, Gokarna Sharma and Sitharama Iyengar S (2010), "FAMPER: A Fully Autonomous Mobile Robot for Pipeline Exploration", *IEEE*, pp. 517-523.
3. Jong-Hoon Kimy, Gokarna Sharmay and Iyengary S S (2010), "Design Concept and Motion Planning of A Single-Moduled Autonomous Pipeline Exploration Robot", *IEEE*, pp. 1500-1505.
4. Navin Prasad E, Kannan M, Azarudeen A and Karuppasamy N (2012), "Defect Identification in Pipe Lines Using Pipe Inspection Robot", *IJMEER*, pp. 20-31.
5. Rattan S S (2009), "Theory of Machines", 3rd Edition, Tata McGraw Hill Education Private Limited, New Delhi.
6. Tatar O, Mândru D and Ardelean I (2007), "Development of Mobile Mini Robots for in Pipe Inspection Tasks", pp. 60-64.
7. Young-Sik Kwon and Byung-Ju Yi (2010), "Development of A Pipeline Inspection Robot System with Diameter of 40 mm to 70 mm (Tbot-40)", *IEEE*, pp. 258-263.
8. Young-Sik Kwon, Eui-Jung Jung, Hoon Lim and Byung-Ju Yi (2007), "Design of a Reconfigurable Indoor Pipeline Inspection Robot", *ICROS*, pp. 712-716.
9. Young-Sik Kwon, Hoon Lim, Eui-Jung Jung and Byung-Ju Yi (2008), "Design and Motion Planning of a Two-Moduled Indoor Pipeline Inspection Robot", *IEEE*, pp. 3998-4004.