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DESIGN AND FABRICATION OF PIPE INSPECTION ROBOT

K.V.P.P CHANDU, B.V.SUBRAHAMANYAM, Assistant professor, Department of Mechanical Engineering, SIR C R REDDY COLLEGE OF ENGINEERING, Eluru, A.P
M.ARCHANA [M. Tech], Department of Mechanical Engineering, SIR C R REDDY COLLEGE OF ENGINEERING, Eluru, A.P

ABSTRACT: Robotics is one of the fastest growing engineering fields of today. Robots are designed to remove the human factor from labor intensive or dangerous work and also to act in inaccessible environment. The use of robots is more common today than ever before and it is no longer exclusively used by the heavy production industries. Inspection robots are used in many fields of industry. One application is monitoring the inside of the pipes and channels, recognizing and solving problems through the interior of pipes or channels. Automated inspection of the inner surface of a pipe can be achieved by a mobile robot. Project aims to create an inspection. The mechanism used involves a central rod upon which a translational element is fitted which in turn is connected to three frames of links and wheels. DC motors are attached to the wheels to achieve the drive required. The mechanism allows autonomous robot used for in-pipe for small accommodation in pipe diameters. An electronic circuit consisting of three relay switches is used to control the entire circuitry of DC motors, camera and translational element. The camera is mounted on the top of the assembly, which in itself can be rotated thus giving a wide field of view in the pipe. The robot allows for detection of cracks, buckle, corrosions, pitting and many others. The fabrication of the robot was successfully completed and an inspection has been done in a sample environment.

INTRODUCTION Pipeline systems deteriorate progressively over time. Corrosion accelerates progressively and long term deterioration increases the probability of failure (fatigue cracking). Limiting regular inspecting activities to the "scrap" part of the pipelines only, results ultimately into a pipeline system with questionable integrity. The confidence level in integrity will drop below acceptance levels. Inspection of presently uninspected sections of the pipeline system becomes a must. This project provides information on the "robotic inspection technology". Pipelines are proven to be the safest way to transport and distribute Gases and Liquids. Regular inspection is required to maintain that reputation. The larger part of the pipelines system is accessible by In-Line Inspection Tools but this access is limited to the section in between the launching and receiving traps only. Unfortunately, corrosion does not have this limitation. The industry looks for means of inspecting these in-accessible pressure holding piping systems, preferably, without interrupting the operations. It is a fact that sufficiently reliable and accurate inspection results can only be obtained by direct pipe wall contact/access. If that is not feasible from the outside, we have to go inside. Since modifying pipeline systems for In-Line Inspection is mainly not practical, PIPE INSPECTION ROBOT pursues development of ROBOTIC inspection services for presently in-accessible pipeline systems. Robotics is one of the fastest growing engineering fields of today. Robots are designed to remove the human factor from labor intensive or dangerous work and also to act in inaccessible environment. The use of robots is more common today than ever before and it is no longer exclusively used by the heavy production industries. The inspection of pipes maybe relevant for improving security and efficiency in industrial plants. These specific operations as inspection, maintenance, cleaning etc. are expensive, thus the application of the robots appears to be one of the most attractive solutions. Pipelines which are tools for transporting oils, gases and other fluids such as chemicals, have been employed as major utilities in a number of countries for long time. Recently, many troubles occur in pipelines, and most of them are caused by aging, corrosion, cracks, and mechanical damages from the third parties. So, continuous activities for inspection, maintenance and repair are strongly demanded. The robots with a flexible (adaptable) structure may boast adaptability to the environment, especially to the pipe diameter, with enhanced dexterity, maneuverability, capability to operate under hostile conditions. The wheeled robots are the simplest, most energy efficient, and have the best potential for long range. Loading the wheels with springs, robots also offer some advantages in maneuverability with the ability to adapt to in-pipe unevenness, move vertically in pipes, and stay stable without slipping in pipes. These types of robots also have the advantage of easier miniaturization. The key problem in their design and implementation consists 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 adaptability of the in-pipe robots to the inner diameters of the pipes. Currently, the applications of robots for the maintenance of the pipeline utilities are considered as one of the most attractive solutions available Pipe Inspection Robot is shown in Figure 1

Fig 1 Pipe inspection robot

The materials used for this machine are to be rigid. Different materials can be used for different parts of the robot. For optimum use of power the materials used should be light and strong. Wood is light but it is subjected to wear if used for this machine. Metals are the ideal materials for the robot as most of the plastics cannot be as strong. Material chosen should be ductile, less brittle, malleable, and have high magnetic susceptibility. Among the metals/metal alloys, aluminum is a good choice. But, mild steel 1018 was chosen as the material for links and a translational element as it is sufficiently rigid and less brittle. It balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components. However, mild steel is denser compared to aluminum and makes the robot heavier. C45 steel is chosen as the material for screw rod as it is a medium carbon steel, which is used when greater strength and hardness is desired than in the "as rolled" condition.

LITERATURE SURVEY FAMPER [10] is designed to inspect 150 mm pipelines and consists of four caterpillar tracks with extendable link systems. Due to its flexibility, it can manoeuvre in damaged pipelines and pass over obstacles. Caterpillar track is attached to rectangular central body platform using four independent suspension links that can contract from 157 mm to 127 mm. Spring and flexible links act as a suspension system to provide sustainable performance in uncertain pipeline condition. Each caterpillar is controlled independently to ensure that the robot can navigate in pipe branches and elbows by differentiating their speeds. The prototype was tested in test bed of 45° and 90° elbow as well as T-branch with outstanding mobility performance. mechanism for self-adjustability and overpass obstacle. The caterpillar wheels are designed to be 5° tilted with respect to the main body to provide self-adjust ability. This enables all caterpillar wheels to get in contact to the surface.Y. S. Kwon et al. [11] applied the same locomotion combination with slightly different arrangement. Three caterpillar wheels are arranged 120° apart and connected by a pair of four bar linkage mechanism each to the triangular main body. Linkage structure enables the caterpillar wheel to adapt pipe diameter change. The robot exterior diameter is 80 mm and can expand up to 100 mm. The advantage of caterpillar wheel in maintaining contact with the surface is further improved by utilizing silicon as outer wheel surface to enhance the gripping and propelling force. Each of the caterpillar wheels is controlled independently. On the other hand, rear module is pulled by expansion force stored in the spring. Due to its light weight design, the 532g weight robot can encounter transition from horizontal to vertical pathway. The prototype was successfully tested in an acrylic pipelines with multiple cast iron elbows and T-branches that is the same as pipeline type 80 used in Korea and Japan.PAROYS-II [12] also implements the combination of caterpillar wheels and wall press locomotion. Caterpillar wheels are located 120° apart to the centre module. Each of the caterpillar wheels can be controlled independently. However, PAROYS-II uses leads screw in centre module to expand and retract its pantograph mechanism to adapt pipe diameter ranging from 400 mm to 700 mm. Another special feature is its caterpillar wheels consists of two segmented module, frontal and rear tracks. Frontal track is connected to a RC servomotor which is attached to the rear track. The ability of frontal track to rotate maintains the track in contact with uneven surface. Revolute joint that connects the track module and pantograph mechanism allows PAROYS-II to turn in curved pipe efficiently without any motion singularity issue. These two special features in PAROYS-II caterpillar wheels strengthen its ability to overcome obstacles. K. Sato et al. [13] developed modular caterpillar wall pressed robot that consist of identical units and connecting links. The number of units needed is determined by the pathway condition and diameter of the pipe. For 300mm diameter pipe, three units are required to move straight. Two types of actuators are used for each unit movement. RC servomotor is used to rotate the links so that the unit is pushed against both side of the wall. DC motor is used to manoeuvre the unit forward and backward directions. The unique feature of this robot is its rotation mechanism. A force sensor is used to control the angle of the links. First, the units are rotated to be in vertical direction and pushed the upper and bottom wall. Then, the robot is rotated sideways of the wall for alignment of the robot movement direction and the joints. In order to move, the robot is changed to a movable mode where the units are arranged alternately to push the both side of the wall. The prototype is tested for straight movement and turning ability. On top of that, this robot is also able to move in vertical pipe by applying sufficient force between 5.0 N and 8.5 N. Y.S. Kwon et al. [14] employed an advanced wheeled wall pressed pipe inspection robot with two wheel chain. Normal wall pressed robots require at least three wheel chains and occupy most of the central module area. Similar to other wall pressed robot, folding mechanism is employed to adapt the diameter change of the pipe. This robot is designed to inspect pipelines ranging from 80 to 100mm in diameter. The wheel chains are installed 180° apart supported with parallel folding mechanism to the main body and the wheels are in contact with the wall.

DESIGN OF PIPE INSPECTION ROBOT

Selection of materials

The materials used for this machine are light and rigid. Different materials can be used for different parts of the robot. For optimum use of power the materials used should be light and strong. Wood is light but it is subjected to wear if used for this machine. Metals are the ideal materials for the robot as most if the plastics cannot be as strong as metals. Material should be ductile, less brittleness, malleable, and high magnetic susceptibility. Among the metals, aluminum is the material chosen for the linkages and the common rod, which is made as hollow for reduction in weight. However, other materials are chosen for the motor. The materials chosen for the motor should have high magnetic susceptibility and should be good conductor of electricity. The materials are copper and so on. But aluminum is chosen as the materials for the linkages and central body because of its much-desired Properties. Aluminum has lightweight and strength; it can be used in a variety of applications. Aluminum alloys with a wide range of properties are used in engineering structures .The strength and durability of aluminum alloys vary widely, not only because of the Components of the specific alloy, but also because of heat treatments and manufacturing Processes. Another important property of aluminum alloys is their sensitivity to heat.Work shop procedures involving heating are complicated by the fact that aluminum, unlike steel, will melt without first glowing red. Aluminum alloys, like all structural alloys, are also subject to internal stresses following heating operations such as welding and casting. The problem with aluminum alloys in this regard is their low melting point, which make them more susceptible to distortions from thermally induced stress relief. The toughness, as measured by crack propagation energy, decreases as yield stress increases. At the same yield stress, the under aged structure has greater toughness than the over aged structure.

Mechanism

The mechanism involved here is a four bar mechanism consisting of three revolute joints and one prismatic joint as depicted.

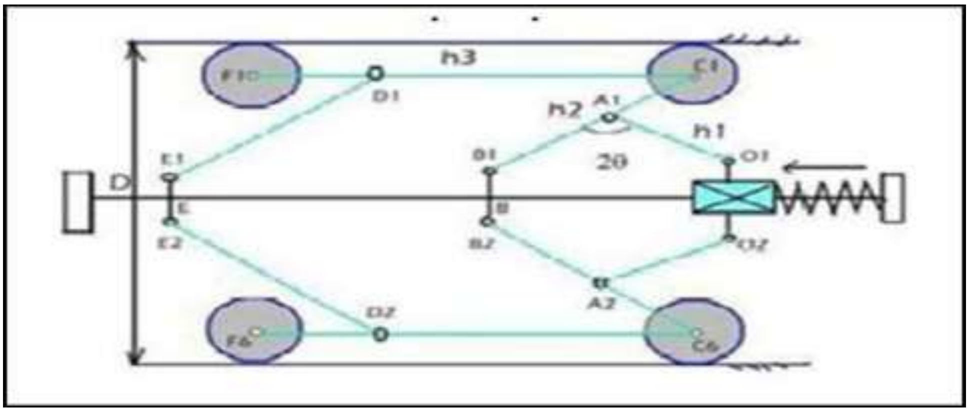

Fig 2 Mechanism of PIR

We have,

H = (2r)+ (2d)+ (2h2)×cosθ,

Where,

h1 = 70 mm

h2 = 70 mm

h3 = 155 mm

r = 35 mm d

= 25 mm

H = (2r) + (2d) + (2h2)×cosθ

H= (2×35)+(2×25)+(2×70)× cos60

H= 190 mm

Where,

D - Diameter of the pipe in mm, D -

Distance between EE’ in mm.

h1, h2, h3 are the length of the links in mm. r -

Radius of the wheel,

H = Height of robot outside the pipe.

Main Components

Arduino Uno The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts. It is also similar to the Arduino Nano and Leonardo. The hardware reference design is distributed under a Creative Commons Attribution Share-Alike 2.5 license and is available on the Arduino website. Layout and production files for some versions of the hardware are also available.

Fig 3 Arduino Uno

L293D Driver

L293D is a typical Motor driver or Motor Driver IC which allows DC motor to drive on either direction. L293D is a 16-pin IC which can control a set of two DC motors simultaneously in any direction. It means that you can control two DC motor with a single L293D IC. In a single L293D chip there are two H-

Bridge circuit inside the IC which can rotate two dc motor independently. H-bridge is a circuit which allows the voltage to be flown in either direction. H-bridge IC are ideal for driving a DC motor. Due its size it is very much used in robotic application for controlling DC motors. The L293D driver module is shown in the Fig 4

Fig 4 L293D driver module

HC-05 Bluetooth Module

The HC-05 Bluetooth Module has 6 pins- Vcc, GND, TX, RX, Key, and LED. It comes pre-programmed as a slave, so there is no need to connect the Key pin, unless you need it change it to Master Mode. The major difference between Master and Slave modes is that, in Slave mode the Bluetooth module cannot initiate a connection, it can however accept incoming connections. After the connection is established the Bluetooth module can transmit and receive data regardless of the mode it is running in. If you are using a phone to connect to the Bluetooth module, you can simply use it in the Slave mode. The default data transmission rate is 9600kbps. It is shown in the Fig 5 The range for Bluetooth communication is usually 30m or less. The module has a factory set pin of “1234” which is used while pairing the module to a phone. The HC-05 Bluetooth Module can be used in a Master or Slave configuration, making it a great solution for wireless communication.

Fig 5.HC-05 Bluetooth Module

Dc Motor

A DC motor is any of a class of rotary electrical motors that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current in part of the motor. The Dc Motor is shown in the Fig.

Fig6 Dc Motor

Camera

This camera uses an advanced 2.0MP image sensor that will capture 720P HD video with accurate color reproduction, the live video can be viewed via iOS/Android Smartphone, Tablet or Windows PC. And this camera has 350° pan and 90° tilt with 75° broad field of view, creating a complete 360° coverage view to monitor every corner. The camera used is shown in the Fig 7.

Fig 7 360^{o} rotating Camera

It also has Auto Tracking feature. It has inbuilt IR LED's with help of which you can clear display in complete dark up to 10 meter.

Translational Element

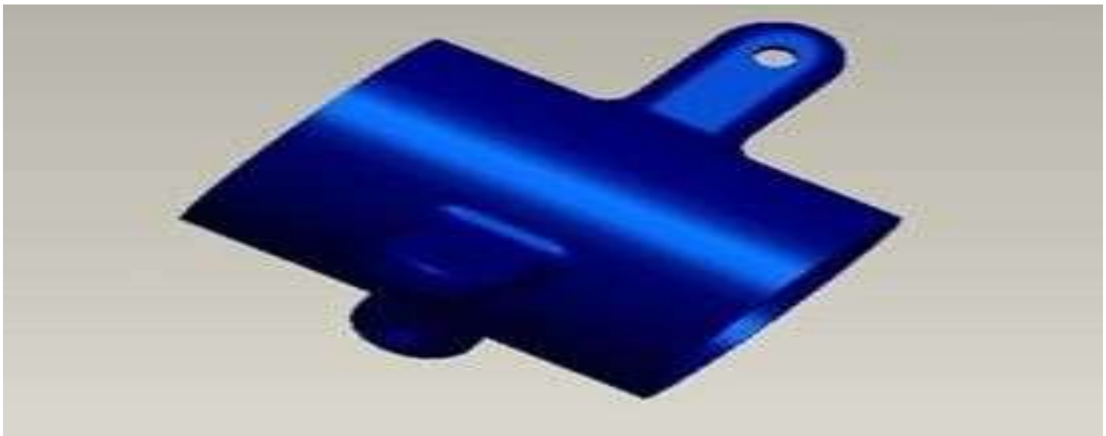

Fig 8 Design of translational element

Translational Element is the movable part in the robot which slides along the central body for repositioning in case of pipe diameter variation. This element is drilled at the centre for the translating along the central body. This will restrict the links to some extreme angles beyond which it could not be translated. The extreme angles are found to be 15 degrees and 60 degrees. The joints are brazed on the translational element at 120 degrees for the links to be fixed onto it.

Fig 9 Translational Element

Links

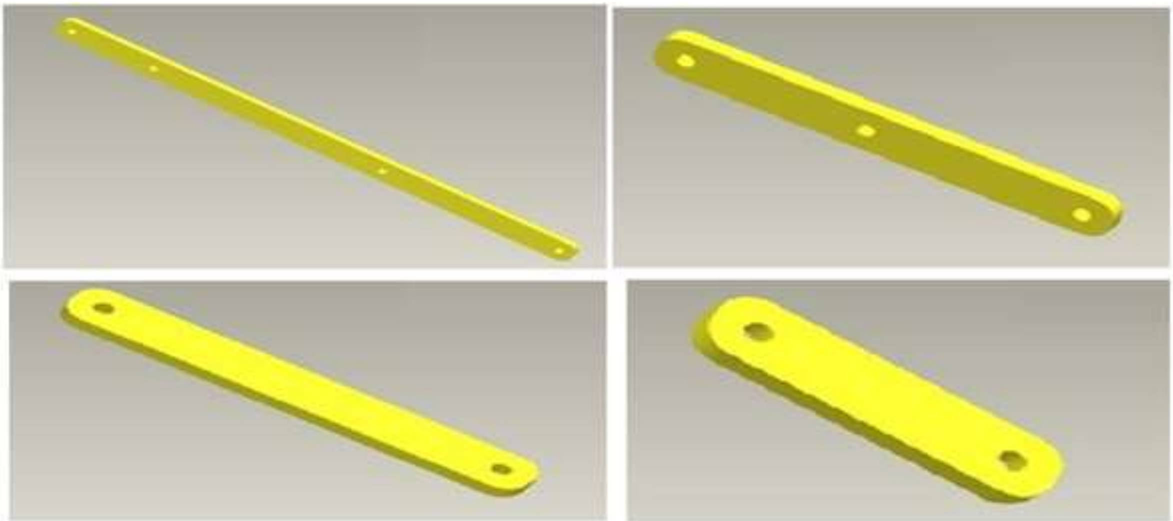

Fig 10 Design of links

Each resistant body in a machine which moves relative to another resistant body is called Kinematic link or element. A resistant body is which do not go under deformation while transmitting the force. Links are the major part of the robot which translates motion. Links are connected to form a linkage. The mechanism involved here is a 4 bar mechanism which has 3 revolute pairs and1 single prismatic.

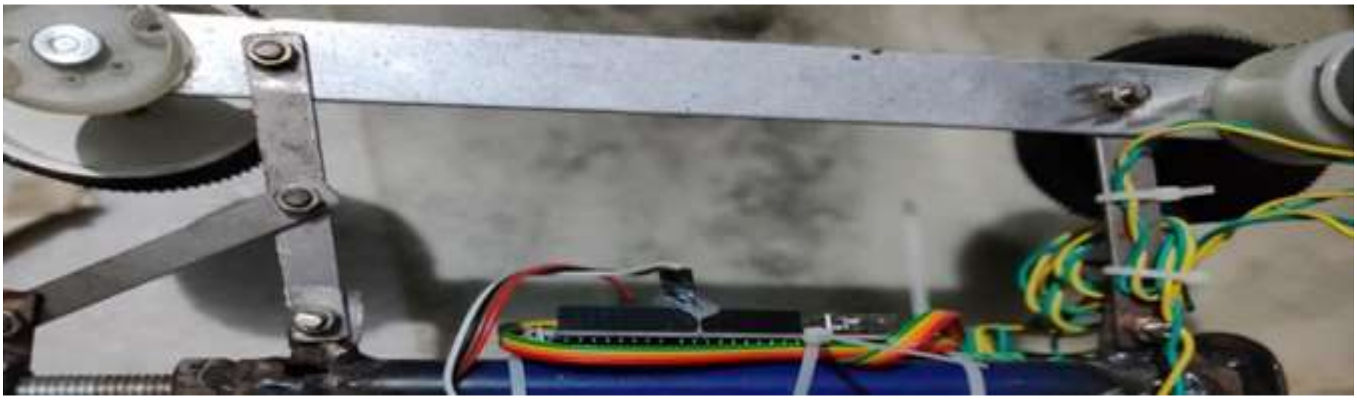

Fig 11 Connecting links

Central Element

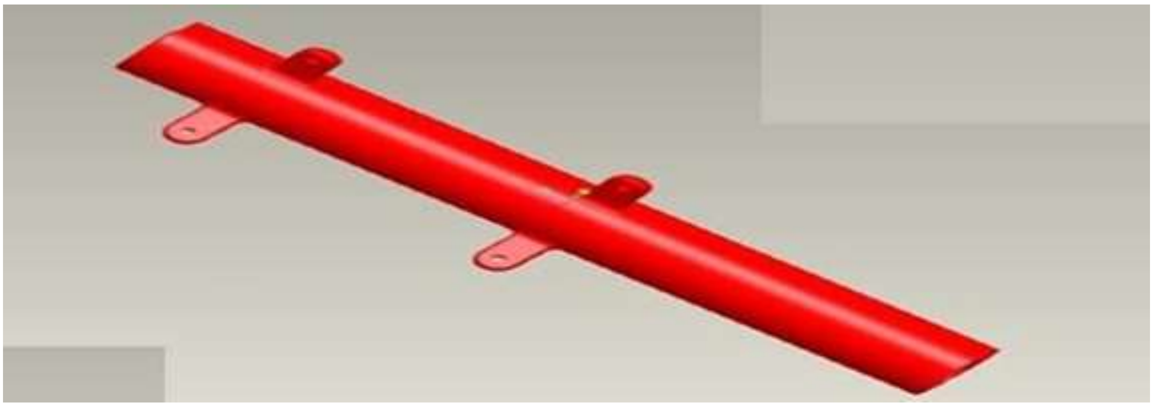

Fig 12 Central Element

Specifications of central element Inner

dia – 15 mm

Outer dia – 20 mm

Length – 220 mm

Material – Mild steel

Wheels Wheel diameter: 50mm Width of the wheel: 6mm Centre hole: 6mm Material: Metal rim with rubber

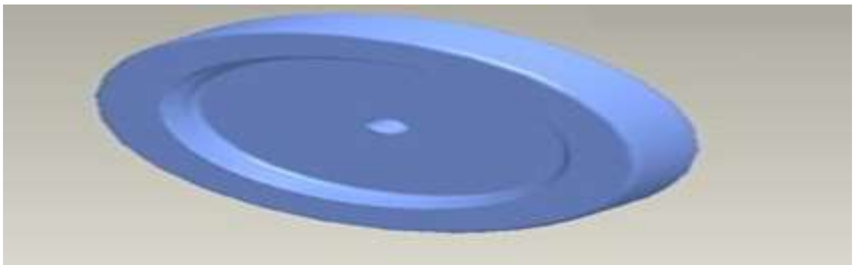

Fig 13 Wheel

Final assembly of PIR

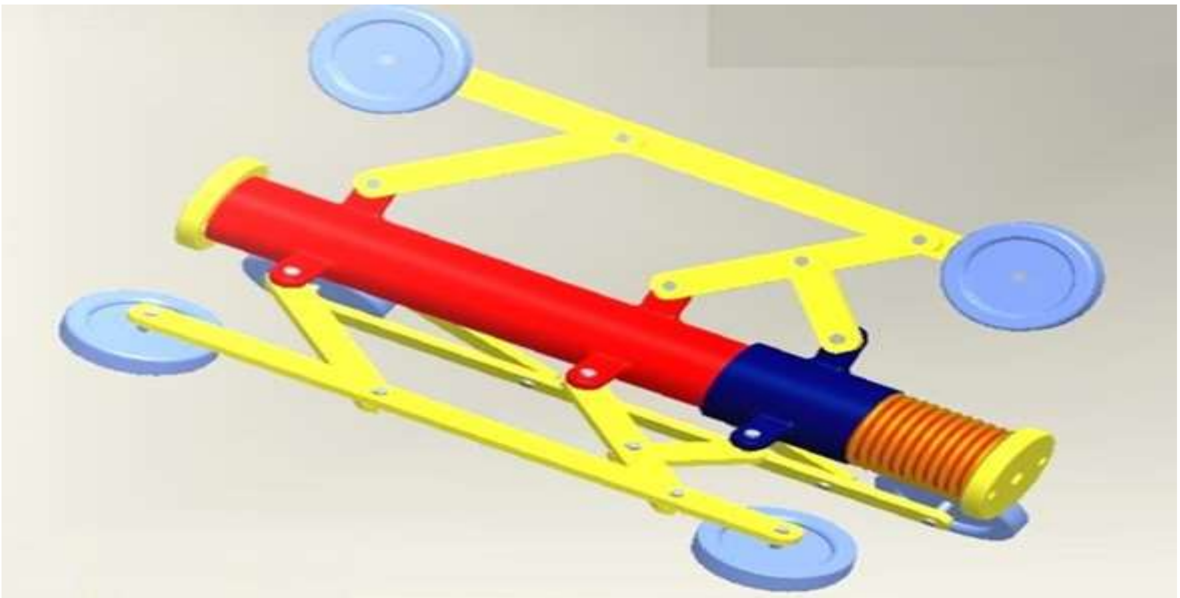

Fig 14 Final assembly

PROCEDURE

Working of the Pipe Inspection Robot

As Pipe Inspection Robot is designed mainly for circular bore pipes, it have ability to move inside any bore diameter pipes ranging from 8 inch to 10 inch (203mm to 254mm). Suitable mechanisms are provided so that it gains ability to move inside the bends and tapered pipes. The PIR have ability to see inside the dark pipes where no human eyes can see. This made possible by mounting the surveillance camera and LEDs on head of the PIACR. The output is send to outside screen where the digital hi-quality image can be received.

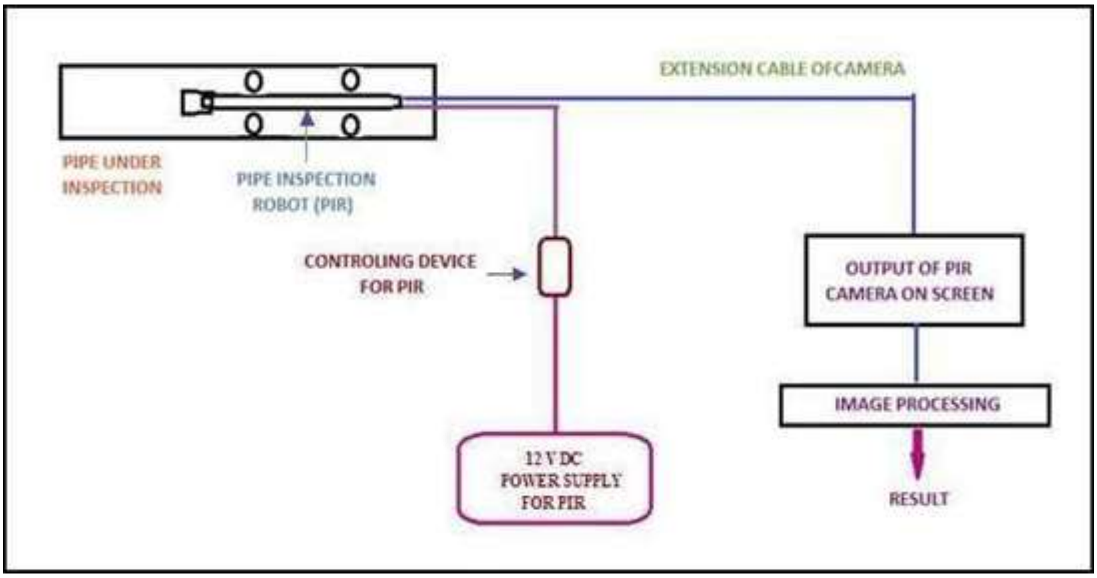

Fig 15 Block diagram showing working principal of pipe inspection robot

The perfect fitness between the pipe and robot is first conformed after inserting the robot in the pipe. Then the supply of DC 12Vdc current from is on for working of robot and the camera is also started. With the help robot control having three buttons, working of robot can be easily control the motions which is forward and reverse by one button and by other two buttons the motion which is swiveling and tilting of the camera head fitted in front of the robot can be control so that we can see the pictures and videos inside the pipe. Working of PIR is starts from its insertion in pipe. The front three arms is compressed by hand and then inserted in the pipe and then back three arms is inserted by pushing the PIR. PIR could have more than three arms for better judgment and perfection but it would increase the weight and cost of manufacturing and hence we need to do tradeoff between money involvement and perfection. PIR wheel motion is provided with 10 rpm, 12 V DC motors hence its speed can be maintained between - 10 to 10 rpm. The power provided to motors is from single 12V dc adapter hence load on each motor will be minimum that expected. As we mentioned earlier that PIR will be able to move inside any diameter ranging between 203mm to 254mm, we had to provide auto adjusting mechanism that can expand and contact as PIR moves inside the pipe. Spring of suitable stiffness is mounted on base rod, as seen in figure, so that as arms gets contracted due to load of compression against pipe, spring get compressed and tend to expand outward trying to push arms back to their normal position but as pipe restrict them, they cannot move. We took good care of stiffness of spring such that it can move against the pipe and do not put too high pressure of tires which can jam it and restrict the motion. Even if the pipe interior is smooth, using pressure between compressed tire and pipe, PIR can move easily. This is another application of spring. The main idea behind providing small shock-ups is not meant to absorb shocks but to make good individual expansion of arms in case of bends and turns. When a vehicle turns, two vehicles cannot have same angular velocity. Hence the outer arm must expand and shorter arm must compress. But as if we have used simple links then this wouldn't be possible. The mini suspension arms (previously mentioned shock-ups) provide individual expansion provision to arms and hence all arms are sticked to the pipe while turning. If wewere not used the mini suspension arms then one of the which might not be able to make constant contact with pipe interior and whole setup would be unstable, might collapse under gravity.

Fig 16 Picture showing working of PIR inside the pipe

The robot is run inside pipe by forward and reverse motion of the wheel which has thespeed of 10 rpm. This constant slow speed is to insure better inspection because of the high speed there may be possibility to miss the any defect. The camera is tilted by another button provided camera head motion on the remote control. The swiveling of camera can be achieved for 180 degree in addition to 180 degrees for tilting and thus in combination the envelope of 180 degree can be easily seen through the camera. The output image from camera is send to Compute. Which gives the visual picture. Operator can control the robot and see the picture of the inside pipe on the output screen and thus if there is any defects such as such as internal material loss , big crack, weld defects dents corrosion erosion or blockage in the pipe . The exact location of the defect is judge by the distance meter provided on the robot it gives distance in centimeters from the starting point from which the robot was inserted inside the pipe. the distance the robot can travel i.e. the length which it can capable to inspect is depends upon the length of the extension cable provided to robot. To insure the tractive force required pulling the long extension cable and other accessories, robot train can be used which can be made by joining the two or more robots through the universal joints at the end. The inspection can be done on the basis of video and pictures inside the pipe provided by camera. The result can be obtained directly on the basis of these pictures or with the help image processing.

CONCLUSION Robots play an important role in inside pipenetwork maintenance and their repairing. Some of them were designed to realize specific tasks for pipes with constant diameters, and other may adapt the structure function of the variation of the inspected pipe. In this project inside pipe modular robotic system are proposed. An important design goal of these robotic systems is the adaptability to the inner diameters of the pipes. The given proto type permits the usage of a mini-cam for visualization of the in-pipe inspection or other devices needed for failure detection that appear in the inner part of pipes (measuring systems with laser, sensors etc). The major advantage is that it could be used in case of pipe diameter variation with the simple mechanism. We developed a pipe inspection robot that can be applied to 203mm- 254mmpipeline. A real prototype was developed to test the feasibility of this robot for inspection of in-house pipelines. The types of inspection tasks are very different. A modular design was considered for easily adapted to new environments with small changes. Presence of obstacles within the pipelines is a difficult issue. In the proposed mechanism the problem is solved by a spring actuation and increasing the flexibility of the mechanism. The robot is designed to be able to traverse horizontal and vertical pipes. Several types of modules for pipe inspection mini robot have been presented. Many of the design goals of the Pipe inspection robot have been completely fulfilled.

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