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Design and Motion Planning of Indoor Pipeline Inspection Robot

Harish P, V.Venkateswarlu

***Abstract*— This project deals with a design and motion planning algorithm of a caterpillar-based pipeline robot that can be used for inspection of 80–100-mm pipelines in an indoor pipeline environment. The robot system consists of a Robot body, a control system, a CMOS camera, an accelerometer, a temperature sensor, a ZigBee module. The robot module will be designed with the help of CAD tool. The control system consists of Atmega16 micro controller and Atmel studio IDE. The robot system uses a differential drive to steer the robot and spring loaded four-bar mechanisms to assure that the robot expands to have grip of the pipe walls. Unique features of this robot are the caterpillar wheel, the four-bar mechanism supports the well grip of wall, a simple and easy user interface.**

***Index Terms*— Caterpillar wheel, Inspection robot, ZigBee, Atmega.**

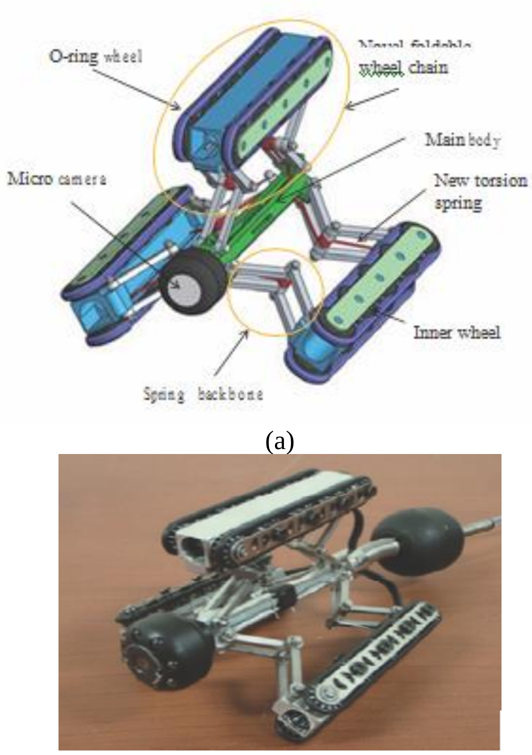
I. INTRODUCTION

Recently technology is growing in such a way that, machines are the part of human life. Now days the industrials are being fully automated. So robots can take control the whole process and work is easer, reduce the production time and increase the safety. Recently many pipeline inspection robot systems have been developed. Development of pipeline robots began for inspecting large pipelines ranging from 100 to 300 mm. These pipelines are commonly used in manufacturing sites as sewer pipes and gas and oil pipelines. They are also used in nuclear power plants. Pipeline inspection robot systems improve safety and reduce work time. Pipeline inspection robots can be said as in-pipe and outer-pipe inspection robots. This project is concentrating on in-pipe robots. In-pipe robots can be classified into several elementary forms according to movement patterns. However, not all of these wheel robots can pass through elbows or T-branches with a small radius of curvature. Inchworm-type mechanisms are suitable for pipelines with a diameter smaller than 300 mm. However, these were not effective because of their low speed and poor reliability. In this project, a crawler-type pipeline inspection robot introduced that is designed to inspect 80-100mm-diameter pipelines that are appropriate for inspection and navigation of indoor pipelines and small industrial indoor pipelines.

II. THE HARDWARE SYSTEM

A. The foldable mechanism

The pipeline robots have three powered chains. Each chain has a linear compression spring and an axis for each spring. However, they are too big to make a small-sized pipeline robot because it is not easy to make the dimension of mechanical parts too small. So, replace the spring axes and compression springs with torsion springs and backbone linkages in order to reduce the size of the wheel mechanism. The new torsion spring has the shape like an alphabet 'w' as shown in Fig. 1. It is similar to an original torsion spring. However, it has two legs. The legs of the torsion spring are interlinked to the wheel mechanism of the main body. If the torsion spring is folded, then the legs work like a prismatic joint. The torsion spring and the spring back-bone were implemented to the wheel mechanism as shown in the Fig.2. The good features of this structure are a large foldable range and a small-sized design, which are adequate to 40-100mm pipeline. The new foldable wheel chain mechanism allows a large change of its external diameter as compared to that of the 4-bar linkage structure used for Tbot-80 [12]. The Tbot-80 with its diameter of 80mm-100mm changes its external diameter by 25%. However, the Tbot-40 with 37mm-73mm diameter can change its external diameter by 97.3%. Tbot-40 can be used for small-sized pipelines with 40mm-70mm diameter.



(a)

(b)

Fig.1. A small-sized reconfigurable robot (minimum exterior diameter of the robot is 37mm) : (a) 3D model (b) the developed small-sized reconfigurable robot

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Fig.2 The range of the exterior diameter of the robot is 37mm~73mm.

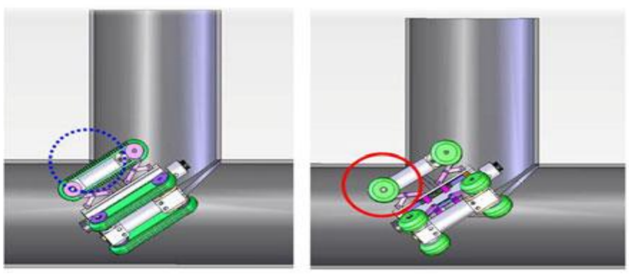
B. A compact wheel structure

The caterpillar wheel structure allows a continuous contact of the wheels to the wall of the pipeline. However, design of the wheel cover is difficult and a fairly large friction exists between the wheel cover and the wall. To cope with such problems, a multi-wheel structure has been tested. However, this type does not completely resolve the contact-losing problem when steering at a corner, though its performance is better than Tbot-80.

Fig. 3

Fig.3 shows the pipeline robot each chain of which consists of 10-wheels (i.e., five wheels for each side). A O-ring is wrapped around each 5-wheel. Each wheel mechanism consists of two rows of wheel mechanism. Each part has one active wheel and four passive wheels. The motor power is transmitted to one active wheel by a bevel gear. The O-ring wrapping the surfaces of the five wheels provides a coupling effect between the active wheel and the four passive wheels.

C. Advantage of the Caterpillar Wheel



(a) (b)

Fig.4: Motion mechanism of caterpillar wheel

This robot was designed to pass through multiple elbows or T-branches using the CWC. A regular wheel mechanism cannot work properly in the pipeline with a small radius of curvature as shown in Fig.4(b) because, sometimes, the wheels lose contact with the surface. However, a caterpillar wheel works properly because all CWCs maintain contact with the surface of the pipeline as shown in Fig..4(a). The robot works stably as each CWC works independently even when there are some irregular surfaces inside the pipeline. If one of the three CWCs contacts a collapsed part or a choked part of the pipeline, then only the corresponding CWC will be folded and adjust itself to the choked part. However, the other CWCs are not influenced.

D. Kinematic modeling of the Pipeline Inspection Robot

1) Mobility Analysis

Mobility is the number of minimum input parameters that are required to specify all of the locations of the system relative to another. The mobility of the robot is one when it moves in a straight pipeline. However, the robot has two additional mobilities. When steering at elbows or T-branches. Specially, at a T-branch, the instantaneous motion of this robot can be modeled as the translation along the pipeline and two rotations about the axes orthogonal to direction of motion of the robot. Thus, these three DOF can be controlled by three actuators, one for each chain.

2) Kinematics

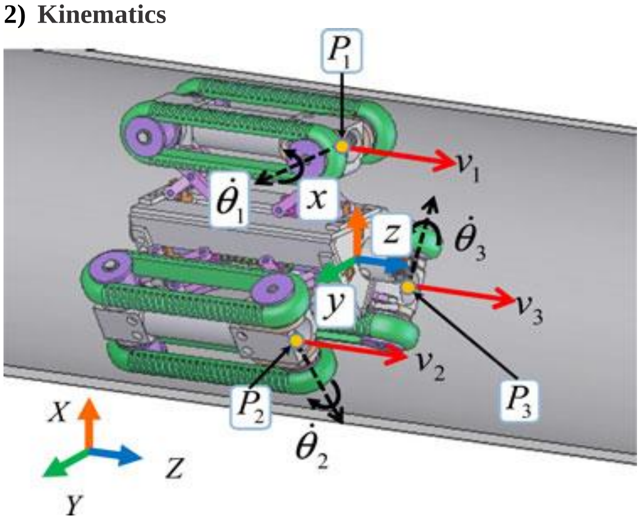


Fig. 5: Kinematic model of Inspection robot

In this section, derive the kinematic model of the inspection robot given in Fig. 5 The detailed structure, the coordinate system, the joint variables, and parameters of this mechanism are given in Fig. *XY Z* represents the global reference frame, and *xyz* denotes the local coordinate frame attached to the center of the pipeline inspection robot; $\hat{i}$, $\hat{j}$, and $\hat{k}$ are the unit vectors of the local coordinate frame. The *x*-axis always points to $P1$ no matter how the robot moves.

Fig.6. shows the cross sectional view of different robot body parts. Design of these parts is by using CAD tool. Fig.6. shows the chip housing section, where the main controlling processor is placed in robot body. Gear box housing and motor housing where DC motor is kept in robot body.

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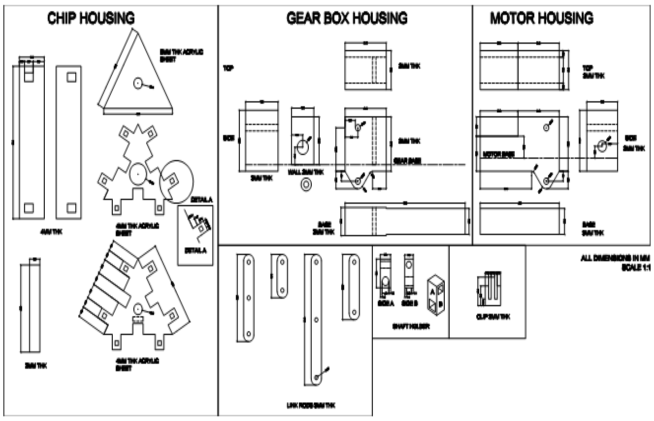


Fig 6: CAD design of different Robot body parts.

III. DESIGN AND IMPLEMENTATION

A. Hardware Architecture

An effort was made to minimize the size of the robot system. A microcontroller was designed to be small enough to install inside the robot body. In addition, a sensor unit, which contains a dual-axis accelerometer and a single-axis gyro sensor unit, is designed for map building of pipelines. The sensor unit plays the role of identifying the rolling angle of the robot body inside the pipeline. In the horizontal plane, the rolling angle can be calculated by the information of the dual-axis accelerometer. However, in the vertical pathway of the robot, the gyro sensor measures the rolling angle by placing it parallel to the gravity direction. Temperature sensor is interfaced to measure the temperature when robot is moving under the earth. LDR sensor is interfaced; it'll help the camera to capture the clear view when there is no light. ZigBee Tx/Rx is used to communicate between user side and robot module, signals are send to and receive form controller. A wireless CMOS camera is placed in front module, so a clear view is displaced in monitor. A video grabber is used to capture video from CMOS camera wirelessly.

Fig.7 shows the system block diagram. When the order of the device control is given by the PC's graphic user interface (GUI), it is transferred to the robot by serial communication. Atmega16U4 controls motors and returns sensor data for display on the GUI. Fig. 7 shows the entire picture of the pipeline inspection robot system. It is mainly divided into two parts: a robot device and a control system (power link circuit, control PC, grabber board). The control PC is a means of GUI, the robot-embedded part contains many sensors and processors for controlling the robot, and the grabber board transfers the signal of a micro-CMOS camera to the PC. The main body contains a main board consisting of a multipoint control unit (MCU) printed circuit board (PCB) (ATmega16), a motor drive PCB. Each linkage structure connects the main body to each caterpillar wheel.

Users use the vision information from the GUI environment to control the robot. The two-axis accelerometer is used to locate the robot with respect to the global reference coordinate while moving inside the pipeline, whereas the gyro sensor is used to measure the rotation of the robot when it goes through a curved path.

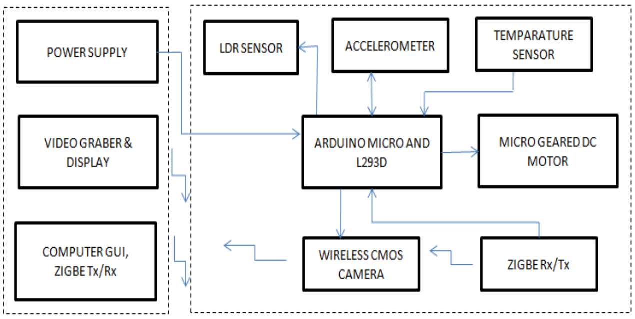
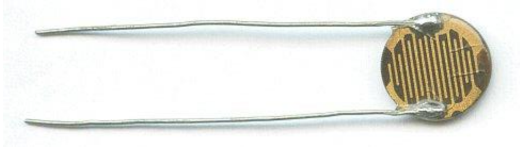
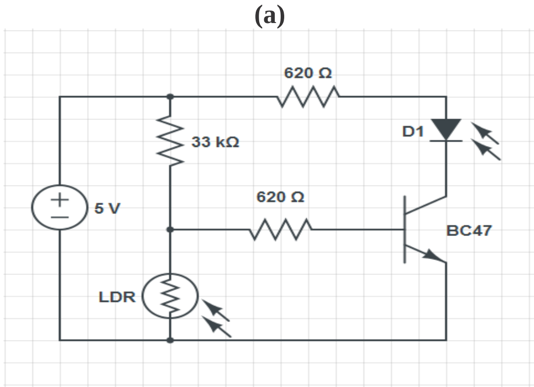


Fig.7: Block Diagram Representation

B. Light Dependent Resistor (LDR)


(a)



(b)

Fig 8 Light Dependent Resistor

The light dependent resistor is a resistor whose resistance decreases with increase in the incident light intensity which exhibits the photoconductivity property. A photo resistor is made of high resistance semiconductor .If the light glow intensity has high frequency photons absorbed by the semiconductor give bound electrons which is enough for the electrons to jump to conduction band. The LDRs normally are housed in Sensor networks which are used for controlling the high value currents being passed through the employed network.

Fig 8(a) shows the LDR device, and Fig 8(b) shows minimum circuit required to operate LDR sensor. By This value of resistors the LDR will operate to small change in light intensity.

C. Temperature sensor (LM35)

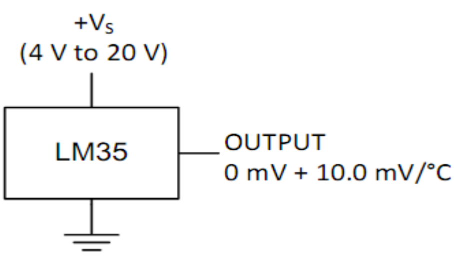


Fig 9 LM35 (Temperature Sensor)

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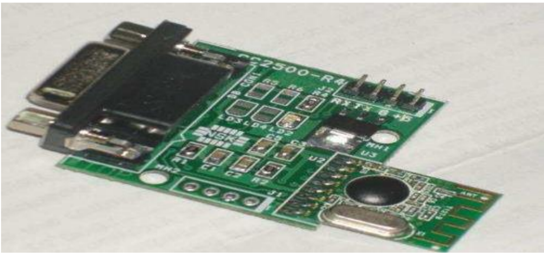
The LM35 series are precision integrated-circuit temperature sensors, with an output voltage linearly proportional to the Centigrade temperature. Thus the LM35 has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full -55°C to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The low output impedance, linear output, and precise inherent calibration of the LM35 make interfacing to readout or control circuitry especially easy. The device is used with single power supplies, or with plus and minus supplies. As the LM35 draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 is rated to operate over a -55°C to +150°C temperature range, while the LM35C is rated for a -40°C to +110°C range (-10° with improved accuracy).

D.ZIGBEE Module



(a)

(b)

Fig 10: ZigBee Module

ZigBee is an established set of specifications for wireless personal area networking (WPAN), i.e. digital radio connections between computers and related devices. WPAN Low Rate or ZigBee provides specifications for devices that have low data rates, consume very low power and are thus characterized by long battery life. ZigBee makes possible completely networked homes where all devices are able to communicate and be controlled by a single unit.

The Figure 10 shows the CC2500 ZigBee module. CC2500 ZIGBEE Module is a transreceiver module which provides easy to use ZIGBEE communication at 2.4 GHz. It can be used to transmit and receive data at 9600 baud rates from any standard CMOS/TTL source. This module is a direct line in replacement for your serial communication it requires no extra hardware and no extra coding works in Half Duplex mode i.e. it provides communication in both directions, but only one direction at same time.

E. Wireless AV Cam

Fig 11 Wireless AV Cam

The Figure 11 shows the wireless AV CAM-6620G. With support for both Motion JPEG and MPEG-4 recording, the AV CAM-6620G is well suited for various recording scenarios. Motion JPEG delivers greater file integrity, making it ideal for critical monitoring situations. MPEG-4 video has smaller file sizes, making it more useful for extended recording periods or for use in low bandwidth networks.

The AV CAM-6620G supports 2-Way Audio with its built-in microphone and A/V port. Attach a speaker to the A/V port1 and remotely communicate with subjects near the camera. An ideal location to use the 2-Way Audio feature includes point-of-entry areas, where you might want to identify a person before granting access. With the ability to record video in low light settings, the AV CAM-6620G can provide exceptional night time surveillance.

F. Control Process

Users choose the steering direction from the camera view. There are five control signal used to control the module. The control signal will send from system to which ZigBee module is connected. By pressing the keys which are defined in program the robot module direction can be changed. The keys are matched to the camera view coordinate to control the steering direction. If the robot is going to turn to the left, then the user will press the corresponding key.

First, the user decides the steering direction based on the camera view. Then, the user controls the steering direction using the keyboard. The user can control the robot by pressing W, X, A, D and S for forward, backward motion, left, right turn and stop respectively. The ZigBee module on user side will communicate with ZigBee module at robot side and sends the signal to controller. The controller performs the corresponding operation.

The video grabbers will capture the video from wireless CMOS camera, and display in monitor on user side. Simultaneously the accelerometer output and temperature sensor values are seen at console of Atmel studio IDE. LDR sensor will automatically lighten up when light intensity of light reduces in pipeline and helps in clear camera view.

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G. Graphic User Interface

The robot runs using the GUI environment after opening a signal port. The GUI makes it possible to view the condition of the pipeline by using a micro-CMOS camera. And user can monitor the robot module motion. The user checks how much the device has advanced from the origin of the global reference coordinate by using the encoder information from the motors. Using the information from the sensors user can decide the next step of robot movement. Autonomous navigation using sensor data will be also one of current research topics.

IV. SOFTWARE IMPLEMENTATION

The software version being used for the proposed work is Arduino IDE 6.1 at ATMEL product which provides the development environment for the coding sequence and also the communication sequence can be viewed in this version. The various implementation blocks of the software implementation can be listed as below,

i) Robot Module controlling block
ii) Digital read block
iii) Digital write block
iv) Analog write block.

These blocks are algorithmically represented in the flow chart form as shown below.

A. Robot Module controlling block:

Fig 12 shows the Flowchart of main program. The control of program starts and check whether serial is enable or not. If serial is not enable the code is not going to execute. If serial is enable the control go on checking which button is pressed, and perform the related operations. Simultaneously it capture the temperature sensor values, accelerometer values and sent to console.

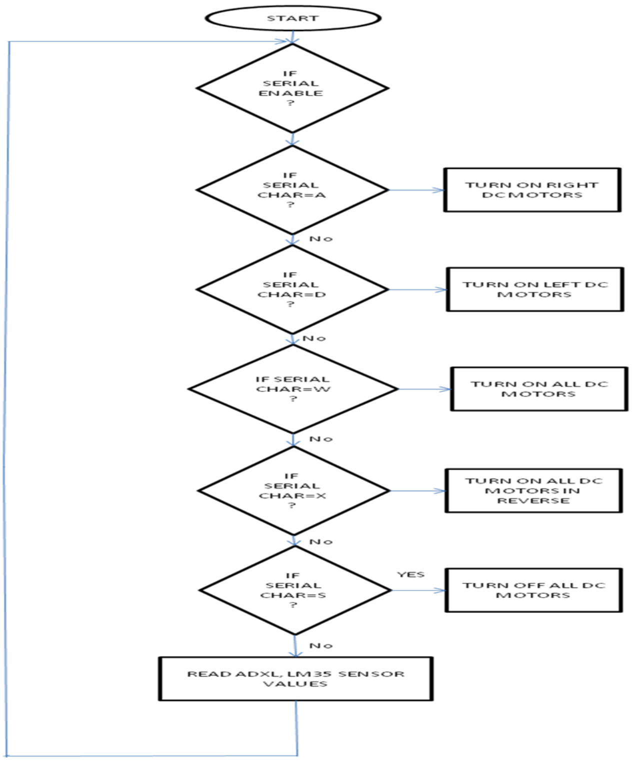

Fig 12: Flow chart for control Robot Module

B. Digital Read block:

Fig 13 shows the Flowchart for Digital read operation. In digital read operation, the controller first check whether PWM pins are used for PWM application or for other. If pins are assigned as PWM pin then control read the data from PWM pins.

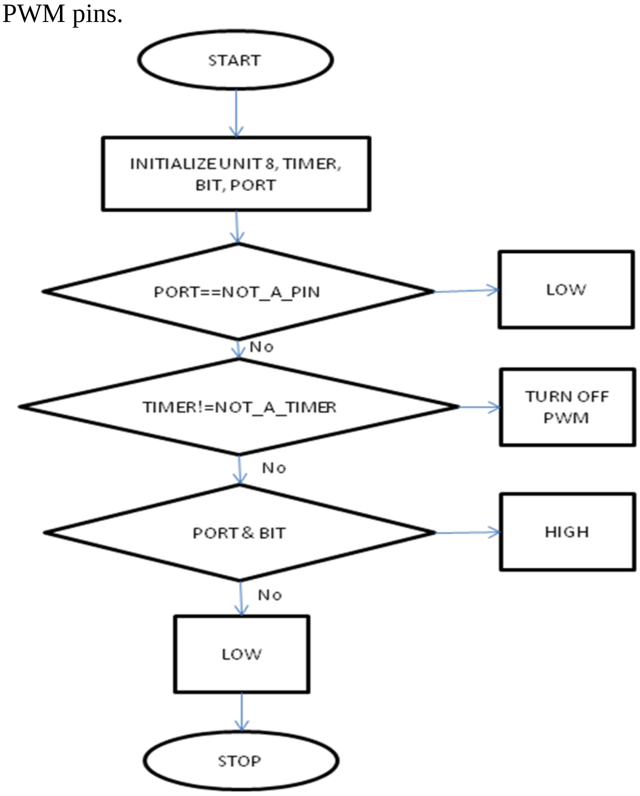

Fig 13: Flowchart showing Digital read operation

C. Digital write block

Fig 14 shows the Flowchart for Digital write operation.

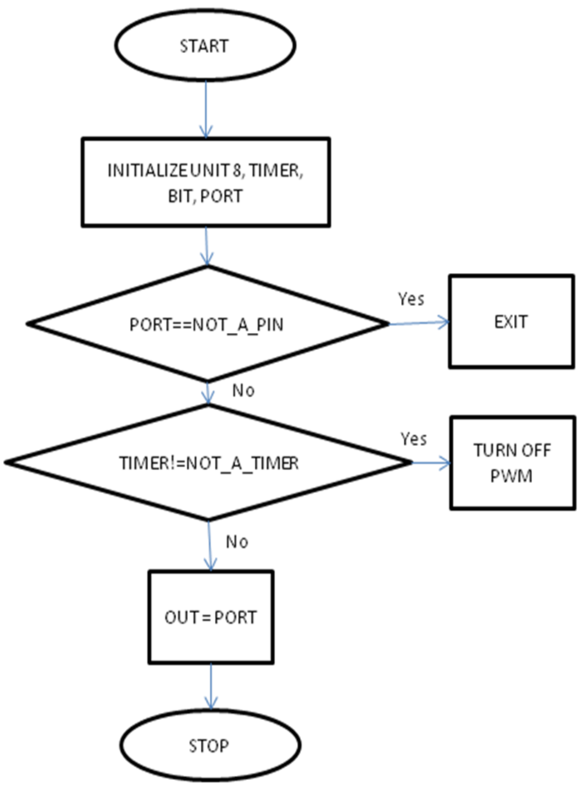

Fig 14: Flowchart for digital write operation

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D. Analog Write Block:

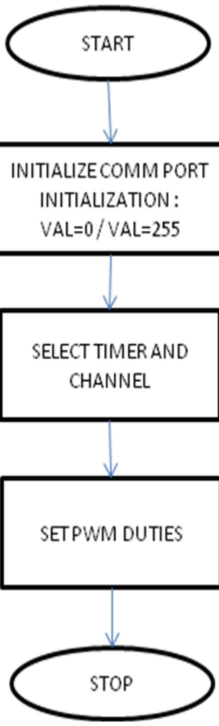

Fig 15: Flowchart showing Analog write block

Fig 15 shows the Flowchart for Analog write operation. The control in this program initializes the comm. port and staring, final values for PWM generation. Then check which timer and channel are selected. Once particular timer and channel selected, depend on user input it generate duty cycles for PWM pin.

V. RESULTS

In the proposed wok a pipeline inspection robot has been developed which can be applied to inspection of pipelines with 80mm~100mm diameter. A pipeline consisting of one T-branch and one elbow was employed in this experiment. The radius of curvature of the elbow is 125mm and that of the T-branch is 110 mm. The maximum velocity of the robot is 9 cm/s, but in the experiment, here the velocity of robot is between 0 and 7 cm/s for safety. In the straight pipeline, the two modules are controlled so as to have a common linear velocity. In curved pipelines the speed of motors is controlled by giving signals via ZigBee. When the robot arrives at the entrance of a T- branch, the operator stops the robot motion and steers the motion direction of the front robot module. The performance of the two-module pipeline inspection robot was verified through experimentation.
In this study, only one used one camera in the front robot. The camera output is wirelessly transmitted and it is captured by AV grabber, which is placed user side and display in monitor. However, by adding an additional camera in front of the rear robot module, it would have helped navigation. In the future, implementing one more camera in order to provide better visual information to the operator. The controlling process is done by using ZigBee communication modules, where user has one module and robot module has one. The communication is serial and its wireless one.
The performance of the proposed pipeline inspection robot system was verified through a variety of experiments in a test-bed environment. This study can be applied to design and control of pipeline inspection robots with diameters ranging from 40 mm to more than 100 mm.

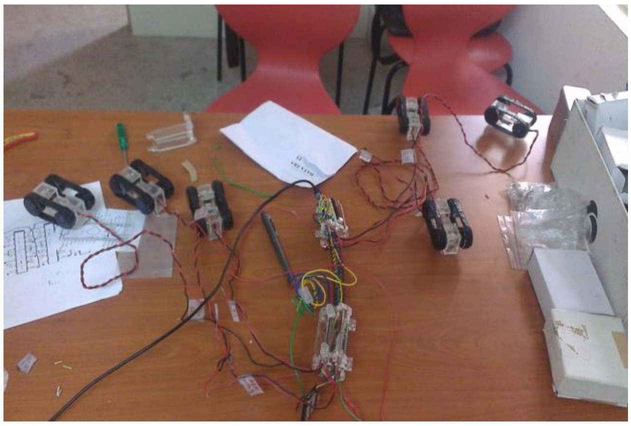

Fig 16: Testing of each DC Motors.

Fig 16 shows the different DC motors under test before assembling in main robot body.

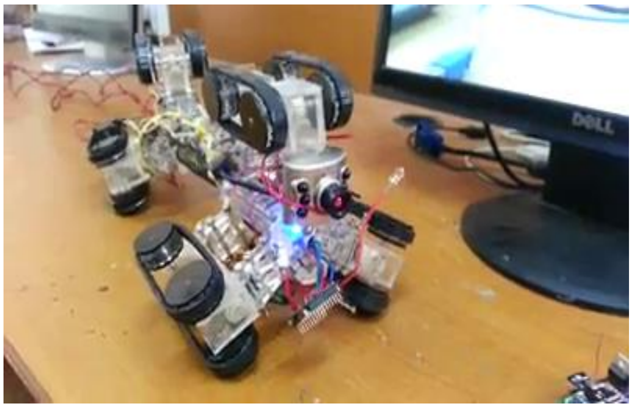

Fig 17: Final Robot module

Fig 17 shows the final Robot module with all interfacing modules such as main controller, temperature sensor, accelerometer, LDR sensor, ZigBee module and wireless CMOS camera.

Fig. 18: Experimental Setup

Fig 18 shows the final experimental setup with Robot module, Wireless camera output on monitor, video grabber, controlling command via ZigBee.

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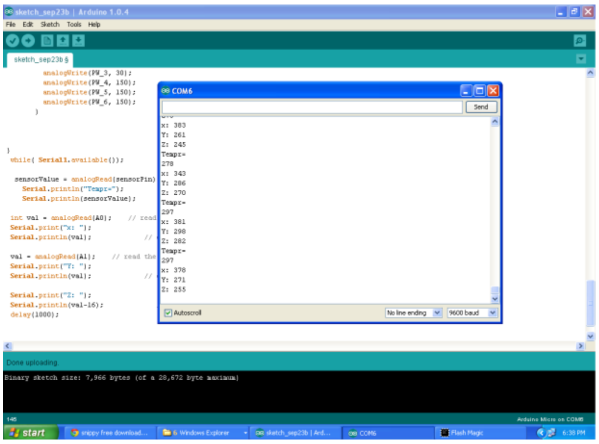

Fig 19: Console output

Fig 19 shows the console output of accelerometer (3dimensional axis values) and temperature sensor on Arduino IDE.

VI. CONCLUSION

Robots reduce human efforts making work simple and efficient. There are many fields where they are employed that include pipeline inspection & maintenance too. This project develops the indoor pipeline inspection robot. This project describes the mechanism of robot that provides good mobility with the velocity of 6cm/sec in pipelines. The developed architecture enables the robot to be an independent system.

In this project, the robot was implemented by using Atmega16 micro controller, a CMOS camera, LM35 temperature sensor and ZigBee module for communication. The robot module was designed with the help of Auto CAD. The spring loaded four-bar mechanism is used to provide the comfortable grip in pipeline. The caterpillar wheels were used because they are well supports the four-bar mechanism. The implemented robot can use for inspection of indoor pipeline of diameter of 80-100 mm. The motion of robot was successfully controlled by ZigBee communication.

REFRENCES

1. Young-Sik Kwon, and Byung-Ju Yi, "Design and Motion Planning of a Two-module collaborative Indore pipeline Inspection Robot", IEEE Transaction on Robotics, VOL 28, NO 3, JUNE 2012.
2. A. A. Transeth and K. Y. Pettersen, "Snake robot obstacle-aided loco-motion: modeling, simulations, and experiments," IEEE Trans. Robot., vol. 24, no. 1, pp. 88–104, Feb. 2008.
3. S. Hirose and H. Yamada, "Snake-like robots [Tutorial]," IEEE Robot.Autom., Mag., vol. 16, no. 1, pp. 88–98, Mar. 2009.
4. J. H. Lee, B.-J. Yi, S. R. Oh, and I. H. Suh, "Optimal design and de-velopment of a five-bar finger with redundant actuation," Mechatronics, vol. 11, no. 1, pp. 27–42, 2001.
5. T. Oya and T. Okada, "Development of a steerable, wheel-type, in-pipe robot and its path planning," Adv. Robot., vol. 19, no. 6, pp. 635–650,2005.
6. S. Hirose, H. Ohno, T. Mitsui, and K. Suyama, "Design of in-pipe inspec- tion vehicles for _25, _50, _150 pipes," in Proc. IEEE Int. Conf. Robot. Autom., 1999, pp. 2309–2314.
7. C. Jun, Z. Deng, and S. Y. Jiang, "Study of locomotion control character- istics for six wheels driven in-pipe robot," in Proc. IEEE Int. Conf. Robot., Biomimetics, 2004, pp. 119–124.
8. S. G. Roh and H. Choi, "Differential-drive in-pipe robot for moving inside urban gas pipelines," IEEE Trans. Robot., vol. 21, no. 1, pp. 1–17, Feb.2005.
9. T. Fukuda, H. Hosokai, and M. Uemura, "Rubber gas actuator driven by hydrogen storage alloy for in-pipe inspection mobile robot with flexible structure," in Proc. IEEE Int. Conf. Robot. Autom., 1989, pp. 1847–1852.
10. A. M. Bertetto and M. Ruggiu, "In-pipe inch-worm pneumatic flexible robot," in Proc. IEEE/ASME Int. Conf. Adv. Intell. Mechatronics, 2001, vol. 2, pp. 1226–1231.
11. H. Lim, J. Y. Choi, Y. S. Kwon, E. J. Jung, and B.-J. YI, "SLAM in indoor pipelines with 15mm diameter," in Proc. IEEE Int. Conf. Robot. Autom., 2008, pp. 2616–1619.

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