DESIGN AND DEVELOPMENT OF A PIPE CRAWLING ROBOT

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Abstract: Industrial ductwork are widely used in metallurgy, petroleum, chemical engineering, water supply and other special professions. The formidable work environment makes pipelines easy to be eroded or fatigued which can lead to leaking accident, so the periodic maintenance and overhaul are necessary for industrial pipelines. Absence of fresh air makes it impossible for humans to perform maintenance task. As maintenance of these pipelines is nearly impossible from outside we need a machine that can crawl inside these long pipes. This paper describes the design and development of such a novel pipe crawling robot. The crawling robot can be wirelessly steered into the long pipelines. A camera is mounted on the robot which provides a complete inside picture of a long pipeline, which would help us detect and fix the leakages or any other technical problems. The Robot is also capable of performing tasks like cleaning of the pipelines. The author has already developed a prototype of the system and it was tested in 8" diameter pipeline.

Keywords: Robotics, RFID, pipeline, crawling robot, design.

Introduction: Pipeline have become an important part of our life as they are responsible for hassle free running of many industries like chemical, petroleum, gas etc. and well-functioning water networks are essential for the sustainability of any community. Any failure of such network would have catastrophic outcomes as it would bring the industry or community to a halt. Due to the high cost of these pipelines and 24x7 workability need the system does not usually provide redundancy to enable decommission for maintenance and rehabilitation.

But aging pipelines often suffer from corrosion, choking or excessive leakage. These problems can affect the flow of materials though the pipe and affect quality due to contamination or may result in wastage due to leaking. In some cases, the pipelines may be structurally weak and prone to breakage. Prevention and early detection of such catastrophic failures need a comprehensive assessment of pipe condition. A proactive inspection approach is critical to the condition assessment as well as cost-effective repair and renewal of water mains. Regular cyclic inspections can provide information on the physical conditions of the pipes and on the rates of material deterioration. Nondestructive technologies for evaluating pipe condition are essential tools for the early detection. However, more research is required to adapt existing technologies to the unique circumstances of large water mains that cannot be taken off service.

This task of inspection and maintenance can be easily carried out if we have a way to take a peek inside the pipe. In this context, a robotic pipe crawler can be useful as it can carry out pipe inspection. The robot can provide real-time visual information about the interior surface of the pipe. Pipe crawling inspection robots (PCIRs) are playing an important and expanding role in remote testing and inspection of 4 in. to 8ft. diameter pipes. PCIRs provide the power, process and pulp industries with an economical and time-saving approach for inspection of insulated, buried or inaccessible pipes.

Rossman [1, 2] built such a crawler at the Technical University of Munich. It is able to crawl in tubes of any inclination from horizontal up to vertical pipes. The robot also manages curved pipes with a diameter of 60-70 cm.To enable this the crawler is equipped with eight legs each with two driven joints, which can achieve torques up to 78Nm. To move the crawler spreads four of its legs against the pipe wall to generate friction forces. These can carry its weight of 20 kg and an additional load.

In order to inspect the seabed petroleum pipelines of ShengLi Oil Field, a robot was developed. The overall length of pipeline was 20Km long, and the inner diameter of the pipe was no more than 297mm. The robot is required to work under 20 meter depth. [3] Autonomous Underwater Vehicles (AUV) and underwater Remotely Operated Vehicles (ROV) are oceanographic locomotion interfaces used for data acquisition in subsea and deep-water missions. The applicability of existing floating robots in the confined environments such as pipes are very limited. Further modifications are needed to make them suitable for inspection of pressurized pipelines.

Concept Development: Since the robot is needed to carry out inspection of pipelines it is necessary that it must be remote controlled wirelessly. RFID tag is essentially a RF transmitter that transmits encoded signals. It can be further classified into following parts:

1. Unique identification code (UIC): This part is unique for every RF Tag. It creates a unique code that is used to identify the tag when the data is read by RF reader. The UIC used here is a 4 bit data. Thus this UIC can be used for unique identification of at most 15 different things.
2. Encoder: This part converts the UIC into an

encrypted data that can be transmitted over RF channels.
3. Transmitter: This part takes the encrypted data from transmitter and transmits it in form of Radio Frequency.

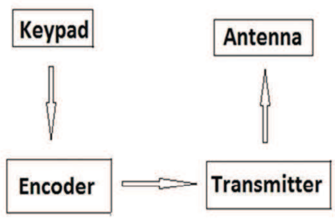


Fig. 1 Block diagram of the remote.

The receiver is basically a RF receiver that receives encoded signals decodes them and displays the tag number on the displaying unit. It can be further classified into following parts:
1. Receiver: It receives the encrypted data in form of RF waves and converts it into electronic signals.
2. Decoder: This part decrypts the data to yield the UIC of the tag. This UIC is fed into the microcontroller.

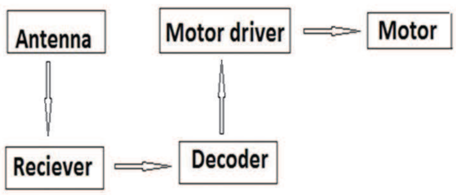


Fig. 2 Block diagram of the device (robot)

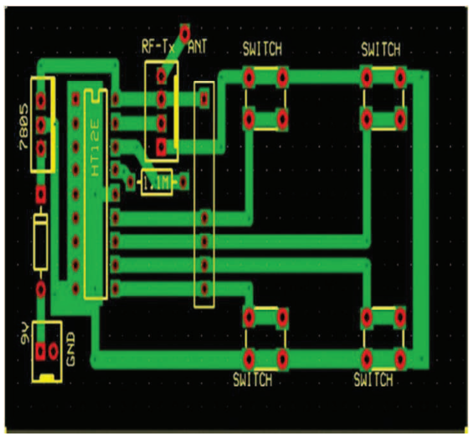
In the robot's hardware design process many requirement and conditions must be care for to ensure its desired functioning. The mechanical structure design must always attempt an adequate robot's proportions. For that reason, mass distributions, CM (Centre of mass) location and the actuators selection are important stage on the mechanical design. Structure design have a direct impact on the robot's performance. In general, the robot's hardware design must keep on mind add less weight as possible. The mechanical stability can be maintained by incorporating the following-
1. Centre of mass near to ground.
2. Centre of mass is turned to heavy weight.
3. Order of symmetry.

Key Features and its applications: Capture real time video with sharp camera–eye – The real time video is critical in detecting faults and for carrying out maintenance work of the pipelines.
Send video and data captured to the server wirelessly- The video obtained can be saved and can be useful for comparing the health and flow of the pipelines later.
Easily controlled through a Wireless Network- Wireless control ensures easy control of the device and less wires would mean less maneuverability problem. The robot can be wireless controlled to probe deeper in the pipe as the ability of the robot to crawl further in the pipeline is dependent on the range of the RF circuit.
Space for mounting number of instruments- The design is such that sufficient space is available on the system to incorporate further modifications. Also the shaft to which the video camera is attached is capable of rotating the camera to give a 360° view of inside of the pipe.

Design Description:

4.1 Specification:
Height: 35 cms.
Weight: 850 gms
Wheel diameter: 7 cm
Min. diameter of pipe: 8"

Fig. 3 PCB Layout of transmitter circuit (Remote Control)



Wheels: 6 (3 powered)
Drive system: 3 DC motors (12v 60rpm) in parallel
1 DC motors (12v 60rpm)
Type: wireless
Control system: RF communication
Range: ~30m
Power supply: 220v, 3phase, 50 Hz, ~ 2 amp.

Transmitter:

The design being used for pipeline, the controller is set wireless so as to increase the versatility. A remote control is designed with four switches, to control four motors of the robot. The PCB design of the transmitter circuit i.e. the remote control is shown in Fig. 3.
HT12E is a 212 encoder, which encodes parallel input signals into a coded serial input for wireless data

transmission. The modulated signal is transmitted via an RF antenna upon receipt of the trigger signal. The encoder is designed using series of CMOS large scaling integration, for low power and high noise immunity. The pin diagram of HT12E is shown in Fig. 4 with a table containing the pin description.

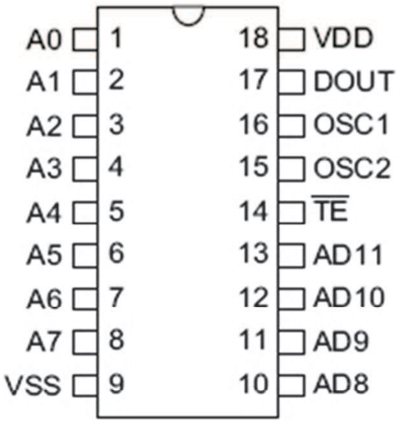


Fig. 4 Pin Diagram of HT12E (Encoder)

The 2^{12} series of encoders begins a 4-word transmission cycle upon receipt of a transmission enable $\overline{TE}$. The transmission enable pin being active low negative edge trigger, the encoder output DOUT transmits the signal as soon as transmission enable pin is low. When the transmission enable is removed during a transmission, the DOUT pin outputs a complete word and then stops. The data transmission timing is shown in Fig 5.

Table I: Pin description of HT12E	
Pin Name	Description
A0~A7	I/P pins for address A0~A7. These pins can be externally set to VSS or open.
AD8~AD11	Input pins for address/data AD8~AD11. These pins can be externally set to VSS or left open.
DOUT	Encoder data serial output.
$\overline{TE}$	Transmission enable, active low
OSC1	Oscillator input pin
OSC2	Oscillator output pin

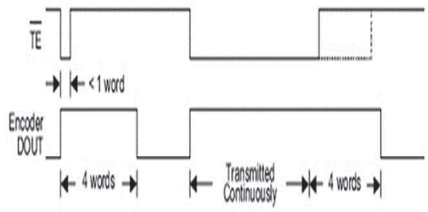


Fig. 5 Transmission timing of HT12E

Address inputs A0 – A7 can be used to provide data security and can be connected to GND (Logic ZERO) or left open (Logic ONE). Status of these Address pins should match with status of address pins in the receiver for the transmission of the data. After the data is encoded the output of DOUT is sent to the transmitter. ASK RF transmitter module is used in this work as a transmitter. The radio frequency transmission is better than infrared transmission as only line of sight communication is possible through Infrared while radio frequency signals can be transmitted even when there is obstacles. The data from DOUT is modulated using amplitude shift keying, which is suitable for small communication systems as it is easy to design. The carrier signal is generated using SAW (Surface acoustic wave) resonator. The carrier signal is product multiplied with the modulating signal (DOUT). The modulated signal thus results a high frequency signal which is transmitted through the transmitter. The frequency of the transmitter used is 434 MHz the surface acoustic waves are produced when an electric field is applied to a piezoelectric material, it gets deformed and produces an acoustic wave with an amplitude that typically decays exponentially with depth into the substrate, like throwing a stone into a pond generates a decaying wave. A surface acoustic wave travels on the surface of the piezoelectric materials used,this wave is used for modulating the data signal. Piezoelectric materials are used for as electrical signals need to be transformed into the surface acoustic wave.

Since the resonant frequency of a SAW device is set by the mechanical properties of the crystal, it does not drift as much as a simple LC oscillator, where conditions such as capacitor performance and battery voltage will vary substantially with temperature and age.

Features of the transmitter module:

- 434 MHz Transmitter Operation
- 500 Ft. Range-Dependent on Transmitter Power Supply
- 2400 or 4800bps transfer rate
- Extremely small and light weight
- Low cost.

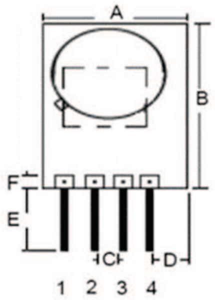


Fig. 6 Transmitter pin configuration.

Table II: Pin description		
Pin	Connection	description
1	GND	RF/DC ground
2	DATA	Data input
3	VDD	3V power supply
4	ANT	RF Output with

Receiver: At the transmitter end, the digital data is represented by different amplitudes of the high frequency carrier wave, and it is transmitted through the transmitting antenna. At the receiver end this high frequency modulated signal is received and is passed through a low pass filter and then demodulated to get the actual digital bit streams. ASK RF Receiver receives the data transmitted using ASK RF Transmitter. The receiver used in this work is RXB1-315Mhz and HT12D 212 decoder is used to decode the serial data signal to parallel data bits.

The RXB1, super heterodyne ASK receiver module, uses the ON OFF KEYING (ASK) demodulation scheme. As it is a super heterodyne receiver, it convert a received signal to a fixed intermediate frequency (IF), which can be more conveniently processed than the original radio carrier frequency. The Local Oscillator is made of PLL (Phase-Locked Loop) structure. It gives an excellent performance for simple uses like remote control. As the demodulation scheme is ASK, so it is easy to design and cost effective. The pin diagram of ASK receiver is shown in Fig. 7.

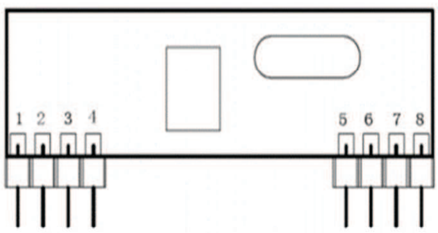


Fig. 7 PIN diagram of ASK receiver module

The demodulated data is now fed to the decoder HT12D. The decoder will convert the received serial data to 4 bit parallel data D0 – D3. The status of these address pins A0-A7 should match with status of address pin in the HT12E at the transmitter for the transmission of data.

The 212 series of decoders are capable of decoding information that consist of N bits of address and 12-N bits of data. The HT12D is arranged to provide 8 address bits and 4 data bits. The pin diagram of HT12D decoder is given in Fig. 8.

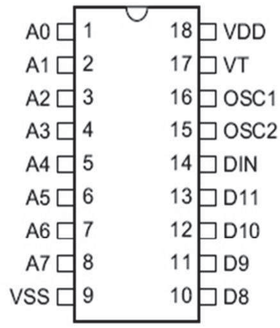


Fig. 8 Pin diagram of HT12D

Table III: Pin description of ASK RF receiver		
Pin	Connection	Description
1	ANT	RF Output with 50ohm matched antenna
2	GND	RF/DC Ground
3	GND	RF/DC Ground
4	VDD	5V DC Supply Voltage
5	VDD	5V DC Supply Voltage
6	DATA	Data Output
7	DATA	Data Output
8	GND	RF/DC Ground

Table IV: Pin Description of HT12D	
Pin Name	Description
A0~A7	I/P pins for address A0~A7. These pins can be externally set to VSS or open.
D8~D11	Output data pins.
DIN	Serial data input.
VT	Valid data transmission. Active high when data transmission is valid.
OSC1	Oscillator input pin
OSC2	Oscillator output pin

The decoders receive data that are transmitted by an encoder and interpret the first N bits of code period as addresses and the last 12-N bits as data, where N is the address code number. A signal on the DIN pin activates the oscillator which in turn decodes the incoming address and data. The decoders will then check the received address three times continuously. If the received address codes all match the contents of the decoder's local address, the 12-N bits of data are decoded to activate the output pins and the VT pin is set high to indicate a valid transmission. This will last unless the address code is incorrect or no signal is received. The PCB layout of receiver circuit is shown in Fig.9.

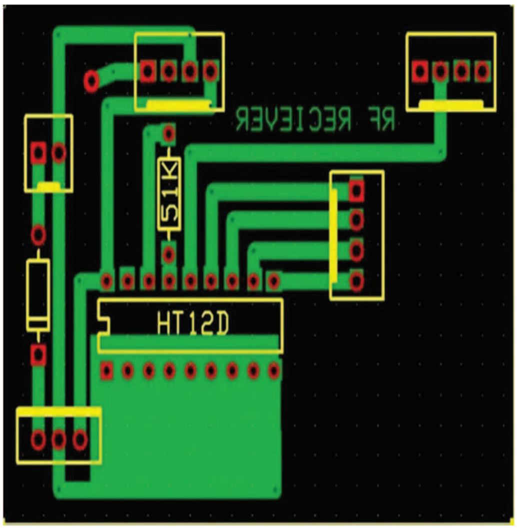


Fig. 9 PCB Layout of receiver circuit

Motor Driver: The driver IC L293D is quad push-pull drivers capable of delivering output currents to 1A per channel respectively. Each channel is controlled by a TTL-compatible logic input and each pair of drivers (a full bridge) is equipped with an inhibit input available at pin 1 and pin 9. The motor will run only when chip inhibit is at high logic i.e. chip inhibit is enabled.

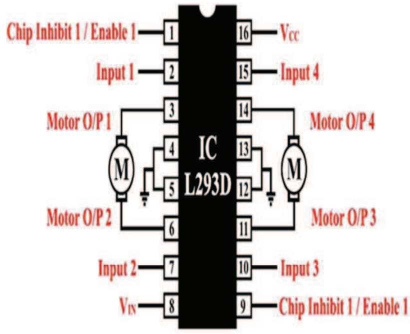


Fig. 10 Connection diagram for L293D

Fig. 11 Complete Prototype.

Conclusion: The robot's scaling capability was tested in an 8" diameter pipe. The inclination of the pipe was increased subsequently to determine its climbing capability.Also the average speed for various inclination angles were recorded.

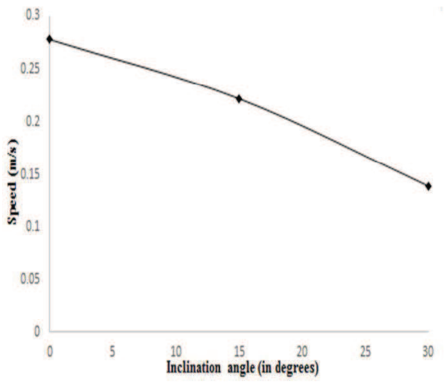


Fig. 12 Robot average speed vs. Pipeline inclination angle.

In this paper the design details of a pipe tube crawling robot are presented. The robot is capable of moving through pipes of 8" diameter, and is low cost. The tests revealed that the robot could crawl through horizontal and downwards inclining pipelines with ease but it lacks sufficient power to scale up a pipe with more than 30^o inclination. The maximum average speed obtained by the robot is 1.008 Km/hr. The average noise level of the system is negligible. To save cost a common household PC web cam was mounted on the top shaft connected to a motor whose sole function is to provide 360^o motion to the camera. This exercise further limited us from examining our prototype to crawl to a depth of more than 3 m into the pipeline. Though further modifications are needed to the augment the functional capabilities of the robot, it gratifies its main task of crawling through pipeline.

Fig. 12 Complete Prototype

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