Pipe Flaws Detection by Using the Mindstorm Robot

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Abstract

The detection of cracks in solid infrastructure is a setback of immense significance. Particularly, the detection of cracks in buried pipes is a crucial step in assessing the degree of pipe deterioration for municipal and utility operators. The key challenge is that while joints and laterals have an expected form, the unpredictability and abnormality of cracks make them hard to model. Oxidization of steel pipes in thermal insulation or padding is a severe problem stumble upon in the petrochemical, oil and gas industries. The most widespread ways at currently is time intense and labour demanding as it entails lagging removal; check using the usual non-destructive assessment practices such as visual, ultrasonic or radiography; and lagging replacement. This can also necessitate that the tools are shutdown adding up to extra financial burden to plant repairs and function. To examine and continue maintaining these pipes cost so much in terms of cash, manual labour and time, therefore automating the process is needed.
Automation has ever since the industrial uprising been used in industries and businesses to improve effectiveness and competency. A greater number of jobs are presently done by machines as an alternative to human effort. Robotics technologies deal with automated machines that can take the place of humans, in hazardous or manufacturing processes, or simply just resemble humans. Robotics has been often seen to mimic human behaviour, and often manage tasks in a similar fashion. Today, robotics is a rapidly growing field, the new research; designing and building of new robots are to serve various practical purposes, whether domestically, commercially, or militarily. Many robots do jobs that are hazardous to people such as defusing bombs, exploring shipwrecks, and mines.

The Mindstorm robot intends to solve the problem of detecting flaws in a pipe through its intelligent sensors to provide a monitoring platform along the entire distance of the pipeline and use its NXT tools to monitor and ultimately predict the occurrence of defects. Using the Mindstorm robot colour sensor, the Mindstorm Lego robot can detect the leakages in a pipe as dark colour modelled with a black tape and can also detect the cracks modelled with a white tape there by reducing the shut down time of the process.

Keywords: Mindstorm Lego, NXT, Pipeline Leakage, Automation, Robot C, NXT-G, Robotics, sensor.

1Introduction

Transportation of fluid from the point of production to different points for easy access for end users has been a necessity and hence the importance of construction of pipelines. Most of these pipelines transport toxic products though very essential for day-to-day activities such as in the oil and gas industry, therefore direct exposure of the pipe to the environment is dangerous and hazardous [S. K. Sinha and F. Karray][7]. Buried pipeline are constructed to protect the pipes from environmental and atmospheric influence such as impact, abrasion and corrosion that can lead to pipe destruction. The different types of flaws in a pipe include: corrosion and wear (which can be as a result of change in atmospheric condition), cracks, dent and hole leakages. These flaws could be as a result of weather changes, long use of the pipe (most pipes are designed to last for 25years irrespective of what flows inside them), intentional and unintentional third party damage such as accident, sabotage, terror and theft. [Timur Chis and Andrei Saguna][8].
Most pipelines operate for many years without much attention to mechanical changes in the pipe. Some of these pipes are left partially full for some period and this can lead to corrosion as some of these products that are being transported are corrosive in nature. The design and construction of the pipeline could lead to leakages at some poor construction joints. Likewise, the operation design guidelines need to be studied. There are times where the pipes are designed for a certain maximum temperature and pressure and usage under a higher degree can lead to the pipeline failure. [Timur Chis and Andrei Saguna][8].

Intentional damage unfortunately seems to be on the high side than the unintentional or accidental damage. This is more common with pipelines transporting high-value products and is usually highly flammable and this has led to loss of lives and properties in so many regions. A recent pipeline vandalisation that happened in Nigeria led to over loss of 100 lives as the pipeline was carrying fuel from a state-owned refinery in the city of Port Harcourt to the city of Enugu which is 140miles away in north direction. [Daily mail news][3]

Therefore, the oil and gas industries and other fluid transport based industries tend to pay attention to leakage detection as failure to detect can lead to loss of life and property, direct cost of loss of products and lie-down time leading to direct financial loss to the industry, environmental pollution and this will necessitate the need for environmental clean-up thereby incurring more production/management cost. In a more critical case, it can lead to possible fines and legal suits costing the company many millions of dollars. [Timur Chis and Andrei Saguna][8].

The detection of flaws that could lead to leakages in buried concrete pipes has been an area of great concern to the oil and gas industry and water resource based industry. The recognition of flaws in underlying channel is an important measure in examining the extent of tube impairment for public and service workers. The major problem is the difficulty in modelling detection of cracks as a result of it irregularity and randomness unlike pipe joints and dents that can be easily detected through it predictable appearance [S. K. Sinha and P. W. Fieguth][6]. Figure 1 shows the presence of a crack on a wall.

Figure 1: Presence of crack on a wall. (This shows the presence of crack in a wall as it appearance vary from one wall to another)

The corrosion of steel pipes as a result of rapid change in weather condition, thermal insulation, pressure and erosion is a major crisis in the petrochemical, oil and gas industries. The most common ways at present is time consuming and labour intensive as it involves insulation removal; assessment using the usual non-destructive assessment practices such as visual, ultrasonic or radiography; and insulation replacement. This can also require that the equipment is shutdown adding additional economic burden to plant maintenance and operation. To monitor and maintain these pipelines cost efficiently and effectively in terms of money, labour and time, automating the process is needed [R. J. Barnes][5].

Automation has from the time of the industrial uprising been used in industries to enhance capability. A growing number of jobs are at present carried out by machineries as a replacement for human effort. The Science of Robotics deals with machines that can be automated in order to take the place of humans, in risky or sensitive environment, or simply perform actions that resemble human capability. Robotics has been designed often time to act like human by mimicking human behaviour, and often has been able to manage tasks in an expected way as human behave. Recently, robotics has been growing rapidly; the new research; designing and building of new robots are to meet different practical purposes, which include domestically, commercially, or militarily. Today's robots perform jobs that can result to loss of lives or could cause severe damage to people. Such activities include deactivating bombs, exploring a shipwreck, and mines.

Robotics has become an effective tool within the scope of education in the past few years [Amini F, Vahdani R][1]. It has successfully incorporated features such as simplified programming skill, and easy way of building robot at a low/middle cost showing interrelationship between courses. This has been the keystone for the achievement of robotic application in education [Amini F, Vahdani R][1]. Lately, a movement which considers robotics as an instrument to shed more light to other components in the curriculum rather than the subject itself may be observed, and particularly in the field of computing and electronics [J. A. G. Ilder, M. I. P. Eterson, and J. A. W. Right][4]. The major advantage has been the practical way of impacting knowledge to students in the course of learn, leading to a better understanding of ideas, and the interdisciplinary order of the work that is to be done. [2][B. Shih, C. Shih, C. Li, T. Chen, Y. Chen, and C. Chen]

Mindstorm lego is a robotic tool set from LEGO that is primarily made for children as a game set. A major component of the Mindstorm set is the NXT which contains the main processor that can control four input sensors with three outputs sensors connected to the NXT externally. The brick can be connected to other different peripherals such as the speakers as effectors, the light, infrared, ultrasound, interactive servomotors and touch sensor. The Lego NXT Software Development module had successfully used challenges and emulations to improve the student experience, but these challenges were somewhat artificial in nature. [2][B. Shih, C. Shih, C. Li, T. Chen, Y. Chen, and C. Chen]

The Mindstorm robot intends to solve this problem through its intelligent sensors to provide a screening stage along the complete length of the pipeline and use its NXT tools to examine and eventually calculate the expected happening of defects.

2 Methodology

To carry out this research, we have used the model robot NXT 2.0 from Lego Mindstorm, the NXT. Program development has been done, a small RobotC-based firmware system that runs on the NXT brick. The Mindstorm software building blocks were also used for this project.

The practice is to get the robot, aided by their functions and motion sensors, get moved through a pipe and detect crack which is modelled with a black tape for a hole and a white tape for the crack on harsh coloured background of the pipe. This was presumed since a hole would leave the point blank and therefore dark while a crack would only cause a little deviation from the original colour of the pipe. In addition, the robot will have to stop if it detects the crack for few seconds and calculate the distance covered by to the get to the point of crack and display the number of cracks detected and if no crack detected, display “no crack”.

2.1 HARDWARE DESIGN

The design was made following the procedure read in the enclosed instructions on the box of parts of the robot.

Modification was then made to the hardware as shown in fig 6 to use the colour sensor. The Mindstorm colour sensor has the ability of performing three functions at a time, colour recognition (which enable it recognises the different colours in the pipe, it is capable of recognising 6 different colours), Measuring light intensity of it environment (with this, it is able to handle light reflection in it surrounding) and it can also be used as colour lamp.

The design incorporates:

- Three servo motors that drive the robot. The motors are connected to port A, B, C,. These motors are responsible for the movement of the robot.
- The NXT which is the brain of the robot. The program is downloaded to the NXT using the Bluetooth or USB port. The NXT display is used to display information running on the program.
- The colour sensor to detect the cracks and holes in the pipe.
- Six AA batteries to power the robot.
- Other things in the design are the connectors that connect the different functional components together.

Figure 2: The Mindstorm robot with the coloured sensor attached to it to detect the flaws

The robot is programmed to give a beep sound and to wait for two seconds once a flaw is detected and to increase its counter by 1.

The NXT brick which manages and controls the other components, and offers a small screen interface and 4 buttons the brick also emits sounds. (Figure 7)

Figure 3: The NXT brick

2.2 Development of flaw detection in RobotC

Robot C has a commercialised program for the Mindstorm thereby giving it an ideal programming environment for Lego Mindstorm. ROBOTC runs a much standardized firmware that permits the NXT to download and run programs in a fast speed, and also compact the files so as to fix a

huge number of programs inside the NXT. Just like any other languages running on NXT, ROBOTC need the firmware to be downloaded from the ROBOTC robot tool in-order to run.
For the implementation of the code has opted for a scheme of priorities within a finite loop, which evaluates the three conditions for which the robot should act.

First it checks if the colour of the surface of the object read by the coloured sensor is black (indicating a hole) as defined in the program. If so, then the robot stops for 5 seconds while the warning sound plays which act as an alarm. It increases it counter by 1 and the total number of cracks detected is displayed by the last detection. The distance covered is also calculated using the motor function and this is also displayed on the NXT display. This check will be carried out within a specified time in the code, to avoid excessive use of the processor in the sensor readings and an infinite loop.

Secondly, it checks for a crack which is modelled with a white tiny colour of 0.2cm wide with the help of it colour sensor. If the white colour is detected, the robot pauses for 2 seconds (not as long as a hole as this is a minor case compared to the hole) and makes a warning sound as an alert. It also increases a separate counter for this and calculates the distance covered and this information is displayed on the NXT display as indicated in the program.

Finally, it runs the code for the case where the robot is not detecting any hole or crack (modelled as the black and white colour). In this case, the robots just move straight as no obstruction is detected. It then displays a “no crack” message to indicate that no crack is detected. However, a time limit has been set to avoid over used of the processors.
The Robot C screen shot is as shown below in Figure 4:

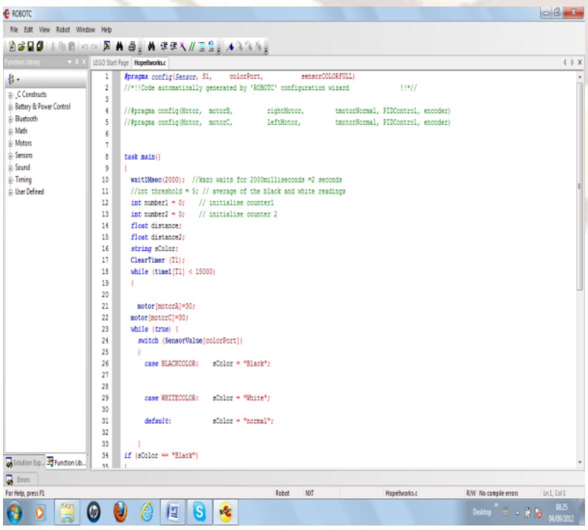

Figure 4: RobotC snapshot

2.3 NXT-G

NXT-G v2.0 is a user friendly graphical interface programming environment that is comes with the NXT kit. With a good assembly of blocks and data wires to sum up complexity, NXT-G is capable of being applied in a real world programming challenge. Similar "sequence beams" are in reality matching threads, therefore this software is pretty fine for running a good number of similar sense/respond loops (For instance: wait 30 seconds, play a "beep" sound at high volume if battery level is good, iterate), or merging independent management using the Bluetooth or any other "remote control". The programming language permits virtual tools for all LEGO labelled and a good number of 3rd party sensors/components. The Version 2.0 (which is the version being used for this project) has new tutorial problems, a remote control, custom images and sound making, and latest Lego colour sensor support.

The graphical program was built by making the robot wait for one second before starting to move. Then the light sensor was applied to detect the range of colour that indicates a hole. If the colour is black which indicate the presence of a hole, it executes the first layer of the program as shown in figure 8 below. If otherwise, it moves to the next layer, where it also tests to see if the colour present is white. If a white colour is detected, then it follows the program on the upper layer of the second phase of the program and if otherwise, the last layer will be run on the robot.
However, in each of these layers, a set of blocks are used to program the activity of the robot and the wires are used to connect one related block to the other.

The first layer, after detecting the hole increases its counter by 1 and this information is converted into the text format and stored in the NXT memory. The text is then displayed on the NXT display and the robot continues its journey. The distance travelled on detection is calculated and displayed.

A similar thing is repeated on the upper layer of the second layer. It also increases its counter by one, converts it into text and display the number of cracks detected modelled with the white coloured tape, and then moves on. The distance travelled is also calculated and displayed.
The lower layer of the program detects no other colour that means no crack has been detected and therefore displays “no crack” on the NXT display screen.

The software building block is as shown below:

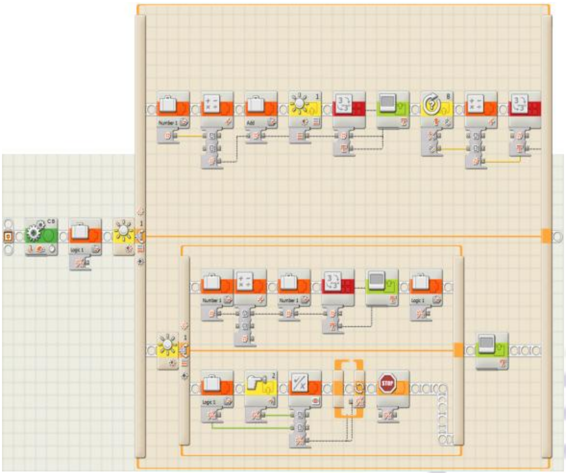

Figure 5: NXT G Snapshot

3 Result

The robot "kazo" was able to move using the three servo motors attached to it. Using the move block in the program enables kazo to move in a straight line. Each of these motors has a built-in rotation sensor which controls the robot movement and was used to calculate the distance covered by the robot. One rotation of the robot is equal to 360 degrees with an error space of +/- one degree. The outcomes of this experiment are shown in Table 1-9 with the summary of the result on table10. The experimental data underlying the transition in time preset in this model were collected during the course of the experiment of the different types of flaws at different length. Each box in table 1-9 shows a yes or no with a value of yes if the robot was able to carry out the specified action at the point of monitoring of the pipe and a no if the action was not carried out at the particular speed.

The overall trend in these results agrees with our qualitative expectations in our aims and objective to automate the detection of flaws thereby reducing the shut down time. The speed rate of 20% takes longest period but demonstrates the greatest reliability, whereas a speed rate of 60% is best in terms of speed with a much lower success rate in detection. Speed 40 tries to balance the two with an average speed and a good reliability. Keeping the speed at 30% is recommended from the result as this gives a better reliability by detecting all cracks except the thread-like crack which causes little or no harm to the pipe and at the same time reducing the shut down time of the system.
The distance covered at each point of the flaw was calculated and displayed through the servo motors sensor by taking account of the rotation in motor A in 360^0 thus:

Circumference = $2\pi r$

The diameter was measured to be 3.5cm. Therefore, the radius is 1.75cm.

Distance travelled = $2\pi r$ **X** number of rotations

= 3.5π **X** number of rotations

=11 **X** number of rotations

The above result can be summarised in the table below:

Table 1: Summary of the result

Flaws/Speed	20	30	40	50	60
3cm hole	Yes	Yes	Yes	Yes	Yes
2cm hole	Yes	Yes	Yes	Yes	Yes
1cm hole	Yes	Yes	Yes	Yes	Yes
0.5cm hole	Yes	Yes	Yes	Yes	Yes
0.1cm hole	Yes	Yes	Yes	Yes	No
0.1cm crack	Yes	Yes	Yes	No	No
0.05 crack	Yes	Yes	No	No	No
Thread-like crack	Yes	No	No	No	No

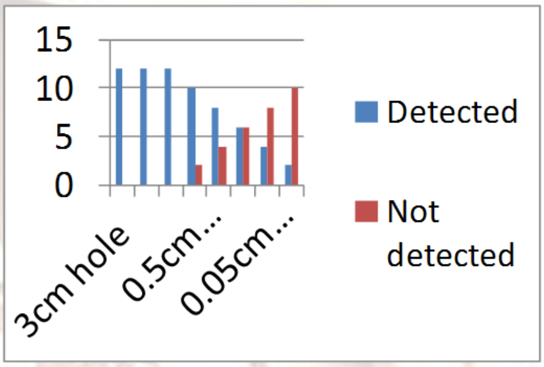

Figure 6: Chart for the result

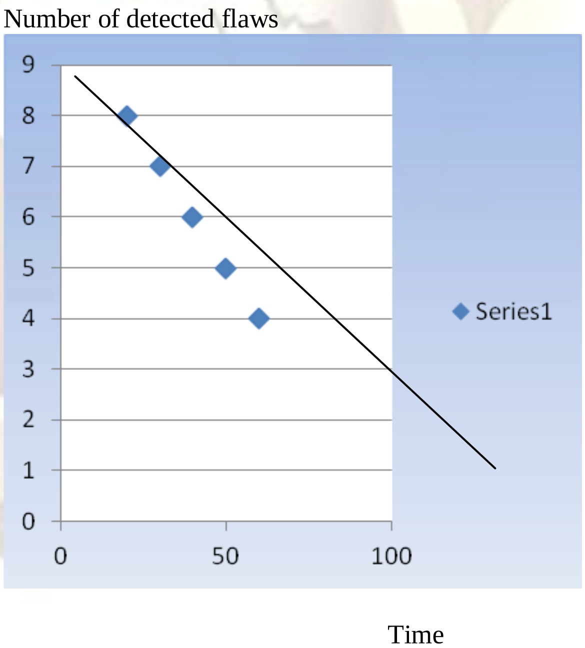

Figure 7: Graph showing the rate of detection as time changes

In general, it was found that the assumption regarding the Mindstorm's performance in detecting the flaws of the pipe varies as the speed increases. A 10% change in speed increases the reliability of detection as shown in the gradient of the graph in

figure 27. While the simplicity of this project's model forces us to accept certain inaccuracies, particularly in the modelling of the flaws, it allows us to perform meaningful analysis on the rate of detection in the Mindstorm robot.
From the above analysis of the experiment, the following can be deduced:

- The bigger holes can be detected even at a very high speed of the robot.
- Kazo is capable of detecting cracks that are more obvious to the eye.
- The higher kazo moves the less likely it detects minor cracks.
- The distance was calculated and this can aid the repair process.

4 Conclusion

This project was able to build and program a Mindstorm Lego robot to detect holes and cracks in a pipe using the colour sensor of the mindstorm robot. This write up shed light on the basic components of the lego from building the robot from the pieces of bricks to the building blocks of the NXT2.0 software for programming the robot. The program run on the robot was explained and the robot was able to detect the major flaws in the pipe in real time.

4.1 FURTHER RESEARCH

This work has been able to successfully detect flaws in the pipe. Nonetheless, there are still areas that were not covered as a result of time limitation and other factors. Further areas of research include:

- The use of a stronger ultrasonic sensor to detect the cracks and holes. This was not covered as it amounts to hacking the Lego Mindstorm and might lead to withdrawal of the guarantee in the kit. However, this need to be tried as it is hope to be more practical and can come out with a better result by detecting the cracks once it is visible to the eye.
- Application of machine learning for detection. This is still an active research area, as we need to know if the Mindstorm Lego can learn the original condition of the pipe. This also seems to be a better approach as some of these pipes are found with minor and ignorable faults initially and the robot should not detect them as a major fault.
- The work of K. Sinha and P. W. Fieguth still need to be looked into using the concept of image processing to take the difference between two images.
- All the afore-mentioned are only detecting the flaws and remain uncompleted if the repair methodology is not yet automated to reduce the downtime of the pipeline. Though, we have been able to calculate the distance travelled before detection so as to make it easy in the course of repair to locate the flaw.

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