Structural Health Monitoring of Water Pipes

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Abstract. Existing techniques used for detecting the appropriate positions of the cracks and distortions in the water pipes (PVC) are invasive and need suspension into the pipes to identify the cracks now and then manually. Even though few noninvasive methods exist, they are expensive as they either use drones, optical methods, or sensor fusion methodology. Hence, the proposed work is an attempt to automate monitoring of pipes through the cloud and also prevent the suspension in operation from interfering in any possible way thus saving time and cost. An automated robot that captures images through cameras, detects cracks accurately using an image processing technique (feature detection) and alerts the concerned person is designed that aid in monitoring the structural health of pipelines.

Keywords: PVC (Poly Vinyl Chloride) · CCTV (Closed Circuit Television) · CBM (Condition Based Maintenance) · CV (Computer Vision) · RPi (Raspberry Pi) · Feature detection · Platform as a Service (PaaS) · Kubernetes

1 Introduction

Efficient utilization of water and loss of water because of leakage is an important issue in the 21st century [1]. Word bank estimates the losses due to water produced and lost by utilities to be getting close to $14 billion [2]. With a mean of 40% losses because of the leak being ascertained around the world, investments in the smart water management system are expected to reach $46.5 billion by 2023 [3]. To overcome the losses due to water leakage, monitoring the structural health of the pipeline is an important aspect, through which the possible leaks could be detected.

Structural Health Monitoring is the process of incorporating damage detection in any structural model. Damages are any changes to the material or the geometrical structure that will have adverse effects on the functionality that the structure is designed to perform. Health monitoring leads to the improvement of the existing structure in an efficient manner. Structural Health Monitoring of water pipes is very important as it could help in detecting cracks and any deformation along the length of the pipe. This prevents a huge loss of water that would leak through the deformations in the water pipes. PVC pipes are more often used for all domestic purposes, hence there is a greater probability of the appearance of cracks on them, which at times go unnoticed. This leads to unnecessary wastage of water. To date, various methods have been employed to detect deformations

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2 Related Work

The paper [4] reports on an acoustic-based approach to detect cracks in PVC sewer pipes. The pipes are excited with acoustic signals and their frequency response is analysed to characterize the difference between a clean and a cracked sample.

Advances in technologies have given rise to new techniques, some of which could be applied to the examination, monitoring, and condition evaluation of covered water mains. The paper [5] presents a state of the review of sensor technologies utilized for monitoring indicators highlighting pipe structural deterioration. Some sensors that could be used for structural health monitoring of water pipes are featured in [6–11]. The paper also proposes a system of wireless sensor networks for pipe condition monitoring where multiple wireless sensors are grouped to monitor large networks of water pipes cooperatively. The system of multi-sensor framework and sensor data fusion for CBM (Condition Based Maintenance) is a technique where the pipes are monitored continuously in real-time and decisions are taken in real-time based on the present condition of the pipe. There will be a set of predefined tasks that will be performed if the condition of the pipe deteriorates. Guided wave radar [12] is based on microwave technology. Microwaves are only affected by materials that reflect energy which means that temperature variations, dust, pressure, and viscosity do not affect accuracy.

Many studies have been done on monitoring the structural health of water pipes. These have focused only on sewer pipes rather than water pipes. The main disadvantage of structural health monitoring using the acoustic signals approach [4] is the cost of the setup. Also, if the operating environment is very noisy, then the acoustic signals will be weak. Thus, signal discrimination can be very difficult. The use of sensor technology for water pipes [11] is also restricted. The relevance of the technologies to water pipes described in the paper has not yet been fully verified. Currently, the acquisition of expensive data is justified only for major transmission water mains, where the consequences of failure are significant. Pipes with less significance of failure do not justify high-cost data acquisition campaigns. Another issue is the lack of a complete understanding of sensor reliability. Reliability and low cost are the most important factors in the development and adaptation of sensor technology to buried water pipes. There have been other technological developments for health monitoring of water pipes such as using image processing to analyse recorded CCTV videos using morphological segmentation and top-hat operation techniques [11]. The CCTV-based methods are not in widespread use due to the cost and manpower requirements of deploying the CCTV-based system. Also, the result of this technique is not reliable as it is not real-time.

From the above, it is seen that there were various techniques to incorporate the structural monitoring, but most of these techniques such as guided wave technique, ultrasonic testing are expensive to be deployed. The acoustic methods involve sound waves which have high probabilities of noise interference, hence reducing its reliability. This paper proposes the design and implementation of an automated robot to identify the cracks and alert the concerned authority to take necessary measures. This paper is an extension of [16] which is the cloud-based leakage detection algorithm where the presence of crack is confirmed.

3 Proposed Design

The proposed design for the crack detection system is as shown above. Figure 1 depicts the flow of the proposed system which is designed to be implemented on a physical network of pipelines. The RPi night vision camera is mounted on the bot where the bot moves along the pipe and captures images of the exterior surface. The bot then sends the captured image to raspberry pi, where the detection algorithm is executed and the result is then updated on the website designed for this purpose. The crack detection is done using the Computer Vision technique. The algorithm processes the image and checks for cracks. If a crack is detected, a signal to the buzzer is sent, and also the message along with a timestamp is posted onto the user page. Hence, helping in detection and localization.

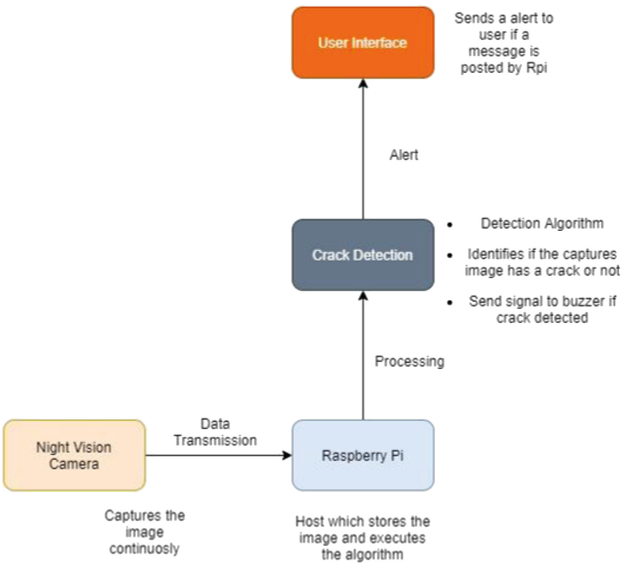

Fig. 1. Architecture diagram

4 Methodology

The design involves the following 3 main objectives:

- Building an automated robot that houses a microcontroller and cameras interfaced with the microcontroller that can capture images of the pipe.
- Feature detection enables the robot to detect the crack as soon as it encounters a crack.
- Testing the model in crack and crack-less conditions.

Prototype Design

This section describes the design and implementation details of the prototype which has been built to identify the cracks.

The basic prototype model:

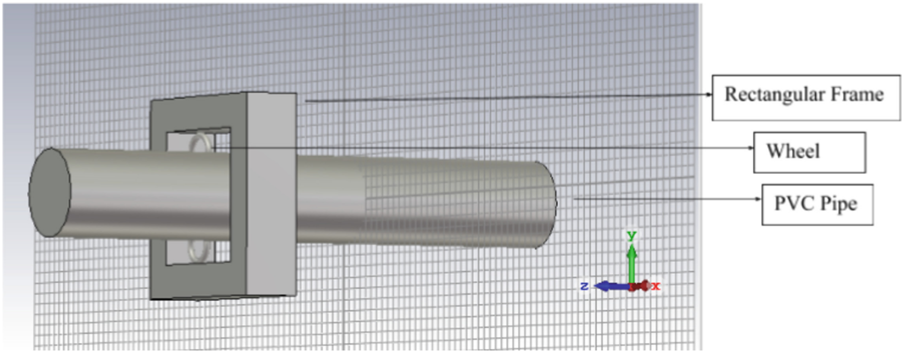

Fig. 2. Lateral view of the structure

A rectangular frame (Fig. 2) that houses the RPi camera module, RPi, and batteries are mounted on the PVC pipe with the help of moving wheels attached to the frame as shown in Fig. 3. Figure 2 shows the lateral view of the entire structure whereas Fig. 3 depicts the top view of the same moving frame. The movement of the wheels will be controlled by the microcontroller. The entire frame moves along the length of the PVC pipe.

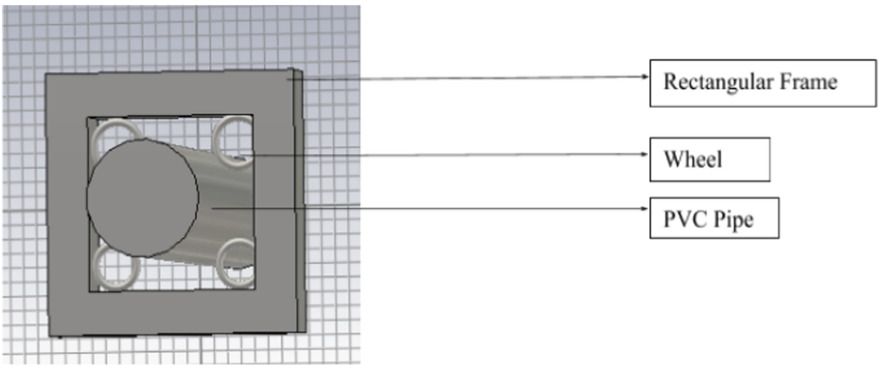

Fig. 3. Top view of the structure

Night-Vision camera in the frame captures the images of the pipe continuously and sends them to the RPi cloud. The microcontroller obtains these data and a feature detection technique is applied to find out any irregularities on the pipe surface. Feature detection is an important task in many CV (computer vision) applications, such as structure-from-motion, image retrieval, and object detection. This technique is very efficient as it enables to locate the exact position of the crack or deformation. The actual prototype is shown in Fig. 4 which has a rectangular frame mounted with raspberry pi, the camera, and battery.

Fig. 4. Prototype model

Feature Detection Algorithm

Detection: Identify the Interest Point

Description: The local appearance around each feature point is described in some way that is (ideally) invariant under changes in illumination, translation, scale, and in-plane rotation. We typically end up with a descriptor vector for each feature point.

The point of interest is calculated using image processing operations such as Gaussian blur [17], Median blur [18], Hough transform [19] and erosion and dilation [20, 21].

+ of feature detection:

Step 1: Extract the structural element from the image
Step 2: Erode and dilate the image using morphological operation
Step 3: Blur the image and extract the edges
Step 4: Shade the border lines that are thick
Step 5: Binarize the image after blurring
Step 6: Skeletonize the image and save the corresponding output
Step 7: Check if there's a crack found, by checking for pixel value.

Hence the location can easily be determined and this information is sent to the concerned authority. The stakeholder can access this information that is deployed on the website which provides a unique login for the user. The user can obtain all the necessary details and hence identify the localized deformation in the water pipes.

The Model after detecting a crack would send an alert to the concerned person and hence can easily locate the crack position.

User Interface
A web portal for users was developed using the Flask framework which gives the status of the system and notifies users of important messages. The application is also containerized using Docker and ready to deploy easily. For demo purposes, the website was hosted using Platform as a Service from Google Kubernetes Engine. The website is shown in Fig. 5. The website has the dashboard, along with the image of location of leaks for flow monitoring.

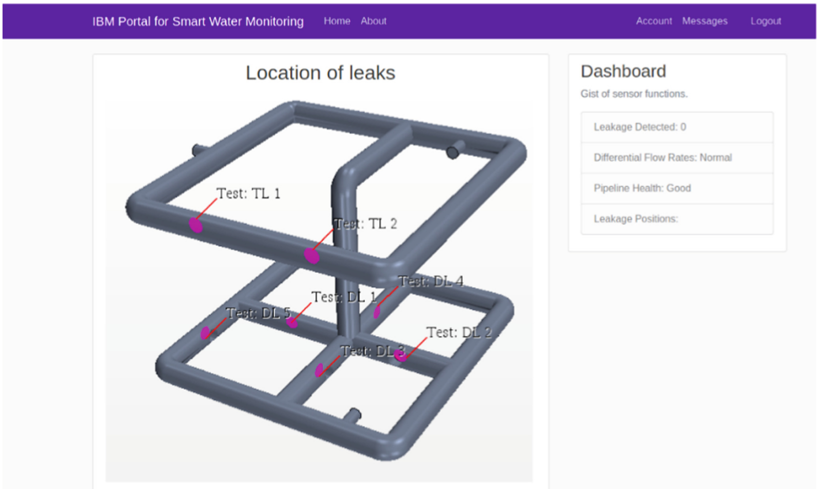

Fig. 5. Website interface

5 Results and Discussion

The designed prototype is moved along the length of the pipe. The pipe had two cracks, one on the surface of the pipe, and a second crack on the edge of the pipe. The prototype successfully identifies both the cracks as shown in Fig. 6, Fig. 7. Figure 6 indicates the crack present on the curved surface of the PVC pipe along with skeletonized image on the right. Figure 7 shows the detection of crack on the edge of the PVC pipe. The prototype identifies the cracks very accurately but fails to identify pinhole cracks or very minor cracks, which might not be very prominent.

Testing for the prototype was done in the following ways:

1. Cracks on the surface were induced and the image of the crack was taken, this was fed to the algorithm for processing. The algorithm successfully detected the cracks on the surface. Nonetheless, the cracks have to be quite significant. Very small cracks induced were not detected properly.

2. Cracks were induced on the edges of the pipe; the algorithm was able to detect these cracks. Here very small cracks will not be detected.

In both cases, the notification when the cracks were detected was successfully posted onto the website without any issues. No significant delay or loss of detected crack notification was observed. Hence, the validation of the prototype has been done in this method. As pointed out earlier, hairline cracks or pinhole cracks are not detected properly by the prototype but worked precisely in all other conditions.

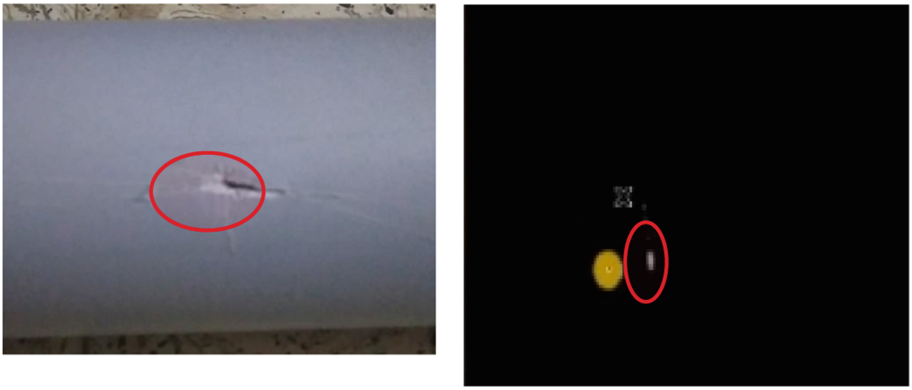

Fig. 6. Detection of a crack on the curved surface of PVC

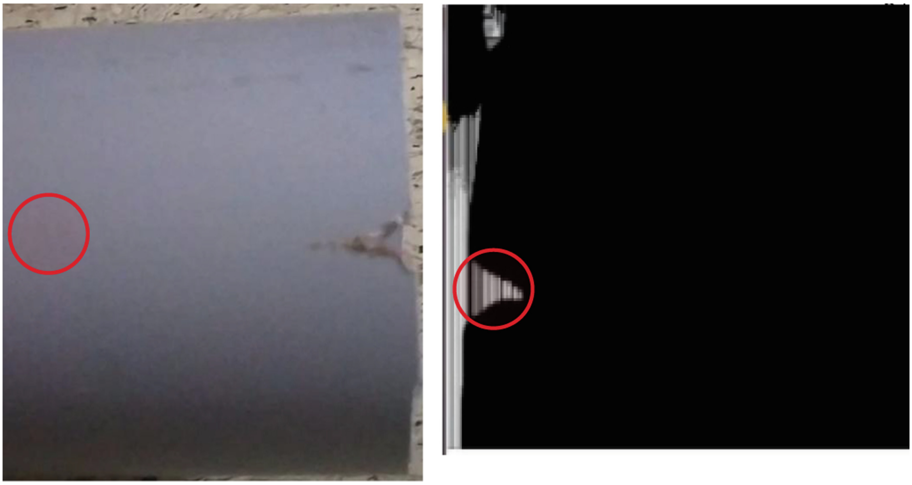

Fig. 7. Detection of a crack on the edge of PVC

The presence of the crack can also be found out at the user end through the web portal. This is shown in Fig. 8 which shows all the notifications obtained once cracks are detected.

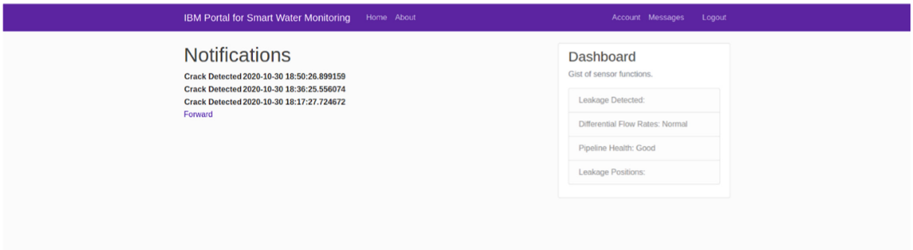

Fig. 8. Alerting user about the crack

6 Conclusion

The automated crack detection system for structural health monitoring of water pipes is based on an image processing technique feature detection, which enables the automated robot to detect the crack as soon as it encounters a crack. The system is employed to detect the cracks and alert the concerned person about them. Once a crack is detected, the robot will send an alert and stop at that location. The basic prototype is built and the results were obtained. The prototype identifies the cracks very accurately but fails to identify pinhole cracks or very minor cracks, which might not be very prominent. The proposed system detects the damages, cracks on the pipe to prevent potential leaks in it. Thus, the proposed system can be implemented to prevent losses in a pipeline system, thereby ensuring the conservation of natural resources.

7 Future Scope

The proposed design in the paper aids in localizing the location of the crack. This idea can be extended to a huge network of pipes. A single robot with multiple arms mounting several such modules can be designed. The system can be made more intelligent to predict the formation of the crack before it affects the water pipes. Thus smart water management can lead to the conservation of huge quantities of water thus contributing to slowing down the effects of water crisis

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