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A Practical Solution of a Plant Pipes Monitoring System Using Bio-mimetic Robots

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***Abstract*—**There has been a growing interest in the field of bio-mimetic robots that resemble the shape of an insect or an aquatic animal, among many others. One bio-mimetic robot serves the purpose of exploring pipelines, spotting any troubled areas or malfunctions and reporting its data. Moreover, the robot is able to prepare for and react to any abnormal routes in the pipeline. In order to move effectively inside a pipeline, the robot's movement will resemble that of a lizard. When situated in massive pipelines with complex routes, the robot places fixed sensors in several important spots in order to complete its monitoring. This monitoring task is to prevent a major system failure by preemptively recognizing any minor or partial malfunctions. Areas uncovered by fixed sensors are usually impossible to provide real-time observation and examination, and thus are dependant on periodical offline monitoring. This paper provides the Monitoring System that is able to monitor the entire area of pipelines—with and without fixed sensors—by using the bio-mimetic robot.

***Keywords*—**Bio-mimetic robots, Plant pipes monitoring, Mobile and active monitoring.

I. Introduction

BIO-MIMETICS [1], [2] is a study of adopting mechanisms found in natural organisms and applying them in engineering. Living organisms evolved their way to perfection over many centuries, and their mechanisms can be very helpful in the field of engineering; many researches in bio-mimetics are being done currently.

Manufacturing bio-mimetic system requires many tools and vast amount of data. Therefore, to monitor thoroughly and successfully, bio-mimetic systems must be able to be used like a computer. Monitoring System allows a robot to formulate an appropriate movement or response once it recognizes a malfunction [3]. The monitoring process goes through several steps, including collecting, saving, and examining data. Minor misplacements and errors, which are both hard to find and hard to reach, are common in factory environments; the monitoring system is thus plays a very critical and practical role in these environments.

However, monitoring a massive factory area is almost impossible. Also, although noticeable pipeline leakage and blockage are easy problems to confront, many system failures starts from a small leakage caused by years of the pipeline's gradual deterioration. A small leakage is difficult to be spotted simply by monitoring. In this paper, we aim to create a set of robots that is able to collect data and disperse sensors, which will prevent it from missing any obscure leakage and deteriorated pipelines. A measurement sensor system is attached in the robot to give intelligence and a better maneuver for it to collect data.

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II. Plant Monitoring System

The monitoring system's appropriate response to finding abnormal conditions in a pipeline is done by collecting, saving, and examining data. Some of the systems that are currently used include DAS (Data Acquisition System), SCADA (Supervisory Control And Data Acquisition System), and MAP (Manufacturing Automation Protocol). These systems collect monitored data and transfer them to a computer through LAN for them to be saved and examined.

The biggest flaw in this monitoring system is that the observed and monitored spots are fixated. It needs to pick the most appropriate area as its standard measuring point, so that it can distinguish what condition is normal and abnormal [4]. Once an abnormal condition is recognized, the robot reports the data to prevent further problems and system failure.

In this paper, the monitoring system adds moveable observatory points in addition to fixed sensors. As explained in section III, moveable observatory points are constantly dispersing and changing according to the movement of the bio-mimetic robot in a pipeline. The robot is equipped with sensors that will wirelessly report the real-time location of the robot; once an important data is obtained by the robot, the sensors can tell where in the pipelines the data was found.

III. Bio-mimetic Robots Moving on Pipes

Pipe monitoring bio-mimetic robots are used in a factory environment to locate abnormal conditions due to depreciation and deterioration of the factory machines. Working as an assistant to a professional engineer, the robot replaces a person having to directly examine hard to reach areas, such as pipelines. The robot also works to collect data and react to its sensors. These bio-mimetic robots are not only useful in industrial environments but also in skyscrapers and any buildings that needs a checkup. The robot collects enough data to locate troublesome areas and even predict a possible malfunction later on.

The most appropriate environment for this bio-mimetic robot would be a factory pipeline, water supply and drainage, gas pipe, or an air duct. All these areas require periodic checkup because deterioration is relatively fast and the replacement is extremely costly. Moreover, due to the complexness of the pipelines, it is a much more suitable job for a small, delicate robot than a human to examine the areas.
Therefore, the robot must be able to move freely throughout the pipelines. A proper robot that is able to withstand factory pipeline's condition is equipped with data monitoring system. The data recollecting a normal condition of a pipeline is collected, and any abnormality—leakage, vibration, or a temperature change—is reported to the server system. In order to perform its job properly as a mobile agent, the robot must be built in a proper shape and attached with driving module and interface including a battery pack. Also, servers are necessary to report the exact location of the robot and communicate information to each other.

IV. Mobile Monitoring System

A monitoring system with fixed sensor provides a variety of real-time measurements and observations. It detects a possible leakage and responds immediately once a malfunction has been found.

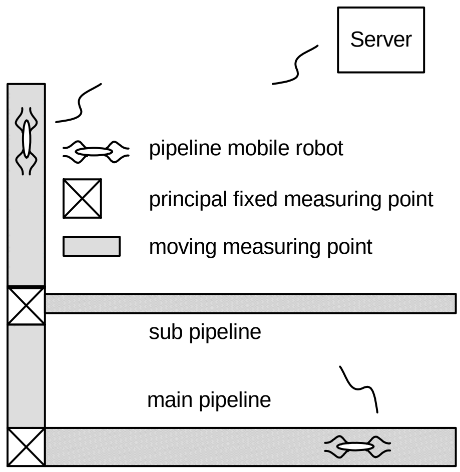

Fig. 1 Schematic diagram of a mobile monitoring system

However, many problems that occur inside a pipeline are miniscule and almost undetectable because the problems arise slowly and gradually due to a depreciation of the pipe. In order to cover the entire pipelines and examine each one thoroughly, a huge number of fixed sensors are necessary. One way to replace this costly operation is to have a moving sensor, or a bio-mimetic robot, that will get to some of the places that professional engineers either cannot reach or fail to examine. The bio-mimetic robot is able to perform the pipeline checkup much faster and more often than an engineer. Moreover, over time the robot is able to use its past data to calculate the speed of the pipelines' gradual deterioration and even predict the possible time of outbreaks.

A. Position Measurement System of Mobile Robots on Pipes

In order to calculate the location of a moving robot, important spots including the fixed measuring points are marked with RF tags. The RF tags then creates the coordinates that will help locating the robot, which moves at a constant speed while collecting and transferring data. This is done by calculating the distance between a RF tag and the robot using the total time the robot took to move, excluding any time spent when the robot was stationary.

Fig. 2 depicts a pipeline with attached RF tags that locate the robot's coordinate. These RF tags are positioned in turning areas of the pipes, and are able to report the distance between one tag to the other. As the robot moves at a constant speed and stops to collect data, it recognizes the nearby RF tags and begins to move to the next tag. In practice, there is no difficulty to assume that the map information of pipe systems for maintained system is available.

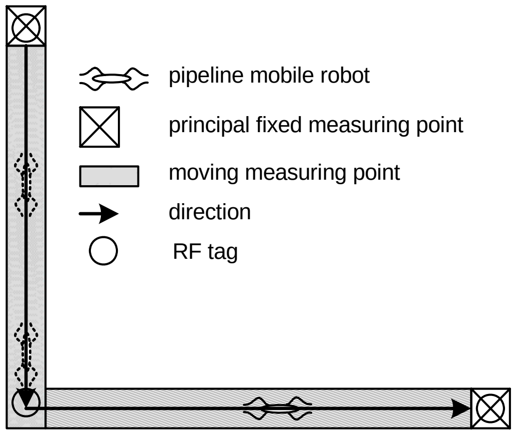

Fig. 2 Position sensing of a mobile robot on pipes

B. Interface Technology of Sensors

The number of pipe conditions the bio-mimetic robot can collect is somewhat limited. It can collect data from just about noise, vibration, and temperature; though these may be few, any sudden changes to one of the three conditions would indicate a serious abnormality. A gradual change is also easily detected by the robot unlike a human engineer, since it has a collection of comparable data [5]-[7].

The level of noise is different throughout the pipelines, but many areas often follow a specific pattern. The robot can further zero in on the pattern by analyzing the history of noise levels it collected. In silent areas the robot is able to use its vibration sensor instead. Vibration is one condition that is almost impossible to be analyzed by a human engineer's perception, so the robot's ability broadens what the monitoring system can detect.

The temperature of a surface of a pipe is also important. For a faster and simpler way of measurement, the robot uses infrared rays to measure temperature. As shown in Fig. 3, the four-legged robot includes several sensors.

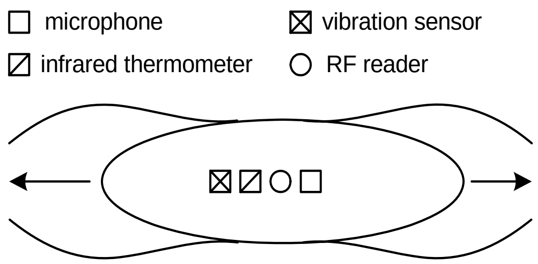

Fig. 3 Sensors of a mobile robot on pipes

C. Data Analysis and Fault Diagnosis

While moving inside a pipeline, the bio-mimetic robot analyzes its data and transfers to the server. Once an abnormal pattern is detected, it must be able to record the data and send out a possible warning as well as its data. This processing applies to every kind of sensors. For this purpose mobile robots contain a set of basic signal processing algorithms.

D. Real-time Data Transmission

When in a small facility, the robot can send its data directly to the server system. However, a set of sensor network nodes is necessary at important fixed locations for data transmission and calibration of positional data in a large pipeline system.

E. Distribution of USN Nodes

In a massive area of pipelines, it is too time consuming to rely on a relatively slow mobile robot. For example, in a nuclear plant or a large water supply plant, it is much more efficient to divide its complicated and wide pipelines into several sections, and place a number of bio-mimetic robots to each section. In order to perform the task swiftly, the robots need to be able to work mutually and collectively. Lastly, the collected data from the robots are combined and analyzed as one to pinpoint abnormalities and predict future conditions. Fig. 4 shows a few mobile robots working mutually as a group.

Many industrial environments go through minor errors and malfunctions. Where there are massive amounts of complex machines and pipelines that go through daily use, even a small deterioration of these materials can eventually lead to not only a costly and large replacement, but also a mass failure. A periodic checkup to detect the deterioration or an abnormality is thus critical, but it is often too difficult to be handled by a human engineer. Using a large amount of fixed sensors to cover the area is one way to monitor this problem. However, we believe that using a number of mobile, bio-mimetic robots to move throughout the pipelines is a much faster, cheaper and more efficient solution.

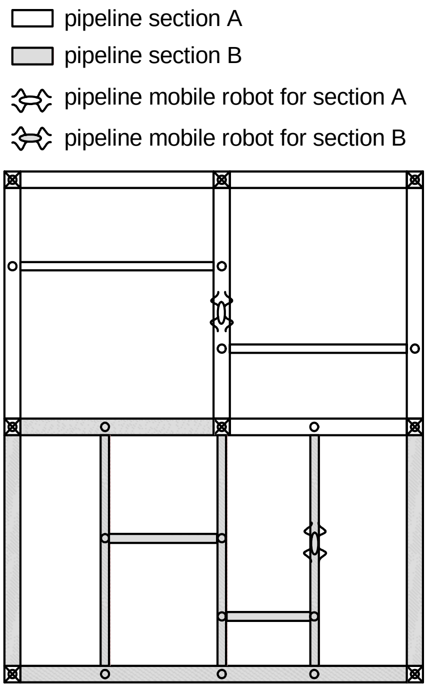

Fig. 4 Distribution of mobile robots on large pipelines

V. Active Monitoring

The conventional methods of pipeline monitoring collect data by sensors attached on fixed posts. The proposed method, however, relies on mobile robots that have a fundamental advantage of mobility over the conventional fixed monitoring posts. Since bio-mimetic robots can move anywhere on the pipes while collecting measurements, it is possible to track directions that have higher possibilities of malfunction in real time modes. Practically this kind of real time dynamic monitoring method is very important in the investigation of possible future failure and protection of plants.

As a typical sensing data for diagnosis, sound data collection of pipelines is described. Many methods of sound source localization have been developed based on audio-visual information [8]-[12]. The basic features of the sound signals to determine the directions and distances of sound sources are the interaural time difference(ITD) and the interaural level difference(ILD) from a sound source to each microphone.

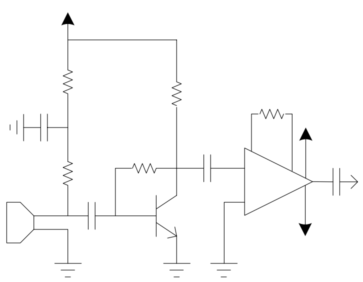

Fig. 5 Circuit of a stereo microphone system

A. Estimation of Sound Direction

A simple estimation method of sound directions employing only microphones is used due to the restriction of computation time and resources in a mobile robot system. The calculations of the interaural time difference(ITD) and the interaural level difference(ILD) from a sound source to each microphone or the analysis of the average magnitude difference function(AMDF) signals for short-time intervals are not applied to get the estimation quickly. Only sampling of microphone signals, A/D conversion and simple algebraic calculations are applied to obtain the differences of the right and left microphone measurements, which are directly related to the sound directions.

The method of sound direction estimation employed at a microprocessor, which handles a set of functions for an autonomous robot, has the following steps:

1. Sampling left and right microphone raw data $m_l(k)$ and $m_r(k)$
2. A/D conversion using eight bits
3. Getting band pass filtered data $b_l(k)$ and $b_r(k)$ of step 1
   Bandwidth for sound signals(clapping is used in experiments)
4. Getting squared data $s_l(k)$ and $s_r(k)$ of step 3
5. Summing 99 previous samples to current samples of step 4: $S_l(k)$, $S_r(k)$
6. Difference data: $d(k) = S_l(k) - S_r(k)$

The sampling rate of 5KHz is applied to microphone raw data considering the computation time of the microprocessor. Only eight bits of the internal 12-bit A/D converters are used.

The results show quite linear relationship between the sound direction and the indices of the above algorithm. It applies to the sound direction of 180 degrees using only a side pair of microphones. The same algorithm can cover the whole direction when both the side pair of microphones and the forward-backward pair of microphones are used.

B. Noise Rejection

There are two main sources of noise: environmental sound around the robot and noise from actuating motors inside a robot body. Since the main spectrum of the motor noise has much higher range than that of signals from pipelines, it is easy to filter out the effect from the motor sound. However, the sound of environmental noises has a similar spectrum range to that of interested signals. The environment signals are rather uniform around the robot, and the measured signals due to ambient noises are similar at each microphone. Therefore, when the measured signal at the left microphone is subtracted from that of the right one, noise components due to ambient noise are nearly cancelled out. The subtraction can reveal the interested component that arrived at the left and right microphones differently due to different approaching angles.

When the sound direction of the interested signals is estimated, a mobile robot turns its head to the near direction which is possible on the pipelines. Sound distances from the sources to microphones are not estimated because of the randomness of sound source levels.

VI. Conclusion

A practical solution of exploring pipelines, spotting any troubled areas or malfunctions and reporting its data by mobile bio-mimetic robots is proposed. In order to move effectively inside a pipeline, the robot's movement will resemble that of a lizard. Areas uncovered by fixed sensors are usually difficult to provide real-time observation and examination. Therefore, this paper provides a practical monitoring system that is able to monitor the entire area of pipelines in active manner by using the bio-mimetic robots.

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