NDT&E International 52 (2012) 144–148

Contents lists available at SciVerse ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

Corrosion detection of internal pipeline using NDT optical inspection system

M.S. Safizadeh [a], T. Azizzadeh [a],*

[a] School of Mechanical Engineering, Iran University of Science and Technology, Narmak, Tehran 16887, Iran

ARTICLE INFO

Article history:
Received 30 January 2012
Received in revised form
24 July 2012
Accepted 27 July 2012
Available online 17 August 2012

Keywords:
Corrosion detection
Pipe inspection
Optical inspection system

ABSTRACT

Internal pipe inspection, in many industries, is usually carried out using CCTV (Closed-Circuit TV) cameras and off-line human surveys through raw image assessment for failure identification. CCTV-based techniques have some limitations that restrict their implementation, namely: (1) the lack of visibility in the interior of the pipes and (2) the poor quality of the obtained images because of difficult lighting conditions.

In this paper, we propose an intensity-based optical system for internal pipe inspection. The proposed optical system consists of a laser diode, an optical ring pattern generator and a CCD camera. The physical sensor behavior is explained using reflectance theory and experimental data. Finally, a surface map of the inside pipe wall is generated by extracting the intensity information existing in the pipe images. Defects and anomalies can be identified using this extracted image. Experiments in a realistic environment have been conducted and results are presented.

1. Introduction

Early detection of pipe faults may avoid severe collapses that can involve environmental damage and high costs. Because of the small diameter of pipes used in pipeline networks, humans cannot access and examine these pipes directly. Standard inspection methods for these pipes are MFL and also UT for liquid lines. In special situations (small sections when using tethered systems, restriction to gas lines), optical systems are used. Optical inspection systems for these pipes consisted of a CCTV camera fitted on a mobile platform that travels through the pipe recording images onto a videotape. The camera platform is connected by means of a multi-core cable to a remote inspection station with video recording devices situated over ground. An engineer then verifies the recorded videos off-line. This is a time-consuming and tedious process that significantly increases the inspection costs. Moreover, only gross defects are detectable by human eye, which reduces the detection of defects at early stages. Considering that the pipe-collapse process starts with the initiation of small primary structural imperfections, the use of current CCTV inspection techniques is not adequate for continuing maintenance plans [1]. Another disadvantage of CCTV surveys is that detection of defects depends on experience, capability, and concentration of the engineer and hence, makes the detection of defect error prone. Thus, an automatic pipe inspection system, incorporating a CCTV camera, would be required to assess the inner surface of pipes and ensure accuracy, efficiency, and economy of pipe inspection.

Other pipe-inspection techniques, such as ground-penetrating radar or infrared thermography, are under study but were so far not able to supercede or even complement the traditionally employed CCTV-based inspection technique practically. A number of automated inspection methods that aim to overcome the disadvantages of the CCTV-based methods have been proposed [2]. Special illuminating and profiler systems have been proposed to enhance the image quality [3]. These systems usually work by projecting either a thin ring of light or successive light spots using a rotary system onto the inner walls of pipes. Tsubouchi et al. suggested a different approach applying a laser spot array instead of a light ring [4]. When the platform travels in the pipe, the sequence of profile measurements allows the creation of a surface map of the inner wall of pipe. Geometrical changes of the pipe surface can be retrieved from the variations in the position of the ring profile on the obtained image applying the principle of triangulation. The KARO robot consists of a mechanism where a camera evaluates light rings projected onto the inner wall of pipe, allowing the detection of pipe deformations and obstacles [5]. All the above mentioned systems are only able to identify deformations of the pipe. One important disadvantage of current methods is that they have problems in identifying structural flaws such as holes and cracks. Detection and classification of pipe surface imperfections from digitized video images using image analysis pattern recognition and artificial neural networks have been proposed [6,7]. Although those systems overcome automation-relative disadvantages of human CCTV evaluation, they still depend on the quality of the raw camera pictures.

---

* Corresponding author. Tel.: +98 21 77240540 50; fax: +98 21 77240488.
E-mail address: t_azizzadeh@ymail.com (T. Azizzadeh).

0963-8695/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ndteint.2012.07.008

In this paper a laser profiler is used to improve the quality of the pipe images. In contrast to previous works, the innovation here is the use of the intensity information instead of the positional information of the ring of light. A defect detection methodology based on image processing techniques is proposed. The proposed inspection approach is particularly well suited to complement current CCTV technology, providing automated detection and locating defects of pipe in the millimeter range utilizing a laser diode as an illumination light source.

2. CCTV-based laser profiler

The proposed optical inspection system consists of a pre-calibrated CCD camera, a light ring projector and an optical diffuser that expands the laser beam into a light ring. Calibration factors for the camera are achieved by a calibration technique suggested by Zhang [8]. The CCD camera and the ring pattern diffuser with a 5-mw, 635 nm–wavelength laser diode are attached together to minimize their relevant distance. The schematic of the optical system illustrated in Fig. 1.

The optical pattern diffuser is made from acrylic material. The light beam from the laser diode passes through the optical pattern diffuser and then projects a predefined circular light pattern onto a confined pipe section. The light path corresponding to the optical diffuser is illustrated in Fig. 1. The location of the surface under investigation relative to the optical system (L) and the illuminated area (A) are calculated by Eqs. (1) and (2), as follow:

$$L=\frac{R}{\tan(\frac{\alpha_1}{2})} \tag{1}$$

$$A=R.\left(\frac{1}{\tan(\frac{\alpha_1}{2}-\alpha_2)}-\frac{1}{\tan(\frac{\alpha_1}{2})}\right) \tag{2}$$

where, R is the pipe radius, and α_1 and α_2 are the diffuser projection angles. These parameters are shown in Fig. 1. It is noted that the angle (α_1) defines the distance (L), while the angle (α_2) defines the width of the light ring projected on the pipe wall. By increasing the wide angle (α_2), a larger area is illuminated and analyzed using the same image and the inspection process is considerably speeded up.

The above equations are used in the ideal case where laser is aligned with the pipe center axis. In a real application angular misalignments may cause the circle shape of the laser ring on the pipe wall becomes an oblique shape. Eqs. (3) and (4) give the upper and lower bounds for distance L when the laser is translated or slanted, respectively:

$$\frac{R-\sqrt{x_0^2+y_0^2}}{\tan(\frac{\alpha_1}{2})}<L<\frac{R+\sqrt{x_0^2+y_0^2}}{\tan(\frac{\alpha_1}{2})} \tag{3}$$

$$\frac{R}{\tan(\frac{\alpha_1}{2}+\theta)}<L<\frac{R}{\tan(\frac{\alpha_1}{2}-\theta)} \tag{4}$$

Where, (x_0,y_0) are the laser position coordinates after misalignments, and θ is the misalignment angle with respect to the pipe center axis [9]. In our set-up, the center axis and the origins of camera and laser diode are not coinciding, but the two devices are as close as possible to each other. A correct design of the inspection system and its optics will cause the best inspection results.

The experimental set-up is illustrated in Fig. 2. During the movement of the optical inspection device in the axial direction of the pipe, the ring projections are constantly captured by the camera. By means of a frame grabber, the camera images are then saved in a PC in format of avi file for further processing.

3. Experimental results and discussion

For analyzing the raw data obtained from pipe test, MATLAB software and image processing toolbox are used. Tests were

Fig. 2. Experimental set-up.

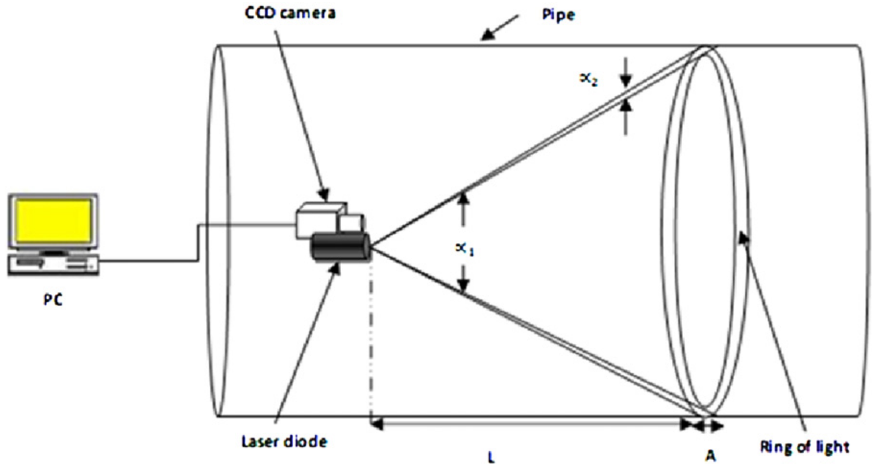

Fig. 1. Schematic of optical system.