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The use of laser range finder on a robotic platform for pipe inspection

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ABSTRACT

In this paper, we investigate the use of a laser range finder on a robotic platform for buried water pipe inspection. A robotic platform carrying and manipulating multiple nondestructive inspection sensors may require accurately locating robot's body in the pipe. The laser range finder provides an accurate distance measurement, which can generate a profile of the pipe inner surface. This profile, on one hand, can be used to identify the location of the laser source and thus the robot's body. Such information can further help the navigation of the robot. On the other hand, the anomalies presented in the profile can be detected and characterized in terms of the range measurement. The simulated and real data tests presented in this paper demonstrate the feasibility and effectiveness of incorporating the laser range finder into a robotic platform for the underground pipe inspection.

1. Introduction

Nondestructive inspection or testing (NDI/NDT) plays an important role for the assessment of pipe performance and conditions. A pipe deterioration model usually needs multiple inputs from inspection [1,2]. Any individual NDI technique has its own limitation; therefore, multiple techniques are preferred to provide complementary information in one inspection. An autonomous robotic platform can be a carrier to manipulate multiple NDI sensors and perform the inspection of pipe. Laser range measurement is one of the NDI techniques considered in an integrated NDI system for buried water pipes. Laser sensor has been used as a profiler for advanced geometry inspection and high-resolution 3D imaging for pipeline assessment on smart pigs and various robotic platforms [3–8].

A laser sensor used for pipe inspection may have two major functions including the assisting platform's navigation and generating interior profile of the pipe wall. Usually, the laser profiler can operate in two working modes. In the first mode, a laser ring is projected onto the internal pipe surface, inspection camera captures the stripes in an video sequence. Post-processing will extract the laser light stripes in the video sequence and reconstruct the profile to characterize the pipe surface [9–12]. The second mode implements a direct distance measurement capable of pinpointing the geometrical and surface anomalies, although the principles behind the distance measure may be different [3,13,14].

The relative position and orientation of the robotic platform provide paramount information for vehicle navigation and inspection. The common method for tracking the position and orientation of the platform is to use a relative positioning device such as gyroscope or inclinometer [7]. However, this type of tracking is susceptible to many errors. Therefore, laser

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Table 1
Summary of laser profiling techniques for pipe interior shape measurement.

Equipment	Approach	References
Omni-directional laser and omni-directional camera	Light section method and structure from motion analysis	[10,28]
Laser projector and CCD camera	3D shape reconstruction from the 2D structured light stripe images	[11]
Structured laser	Inner-contour reconstruction through a mathematical model	[22]
Laser profiler and camera	Recursive Gaussian filtering and Hough transform; sensor calibration	[12,24]
A laser pointer and range camera	Optical triangulation and image mapping	[29]
Laser (diode) light source and CCD camera	Edge detection for laser ring; neural network for defect detection	[30–32]

sensor is used for the tracking purpose. In [15], a conical laser light projected on the pipe wall was acquired by a camera. The features of the image, namely centroid and shape signature, are extracted and matched with the features in a database to estimate relative position and orientation. However, the feature database has to be prepared in advance and has an impact on the estimation accuracy and performance. Nassiraei et al. used a rotating laser scanner on their robotic prototype, namely KANTARO, to detect pipe manholes and joints as the navigational landmarks [16,17]. The laser scan data were fused with image data from a fish eye camera to implement pipe fault detection [16]. In [18,19], a line laser beam projected on the internal surface of the pipe was used to detect landmarks, such as elbows and branches, by matching the line pattern. Together with the information from motor encoders and 3D orientation sensor, a 3D map for the pipeline can be reconstructed [18].

Laser profiling inspection provides information on the post-installation behavior of pipelines. In [20]. Zhuang et al. presented the potential of using a circular optical cutting method for pipe inner wall inspection. The proposed system consisted of a laser diode light source, an optical ring pattern generator, and a CCD camera. However, the detailed discussion about the inspection results was not available in their publication [20]. Duran et al. used a laser projector together with a diffuser to generate lighting profiler on the inner surface of sewer pipes [9]. A CCD camera captured the ring projections and a neural network (NN) was trained to discriminate the shape of defects. One advantage of this method is that it utilizes image intensity variations to characterize defects and is not affected by the misalignment of the center line. In [21], Sinha et al. presented the use of neuro-fuzzy algorithm to classify defects from CCTV (closed-circuit television) survey. However, a heuristic learning like NN based approach needs “good” training data, which might not be always available in practice. Wang et al. proposed using a distributing laser-spot method, where multiple laser beams were simultaneously projected onto pipe surface [22]. A real-time model was developed to calculate the coordinates of these laser spots and a 3D contour was built. However, this application did not target the inspection of the pipe's inner surface. The use of laser range finder for railway tunnel inspection was also reported [23]. A summary of laser profiling techniques is given in Table 1. As stated in [7], the limitations of currently available commercial systems may generate inaccurate measurements of the pipe and negatively impact the data due to the setup issue between the laser and the camera. Ritter et al. proposed a laser scanning system with four laser triangulation modules, which allows a very precise measurement of pipe geometry [24]. A comprehensive description of the methodologies for automated sewer pipeline defect detection is presented by Guo et al. in [25]. Similar applications of laser scan were also reported by the literature [26,27,24].

In this study, we investigate the potentials of using laser range finder for purposes of robot navigation and pipe inspection. Rather than using a structured light, a laser range finder is employed to profile the surface with direct distance measurement. Such range measurement is used for both the alignment of center line and characterization of surface anomalies. This paper proposes the algorithms to position the robot's body and detect pipe surface anomalies from the precise distance measure.

The rest of the paper is organized as follows. Section 2 describes the laser range finder and algorithms used for data pre-processing, center alignment, and anomaly detection. Experimental results are presented in Section 3. This paper is summarized in the final Section 4.

2. Pipe inspection with laser range finder

2.1. Laser range finder

Laser range finder uses a laser beam to determine the distance to a reflective object. It operates on the time-of-flight principle. A laser pulse in a narrow beam is sent out to the object and the returning time of the reflected pulse is recorded.

An *AccuRange*-4000 laser range finder, which can take laser range measurements in a 360° profile, was used in this study. One distinguished feature of this laser range finder is that the laser emitter and return signal collection lens are concentric [33]. This allows to redirect the laser light by putting a mirror in front of the laser sensor.

2.2. Data pre-processing

Every measurement from the laser range finder has an amplitude reading from 0 to 255, which indicates the signal strength. If the signal strength is very low, the measurement is more likely to have a greater amount of error involved.