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Real-Time 3D Image Reconstruction of Urban Underground Water Pipeline Network: A Review

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ABSTRACT: Underground water pipelines, though capitally intensive, present an impressive cost saving benefits and exhibit complex scalable spatial distribution network. These intricate networks are the arteries and veins that efficiently carries water from one or more sources to homes, industries and farms for use. However, over time, these capitally intensive assets are affected by varying conditions such as aging, corrosion, earth mass movement, etc. that threatens the structural integrity and quality of water supply. Therefore, the need to maintain and sustain an un-interruptible distribution of water through underground pipeline network depends on the development of a comprehensive, cost effective and precise inspection strategies. Traditionally, manual methods by visual inspections, digging and cementing have been used to maintain underground water pipeline systems. This method requires many hours of time consuming labor relying only on visible leakages to repair. Manual method lacks in many aspects and it cannot be used to inspect internal structure of water pipelines and study the effect of corrosion or aging. More so, it is not effective in timely intervention of water contamination and pollution. In this paper, we review very effective and a promising method of underground pipeline inspections and maintenance based on the 3D object reconstruction and surface mapping that has a foundation in the field of machine vision and imaging.

KEYWORDS: data,monitoring,remote monitoring, solar, wind.

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I. INTRODUCTION

Water distribution is an essential aspect of human existence and its importance cannot be overemphasized in our society. One of the most efficient means of water distribution in urban areas is underground pipeline network, which are buried deep underground, away from human activities and artificial structures that might affect the structural integrity of the pipelines (Wout, 2013). This makes the construction of such a system of water distribution both capitally intensive and expensive to maintain. However, underground pipelines, despite their robust construction and corrosion-resistant properties, suffer from inflow and infiltration of debris that can obstruct the flow of water, causes wastage of water, affect the quality of water and introduce pollutant into drinking water (Thapa et al., 2018; Xujie et al., 2019). These conditions affect the sustainability of water supply, which can be linked to loss of revenue, cost of clean-up and maintenance. Therefore, the need for systematic and proactive inspection and maintenance strategies of underground water pipelines is an active area of research that requires interdisciplinary approach.

Several methods have been developed for underground pipelines inspections. The traditional methods of pipeline inspection rely on visual inspections to identify area where water is leaking, then manual excavation and sealing of ruptured pipes. This method is simple but marred with several limitations especially when dealing with complex network of underground pipeline networks (Xujie et al., 2019). With fast changing landscape in the area of advance sensors developments, 3D imaging and laser, offers new possibilities and unprecedented opportunities in developing new imaging techniques for underground pipeline inspection and maintenance strategies. 3D imaging methods eliminate the need for manual inspection and pave ways for robotic, automation and remote sensing. Data acquisition method such as laser, scanner, structured light and time of flight have been used to sample the real work into computer world (Bernardine and Rushmeier, 2002).

II. 3D OBJECT RECONSTRUCTION

The selection of data acquisition method depends on factors such as line of sight accuracy, the quality of surface details, the nature of the surface color and texture of mapping (Bernardine and Rushmeier, 2002; Bruno et al., 2010). In terms of physical data capturing method, optical techniques is better and more accurate than radio waves and ultrasonic methods (Bruno et al., 2010).3D optical scanning has gained popularity as a viable technique for capturing real world data. Optical scanning systems based on techniques such as laser scanning, fringe projection, photogrammetry etc. are being applied successfully for the 3D measurement and virtual reconstruction of object surfaces in many areas (Kus, 2009).

Fringe projection scanning systems generally work with whitestructured light where the light pattern is projected on the object's surface while one or two cameras record the reflected light while laser scanning systems can obtain data by sending laser light onto the object and processing the data obtained from the returning light (Bruno et al., 2010; Kus, 2009). The advantages of these scanners are that they are more portable compared to contact systems and their sensitivity levels are partially independent of the inspector.

III. 3D OBJECT RECONSTRUCTION METHOD

There are several 3D reconstruction techniques using optical method and autonomous vehicles for underground applications such as inspection, mapping, monitoring, scientific investigation (Galceran et al., 2015; Bernardine and Rushmeier, 2002; Bruno et al., 2010). In addition data capturing, several framework for reconstruction of the geometrical features of an object (pipeline) and data visualization have been proposed such as the X3D, X3DOM and WebGL (Guerrero et al., 2013). This developments led to implementation of database management systems for storing data information of the reconstructed information.

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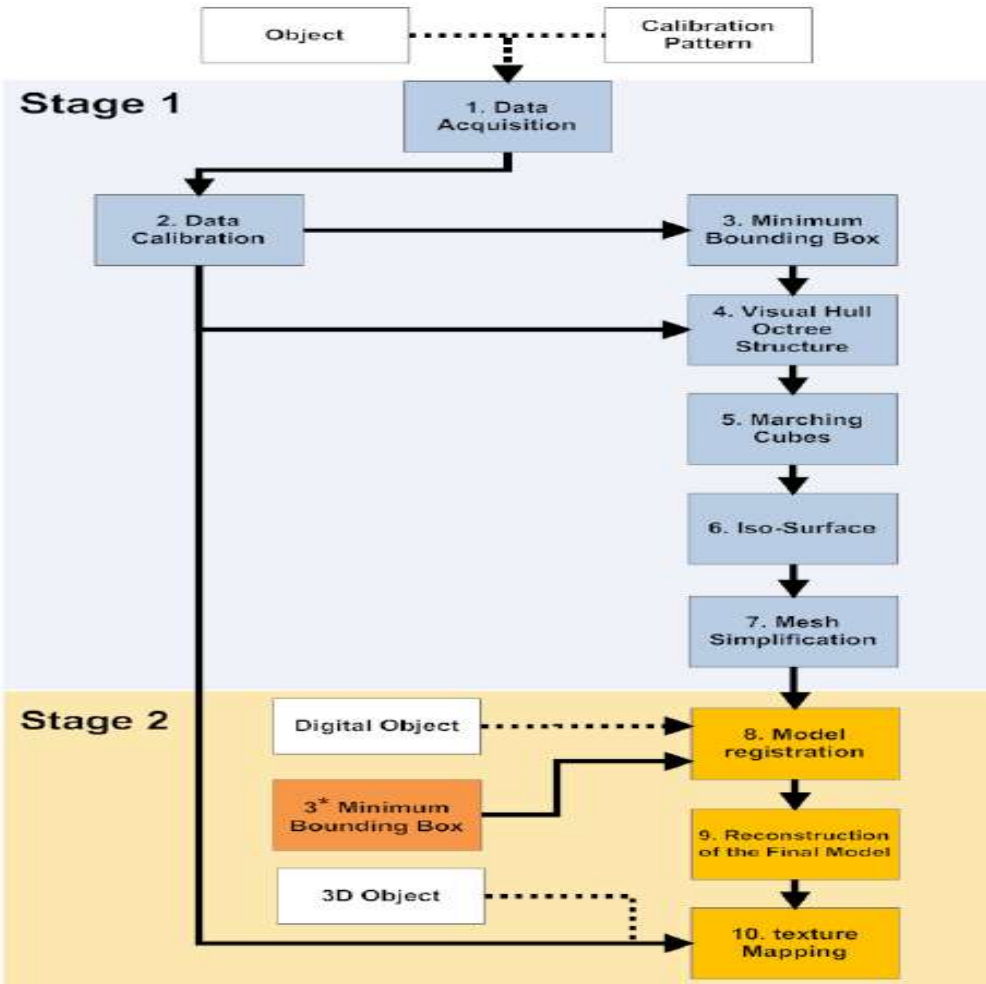

Fig.1.Flow process of 3D object reconstruction (Pacheco et al., 2014).

In fig.1, approach for 3D object reconstruction is represented in the form of flow diagram. Data is physically captured using scanner or optical sensor by scanning the target area or object under varying light condition and surface texture. As earlier mentioned, several technologies such as LIDAR, time-of-flight (TOF) cameras, structured 3D cameras, and structured laser ring can be used for data acquisition (Gunatilake et al., 2019; Vrubel et al., 2008).Among those technologies, LIDAR was less preferred for the proposed application due to low resolution in range measurements and accuracy of LASER (Vrubel et al.,2008).

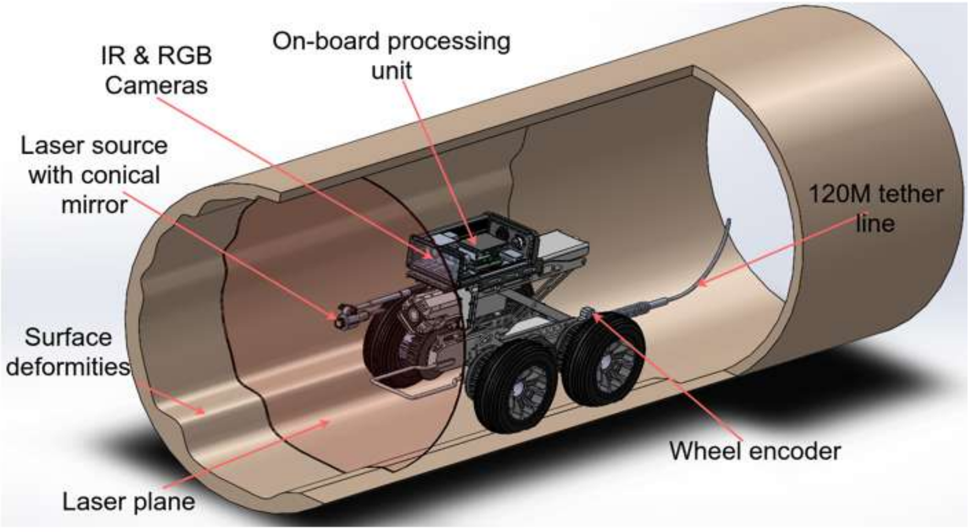

Fig.2. 3D imaging using autonomous robot for Pipeline inspection (Gunatilake et al., 2019).

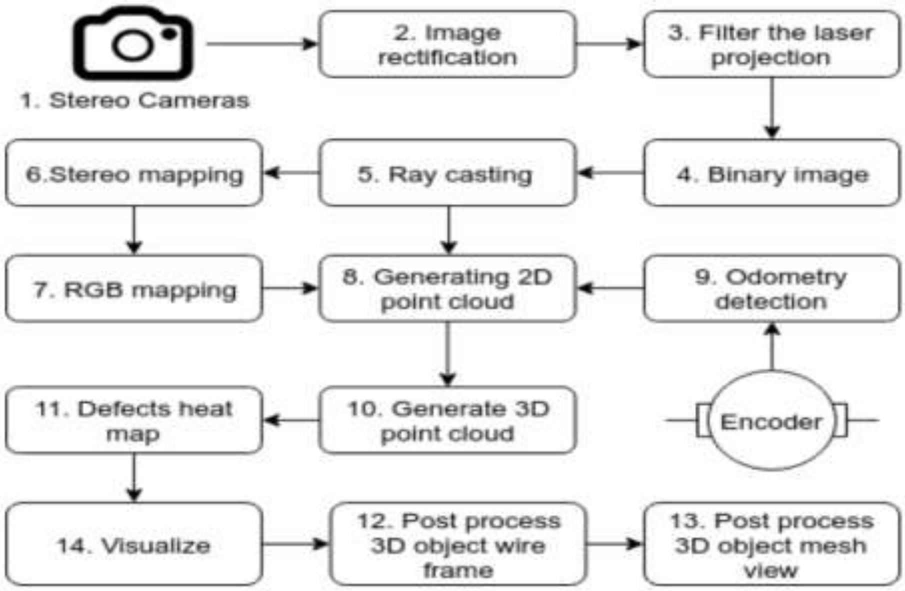

Fig. 3.Algorithm for 3D reconstruction of pipeline internal structures for inspection

The use of autonomous vehicle for 3D pipeline inspections provides an extension of robotic application to underground pipeline inspection and maintenance. Vrubel et al. (2008) presented 3D reconstruction pipeline as shown in fig.4.

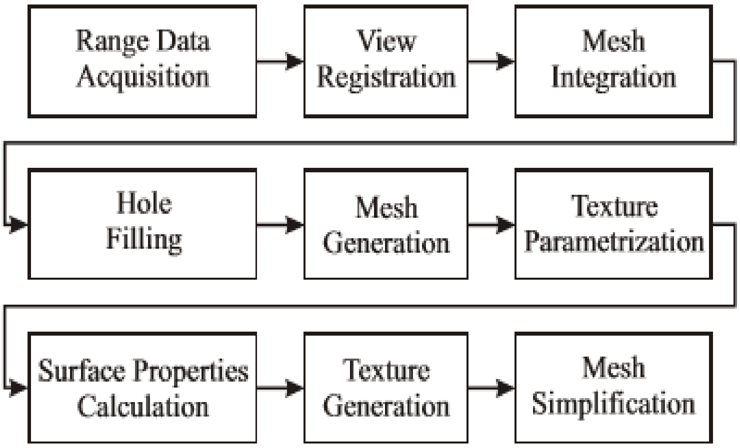

Fig. 4.3D pipeline reconstruction (Vrubel et al., 2008).

Yu et al.(2007) developed an integrated approach towards the generation of photo-realistic, geometrically accurate, geo-referenced 3Dmodels of road surfaces as shown in fig.5.

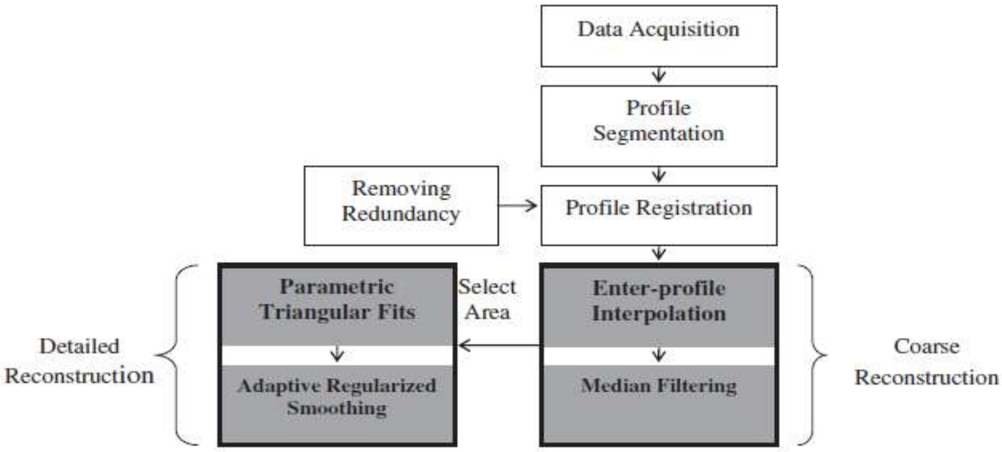

Fig. 4. Third method for PV monitoring system

Regardless of the reconstruction method selection, 3D object reconstruction can be divided into data acquisition, Image-processing and 3D object model.

Data acquisition: LiDAR Sensor

LiDAR, light detection and ranging, is a widely used laser based measuring sensor that captures data by sending a light and scans for the fraction of the light being reflected by the surface of that object. In pipeline inspections, LiDAR technology proved to be a very efficient in developing solutions for underground inspections. In fig.2, the internal structure of the pipeline is scans and geometrical structures are acquire and process using the onboard computer that centrally coordinate the activities of the robot.Depending on the area of applications, variety of LiDAR technology exists both in high definition and low resolution quality (Schwarz, 2010; Vrubel et al., 2008). In general, laser based scanners are precise and accurate in distance ranging (Vrubel et al., 2008). In pipeline inspection using 3D reconstruction, the autonomous vehicle can be equipped with camera, global positioning systems and inertial measurement unit to compensate for the 3D laser (Yu et al., 2007).

Pre-processing

Different scheme have been developed to filter and eliminate redundancy in the data captured from the physical data acquisition system such as the laser. This allow the system to cope with imperfection during the 3D reconstruction of the pipeline internal structure models (Yu et al., 2007). This process practically reduces time and space computational complexity during computations.The raw data are functionally map from input space to a desire output space by either rotation, translation or feature extractions (Esquivel et al., 2013). This functionality can be implemented on the autonomous vehicles onboard computer. To realize on-board processing, there are several microcontroller based products such as Arduino, Raspberry pi, etc. which offer cost effective solutions to automation and low intensive data processing. Pre-processing provides clean data represented in a proper coordinate and matrix form (Vrubel et al., 2007).

Image processing and 3D object

Image can be processed online or off-line depending on the intended implementation. At the stage, the features extracted at the pre-processing which contains the positions and sparse scene geometry from image point correspondences between subsequent images are computed. This process is where points triangulation, interpolation and mesh integration are perform (Yu et al., 2007; Esquivel et al., 2013; Pacheco et al., 2014). Wide range of algorithms are used to perform the 3D reconstruction such as stereo mapping algorithm, Hough transform algorithm and color mapping algorithm (Gunatilake et al., 2019).

IV. CONCLUSION

3D object reconstruction provides a novel approach to developing an effective strategy for scheduling and planning of underground water pipeline maintenance. Using this approach, preventive and corrective measures can be implemented as defects can be identifying even before they degenerate into leakage, water contamination and water pollution.

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