Optical 3D measurements aid pipeline inspection

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A new approach enables precise, quantitative, and autonomous pipeline inspection, which improves the effectiveness of proactive maintenance.

Pipelines are central elements of our society’s infrastructure. Since failures can be costly and critical, continuous inspection is necessary to ensure reliable operation. Today’s primary inspection technique is manual visual inspection of 2D camera images, which is labor-intensive and nonquantitative. Our research foundation has participated in several projects that use optical 3D imaging techniques to automatically inspect pipes and pipelines. The advantage of optical 3D measurements is that they provide high accuracy and allow for fully automated inspection.

We experimented with an autonomous vertically climbing robot for internal inspection of pipelines (see Figure 1). The snake-like robot is able to climb due to its strong, motorized joints and pairs of wheels on top and underneath. By using the active joints, it is able to move over the pipe so that both top and bottom wheels get sufficient contact. The friction achieved through this spanning operation allows the robot to climb. The robot’s success depends on obstacle avoidance as well as automatic recognition of landmarks, such as junctions and bends. To achieve this, we used a time-of-flight camera to provide 3D scene information in real time. The camera illuminates the scene with IR light modulated with a 20MHz sine wave and uses a camera sensor working in lockstep with the illumination to record the phase shift of the sine wave for each location in the image. The phase shift is subsequently converted into a per-pixel distance measurement. By applying recognition algorithms to this data, we found that it is possible to detect landmarks and avoid possible obstacles in the pipelines. When supplemented with other sensors, this method can provide a robot that automatically inspects challenging pipeline scenarios.

In a similar project, we developed technology to inspect pipes used in offshore oil wells. This system is based on laser triangulation and an automatic feeding mechanism, which demonstrates submillimeter accuracy for measurements that are made during drilling (see Figure 2). Typical defects that can be detected include deep corrosion pits and mechanical damage caused by pipe handling, e.g., slip marks. These defects can cause premature fatigue failures in drill pipes. Robust algorithms recognize the different types of pipe damage, and we have shown that it is possible to automatically detect faults, which avoids pipe failures and leads to efficiency gains and substantial cost savings during oil drilling.

Based on Gray codes and phase shifting, our structured light technology for 3D data acquisition has been used to verify other sensing techniques, such as ultrasound, that are used for pipe inspection. Structured light technology is a method to acquire 3D surface topology. The setup includes a projector and a camera that are mounted some distance apart from each other.

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Figure 2. Laser triangulation system for automatic inspection of pipes used during oil drilling. (a) Lab setup used during development. (b) Resulting deviation measurements. These submillimeter measurements allow for precise detection of pipe faults.

Figure 3. Comparison of measurements from acoustic resonance technology and structured light for verification of new measurement methods. (a) Normal camera image. (b) Result from acoustic resonance technology. (c) Result from structured light, which is used to acquire 3D shape and verify the results of acoustic resonance imaging.

Multiple light patterns are then projected onto the surface, and images of the patterns are captured. By doing triangulation-based analysis of the recorded images, the surface topology is measured with submillimeter accuracy. The acquired 3D images have high and verifiable precision, so they can serve as a standard for other sensor methods where circumstances (such as operation in nontransmissive media) exclude the use of optical measurement methods. We performed this type of verification for a pipeline inspection gauge robot (or ‘pig’) developed by Breivoll Inspection Technologies, where we demonstrated that their new sensing method, based on acoustic resonance technology, provided results that corresponded with the reference optical method (see Figure 3).

Optical 3D measurement methods enable rapid, repeatable, and automated precision inspection of complex and dense pipelines. Future research will focus on industrializing these measurement methods and combining them with other complementary sensors.

References

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