Continuous robotic inspection of pipes for data rich asset management

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ABSTRACT

An aging network in combination with stricter stakeholder requirements force the Dutch drinking water sector to improve the asset management of their water transport and distribution networks. Autonomous inspection robots (AIRs) provide a means to obtain knowledge on the condition of more pipes against lower cost, resulting in more focused rehabilitations and replacements, reduction of water loss through leakage, and a better knowledge and understanding of the system. In this paper, we describe the concept, a first prototype, and further steps that are currently being taken towards the development and application of this tool.

Keywords: Pipe inspection, condition assessment, robotics

1 INTRODUCTION

An aging network in combination with stricter stakeholder requirements force the Dutch drinking water sector to improve the asset management of their water transport and distribution networks. Pipeline inspection is an important aspect of improved asset management programs, and serves the following purposes:

1. supporting pipeline replacement decisions for individual pipes, to prevent destruction of capital due to replacing pipes that are in good condition;
2. supporting long-term planning of investments in the drinking water infrastructure, by increasing knowledge of the condition of both individual pipes and pipe cohorts;
3. verifying the exact location of water distribution assets, as well as their characteristics;
4. finding leaks to reduce water losses.

Although the relevance of pipeline inspection is understood and accepted, high costs, hygienic risks and nuisance to the environment currently prevent the water utilities from applying pipeline inspection on a large scale. Therefore, asset management of the drinking water transport and distribution system is currently based on generic knowledge and models of pipe cohorts, supplemented with inspection data for only a limited number of pipes. High inspection costs, hygienic risk, and environmental nuisance are mainly caused by the insertion and extraction of inspection tools that are nowadays inherently part of pipeline inspection. Autonomous inspection robots (AIRs) provide a means to keep tools in the network for a longer time, thereby significantly reducing the number of insertions and extractions. In this way it becomes possible to obtain knowledge on the condition of the majority of pipes with a diameter greater than the minimum diameter for the robot system (in our case 100 mm). This results in more focused rehabilitations and replacements, reduction of water loss through leakage, and a better knowledge and understanding of the system. In addition to this, robots may contribute to improved water quality monitoring.

2 VISION

Drinking water networks are complex pressurized underground networks with many bends, branches, diameter changes and material changes. They are typically situated in a built environment, and they are intendedly inaccessible in order to reduce the risk of contamination. Because of these characteristics, the drinking water transport and distribution networks are very distinct from other pipe systems in which condition assessments are performed. In order to meet all the specific requirements which come with this special nature, an inspection concept is proposed that is different from all approaches that are currently applied: a system of autonomously operating robots (AIRs, autonomous inspection robots) that "live" in the network and are fitted with several sensors for condition assessment of pipe walls and other purposes (Figure 1).

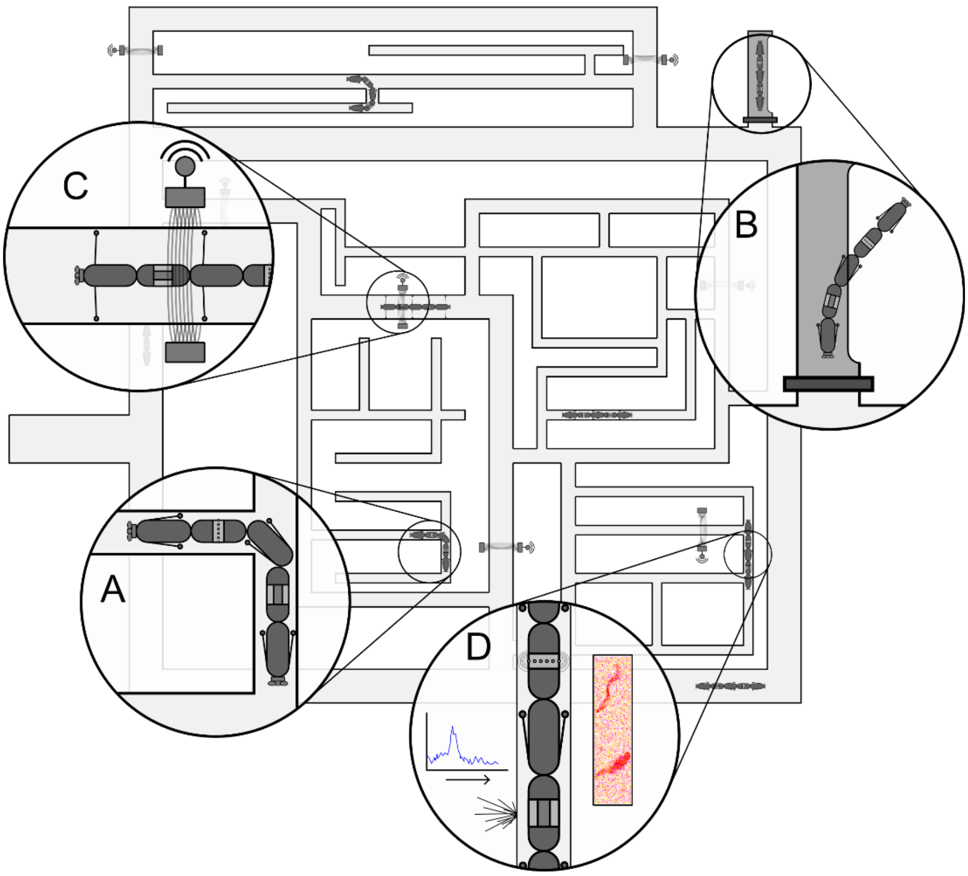

Figure 1: Vision of a system of autonomous robots that can freely move through the network (A), with access points for maintenance (B), facilities for energy and data transfer at several locations in the network (C), that is fitted with relevant sensors for pipe condition assessment, leak detection, etc.

3 DESIGN CONCEPTS AND PROTOTYPE

With the requirements described above and a number of additional requirements in mind, a range of design concepts were generated and evaluated. Mainly because of space and buoyancy considerations, a segmented snake like design was selected. The essence of this concept is shown in Figure 2. The concept consist of specialised modules for vision and propulsion, energy, clamping, electronics and sensors. These are joined by actuators, allowing bending in the horizontal plane. The modules have an ellipsoid cross section to maximize the use of space in the vertical dimension without compromising the ability of the robot to negotiate bends in narrow pipes.

A tethered prototype was constructed based on the selected concept. The purpose of this prototype was to investigate the feasibility of hull construction and articulation and propulsion. In this stage, autonomy or sensing capability (apart from cameras) were not pursued. The prototype was designed to be able to pass through miter bends in 150 mm inner diameter pipes. The resulting prototype is shown in Figure 3. It was made using rapid prototyping techniques (3D printing and laser cutting) using plastics and stainless steel. Already at this stage, legal and hygienic requirements with respect to materials in contact with drinking water were taken into consideration. For this reason, a custom actuator for the joints was designed and realized, which is completely sealed and uses a magnetic coupling to transfer moments.

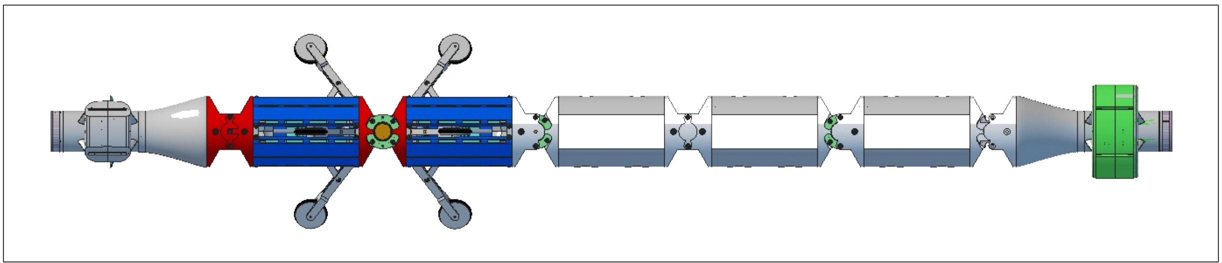

Figure 2: CAD model representing the selected design concept. From the left to the right, the following modules are present: propulsion + vision, centering (2x), battery/electronics (3x), propulsion + vision.

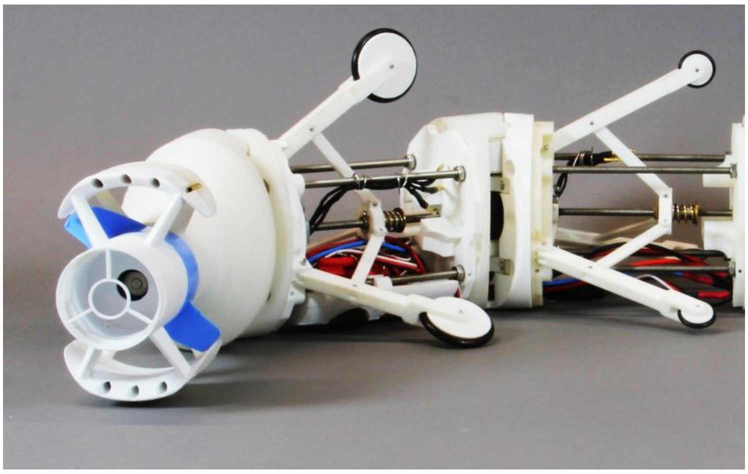

Figure 3: Robot prototype. One propulsion + vision module and two clamping modules are shown.

4 TESTS

During and after the process of creating a prototype, both the robot itself and its individual components were subjected to a series of tests. For individual components, water tightness and pressure resistance were tested. For the assembled system, the tests had two specific purposes: 1) to ensure the robot's capability to negotiate 90 degree bends (see Figure 4), and 2) to determine the power requirements for propulsion of the robot. The tests have demonstrated the importance of the centring modules for stabilizing the robot during bend negotiation. Also, it was found that propellers at both ends of the robot are necessary to provide propulsion and stability at the same time. Power consumption tests showed that the robot requires 6W of power for travelling at 0.2 m/s. The top speed achieved in the test setup was 0.6 m/s at a power consumption of 34W. More details on the tests are presented in [1].

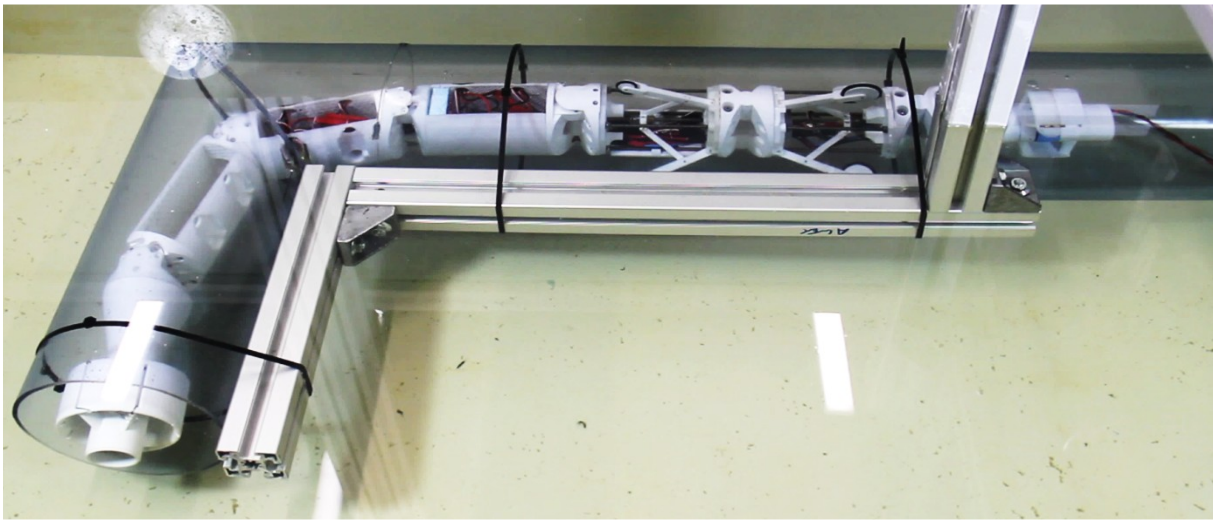

Figure 4: Test passing a miter bend, using a 150mm I.D. pipe placed in a tank filled with water. The robot is self-centering and self-propelled, but is controlled manually by cable.

5 MEASUREMENTS AND PRINCIPLES

In the end, the robot is merely a carrier for equipment used to obtain data on the condition of pipe walls (and some other parameters). An overview of the desired parameters with their resolution and the foreseen measurement principle is given in Table 1. Note that there is already experience with the application of ultrasonic sensors on AC leaching [2]; the application of new techniques for the determination of material ageing in PVC is subject of ongoing research [3].

Table 1: **Overview of parameters to be measured and the associated measurement principles.**

Pipe material	Inspection parameter	Proposed observation principle	Resolution
PVC	material ageing	ultrasonic	measurements on 12 clock positions / 0.1 meter
AC	leaching	ultrasonic	measurements on 12 clock positions / 0.1 meter
AC / PVC	differential settlement	ultrasonic	gap width in mm on 4 clock positions / joint
cement lined cast iron	corrosion	ultrasonic / electromagnetic	measurements on 24 clock positions / 0.1 meter
all materials	location	accelerometer / gyroscope combined with known reference points	X,Y,Z-value / 0.3 meter
all materials	visual	180º camera	180º picture / 0.5m
all materials	leak detection	hydrophone	detect any leaks > 25 L/min

6 TOWARDS PRODUCT DEVELOPMENT

The prototype shown in the previous sections has served to illustrate the potential of autonomous inspection robots in drinking water distribution systems to the Dutch drinking water sector. All ten utilities have committed themselves to the development of a commercially applicable system. Currently, a prospective consortium has provided an encouraging product development plan, which is now in the decision forming process.

7 OUTLOOK

We envision a future in which AIRs inspect our drinking water networks with minimal intervention from 'outside', providing us with a constant flow of valuable data about the physical state of our assets. We believe that the application of a system with AIRs will lead to a giant leap in knowledge that allows us to manage our networks in a better, cheaper and safer way. Pipes will be replaced at the right moment, removing costs of early replacements, as well as costs of incidents resulting from late replacement (e.g. pipe bursts). Investment planning will be more accurate as it will be based on actual condition data instead of model-based predictions. Construction and maintenance works will be executed more efficiently as the location and characteristics of our assets are known. And less water will be spilled due to leaks that remain unnoticed.

Our main challenges for now, both in terms of technology and organization, are to build and implement this system, and to get ready for valorization of the huge amounts of data that will become available.

References

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Acknowledgments

The authors gratefully acknowledge the making available of facilities for and supporting the testing of the prototype by Rudy Dijkstra of Acquaint B.V.