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Robots inspecting drinking water pipes

Drinking water pipes should not be replaced before the end of their life. This would be a waste of resources. But neither should they be replaced late, because the possibly ensuing calamities may also be costly. What is the most accurate way to determine the remaining life of a pipe and which role can robots play to answer this question? KWR, Wetsus and the Dutch drinking water companies are building a prototype.

With some exceptions large-scale extensions of the Dutch drinking water networks are no longer being implemented. About two decades ago, a new phase, the phase of network maintenance, started. The new key question is how to keep these networks in a good condition at acceptable cost.

Many pipes are reaching the end of their lifespan and will have to be replaced in the coming decades. In order to do this efficiently, it is important to know the real condition of the pipes. In this way, only the pipes, which are actually close to failing, will be replaced.

Pipe material and age are not the only determining factors; other factors also affect the aging of pipes. Current technologies can provide the required information about pipe condition to some degree, but have limitations, which prevent a widespread application on a sufficiently large fraction of the network. A different approach, described in more detail here, is expected to provide a solution.

Challenges

The internal inspection of a drinking water pipe is quite different from inspecting an oil or gas pipeline, for which many techniques have been developed. The nature of the drinking water network is different because of its shape (meshing, bends, T-joints, valves, changes in diameter, access points), variability of flow (velocity and direction), positioning (one meter below the ground and right in the middle of both customers and other infrastructure) and the prime importance of hygiene and continuity of supply. The use of different materials in the network also means that a single sensor cannot be used for all pipe sections. Therefore, a universally applicable inspection tool needs to be equipped with multiple sensors.

Proposed solution

A concept has been developed within the project Ariel, which is collaboration between the Dutch drinking water companies, KWR Watercycle Research Institute and Wetsus. A prototype is currently being developed from this concept. The concept provides a solution for the challenges discussed above and specifically focuses on the special requirements posed by the application in drinking water. It is a system of autonomously operating robots (AIRs, autonomous inspection robots) which continuously reside within the drinking water network and which are equipped with multiple sensors for the determination of pipe condition and other parameters. The robots are self-propelled and can clamp inside a range of diameters. Throughout the network, pipe segments are equipped with facilities for inductive charging of the robots and data transfer (measurements and new instructions). The robots move and navigate autonomously through the network. Because of their autonomous operation, they can perform measurements 24 hours per day without requiring active control by an operator. This concept is illustrated in Figure 1.

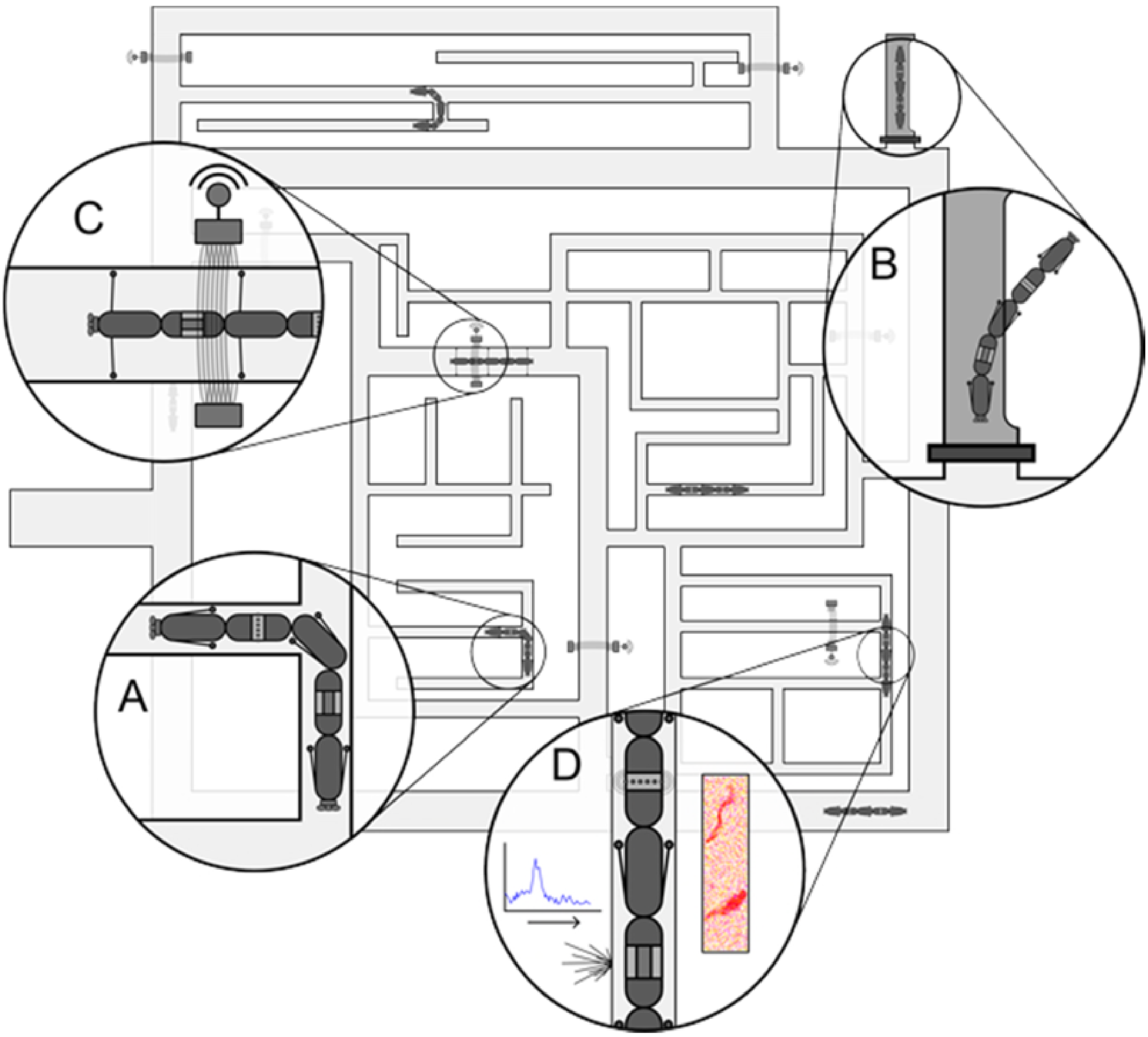

Figure 1 - Vision of a system of autonomous robots that can move through the network (A), be inserted and extracted at specific locations for maintenance (B), be charged and transfer data at several locations in the network (C), and perform measurements everywhere they go (D).

Principles and design philosophy

The system that has been conceived is basically complex. However, rapid developments in the fields of microelectronics, actuators (components that can affect their surroundings, for example servo motors) and software of the past decades allow the use of many components 'off the shelf'. This is the main principle of the project: the reduction of complexity and the number of tasks in the development project by using as many tried and tested components as possible. For some specific components, this approach could not be followed. An example is discussed later on.
The focus of the development is on the robot as a carrier of sensors and initially not on the sensors themselves. This field shows rapid developments as well. Initially, the robot will be equipped with a newly developed ultrasonic sensor for the determination of the effective wall thickness in cementitious pipes and a sensor for the detection of defects in PVC pipes, currently under development. And of course a camera and positioning sensors.
However, the robot is designed in such a way that it is well prepared for several additional sensors which are expected to become available in the near future.

Design and construction

Several possible shapes can be conceived for the robot. However, not all shapes are equally suitable, e.g. because of carrying capacity for batteries, or the ability to move through T-joints or stably position itself with respect to the pipe wall. From a wide range of ideas, the one that best meets the demands and boundary conditions was selected (together with experts from the water companies): a segmented snake.

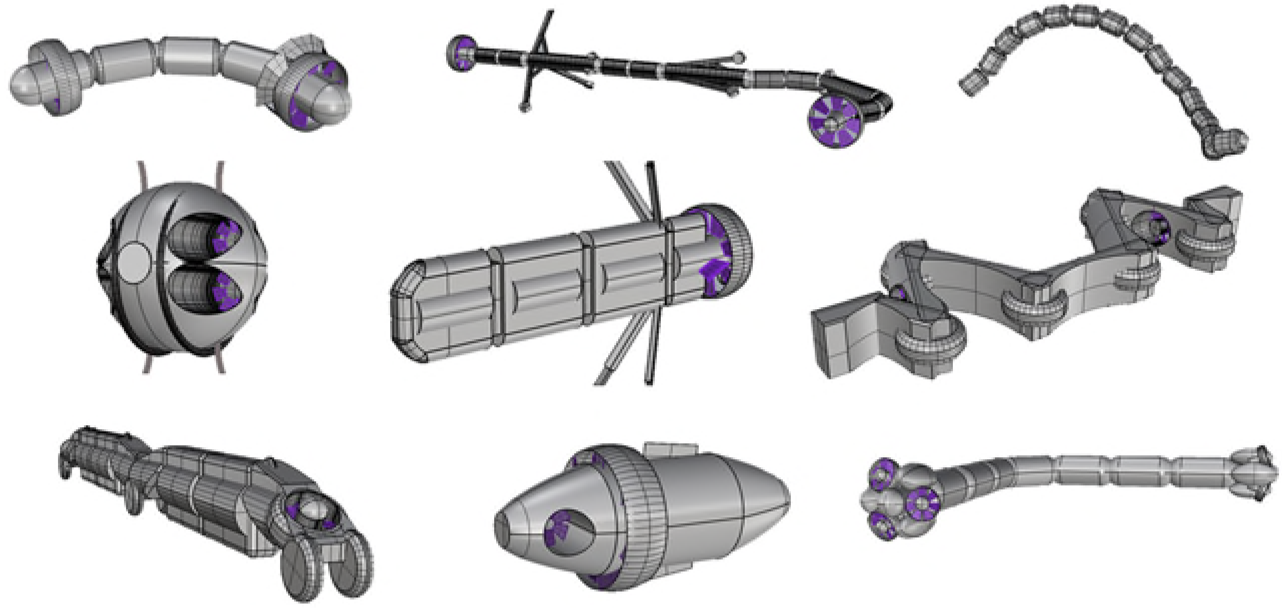

Figure 2 - Visual concepts have been produced for several design ideas in order to facilitate the discussion on the selection of a concept. The selected design is in the middle.

The segmented snake can actively bend between all segments in a single plane. This requires a significant number of actuators and control systems, but it results in stability, flexibility and interior space for all required functions. Because a chain of modules is used, components can easily be relocated in order to achieve optimal performance.

3D printing is ubiquitously applied in the construction of the prototype, because of the short production time and large freedom of design. It also facilitates the application of lightweight and waterproof materials. When necessary, the selected off the shelf components are modified for functioning in drinking water and under pressure.

Specific components

The selected design allows us to use many existing tried and tested mechanical and electronic components, in line with the design philosophy. An example of a component for which this proved impossible, is the rotation of the segments relative to each other. Existing solutions use a motor with a lubricated shaft penetrating the hull and keeping the inside dry under outside pressure. This is technologically achievable, but from a hygiene point of view, a solution without penetration of the hull or the use of lubricant is preferable. We have developed a solution, which uses a magnetic coupling to transfer rotations through a hull. Figure 4 shows its design and realization.

Current status

A large part of the first prototype of the inspection robot has been built and is being subjected to tests. This includes the hull, propulsion, and a clamping mechanism for centering and stabilizing the robot (for measurements and guidance through bends). Actuators between the modules allow the negotiation of bends. These are currently still actuated by remote control; autonomy is outside the scope of the current project. The modules have been built in such a way that they are interchangeable, allowing the selection of optimal combinations of modules. A camera mounted on the front module gives the user visual feedback.

Outlook

The tests currently being performed within the Ariel project (e.g. on energy consumption) render insights that will not only allow further refinement of the design but also give an indication on power requirements. Following from that information the number of required battery modules for a long-term stay in the network can be determined and this defines the length of the snake.

This shows a big step from the original idea to a wired prototype. However, eventually we want to have a completely functioning autonomous robot system. In order to achieve this, the Dutch drinking water companies have decided to set up a new, more substantial project, which aims to develop just this. This means that aspects such as autonomy, sensors and data storage for condition assessment, communications; energy transfer etcetera will also be addressed. Currently, this new project is being initiated, and it should lead to the desired system within a couple of years.

Perspective

The application of a robotic system in the drinking water network will lead to a giant leap in knowledge. Currently we think that we know the condition of some small parts of the network, but with this application we will actually know the condition of pipes in all parts of the network that can be visited. This means that the pipes can be replaced at the right moment, avoiding costs of early replacements, as well as costs of incidents resulting from late replacement (e.g. pipe bursts).
Additional results like knowing the exact location of leaks and a better localization of pipes further increase the actionable knowledge base for water companies. The main challenge for now is (to be worked on in parallel with the development of the robot system) to get ready for the huge amounts of data that will be available, both in terms of technology and in terms of organization, to allow an effective application and valorization of the data.

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This project is collaboration between Wetsus, European Centre of Excellence for Sustainable Water Technology, in the framework of the Smart Water Grids theme, and KWR Watercycle Research Institute, in the framework of the joint research program of the Dutch drinking water companies (BTO). Participating parties of the Smart Water Grids theme are Vitens, PWN, Brabant Water, Oasen and Acquaint. Participants of the BTO are all Dutch drinking water companies and De Watergroep (Belgium).

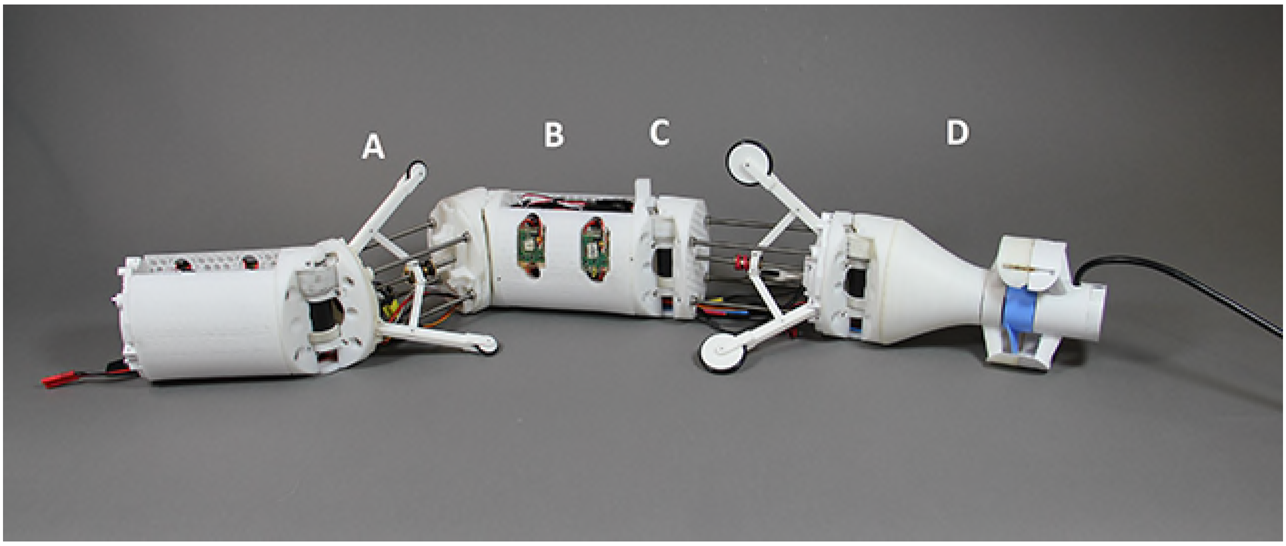


Figure 3 - Current prototype of the inspection robot, with clamping modules (A), electronics modules (B), actuators for bending movements (C), a propulsion module with camera and lighting (D).

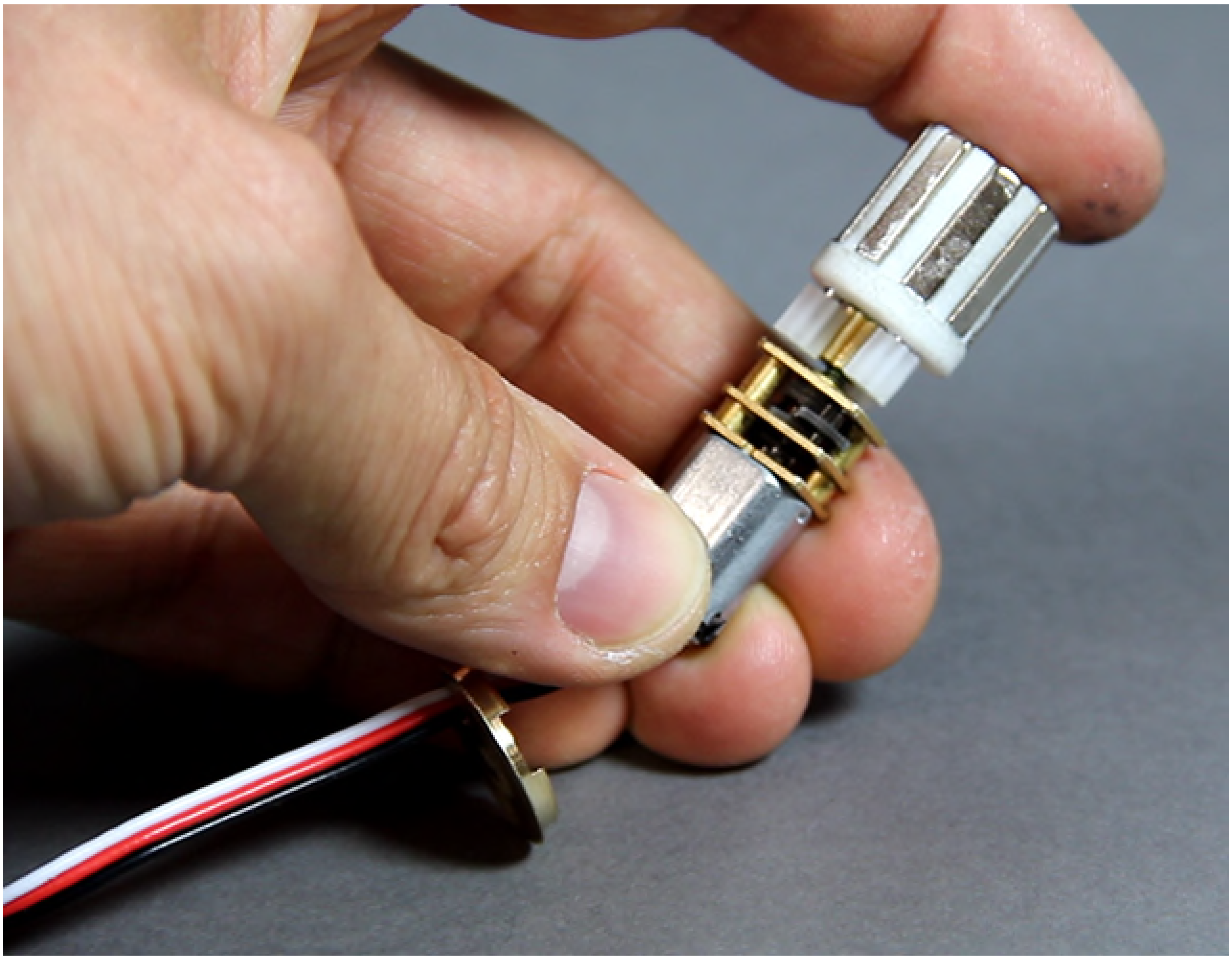
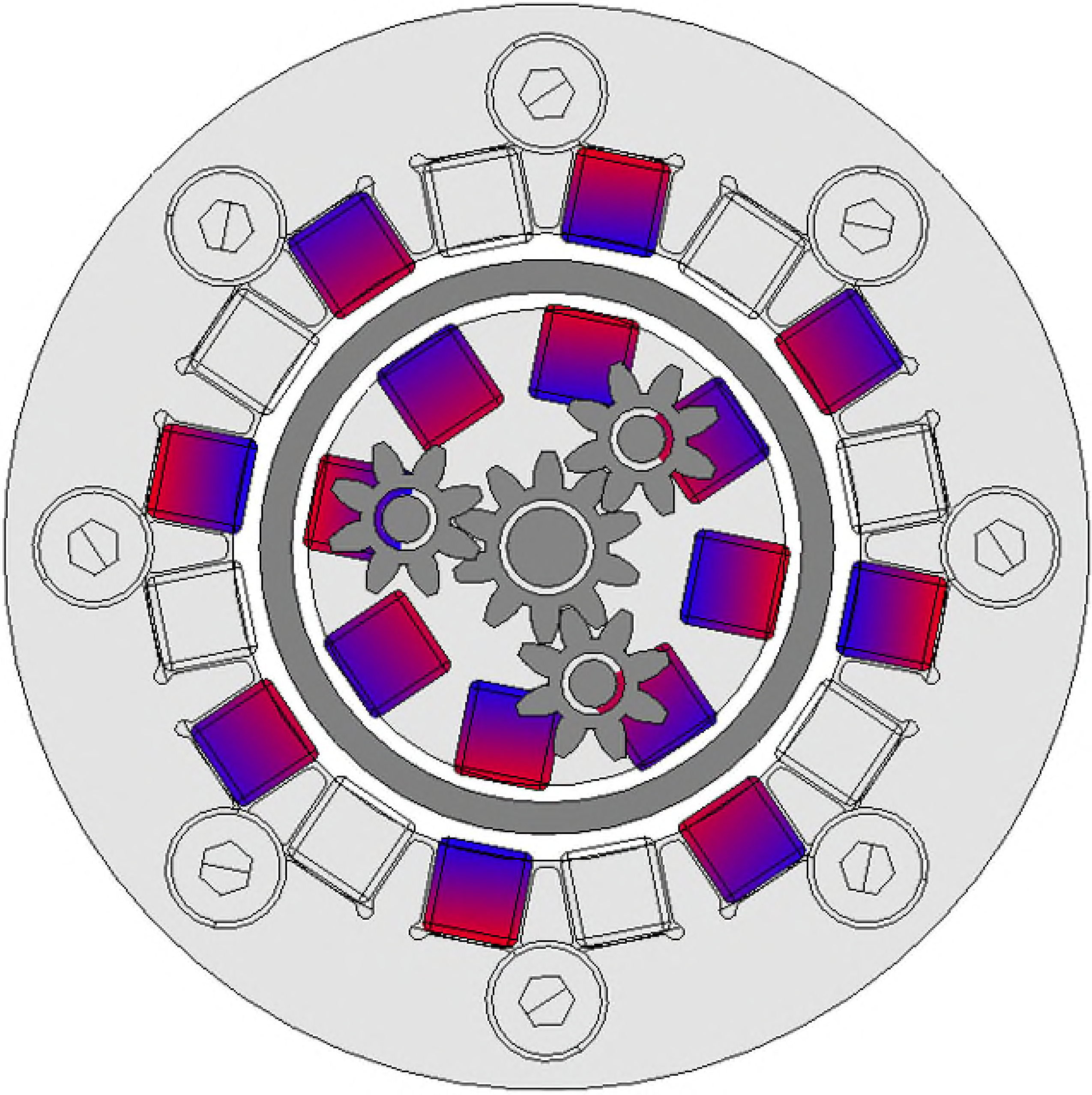


Figure 4 - Photograph of the inside of the waterproof actuator, containing a motor, gearing and a ring of magnets. Force and rotation are transferred onto the outer ring with magnets trough the watertight hull (under).



Summary
In order to carry out pipe replacements in the drinking water network in the coming decades in a cost effective manner, a better knowledge of the condition of these buried pipes is essential. Because current techniques can only meet this need to some degree, KWR and Wetsus collaborate with the drinking water companies on the development of an autonomous robotic system aimed to make this information available on a much larger scale.

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