Review of Current Embedded Sensing Technologies for Monitoring Water and Wastewater Pipe Linings and Infrastructure

Context

The Cooperative Research Centres Program (CRC-P) on 'Smart Linings for Pipes and Infrastructure' led by the Water Services Association of Australia (WSAA) will develop standards and specifications for fit-for-purpose linings, and smart sensing and robotic capabilities for quality assurance. It aims to increase the use of lining technology in collaboration with manufacturers, applicators, water utilities, and researchers. Within the scope of the CRC-P, a research team led by Professor Sarath Kodagoda from the University of Technology Sydney (UTS) is developing smart sensing and robotic systems for post-application quality assurance (PAQA) and long-term performance monitoring (LTPM) of liners and coatings. Further, the UTS team is conducting a scoping study on the potential to embed sensing technologies in linings to monitor long-term performance. In this context, this factsheet presents an overview of the embedded sensor technologies that are currently in use for condition assessment of water utility infrastructure and describes the UTS approach to moving this technology forwards.

Embedded Sensing Technologies for Monitoring Water Pipe Linings

Temperature is an important parameter to monitor in water pipe linings especially while the installed pipe hardens following installation (curing). Periodic monitoring of temperature conditions between the host pipe and linings can be a proxy parameter to indicate the state of the curing process. In the long-term, the humidity conditions can indicate the intrusion of water between the host pipe and the liner. Fibre optics [1] is a potential technology that can be exploited to monitor temperature conditions along CIPP liners as a proxy measure of curing. The fibre-optic cables are installed before the application of the CIPP liner. Then, the sensor utilizes laser light signals to measure temperature along the entire length of the fibre-optic cable. Changes in quantities like temperature, humidity and strain can affect the internal structure of the fibre-optic sensor - changing the way light transverses in the fibre. This sensing technology may also be used to measure humidity along the fibre-optic cables over a long distance. For polymeric spray lined pipes, there are no reported embedded sensing technologies for monitoring temperature and humidity conditions to the best of our knowledge. Further investigation to evaluate the sensor performance, as well as the inherent challenges that can occur during the installation of the sensor along the pipeline, is recommended.

Embedded Sensing Technologies for Monitoring Wastewater Pipe Linings

Acid permeation is widely regarded by water utilities and researchers as the most important parameter that needs to be monitored in the long-term to evaluate sewer pipe coatings. Currently, there are no non-destructive sensing technologies available in the literature that can directly measure the levels of acid permeation inside sewer pipe coatings. The measurement of pH levels at different depths is used as a proxy parameter to estimate the penetration of acids inside the coatings.

Researchers from the University of London (UoL) in collaboration with Sydney Water Corporation have developed an optical fibre based sensor system for monitoring humidity conditions in concrete sewer pipes [2]. This sensor operates based on the fibre Bragg grating (FBG) technique and it is used inside sewer infrastructure with aggressive corrosion conditions. This FBG fibre-optic sensor provides sewer air humidity data to the predictive analytic model to estimate the concrete sewer pipe corrosion. The UoL research team has recently developed coumarin based pH sensitive fluorescent probes [3]. Their fluorescent behaviours were evaluated with aqueous solutions of different pH levels. The developed material can be used with optical fibres to measure pH in alkaline media. However, it is challenging to build a sensor that is robust enough to withstand the acidic conditions of concrete sewer pipe coatings over a long period. Similar to the University of London's fibre-optic humidity sensor, Macquarie University, in collaboration with the Sydney Water Corporation, is developing embedded fibre-optic sensing technology to measure the relative humidity conditions inside the concrete sewer host pipe for estimating corrosion [4]. This sensor's suitability to measure pH at different levels is yet to be proven. Nuron, a UK based company located at Sheffield has developed a next-generation fibre-optic sensing technology to monitor multiple flow parameters within the sewer network in real-time. Such sensing technologies can be used to monitor blockages, e.g. fatbergs, inside the sewer pipe. The University of Sheffield utilises the propagation of sonic waves for monitoring changes in pipe walls, valves, joints, and lateral connections. This project is still in the early stages, and not much information is available in the public forum.

Embedded Sensors: Forward Thinking

Fibre-optic sensors and radio frequency identification (RFID) sensors are compelling sensor technologies, which warrant further study. Sensing humidity or moisture or the presence of water seems to be an important parameter in water pipes, CIPP and polymeric spray liners whereas sensing pH seems to be an important parameter in sewer coatings.

The fibre-optics sensor technology has been used for monitoring the temperature conditions of CIPP linings. However, this sensing technology needs to be studied in detail for application in polymeric spray lined water pipes. The presence of fragile fibres (in particular their thickness) may have an effect on polymeric spray lined pipes, as application thickness is typically low (3mm or higher). This needs further study. The measurements will be taken along the fibre-optic cable (eg. discrete locations along the pipe) and it may limit the predictability of the conditions around the pipe. Placement of embedded sensors at random, discrete locations is an option to improve spatial monitoring and to minimizing the adverse effects such as debonding (this needs further study). In this context, passive RFID based sensors combined with smart materials are a potential option for monitoring temperature conditions in CIPP and polymeric spray lined pipes.

For monitoring pH conditions in concrete sewer pipe coatings, UTS conducted a review of the sensing capabilities and shortlisted a few types. Smart material based RFID sensors embedded in coatings combined with robotic observers seems very promising. Therefore, we did preliminary sensor simulations to understand their characteristics specifically focusing on localization, acid permeation (pH) and moisture ingress. This is a blue sky research, which is currently supported through the UTS blue sky research grant.

Snapshot of the Research So Far

Through the UTS blue sky research grant, we are simulating an implantable RFID sensor for monitoring sub-surface concrete conditions. This is a passive type of sensor. When the radio frequency signals strike the sensor, it gets activated and reflects a portion of the signal back. The reflected signals can be interpreted for monitoring. Figure 1 shows the sensor design in simulation and a fabricated sensor prototype, Figure 2 shows the laboratory experimental setup and Figure 3 shows the enclosure for the sensor.

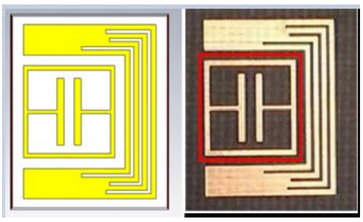
(a) (b)

Figure 1: RFID sensor. (a) Simulation design. (b) Fabricated sensor.

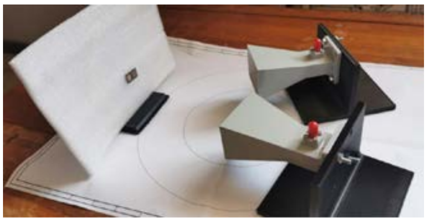

Figure 2: RFID sensor experimental setup with horn antenna.

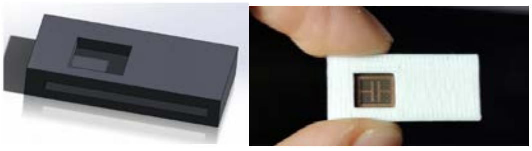
(a) (b)

Figure 3: RFID sensor enclosure. (a) 3D CAD design. (b) Prototype.

Research Plan for Future Work

Use with wastewater pipe coatings: By the end of the CRC-P, UTS should be able to provide simulation results on how sensors behave in embedded concrete and what effects they have when embedded in different materials.

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Note that further work is needed to closely simulate effects of pH differences and moisture differences as proxy parameters for acid permeation and moisture ingress. There is an opportunity for any water utility or a consortium to collaborate with UTS to further develop the sensors and evaluate the feasibility of using them in coatings. Sensors may be developed either as a smart aggregate or a sensor which can be placed on the host pipe surface before a coating is applied.

Use with water pipe linings: A significant increase in temperature is common during the drying phase of polymeric spray linings. A robust sensor is required to survive the drying phase of CIPP and polymeric spray liners in order to provide reliable monitoring. Also, for detecting water leaks, humidity or moisture sensors are suitable. This needs further study and experimentation to evaluate RFID sensors made of different materials. Active collaborations with CIPP and polymeric spray lining manufacturers and applicators for testing the potential sensing technology is a way forward for realizing this innovative technology. The UTS research team currently has access to a robotic system as part of Sub-Project 3 for monitoring liner imperfections and uneven thicknesses in polymeric spray lined pipes. The RFID sensor readers can be integrated into the robotic platform for data collection and evaluation.

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Note: This fact sheet was updated on 05/08/20.

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