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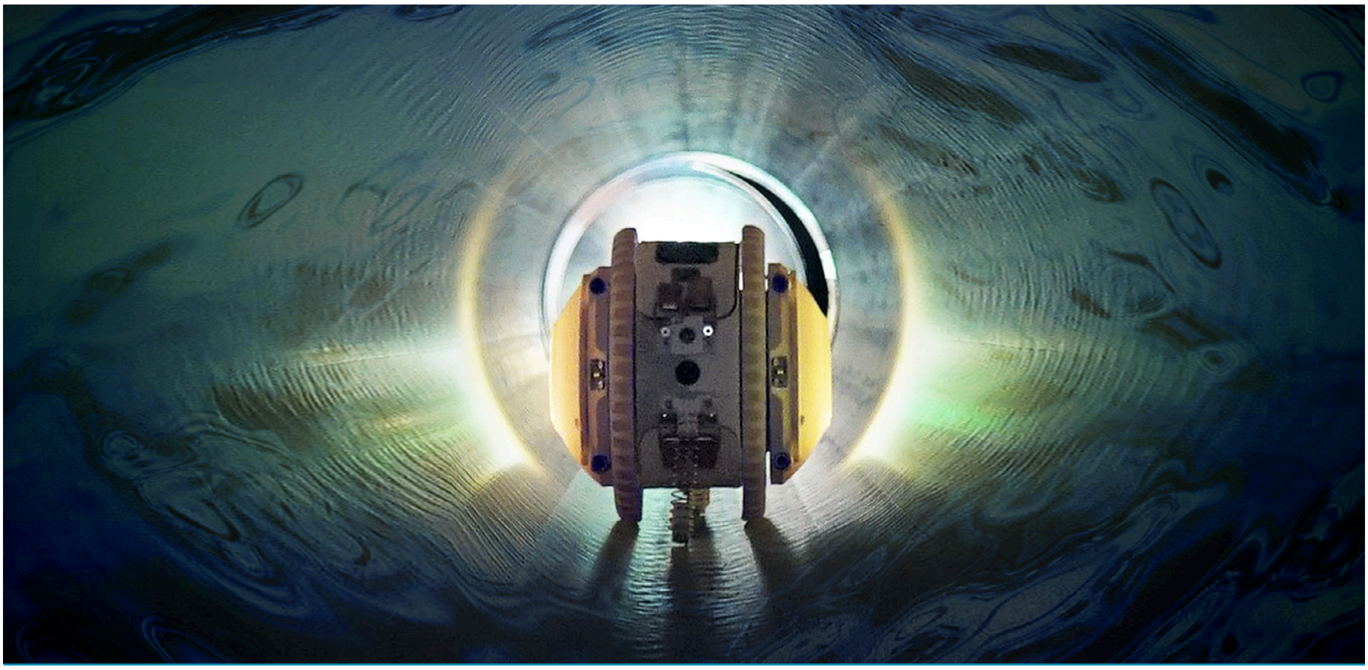
Autonomous robotics for water and sewer networks

By Stephen R. Mounce, Will J. Shepherd, Joby B. Boxall, Kirill V. Horoshenkov and Jordan H. Boyle



Smart water networks are at the forefront of investment plans for water companies in the developed world as part of a progression to a circular economy. Technological advancements allow water companies to gather more information about their networks and assets than ever before and to connect the sector to the Internet of Things (IoT). Edge computing will help make IoT rollouts more integral and core to the way businesses work in coming years using new sensing approaches including using in-pipe robotics. Pervasive Robotic Autonomous Systems (RAS) will facilitate a move from reactive to truly proactive practice, enabling ongoing and repeat assessment of pipe condition and operational performance. It is foreseen that robotic inspection and data collection will add increasing amounts of data to more traditional data sources. The more intelligence that is captured, the more that can be learned, understood and predicted about the network. Extra data provides new opportunities for asset condition monitoring, performance assessment, maintenance and event analytics. This article provides background on cutting edge research which aims to revolutionise buried pipe infrastructure management with the development of swarms of micro-robots designed to work in underground pipe networks autonomously and cooperatively. New Artificial Intelligence algorithms are being developed that uniquely incorporate Lagrangian (mobile sensing) rather than traditional Eulerian (fixed sensing) based coordinate systems. The resulting big data can be used for pipe condition assessment and to inform simulation of hydrodynamic performance of pipe networks, for example identifying pinch points or spare capacity.

Water utilities operate large, complex pipe networks with often limited information on system connectivity and asset condition. The unknown condition, performance, and often even location, of such buried assets is a significant problem for the companies that manage large networks of pipes. In the EU, buried water and wastewater networks have a combined length of approximately 6.1 million km; the replacement value is an estimated EUR 3.5 trillion[1]. While pipe inspection technologies used by these industries have progressed, the lack of comprehensive knowledge about the condition of buried pipes results in sporadic, unforeseen failures. For example, there are 1.5 million road excavations per year in the UK causing full or partial road closures and a cost to the UK of at least GBP 5.5 billion per year (GBP 7 billion including dig costs)[2]. The repairs are conducted in a reactive fashion, with well-developed and efficient industry protocols. However, with current industry replacement rates of less than 1% annually[3] inferred asset lives are 100-800 years. Without the transformative step-change in pervasive sensing proposed herein, this situation will worsen exponentially as infrastructure ages.

Most utilities manage their pipe networks using several data sources: (i) historical records such as pipe location; (ii) age and material; (iii) system failure notifications (including surface leaks, no customer supply, sewage spills, etc.); (iv) and, in the case of sewers, limited contemporary inspections. Action is typically only taken reactively once failure occurs and performance is compromised. Such asset failure is undesirable because it can cause service disruption or economic loss to the customer, damage to other infrastructure such as roads plus the potential polluting environmental impact of spills and added congestion when unplanned roadworks are required to repair or replace the asset.

There are no 'business as usual' inspection systems which measure pipe condition accurately over time at a high spatial granularity (thus enabling models of degradation). As an example, currently wastewater networks are generally inspected using CCTV, requiring a manually operated camera to be passed through the network. The collected footage is analysed by a trained engineer. Manual techniques such as listening sticks or acoustic noise loggers are similarly utilised in drinking water distribution systems. All these reactive approaches require human intervention, cause disruption at the surface, particularly on roads, and are difficult to apply in complex networks.

Internet of Things (IoT) objects and sensors with IP addresses can be connected via the cloud giving rise to the concept of 'smartness' and the development of 'Smart cities' and 'Smart Water Networks' (SWaN). Smart water means using technologies for optimising water resources and waste treatment, monitoring and controlling water, and providing real-time information to help water companies and households manage their water better [4]. SWaNs are currently being rolled out on scale[5] and autonomous monitoring systems hold the key to transform our awareness of inaccessible buried pipe infrastructure. SWaNs have been described as a layered architecture, beginning with the sensing-and-control layer through continuous and pervasive data collection, proactive data management, and ending with the data fusion-and-analytics layer[6]. It seems clear that in the future the whole water sector is going to be completely penetrated by Information and Communications Technology (ICT) and IoT-like technologies. In a decade, tens or even hundreds of petabytes of data may be routinely available. As these technological capabilities advance, so does the ability to collect information from remote devices and correlate that information across diverse systems. An infrastructure that can connect the monitoring and control systems to an IoT platform allows effective use of the operational information that the systems hold to help achieve near-real time situational awareness. Demands for solutions and tools will become more urgent to meet the aspiration for intelligent water networks, proactively managed through access to timely information. While a step change, the spot sensors of a SWaN can only be installed where there is access to the pipe network, e.g. manholes and fire hydrants. While frequent in the networks such features are still only a tiny fraction of the total systems, and commonly only the performance at these points can be measured, not the condition of the infrastructure between these access points. Autonomous pervasive robotics offers the potential to radically transform this situation by going from spot sensing (at fixed locations) to pervasive, Lagrangian (mobile) sensing.

State of the art robotic devices for buried water pipes

A comprehensive review[7] of robots for pipeline inspection revealed that robots currently available are mainly laboratory prototypes designed for large diameter pipes, human controlled, heavy (tens or hundreds of kg) individual devices suitable for a single short duration intervention. Locomotion is often limited to wheeled or tracked approaches. Hardly any of these devices are autonomous.

Autonomous robots appear to have great potential for inspecting difficult to access water pipe networks[8]. A report[9] on Robotic Autonomous Systems (RAS) by TWENTY65 (www.twenty65.ac.uk), a UK collaborative initiative between academic research institutions and the water industry, sets out the opportunities for the use of RAS in the Water Industry, specifically for use in underground infrastructure and more generally in all operational activities in water. A key opportunity was identified as "mapping, condition assessment and rehabilitation within underground pipe assets". The report confirms that Inspection Robots are usually multi-sensor platforms that carry a variety of condition assessment tools inside the pipeline in a single deployment that also provides live video (CCTV) that can aid in detecting anomalies within the pipe. These also tend to be tethered tools which provide condition assessment with limited spatial and temporal resolution, and require human intervention and service disruption.

Tethered robotic crawlers suitable for water and wastewater are available with multiple sensors for condition assessment including laser profiling. There are technologies that can assess a variety of pipe materials to identify structural deterioration that could lead to pipe failure. Examples are the PipeDiver® and Sahara® which are free swimming and tethered devices, respectively.

An alternative to crawlers is the so called 'soft' robot, such as Lighthouse (https://www.digitaltrends.com/cool-tech/ leaky-pipe-detecting-robot-james-dyson/) that is a low-cost unit designed to travel through water pipes hunting for leaks before they turn into major problems. Lighthouse is inserted into a water pipe by way of an existing hydrant. It then passively flows through the pipe, traversing around pipe elbows, discovering leaks by measuring the suction associated with escaping water. The device can then be retrieved when it is flushed out of the pipes through a hydrant, and wirelessly downloads a map of leaks. Smartball (https://puretechltd.com/technology/smartball-leak-detection) is a similar passive untethered approach which is a 'dumb' ball following the current (flow) through water, wastewater, and oil and gas pipelines that can complete long inspections in a single deployment. It should be stressed that such devices are non-autonomous and driven by network flow, designed for single release and inspection. Positional and condition data is of poor quality and stored on-board, and since they are used alone, data coverage is sparse because these devices must follow the flow and are not able to deviate from this path. Recovery of such passive devices can be challenging in complex and uncertain networks.

In the last decade, a number of interesting projects and initiatives have explored the feasibility of RAS for the water sector and several of the more promising are now outlined.

Ariel. KWR Watercycle Research Institute and Wetsus, alongside

Dutch water utilities, developed an initial prototype for an Autonomous Inspection Robot: Ariel (https://www.kwrwater.nl/en/actueel/autonomous-inspection-robots-game-changer-for-asset-management/). Van Thienen *et al.*[10] provided details on a tethered prototype and its testing, in particular its modular design as a segmented 'snake like' train with modules for propulsion/vision, centering and battery/electronics. Van Thienen *et al.*[11] provided further progress with prototypes and the design of a large pilot scale network for testing and presented a comprehensive business case study by way of costs and benefits. The robot's further development has resulted in autonomously operating robots equipped with various sensors which determine the condition of the pipe with exact positioning (x, y, z coordinates). Base stations provide locations for up/downloading of route/inspection data and recharging of batteries. A data ecosystem framework facilitates the analysis of large volumes of sensor data. In practice, testing is ongoing, with further development under the banner of SubMerge b.v.

EU TRACT project. In collaboration with SINTEF and Spanish and Italian research partners, the project (https://www.sintef.no/en/latest-news/2014/robot-water-pipe-inspectors/) has developed a long, torpedo-like and propeller-driven robot equipped with 64 large ultrasound transducers. This is designed to operate in branched water and district heating pipe systems in pipe diameters from 0.1 m, with a range of 150 m. It collects data which enable the calculation of the thickness of, and levels of corrosion in, the pipes.

TISCA. In Netherlands, the Technology Foundation STW, together with Stichting RIONED, STOWA and Kennis Programma Urban Drainage (KPUD), have been cooperating since 2016 on the programme Technology Innovation for Sewer Condition Assessment (TISCA) (https://www.nwo.nl/en/researchprogrammes/joint-programme-technology-innovation-sewer-condition-assessment-tisca). Five projects are currently in progress and of particular interest is FOULC (Fast Over-all scanning of Underground and Linear Constructions). An aquatic drone is being developed as a sensor platform and data-acquisition system for sewer systems. Use of a laser scanner, IR camera and turbidity/velocity profiler were investigated, with preliminary laboratory results reported in [12].

PUB robotics. Singapore's National Water Agency and NTU, with co-funding from the National Research Foundation, developed a mobile robotic platform that can travel in trunk sewers, which is equipped with CCTV, profiling sonar and laser scanners for monitoring the sewers[13]. The initial objective was to design and develop a sewage inspection robot to inspect concrete sewage tunnels with internal diameter of 3 m or larger and for incursions of up to 400 m. An Unmanned Aerial Vehicle (UAV) system[14] equipped with cameras and sensors has also been developed and deployed to inspect the Deep Tunnel Sewerage System. The system is capable of autonomous operation in a signal-denied environment.

Despite these interesting studies, it is reasonable to question why products have not in general reached the market to date. One of the barriers is the difficulty in testing prototypes in realistic networks (note that[11] tackles this by means of a full scale network above ground with various network elements). Other challenges limiting deployment relate to:

- Developing a timely and affordable capability to inspect and quantify performance of individual assets in large pipe networks.
- Synthesizing the inspection data to enable planned intervention at an asset level and prevent unforeseen failure and unplanned repair.
- Ensuring end user requirements are strongly embedded so that pervasive data can be transformed into knowledge that is actionable to prevent failures.
- Implementing maintenance based on such additional information derived from data i.e. providing capacity to act in a timely manner.

A future RAS highway for water infrastructure

Significant problems must be addressed and solved to make buried water pipe infrastructure a robot-friendly RAS highway. Autonomous robots can cover the whole infrastructure moving freely whenever required to detect objects, obstacles and contraventions to the norm, supplying data continuously on an unprecedented scale and integrating safety into their decision making including motion control through dynamic motion planning. High level communications, map generation and adaptive planning through optimisation of space and time usage, analysing motion and analysing power usage will all be essential components to enable adaptive strategies in complex pipe networks.

Robotic autonomous systems are differentiated from other machines by their ability to perform physical tasks with little or no human intervention. They have the potential to enact a wide range of individual tasks without direct human supervision. Their work is a combination of the following three sub-tasks: (i) manipulation and processing; (ii) data gathering and monitoring; (iii) data sorting and storage. Artificial Intelligence (AI) methods and tools are essential for success with these tasks because of the massive volume of data and complexity of the problem associated with the inspection of buried pipes. AI methods have already been embraced by many water utilities which use them to support the planning, operation and maintenance of their distribution and sewerage networks, improve customer service and predict demand[15]. Robots are widely used in other industrial sectors and the significant development of AI and machine learning will result in a rapid growth of RAS having a major impact on nearly all market sectors within the next decade. This economic impact is not just related to an expansion in the market for robotics technology but also to the deep impact robotics technology will have on competitiveness and service provision across all economic sectors. The early signs of this impact are visible

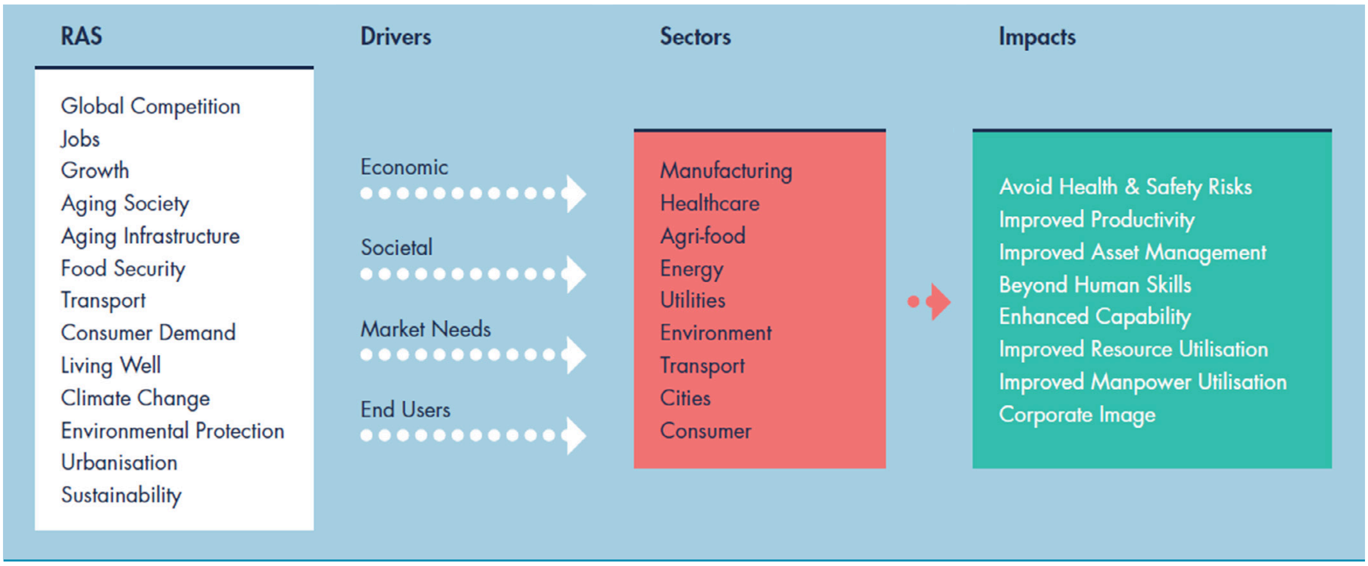


Figure 1 | Global drivers, sector applications, and potential impacts of RAS[9].

in manufacturing, utilities, agriculture, transport, logistics, energy supply and healthcare. In these sectors robotics and autonomous systems are already deployed in niche applications. There are numerous drivers for change which are common to numerous market sectors and these have significant impacts as illustrated in Figure 1.

As RAS developments continue to progress it is clear that commercial robots will no longer be largely confined to use within manufacturing and consumer applications but expand to environmental and utility applications. In the first instance this is likely to be centred on mapping and condition/performance assessment in underground infrastructure. Such application will ultimately transition to a full "find and fix" solution in the future which integrates with other city transport and utility systems.

It is reasonable to expect that most water companies in the developed world will be using the impact of AI and big data analytics in the current decade. It should however be noted that this is unlikely to be the case in many other less economically developed countries, with a more gradual trickle down of technology transfer occurring over time. RAS inspection, collection and condition monitoring will add increasing amounts of data. It is the data frequency from sensors and geo-distribution of data points that provide the granularity required to produce actionable information and knowledge. Further, the transition from Eulerian (fixed) sensors to Lagrangian (mobile) sensors opens up both the prospect of repeat sensing for condition monitoring as well as converting performance data to actionable information (such as identifying pinch points and spare capacity). The reliability and information content of low-resolution monitoring has been such that its use is typically confined to reactively demonstrating compliance to regulators and/or to calibrate idealised single snapshot deterministic network models derived from generic understanding of processes. High resolution monitoring is now sufficiently reliable that it should be integral to derivation of information from data through the building and running of site-specific, continually updated predictive models that can be used proactively to make management proactive, more cost-efficient and effective. These deployments will enable the shift to much richer detailed water network models such as digital twins based on real-time pervasive sensing. In relation to such digital twins, autonomous robots promise a step change in the data driven construction, calibration and utilisation of such models.

Vision for autonomous pipe robots

In 2019 the UK government invested in research to develop pervasive sensing for buried pipes which will be based on autonomous robotic systems[16]. The vision for the UK Engineering and Physical Sciences Research Council (EPSRC) Pipebots Grant (2019-2024) is of intelligent, robust and resilient buried pipe systems with the development of autonomous and pervasive micro-robots which are smart and (almost) failure free[17]. Such systems reduce the service disruption to society by avoiding unnecessary and unplanned road excavation. Key challenges that have been identified in the industry are Asset Mapping, Leakage, Condition Monitoring, Cost-Benefit, Blockages and No Disruption. Ideas of timescales have been developed for some of these applications (such as asset mapping) expected to be feasible at a small scale by 2025, compared to full implementation of swarms of robots by 2030. The experimental validation and demonstration proposed is taking place both in the new UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC) facilities at Sheffield (Figure 2, https://icair.ac.uk/), and on carefully selected field sites with support from industry partners to guarantee the safety of the robotics technology platform.

Pipebots prototypes

Sprintbot is Pipebot's first autonomous sewerage inspection platform which is a result of a 4-week long hardware sprint exercise conducted in March 2020. Sprintbot is designed like a ball (Figure 3) allowing it to easily move and turn around inside a pipe[18]. As a first prototype, the Sprintbot is designed

Figure 2 | UKCRIC facilities at Sheffield.

to operate in relatively dry pipes, but future prototypes will be designed to operate in live sewers. The physical platform is custom-designed and largely 3D printed. The electronic package is built around a Raspberry Pi 4 as the primary controller, interfaced with an Arduino Nano as a secondary low-level controller. The sensor payload consists of a camera (Arducam MIPI), Inertial Measurement Unit (IMU, Arduino Nano 33 BLE Sense), laser range finders (STMicroelectronics VL53L1X), ultrasonic transducers (Murata MA40S4R), speaker (Pimoroni 4Ω COM1601) and microphones (Adafruit I2S MEMS Microphone Breakout). These provide data for localisation, autonomous control and blockage sensing.

Sprintbot has been tested and videoed at the Integrated Civil and Infrastructure Research Centre (ICAIR) facility at the University of Sheffield. The Sprintbot is relatively large needing a minimum pipe diameter of 300 mm to safely operate. However, this size was a function of using off the shelf electronics for the short development period. The design also highlighted the need for the platform to be stable to allow camera images to be processed. Using experience from the development of Sprintbot, a new pipe inspection robot has been designed and is being assembled for testing. The new robot is significantly smaller than the original with a maximum dimension of 60 mm (**Figure 4**). The team is experimenting with the use of whegs (a hybrid of wheels and legs) for motive traction. The reduced size of robots means that the internal electronics can rely much less on off the shelf modules, so custom electronics boards are being designed and built. Initially twenty of these new robots will be constructed to allow a variety of tests to be carried out, including swarm applications, involving the use of a larger 'Marsupial' robot for deploying the swarm. An iterative prototyping approach to design will continue to be employed throughout the project lifetime. Robots for deployment in pressurised water supply pipes face a different set of challenges and design of these will commence soon.

Software integration and AI control

A full software architecture has been produced following the development of the Sprintbot, by holding a further sprint. This three week event was run using agile methodologies, specifically Scrum (https://www.scrum.org/), and brought the Pipebots themes[16] together daily to ensure smooth communication to establish intermodule dependencies. The aim was to agree a flexible software architecture that would allow reconfiguration of a Pipebot across different variants with different sensing capabilities. This software architecture (see **Figure 5**) is now available to the team on the Pipebots Github repository (https://github.com/pipebots), providing a software skeleton for any Pipebot and allowing each theme to populate black-box elements with code developed through their research. This will enable the rapid development of future use-cases, as interoperability between modules has been captured within the model. This software approach helps in the design of control algorithms that can easily adapt to the robotic and sensor designs that have yet to be created. An example of such control is that required for self-assembly Pipebots, in which robots would link together and cooperate to perform certain tasks such as collaboratively moving against a strong flow, ascending steep pipes or climbing steps and obstacles. Ideas for algorithms have been proposed and simulation models are currently being built for evaluation.

Autonomous navigation

Effective interventions in buried pipes rely on accurate knowledge of the pipe network itself and on the location of the robot sensors

Figure 3 | Sprintbot first prototype testing in mock pipe network.

Figure 4 | Swarm Pipebot prototype concept.

within the network. The former is for the operators to have accurate and up to date information on their assets. The latter is to ensure that the robot swarm efficiently inspects the whole network in a timely fashion and to pinpoint faults for interventions. It is also critical to the success of the distributed (swarm) robotic sensing that the sensor node positions are known accurately. Novel algorithms are being developed by researchers for simultaneous localisation and mapping (SLAM) and subsequent navigation in feature-sparse pipe networks[19]. The first major challenge is to generate accurate 3D maps of pipe networks using 1D and pseudo-2D movements in feature sparse environments in the pipes below the ground. The second challenge is to incorporate prior knowledge (e.g. from geographical information systems) to enhance SLAM initialisation and performance. The third major challenge is to combine SLAM information from swarm robots to produce a real-time fused pipe network map. Researchers have been determining the feasibility of tuning the parameters of visual odometry methods to recover the camera position along the pipe without the use of a tether[19]. Simulations with the water distribution network model EPANET were used to show that a swarm of autonomous robots could operate without a centralized controller and benefit from having some degree of in-pipe communication[20]. Results indicate that 10-20 robots with simple 'ant colony' style intelligence could be used to autonomously inspect an (approximately) 30 km water distribution network with a regularity of at least one inspection/month.

Applications

Real world applications, and integration, of the various technologies are being investigated by means of a number of case studies. Four example challenges are now provided.

Asset mapping. Asset databases for buried pipe networks are regularly incomplete and uncertain, both in terms of network coverage and specific details, such as material and diameter. This is due to the age of the network, changes in ownership over time, changes in database technology (e.g. from paper records to computer), and repairs and replacement of the original pipes. Overcoming such challenges relies on the development of pipe network SLAM described above. Research using pose-graph optimization for localisation of a robot in an underground water pipe has been demonstrated[19]. As an alternative to visual localization methods, four methods of incorporating information from the measurement of an acoustic spatial field were developed and designed to be applicable to any spatially varying property along the robot's trajectory, such as magnetic or electric fields. Experimental results in[19] showed that the use of acoustic information in pose-graph optimization reduces errors by 39% compared to the use of typical pose-graph optimization using landmark features only.

Blockage. Blockage of sewers, specifically small diameter laterals and pipes downstream of combined sewer overflows can result in flooding and spills from the network. Blockages of smaller pipes can accumulate rapidly hence the robot swarms would likely need to be based in a local area in order to visit the small pipes close to properties that are most prone to blockage. Existing and emerging technologies monitor water levels in Combined Sewer Overflows (CSOs) and are widely used in the UK to monitor spill durations. Robots could react to investigate alerts from automated analysis of the water level data.

Condition monitoring. The condition of buried pipes is very difficult to assess, but understanding the condition accurately is important to maintain or improve service performance and extend the life of assets at an affordable cost. This is a major challenge due to the many potential failure modes between water distribution and drainage, different pipe materials, different ground conditions, etc. Condition monitoring robots could carry

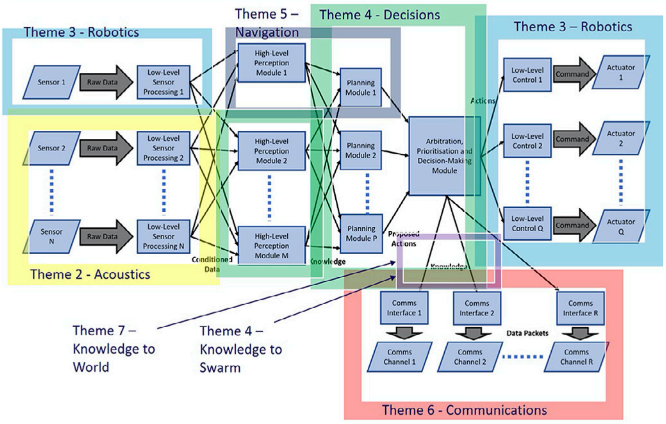


Figure 5 | Pipebots software integration diagram.

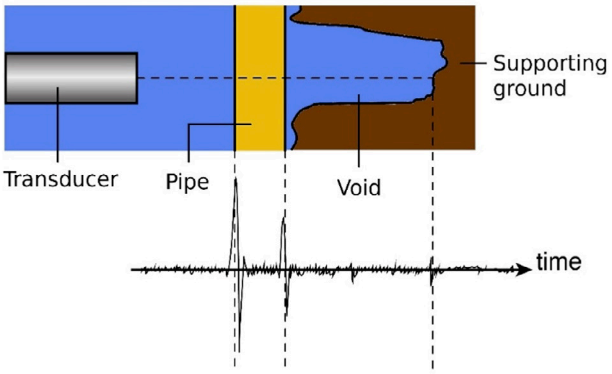


Figure 6 | Ultrasonic detection of voids in water pipes[30].

out repeat surveys (with frequency based on the known condition of individual pipes) in order that changes in condition can be recorded and to inform accurately the predictive condition modelling. Robots do not need to communicate condition back to the cloud regularly, the frequency is likely to be determined by the available data storage, or the frequency with which it passes a hub that allows communication back to the water utility. Work has been conducted on the ultrasonic detection of voids (and water content in soil) as an early indicator of the onset of failure in plastic water pipes[21]. The ultrasound technique is shown to be capable of detecting water filled voids and assessing the soil support, both of which are critical early indicators of failure (Figure 6). Such solutions are ideal to be deployed on Pipebots working inside pipes. Work has explored using acoustic sensing for blockage detection in sewer pipes to characterise the blockage shapes and sizes[22].

Leakage. The leakage from piped water distribution networks is a key (and enduring) challenge. While water utilities are able to locate larger leaks the process is time consuming. Locating smaller leaks, especially in plastic pipes, remains challenging. Leakage detection robots would continuously trawl the network, listening and searching for new (or changed) leaks and intrusion. A main advantage of autonomous robotic technology is that it will be possible to deploy leak sensors sufficiently close to the position of each leak to pinpoint it much more accurately and over a shorter period of time than is currently possible with Eulerian based leak detectors. Initially these robots could be deployed for a short period at a local level targeting areas with high leakage. A challenge for Pipebots is to detect and locate smaller leaks with reasonable precision (e.g. within centimetres) and to do this in a timely manner.

Conclusions

Water distribution and wastewater pipe infrastructures are ageing, resulting in regular failures requiring costly, disruptive, reactive maintenance. Mobile robots could be used for autonomous, persistent monitoring of a buried pipe network, locating faults and reporting information enabling proactive rather than reactive interventions. This article assesses the state-of-the-art in the development of autonomous robots for monitoring of buried pipe networks and describes technologies being developed by Pipebots[16]. This collaboration between four UK universities and industry aims to revolutionise buried pipe inspection with the development of autonomous micro-robots designed to work in complex pipe networks (clean and waste water) to generate potentially massive amounts of real-time data. Swarms of miniaturised autonomous robots equipped with novel sensors will be deployed in buried pipe networks. New algorithms uniquely incorporating Lagrangian (mobile) rather than traditional Eulerian (fixed) based coordinate systems are being developed to process the autonomously collected data to inform condition assessment and system performance. The outputs from these algorithms could be directly mapped to the hydrodynamic performance of single pipes or fed into pipe deterioration models that can predict, with AI and machine learning support, the remaining service life of a pipe. Robotic autonomous systems will enable maximising the capacity of existing infrastructure, detecting deterioration proactively, increasing safety and reducing downtime of city infrastructure and generating data to drive better maintenance and investment models. However, significant problems must be solved to result in pipes becoming a RAS highway. Technologies are required for effective robot deployment and recovery, navigating in often unmapped and uncertain pipe environments and communicating in order to contextualise the condition and allow rehabilitation work to be planned. With sufficient technological and governance progress utilities would be empowered to run a fully automated inspection, repair and maintenance system (using find and fix swarming robots). This would radically reduce the risk of service failure and along with new repair technologies significantly reduce the cost of individual repairs – releasing funds to rehabilitate assets over the longer term. The Pipebots team intends to have a full Pipebots system demonstrated in a realistic (initially sewerage) network before 2024. Once that is successful, a thorough certification and compliance process will be required to ensure that pervasive autonomous Pipebots will be safe to adopt and deploy in live water and sewer networks for mapping, sensing and communicating.

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Joby Boxall is professor of Water Infrastructure Engineering at the University of Sheffield, and head of the department of Civil and Structural Engineering. He is a chartered engineer and environmentalist and fellow of the Chartered Institution of Water and Environmental Management. Joby's research interests are concerned with understanding and modelling hydraulic, water quality and infrastructure performance and interactions, usually with a focus on water supply. He is focused on research addressing the grand challenges facing water, including leading the EPSRC grand challenge consortium on sustainable clean water for all, TWENTY65.

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Jordan Boyle is associate professor in the School of Mechanical Engineering at the University of Leeds. His primary research area is miniature mobile robotics for infrastructure inspection. His PhD research in the School of Computing at Leeds involved computational modelling of the neural control of animal locomotion, and he maintains a particular interest in biologically-inspired robotics.

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