FURO: Pipe Inspection Robot for Radiological Characterisation

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I. INTRODUCTION

In the 1930s nuclear fission was discovered, this led to many countries including the United Kingdom, to begin research into nuclear materials [1]. At the time, the major interest in fission was weaponising it, leading to projects such as the Manhattan Project in the early 1940s [1]. After World War II the race for nuclear arms continued, leading into the cold war [2].

Nuclear facilities required for research were constructed quickly to keep up with the arms race. Due to the speed and limited knowledge of the dangers of exposure to nuclear material, fewer precautions and exact records were taken at the time. Once these nuclear facilities had been fully utilised they were retired and sealed off. 70 years after the race began there is a need to decommission the facilities as the structures are starting to age and if they are left it could lead to further contamination of the surrounding environment.

All of these facilities contain pipework, meaning there is miles of uncharacterised pipes within them. If it is uncharacterised it must be disposed of as contaminated waste which is a costly procedure. Workers currently check the pipework manually by entering the hazardous zones to dismantle and scan it for radiation. This is not only difficult and unconformable work but it is a risk to the workers health. The processes of dismantling the pipework also generates a large amount of secondary waste in the form of hazmat suits and tools, which all need to be disposed of.

If a low-cost robotic system existed that could autonomously scan the miles of pipework and characterise (both radiologically and geometrically) sections of pipe, it could significantly reduce the cost of decommissioning without the risk of exposure to the workers.

The aim of this research is to produce a low-cost, disposable robotic system that can navigate through an unknown pipe network with a minimum diameter of 50 mm, whilst radiologically characterising and mapping the pipework.

Fig. 1. Photo of pipework from an exemplar facility

There has been a large drive in the utility industry for the development of pipe inspection vehicles, these predominantly operate within pipework with diameters of 160 600 mm [3], [4]. Robots that are able to travel within smaller pipes exist [5], [6] but these are unable to safely navigate junctions or too complex in their design. A bespoke pipe inspection robot has therefore been developed.

The development of a 50 mm pipe inspection robot is very challenging due to issues relating to miniaturisation. For theevaluation stage of the research, a 150 mm prototype (named FURO) has been developed, which later will be miniaturised.

FURO has three radial tracked drive units each capable of producing 4 Nm of torque, which is sufficient to allow the robot to climb with a 1 kg payload. The tracks aid in grip within the potentially low friction pipework. FURO is shown in Fig.2.

A fourth motor drives a central lead screw mechanism that is able to vary the diameter of the robot between 126 175 mm. The lead screw is also used for active wall pressing to allow the robot to climb. Due to the sacrificial nature of the robot, it is designed using low-cost 3D printed parts. This not only aids with the cost but allows bespoke small parts to be made.

FURO operates on the ROS framework [7]. The current prototype uses a PC base station with a joystick for manual control. The manual control is used to verify the robot is mechanically able to navigate different scenarios. FURO is able to reliably overcome horizontal, vertical and corner sections of pipe with the manual control.

The first major challenge associated with navigating within pipes are junctions; the simplest of these is the 90◦ bend. As discussed FURO is able to navigate corners with manual control. The user manual set the corner direction (in relation to the robot) and radius, the robot uses that to calculate the required velocities for the drive unit. To make this system autonomous, the robot must be able to detect the parameters of the corner so it can determine the path lengths for the velocities.

Current sensing solutions are either too large, expensive or computationally heavy to be deployed on FURO. A mechanical feeler sensor has been developed to detect the pipe features ahead. These feelers are depicted on the FURO prototype in Fig. 2.

The feelers consist of a potentiometer, spring, arm and encoder which are not only mechanically simple but also makes the sensor computationally light to sample. The voltage change over the potentiometer relates to the angle of the feelers this is passed to the prediction algorithm to determine the pipe parameters.

Fig. 3 shows the raw data from the feeler sensors as they enter the corner. The red feeler entered the corner in line with the inside of the bend, whist the other feelers were at 120◦. It can be seen that the red feeler changes with the largest magnitude to the other feelers, this is expected as the greatest change over the entrance distance is experienced here. The blue and green feelers are expected to change by a similar magnitude to each other but less than, and in the opposite direction to, the red feeler which is exactly what is observed.

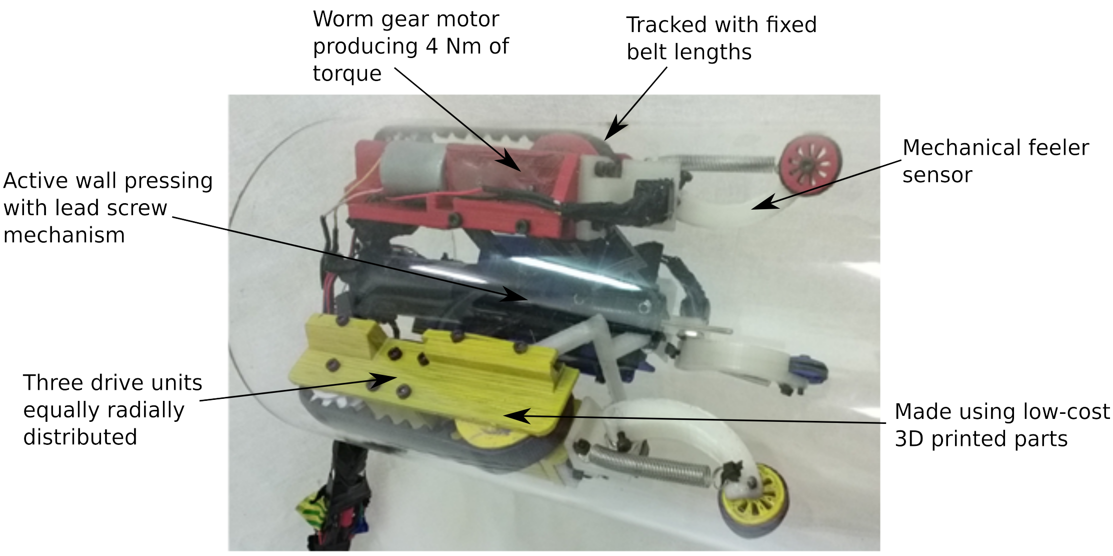

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Fig. 2. FURO prototype

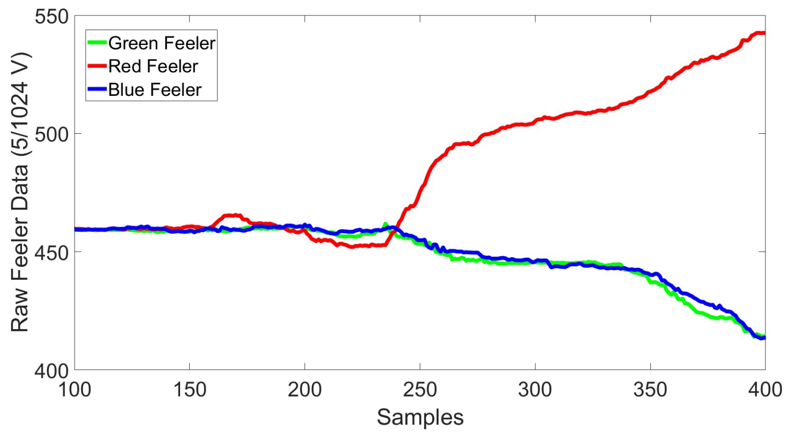

Fig. 3. Raw data from feeler sensors entering a corner

Once the raw data from the feelers is gathered, a method of detecting the corner parameters from this information is determined. The raw data is converted to angles and is used with a kinematic model to determine the location of all three feelers. A prediction is made on the direction (in relation to the robot) and radius of the corner. Once the parameters of the corner have been estimated they can be used to determine the required velocities from the drive units to allow FURO to pass through a corner.

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To summarise, using three mechanical feeler sensors, the proposed sensor will detect the paraters of the corner to allow the FURO prototype to autonomously navigate around any corner with a minimum radius of 150 mm (short elbow) up to 90◦ in any direction. Further work for FURO includes characterising the performance of the feelers, extending the feeler detection to varying radii and angle corners and miniaturising the system to a 50 mm pipe.

REFERENCES

1. Wagemans, The nuclear fission process. CRC press, 1991

2. Kaysen, R. McNamara, and G. Rathjens, “Nuclear weapons after the cold war,” Foreign Affairs, vol. 70, no. 4, pp. 95–110, 1991.

3. S. Ryew, S. Baik, S. Ryu, K. M. Jung, S. Roh, and H. R. Choi, “In-pipe inspection robot system with active steering mechanism,” in Proceedings, 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2000.(IROS 2000)., vol. 3. IEEE, 2000, pp. 1652–1657.

4. J. Okamoto, J. C. Adamowski, M. S. Tsuzuki, F. Buiochi, and C. S. Camerini, “Autonomous system for oil pipelines inspection,” Mechatronics, vol. 9, no. 7, pp. 731–743, 1999.

5. A. Kakogawa, T. Nishimura, and S. Ma, “Development of a screw drive in-pipe robot for passing through bent and branch pipes,” in Robotics (ISR), 2013 44th International Symposium on. IEEE, 2013, pp. 1–6.

6. S.-g. Roh and H. R. Choi, “Differential-drive in-pipe robot for moving inside urban gas pipelines,” Robotics, IEEE Transactions on, vol. 21, no. 1, pp. 1–17, 2005.

7. “ROS - Kinetic Kame,” 2017, Open Source Robotics Foundation.