Explorer: Untethered Real-Time Gas Main Assessment Robot System

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I. ABSTRACT

Federal government agencies and an industrial industry consortium have funded Carnegie Mellon University (CMU) for the development of ***Explorer***, a long range, untethered, modular inspection robot for the visual inspection of 6” and 8” natural gas distribution system pipelines. The robot can be launched into the pipeline under live conditions utilizing a commercial no-blow system via a specially designed attachment, and can negotiate diameter changes, 45-deg and 90-deg bends and tees, as well as inclined and vertical pieces of the piping network. The modular design of the system allows it to be expanded in the near future to include additional inspection and/or repair tools. The range of the robot is an order of magnitude higher than present state-of-the-art inspection systems and is expected to fundamentally alter the way gas utilities maintain and manage their systems. A prototype system has been built, and is undergoing extensive laboratory system testing prior to scheduled field demonstrations, expected for the summer and fall of 2003. This paper will describe the overall engineering design and functionality of the design, as well as present preliminary laboratory testing setup (a video of system in operation will be shown at the conference).

II. BACKGROUND

US gas companies spend over $300 million annually detecting and repairing gas leaks in urban and suburban settings. The current approach is one of above ground leak detection and pinpointing, followed by excavation, repair and restoration. The major cost incurred is typically that of digging and restoring the excavation site. If a tool was available that could provide real-time and long-term inspection capabilities in order to allow for rapid and pre-planned inspections and repairs wherever needed, national utilities would be able to better manage and allocate their operating and repair budgets, potentially reducing costly emergency repairs.

III. STATE OF THE ART

In the area of in-pipe inspection systems, there are many examples of prior-art robotic systems for use in underground piping (transmission-pipeline pigs excluded). Most of them however are focussed on water- and sewer-lines, and meant for inspection, repair and rehabilitation (Pearpoint, Beaver, KA-TE, etc.). As such, they are mostly tethered, utilizing cameras and specialized tooling, etc. (see Figure 1).


SewerSys ***Beaver***
Advantica ***KA-TE***
Baker-Hughes ***Pearpoint***
Advantica

Figure 1 : Prior art in in-pipe inspection systems

Three of the more notable exceptions are the autonomous *Kurt I* system from GMD (Germany) used for sewer monitoring (not commercial nor hardened), the (albeit tethered) cast-iron pipe joint-sealing robot (*CISBOT*; ConEd), which is deployed through a bolt-on fitting and injects anaerobic sealant into the leaking jute-stuffed joint, and *GRISLEE (GTI, CMU & MTI)*, a coiled-tubing tether deployed inspection, marking and in-situ spot-repair system. These systems are shown in Figure 2:

Figure 2 : Tethered gasmain (CISBOT - right; GRISLEE - bottom) and untethered autonomous (Kurt I) robots developed to date by industry and researchers

IV. SYSTEM OVERVIEW

In order to explore this possibility, the New York Gas Group (NYGAS-current), DoE (current) and NASA (past), are funding a program at Carnegie Mellon University's (CMU) Robotics Institute (RI) to develop an advanced remote and robotic inspection system, capable of multi-mile long-duration travel inside live gas mains for in-situ assessment and pipe-network cataloging.

Under this program, CMU has developed ***Explorer***, a real-time remotely controllable, modular visual inspection robot system for the in-situ inspection and imaging of live 6- and 8-inch diameter distribution gas-mains (see Figure 3 for an image of the prototype in a test network setting). ***Explorer*** is capable of locomoting through straight pipe segments and sharp bends, elbows, Ys and Ts, using a combination of its on-board driving-arms and steering-joints. The system is sealed and purged (and thus can safely operate in natural gas environments) and capable of negotiating wet and partially-filled (water, mud, etc.) pipes.

Figure 3 : Explorer - Pipe Inspection System

The architecture of the robot is simple and symmetric. A 7-element articulated body-design houses a mirror-image arrangement of locomotion, battery-, support and computing electronics in purged and pressurized housings (see Figure 4). Each module is connected to the next through an articulated joint; the joints connecting the locomotor-module(s) to the rest of the 'train', are pitch-roll joints, while the remaining (four) joints are only pitch-joints. This allows the locomotor-modules to articulate in any direction, with subsequent rotation-plane alignment of the remaining joints to enact a turn in any plane. The system is capable of multi-mile travel inside pipes using custom on-board battery-packs, which can use any desired chemistry depending on desired range and cost.

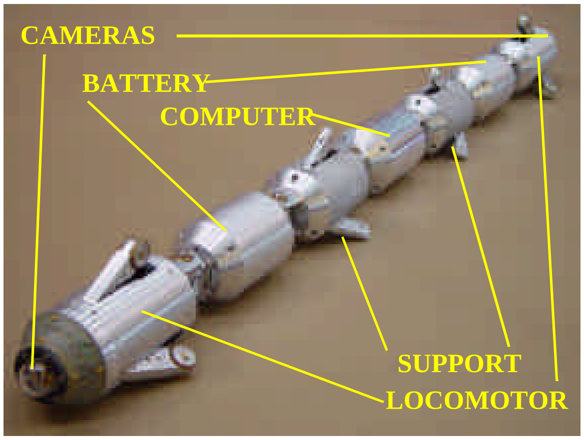

Figure 4 : Overall architecture of Explorer

The locomotor-module contains the forward-looking mini fish-eye camera, -lens and -lighting elements, as well as dual drive actuators. These actuators allow for the deployment/retraction of a set of three ‘arms’, at the end of which are a set of custom-molded wheels used for pulling/ pushing the train through the pipe; sustained speeds of up to 4 in/sec. are achievable. The battery-module(s) contain custom battery packs to allow for a full 10-hour mission with all systems consuming maximum power. The support modules also have extendable ‘arms’, but the wheels at their ends are passive and are used for accurate displacement-encoding. The computer-module contains the custom-packaged 32-bit low-power (< 1 Watt) processor and support hardware for control and communications, as well as power-conversion and -conditioning.

The system carries with it fish-eye cameras on either end, capable of imaging, dewarping and mosaiquing pipe-internal imagery at frame-rates with a combination of edge-finding and laplace-operations performed on image-slivers), and displaying these remotely at the operator console.

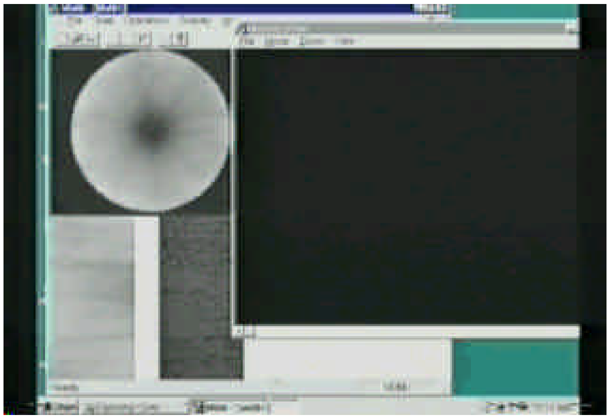

Figure 5 :Fisheye and dewarping imagery user interface

The overall electronics architecture, shown in Figure 6, depicts the on-board scheme of using a central high-MIPS low-power CPU to communicate with a set of I^2C-connected microprocessors to achieve all control, data-gathering and I/O functions over a customized wireless ethernet backbone implementation. A custom-developed 32-bit low-power central processor controls all the locomotion and steering functions based on real-time operator control commands. All on-board functions are served through a network of distributed 8-bit microprocessors communicating over an internal I2C-bus. Real-time external communications is through a wireless 802.11b implementation of UDP, using the pipe as a waveguide for long-range communications.

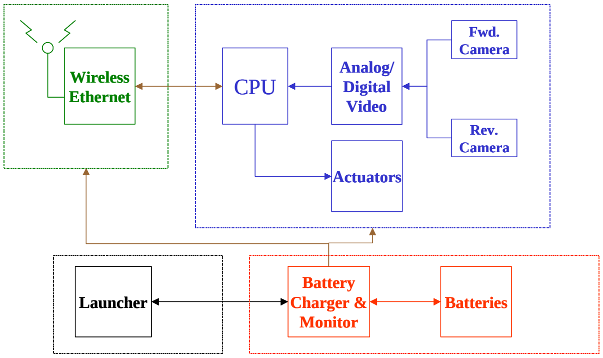

Figure 6 : Explorer overall electronics architecture

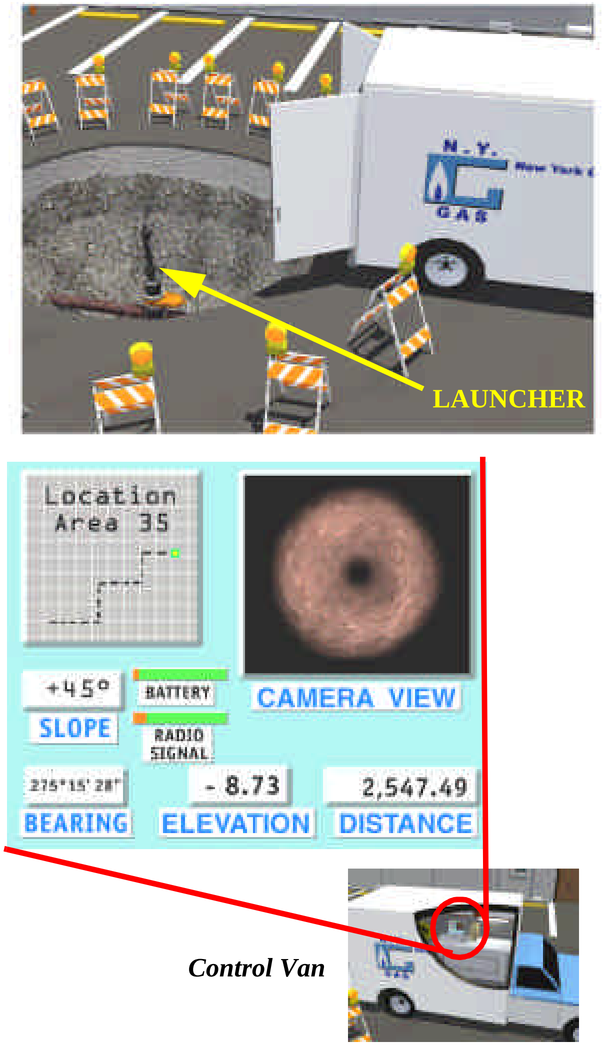

Figure 7 : View of the launching and control setup

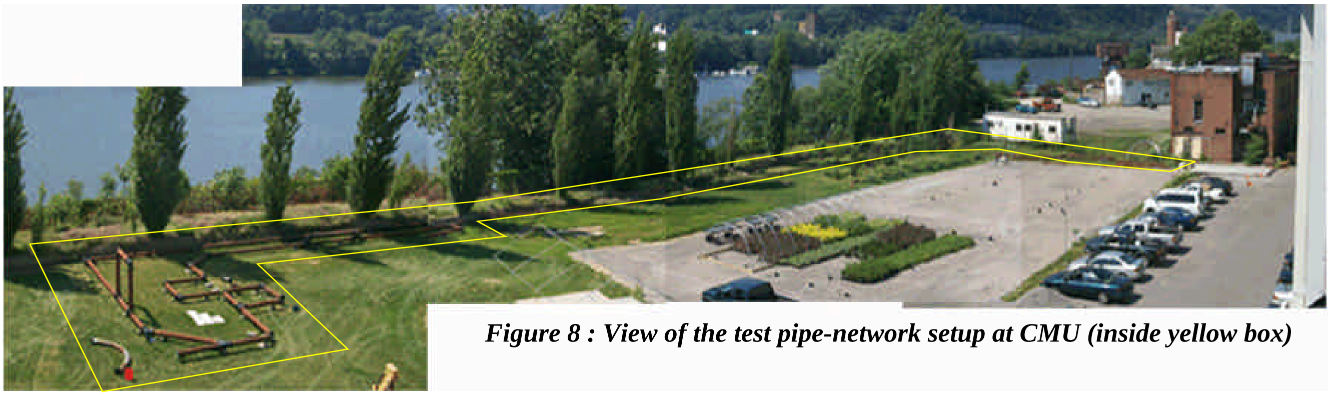

Figure 8 : View of the test pipe-network setup at CMU (inside yellow box)

V. DEPLOYMENT

The system is launched through a live installed vertical launch-chamber (see Figure 9), after a hole has been dug in a 'low-cost' location selected by the utility, where custom antennaes are used to link the operator console to the robot. A user controls the robot using a simple forward/reverse joystick interface, while the on-board computers generate all the individual joint-steer and driving commands (see Figure 7). Turns are possible by positioning the robot at the proper place in the pipe, identifying the direction of the turn on the touchscreen monitor, and engaging an automated scripted routine to coordinate the turning and driving motions to allow for a turn through a non-straight section of pipe.

Figure 9 : Live-access launching hardware systems

VI. FUTURE PLANS

Laboratory testing for live-launching, turning, climbing, while communicating data and video wirelessly, are currently underway in an indoor and outdoor steel pipe loop network at CMU (see Figure 8). The prototype unit is expected to be test-launched in March 2003, with endurance-testing in an outdoor test-loop to occur in the spring of the same year. Live gas main field-trials are scheduled for the summer/fall of 2003 in New York/ Boston. Patents are pending, with licensing completed and commercialization efforts well underway.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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