An underwater robot for pipe inspection

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Abstract

This paper describes the design of an autonomous mobile robot for use in the inspection of water-filled pipes of 900 mm and larger. The design is based upon extensive market research amongst potential users.

Novel aspects of the design include ultrasonic communications, thus obviating the need for an umbilical cable. The control of the robot is distributed on a local area network which connects all the actuators and sensors.

The robot has four legs, powered by compressed air, which allows the robot to 'walk' over obstacles. As it can also have negative buoyancy, it can also 'walk' along the roof of the pipe if there are obstacles on the floor. The robot also has electrically driven propellers, so that it can 'swim' when having neutral buoyancy.

Sensors include a tv camera and ultrasonic imaging of the inside pipe surface.

The project described is a joint-venture between City University of Hong Kong, through Pearl Technologies Ltd., Portsmouth Technology Consultants (Portech) Ltd. and the Robotics Research Institute at Harbin Institute of Technology in China. The project has been funded with a HK$4.63 million award from the Industry Department, Government of the Hong Kong Special Administrative Region, China, under its Cooperative Applied Research and Development Scheme (CARDS).

1 Introduction

There is much current interest in pipe maintenance by unmanned robot vehicles for the gas and oil industries and the attached references show the range. In general they are divided into three groups; free swimming vehicles, pipe crawling machines which adhere to the outside of the pipe, and internal vehicles which mostly use the pressure of the fluid to derive their motive power. The known vehicles use an umbilical cable for communication and as means of safe recovery.

In general the oil and gas industry vehicles are large and expensive. A typical gas industry "Pig" is about 3m long and 1m diameter and is used for internal inspection and cleaning; they are expensive.

Visits to a number of HK based diving companies, as well as utilities such as the Water Supplies Department, Drainage Services Department and China Light and Power have verified the need for the low cost simple system.

There are three basic classes of underwater inspection robots. The first class crawls along the pipe floor, pulling an umbilical. Through this are carried the power and control signals as well as the video/sensor information. This type of vehicle has the disadvantage of being stopped by large obstacles, as well as being limited by the umbilical. A second class of pipe inspection robots is pulled through the pipe on a cord. These are generally used in pipes up to 0.5 m in diameter. The third type are autonomous vehicles, as the robot is neither tethered or pulled. The underwater vehicle outlined below is described in greater technical detail in other papers at this conference. This is just an overview.

2 The vehicle

The vehicle consists of a smooth streamlined plastic body housing a buoyancy control unit, the propulsion mechanism, the inspection package, the control electronics and compressed air actuated legs for walking and positioning in the pipe.

The inspection package consists of an underwater TV camera on a pan and tilt mount. The TV pictures will be compressed by a patented algorithm developed by CityU and transmitted back to the remote operator on an ultrasonic carrier so that the view can be displayed at the remote control station as a series of still pictures. It is estimated that a repetition rate of one picture per second can be achieved and this is quite sufficient for the likely speed of the vehicle.

An ultrasonic scanner may be added to the vehicle to assist with the pipe survey but this additional equipment will be offered as an option for future inclusion.

One of the important criteria when inspecting ducts is the location of the fault. Since the communication link is by ultrasonics a method of range finding can easily be implemented using these ultrasonic signals. By launching a pulse at the base station and using the vehicle communication package as a repeater, the time of flight can be measured and hence the location of the vehicle within the pipe determined. The method

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inherently corrects for any flow velocity in the pipe.

The vehicle will be around 1 metre in length with an approximate diameter of 300 mm. Propulsion through the water will be by electrically driven propellers placed either side of the body at the rear. The vehicle will have controlled buoyancy, neutral, negative or positive, such that it can 'swim', or 'walk' on the bottom or top of the pipe respectively

This will allow it to overcome any obstacles that may be in the pipe. 'Walking' is by means of four pneumatically controlled legs. The vehicle can flip over so that these legs are either on the bottom or top of the pipe. Buoyancy will provide the force for the legs to grip the surface.

The vehicle will be based around a chassis with the various sensors and actuators attached to it. This will facilitate easy reconfiguration of the robot for different tasks.

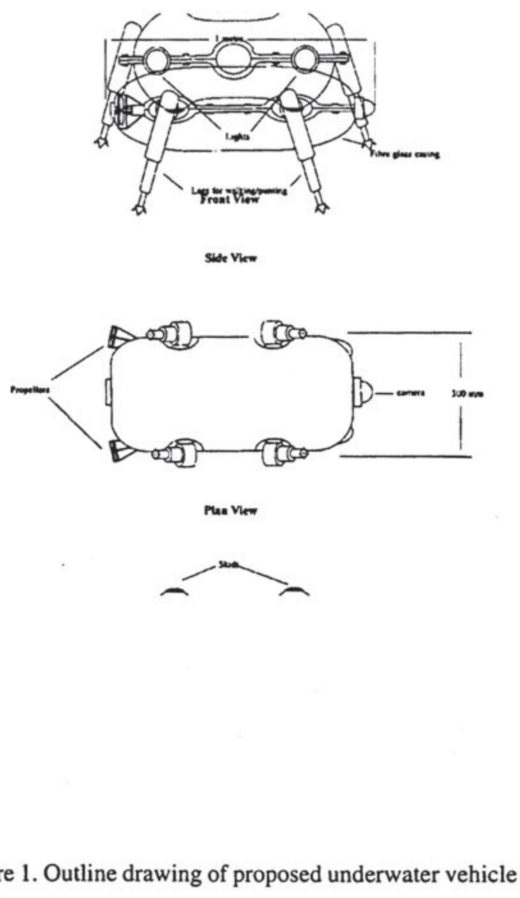

Figure 1. Outline drawing of proposed underwater vehicle

3 Communications

The key element of the design is an ultrasonic communication link of adequate bandwidth and power able to provide a sufficiently high signal to noise ratio in a duct. [1] [2][3][4][5]. This link would have a maximum transmission rate of 9,600 bps. In situations where the water flow was too turbulent, where there was a large amount of suspended solids, or bends or water bubbles which made the ultrasonics communications unstable or noisy, two alternative communications methods can be used. The vehicle is provided with both rf and infrared/fibre optic interfaces.

In concrete or plastic pipes with little reinforcing steel, the rf communications can be used. Experiments have shown that this is possible and quite adequate for pipes underground. A model of the vehicle has been controlled by rf communications at a depth of 2.5 metres in an open pool. Whilst there seem to be few problems with fresh water, experiments are contuing into the feasibility of using rf communications ins sea water.

In really difficult conditions a reinforced fibre optic cable can be attached. This will be stored inside the robot and be fed out of the rear via a cable management system. On its return the cable will be retracted back into the body of the robot. This overcomes the problems of using the on board power source for pulling a cable - the usual method for such underwater vehicles.

The communications system is bidirectional, but as the data rate for the control signals is far lower than the returned sensor/camera data, only a low bandwidth link is needed for transmitting from the control console.

4 Control system

The vehicle is controlled from a remote console, either on land if it is to be used in sub-surface pipes, or on the deck of a boat if it is to be used in submersed pipes. The console is based upon those used by Portech for controlling legged walking robots for hazardous environments, such as in nuclear power stations. [6]

The console will have a joy-stick controller for controlling the attitude and movement of the vehicle The console will have a video monitor that will show the real time pictures from the on-board camera. Initially these will be monochrome, but it is envisaged that colour video will be achieved within the same bandwidth by video processing of separate RGB signals produced by coloured flashes from a xenon flash unit on the vehicle.

There is the option of an on-board video recorder to tape information in the event of a communications failure.

Any other sensor data will be relayed to the remote console. An hierarchical structure will be used in the communications system, probably using a form of asynchronous transmission mode protocol.

As the vehicle is autonomous, and the bandwidth of the control signals is low, as much control processing will be done within the vehicle itself. A devolved and distributed control system is used. This is based around a local area network

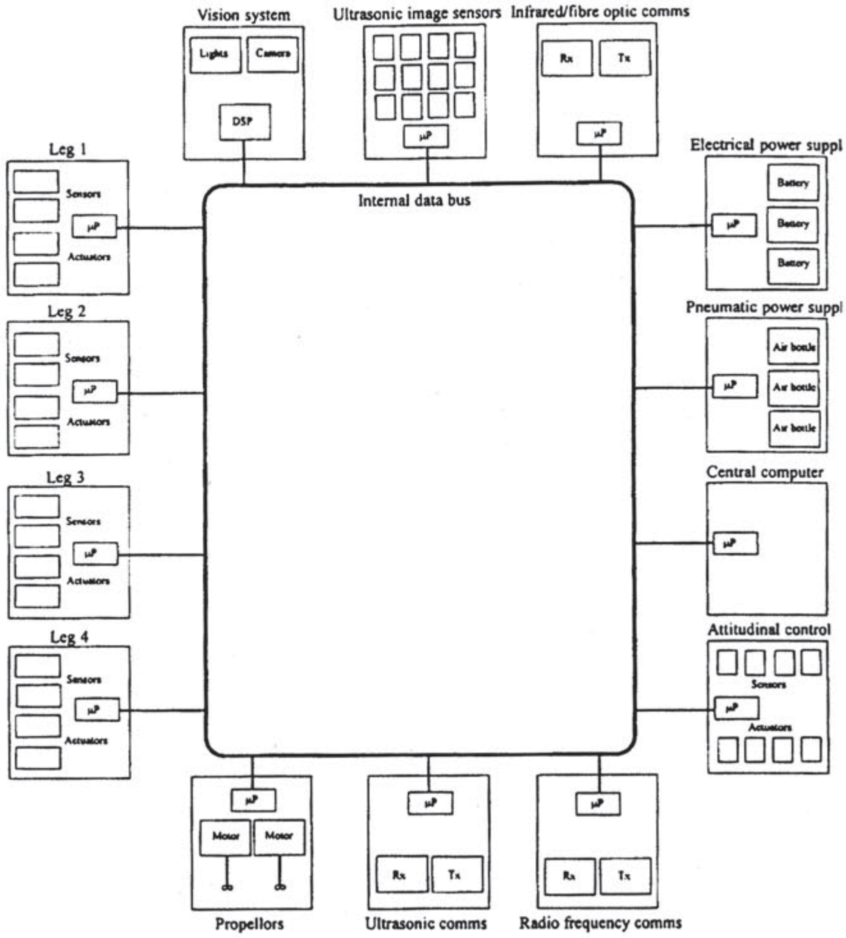

Figure 2: Schematic drawing of the control system

within the vehicle. Figure 2 shows the schematic diagram of the control hardware.

Each actuator and sensor has its own processor, which is linked via the bus to all the other processors. The actual structure of the bus has not yet been determined, but a simple two-wire system would be the optimum. Typical of the bus formats being investigated include the I^2C bus, which has been used in a number of modular mobile robots. [7] A two wire system is preferred as the shell of the vehicle is for hydrodynamic efficiency only, although it will also provide some physical protection to the electronic parts. As water will be circulating around the inside of the robot the least number of electrical connections the better. The use of a bus like the I^2C bus allows a mixture of processors to be used, thus optimising the control of each component.

5 Power and propulsion system

The vehicle has two internal power sources. The first is a compressed air supply from two carbon fibre composite cylinders, similar to those used by major fire departments. At 300 bar these can contain 1815 litres of air in a 6.8 litre water capacity. The compressed air is used for moving the legs when 'walking'.

There is also a NiCad battery on board for powering the electronics and thrust propulsion system. This has a capacity of 17 AH and can power the vehicle for about 45 mins.

The vehicle is moved by two motive power systems. The first uses compressed air to move the four legs. This allows the vehicle to traverse any small blockages. If the blockage is large, then the vehicle can turn over and go to positive buoyancy, where it can walk along the top of the pipe.

The legs are each powered by two pneumatics cylinders. The exact geometry of the legs is being investigated.

Vertical propulsion propulsion is achieved by the use of two electrically driven ducted propellers. These ducts may be movable to assist with the guidance and positioning of the robot.

6 Conclusions

An underwater autonomous vehicle has been designed that uses both legs and propellers for movement. The use of ultrasonic communications obviates the need for an umbilical. This allows the robot to have a greater range than existing vehicles. In the event that the water filling the pipe becomes too turbulent or has a large amount of suspended solid waste, or the signal becomes noisy due to air bubbles or bends in the pipe, the robot has either an rf or fibre optic communications capability.

The use of both electrical and pneumatic power for movement also adds redundancy to the motive system, thus making the robot more reliable. The use of legs for walking, buoyancy and attitude control allowing the robot to move along either the floor or roof of the pipe, and ducted propellers for swimming, gives a great degree of manoeuvrability as well as control.

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8 Appendix

<u>**Commercial Specifications for Pipe Rover**</u>

The proposed remote operating vehicle is a submersible autonomous and intelligent robot that consists of a variable buoyancy body shell fitted with both propellers and legs to provide mobility within the confined space of water filled tunnels, drain pipes, sewage outfalls having a diameter of 900 mm or greater.

The rover is aimed at the inspection and maintenance service industry. Initially, the Pipe Rover will carry a video camera with lighting. Communication will be achieved via an ultrasonic link, eliminating the need for an umbilical. In situations where such a link is not feasible, there are options for fibre optic and/or radio frequency communications.

The Pipe Rover is capable of propelling itself, after being deployed, along the pipe to the inspection point. It can then either walk along the bottom of the pipe, or, if there is debris and residue on the bottom, float upwards. It will then acquire a grip walk along the roof. Meanwhile cameras will transmit real-time images of the tunnel surface. An optional ultrasonic scanner will provide a 360^o profile of the pipe surface. This, combined with the sensors will enable to operator to inspect the pipe's condition and immediately know the Pipe Rover's location.

As the Pipe Rover is intelligent with multiple back-up systems, it can automatically recover from potentially terminal situations such as power loss or communications breakdown.

Key points:

* No umbilical (in most applications)
* Real-time video feedback
* Totally autonomous
* Intelligent
* Multiple back-up systems
* Many optional features, such as fibre optic and/or radio frequency communications

Main Features

Dimensions

Length:	850 mm
Swim mode speed:	2 m/s relative water speed
Width:	350 mm
Crawl mode speed:	0.3 m/s
Height:	250 mm
Total mission range:	1 km
Weight:	35Kg

Power

The Pipe Rover will be powered by an on-board battery pack, for the electronics and a compressed air cylinder for the legs.

Video System

Remotely controlled pan and tilt video camera.

Position Accuracy

Radial:	+/- 10 mm
Axial:	+/- 50 mm

Swim mode propulsion

Electric drive via twin contra-rotating slow propellers with protective cowl.

Crawl mode propulsion

Pneumatic cylinders provide the propulsive effort for each leg. The vehicle body is sledge shaped and, in crawl mode can proceed by either slide or walk along the bottom or top surface of the pipe using the legs.

Control Console

The control console is based upon the tried and tested Portech design.