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ROBOTIC SYSTEMS FOR INSPECTION AND EXPLORATION

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Abstract: In this paper, a classification of the in-pipe robots is presented, some representative examples of in-pipe modular robotic systems are analyzed, locomotion methods of in-pipe microrobots and the authors' contribution in this field are emphasized.

1. INTRODUCTION

The pipelines are the major tools for the transportation of fuel oils, gas, drinkable water and effluent water. A lot of troubles caused by piping networks aging, corrosion, cracks, and mechanical damages are possible, so continuous activities for inspection, maintenance and repair are strongly demanded. These specific operations as inspection, maintenance, cleaning a.s.o. are expansive thus the application of the robots appears to be one of the most attractive solutions at this time. The inspection of pipes may be relevant for improving security and efficiency in industrial plants too.

The in-pipe robots are an integration of mechanical, electrical and software subsystems, supporting one or more sensorial elements for measuring the pipe's overall state and structural integrity. One of the main subsystems in such inspection mobile systems is the mobile platform that carries the sensing and explorative end of the tool.

The robots with flexible structure may boast adaptability to the operating environment, especially to the pipe diameter, with enhanced dexterity, maneuverability, capability to operate under hostile conditions.

2. IN-PIPE ROBOTS CLASSIFICATION

• In-pipe robots can be classified into several elementary forms according to the locomotion mechanisms as shown in figure 1 [8].

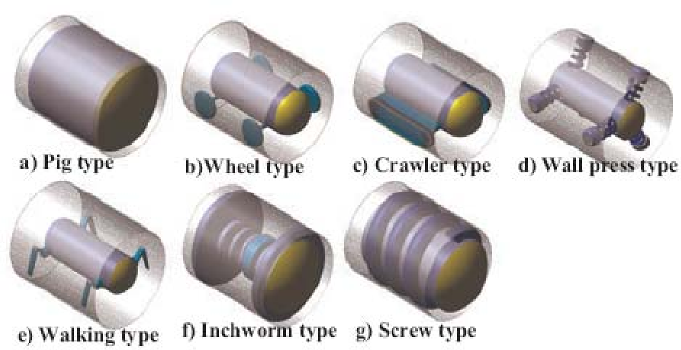


Fig. 1 Classification of in-pipe robots according to the locomotion mechanisms

- *pig type* robots – they move inside the pipelines pushed by the pressure exerted by the fluid that travels trough the pipe. The main disadvantage is that they can be drawn to rotate around their central axis

- *wheeled* robots – they have the advantage of easy speed and direction control but they are limited by the energetic factor and they can also tip over, therefore remaining blocked inside the pipe
- robots *with tracks* – they are very stable and they can pass certain obstacles that may appear inside the pipes, but like the wheeled robots, these too can tip over
- robots *with flexible elements* – they are built with flexible elements that press against the interior surface of the pipe therefore fixating them completely. They have the advantage of being able to move trough vertical pipe sections and adapt to different pipe diameters
- *legged* robots – they are built with articulated legs and can perform several types of movements inside the pipes
- *inchworm type* robots – they are used mostly for small diameter pipe inspections
- robots *that move using axial rotation* – they move by imitating the helical rotation of a screw.

Most of this robots were designed to perform certain tasks.

• According to their *autonomy,* the mobile in-pipe robots for inspection-exploration tasks can be classified as follows:

- *permanently* remote controlled robots by human operators, which command and control all the tasks, including the elementary ones;
- *periodically* remote controlled robots by human operators, which control only global decisional level;
- *autonomous* robots that are able to perform the predefined tasks based on their own decision ability, working in a partially known environment.

• According to their *mechanical structure,* the in-pipe robots are:

- *robots with a rigid structure* – used to inspect pipes with a certain diameter,
- *robots with an adaptable structure* – they contain mechanisms that allow to adapt to different pipe diameters.

The above mentioned robots generally travel along horizontal pipelines, but some of them move along vertical pipelines or elbows bend pipes or L-shaped pipes. Only few of them can navigate trough T-shaped pipes or in vertical pipes.

An important feature of these robots is the ability to navigate trough several pipe configurations, overcoming obstacles and achieving their main objective as well.

A special category of inspection systems are the *modulated robotic systems for inspection and exploration* that have an adaptable structure which allows them to adapt to the diameter and shape of the pipe they are navigating in.

These mobile systems are developed in several constructive types and they are designed to use different types of locomotive systems, actuating systems, sensorial subsystems and special communication modules.

Generally, movement inside the pipes is accomplished using wheels, legs, tracks or a combination between these three.

When developing such a robot, along with their locomotive system, a series of constraints must be considered: the aspect of the pipe, the debris inside the pipe, the pipe curvature (depending on the radius of the curved pipe the system may encounter problems when traveling), the alternance between horizontal and vertical pipe sections, the variation of the pipe diameter, the state of the inner surface of the pipe, the distance that the robot must travel, the pipe’s rigidity, cracks that may appear in the pipe’s surface, the material that the pipe is made of (electric conductors or isolators).

Most of the urban or industrial environments contain pipe systems used for the transport of water, oil, gas or other fluids. The pipe systems have variable configurations and diameters, from several centimeters to even meters. For this kind of pipe systems the need for a robotic system with superior mobility is perfectly justified.

Some of the most representative modulated systems for in-pipe inspection and exploring are presented in the following images [1], [2],[3], [4], [5], [13], [12].

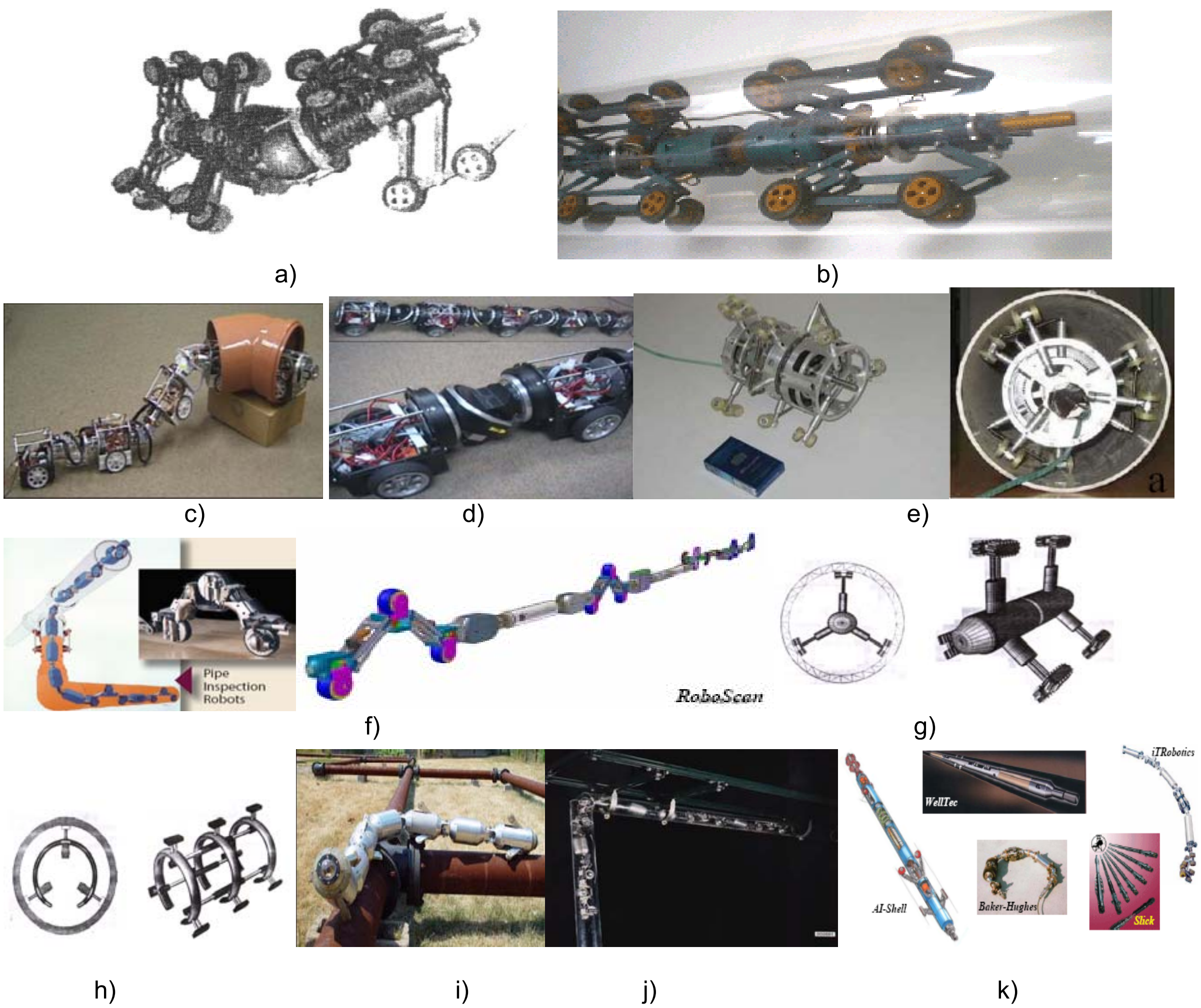


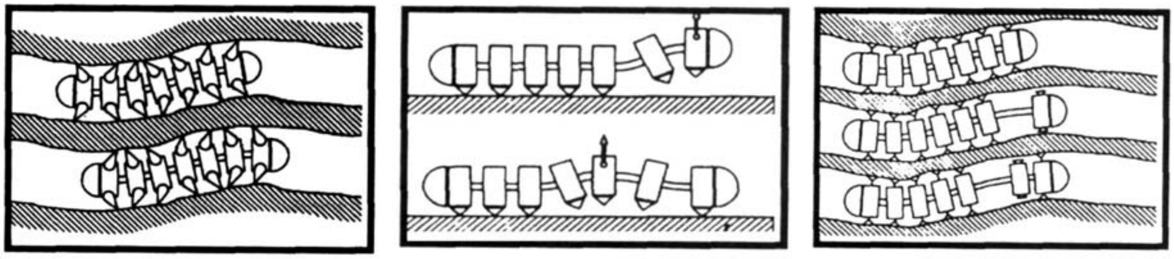
Fig. 2 Some representative robotic systems for inspection and exploration

3. LOCOMOTION METHODS OF IN-PIPE MICROROBOTS

In case of microrobots displacement in pipes or in narrow spaces or sinuous are distinguished three ways of locomotion:

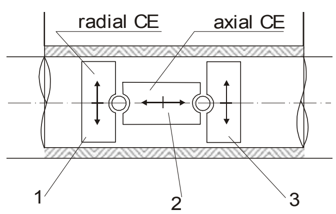
- *scolopendric locomotion (*Fig. 3a*)* – that is used in inextensible structure, articulated after two orthogonal axis;
- *peristaltic locomotion* (Fig. 3b) – at which it is realized the lateral displacement of a new module (cell) compared to the neighbor modulus;
- *locomotion of type inchworm* (Fig. 3 c).

The structure of an in-pipe inchworm microrobot is presented in figure 4. Figure 5 shows the successive stages of one step [11], [10].



a) b) c)

Fig. 3 Locomotion in pipe microrobots



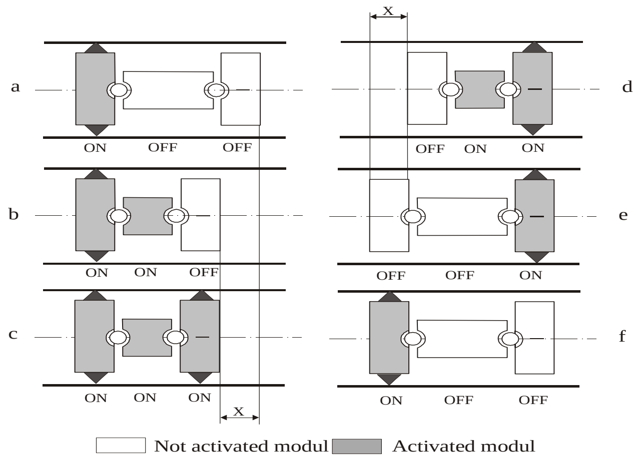


Fig. 4 The structure of an inchworm minirobot

Fig. 5 The cycle of inchworm locomotion

The microrobot body is constituted by three modules: two of them (1, 3) are able to work in radial contraction-extension (C-E) to take support on the walls, called blocking / support modules or grippers and one module (2) is able to work in axial contraction-extension to create a step (it is called central module or extensor).

The main advantage of the microrobot of three modules is the possibility to take bends well or to change direction at forks. Using high-performance actuators, locomotion in vertical pipes is possible. The speed of this mobile system is given by the frequency of the locomotion cycle stages. This variant takes the advantage of an unsophisticated structure, allowing miniaturisation.

Figure 6 shows an image of microrobot, which is operated under complete wireless link condition. This microrobot travels in a 10mm metal pipe without wire, takes pictures of inside the pipe, and transmits the image data back to an outside host. Image transmission, signal communication and energy supply are done via microwave and light.

The locomotive mechanism consists of eight layered PZT bimorph actuator, a center shaft which connects the center of the each bimorph, and four cramps which connect the edges of the each bimorph as shown in Figure 7 [6].

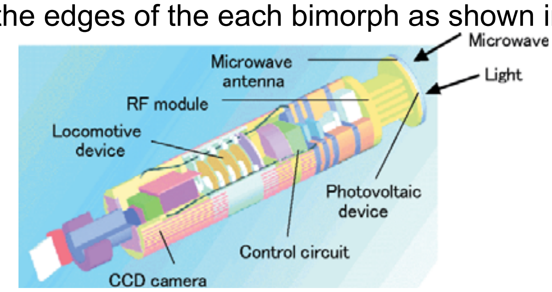


Fig. 6 System image of wireless microrobot for inspection on inner surface of tubes

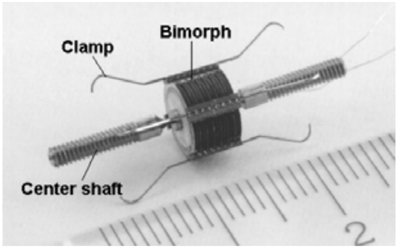


Fig. 7 Locomotive mechanism of 8-layered PZT bimorph actuator

In figure 7 there is presented a microsystem used for inspecting and repairing of complex equipments. This system is composed from: base module, inspection module, repair module and capsule.

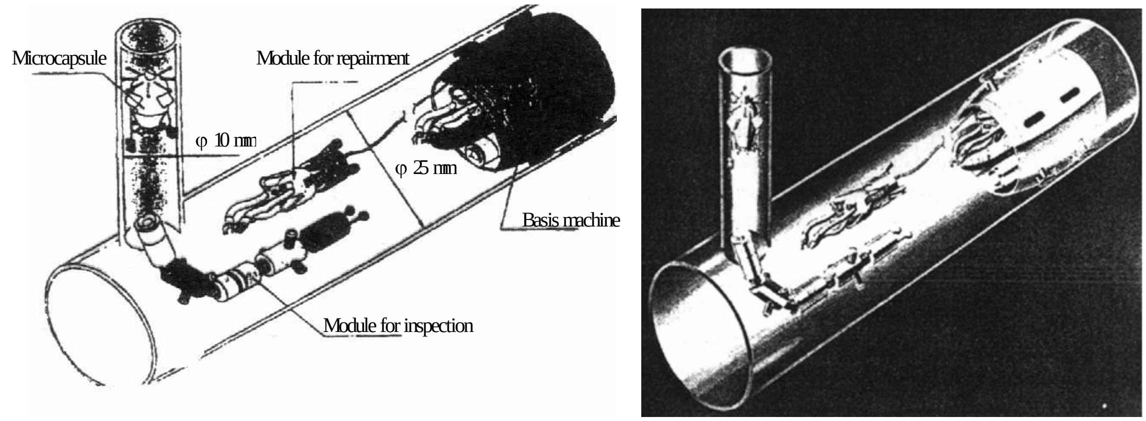
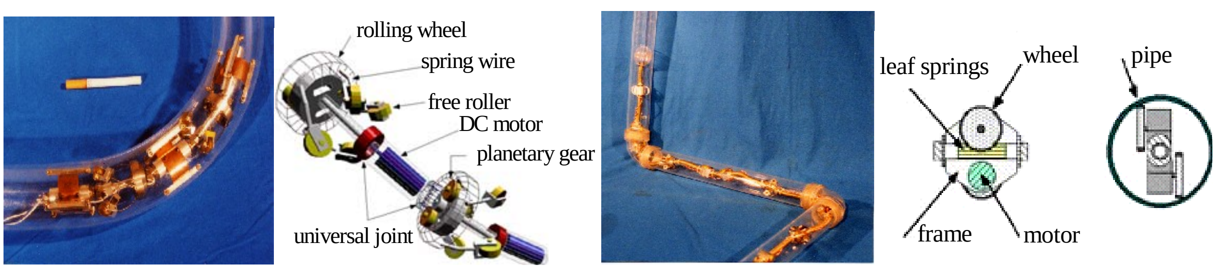


Fig. 7 Microsystem for inspecting and repairing

Other examples of microrobots with wheels from this category are presented in figures 8 b and 8 c [5].



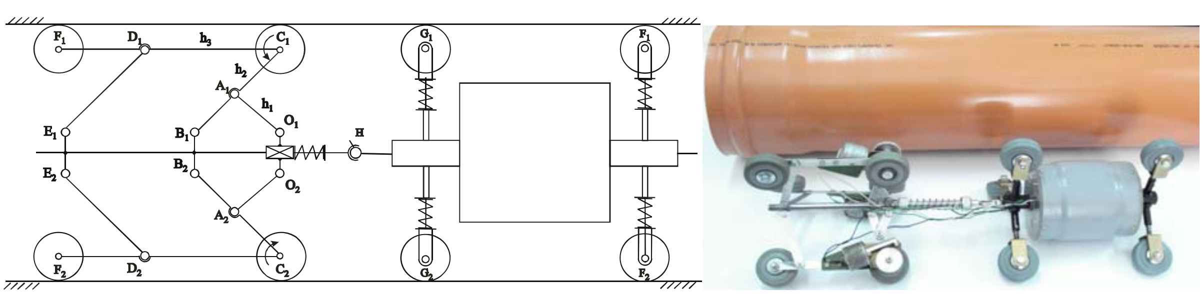
c)

Fig. 8 Some representative microrobotic systems for inspection and exploration

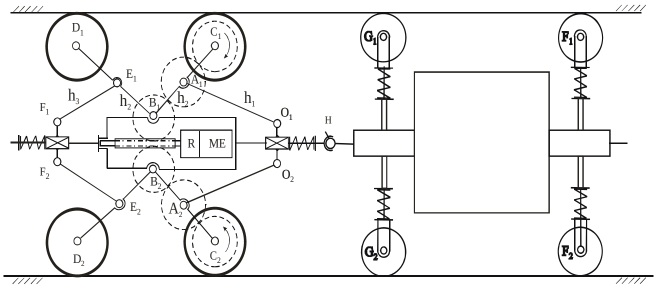
4. THE DEVELOPED SYSTEM

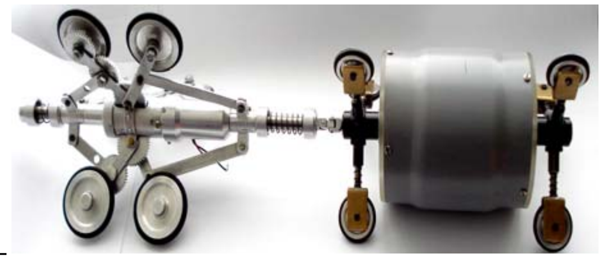
In this paragraph is presented the contribution of the authors in the field of in pipe modular robotic systems (Fig. 9).

These modular systems are composed of driving modules (which use mechanisms with articulated elements) and passive modules. The first module (driving module) generates the traction force. The passive module is necessary to carry the control electronic equipment and for the transport of the needed equipment for realization of the in-pipe inspection.



a) b)





c) d)

Fig. 9 Structural schemes (a, c) and the photograph of in pipe modular robotic systems (b,d)

CONCLUSIONS

In-pipe robots play an important role in the pipe-network maintenance and their repairement. Some of them were designed to realize specific tasks for pipes with constant diameters, and other may adapt the structure function of the variation of the inspected pipe.

In this paper two wheeled-type in-pipe modular robotic system are proposed. A very important design goal of these robotic systems is the adaptability to the inner diameters of the pipes. The two presented prototypes and realized permit the usage of a minicam for realization of the in-pipe inspection or other devices needed for failure detection that appear in the inner part of pipes (measuring systems with laser, sensors etc).

BIBLIOGRAFY

[1] Explorer: Untethered Real_time Gas Main Assessment Robot System, 1st International Workshop on Advances in Service Robotics, ASER'03, Bardolino, Italy, March 13-15, 2003.
[2] Elkmann, N., Saenz., J., Felsch, T. Altrock, M., Sack, M., - Investigating kinematics concept for the automatic inspectio and cleaning of a sewer canal, Proceedings of 5th International Conference on Climbing and Walking Robots, (CLAWAR 2002), Paris, France, 2002, pp. 971-977.
[3] Gradetsky, V., Veshnikov, V., Kalinicchenko, S., Kniazkov, M., Solovtsov, V., - Miniature robot control motion inside of tubes, Proceedings of 5th International Conference on Climbing and Walking Robots, (CLAWAR 2002), Paris, France, 2002, pp. 643-650,
[4] GRISLEE: Gasmain Repair & Inspection System for Live Entry Environment, CLAWAR'01 Special Issue of the International Journal of Robotics Research, March-April, 2003, Vol. 22, Nos 3 and 4.
[5] Hirose, S., Ohno, H., Mitsui T., Suyama, K., - Design of In-Pipe Inspection Vehicles for ø25, ø 50, ø 150 Pipes, Journal of Robotics and Mechatronics 12, 3, 2000, pp. 310-317.
[6] Mitsumoto, N., Tsuruta, K., Shibata T., Kawahara, N., - Wireless Link System for Communication and Energy Transmission of Microrobot, International Symposium on Micromechatronics and Human Science, 2001, pp. 107-112.
[7]. Roh S.G., Ryew S. M., Choi, H.R., - Development of Differentially Driven In-pipe Inspection Robot for Underground Gas Pipelines. Proceedings of International Symposium on Robotic (ISR 2001), 2001, pp. 165-170.
[8]. Roh S., - Navigation Inside Pipelines with Differential Drive Inpipe Robot, IEEE International Conference on Robotics and Automation, ICRA 2001, Seoul, Korea.
[9] Ryew, S.M., Baik, S.H., Ryu, S.W., Jung, K.M., Roh, S.G., Choi, H.R. - In-pipe inspection robot system with active steering mechanism, Intelligent Robots and Systems, (IROS 2000); Proceedings. 2000 IEEE/RSJ International Conference on, Vol. 3, 2000, pp. 1652 -1657.
[10]. Tătar, O., Maties, V., Mandru D., - Mini si microroboti, Editura TODESCO, Cluj-Napoca, 2005.
[11] Tătar, O., Mândru, D., - In-pipe robots, Proceedings of the 8th International Conference and Mechatronics and Precision Engineering COMEFIM 8, in Acta Technica Napocensis, 49, 2006, vol. II, pp. 157 – 162.
[12] Tătar, O., Mândru, D., Ardelean, I., Development of mobile minirobots for in pipe inspection tasks, Mechanika Journal, Nr. 6(68), 2007, pp. 60-64,
[13] State-of-The-Art Review - In-Pipe-Assessment Robot Platforms Carnegie Mellon University The Robotics Institute Pittsburgh, November 30th, 2004.