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Development of mobile minirobots for in pipe inspection tasks

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1. Introduction

Robotics is one of the fastest growing engineering fields of today. Robots are designed to remove the human factor from labour intensive or dangerous work and also to act in inaccessible environment. The use of robots is more common today than ever before and it is no longer exclusively used by the heavy production industries.

The inspection of pipes may be relevant for improving security and efficiency in industrial plants. These specific operations as inspection, maintenance, cleaning etc. are expensive, thus the application of the robots appears to be one of the most attractive solutions. The pipelines are the major tools for the transportation of drinkable water, effluent water, fuel oils and gas. 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 [1, 2].

The robots with a flexible (adaptable) structure may boast adaptability to the environment, especially to the pipe diameter, with enhanced dexterity, manoeuvrability, capability to operate under hostile conditions.

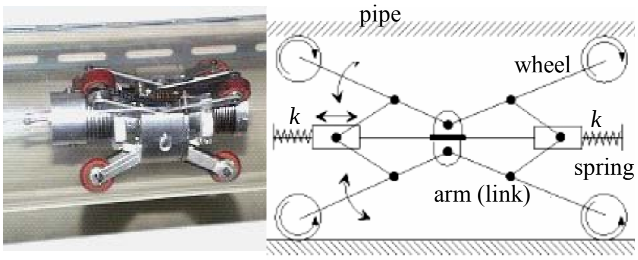
The wheeled robots are the simplest, most energy efficient, and have the best potential for long range. Loading the wheels with springs, robots also offer some advantages in manoeuvrability with the ability to adapt to in-pipe unevenness, move vertically in pipes, and stay stable without slipping in pipes.. These types of robots also have the advantage of easier miniaturization.

The key problem in their design and implementation consists in combining the capacity of self-moving with that of self-sustaining and the property of low weight and dimension. A very important design objective is represented by the adaptability of the in-pipe robots to the inner diameters of the pipes.

2. Analysis of the linkages in the structure of adaptable in-pipe robots

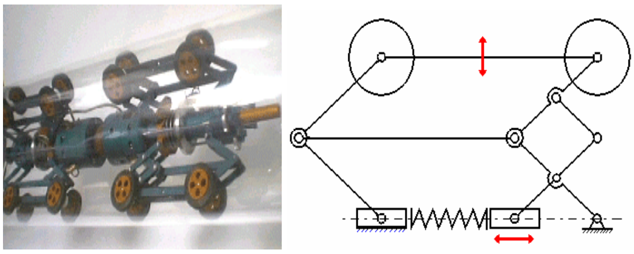
Most of the in-pipe robots take the mechanisms derived from several basic mechanisms or their combinations. For example, the robots in Figs. 1, a, 2, a, 3, a are based on the mechanisms given in Figs. 1, b, 2, b respectively 3, b [2, 3].

In Fig. 1, the picture and the kinematic scheme of the in-pipe inspection robot called MRINSPECT I (*Multi-functional Robotic crawler for INpipe inSPECTion*) [2] is presented. It has six slider-crank mechanisms, arranged at 120° one from each other, each of these having a driving wheel. The wheels are actuated by DC motors, and belt transmission. The robot is designed as the springs to actuate the mechanisms with equal forces. This structure allows the robot to move within pipes with horizontal, vertical, and elbow-typed portions. The movement of the robot within *T* junctions is not possible.



a b

Fig. 1 MRINSPECT I in-pipe robot (a) and its basic mechanism (b)



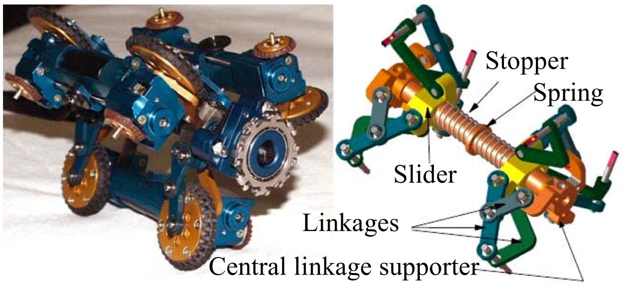
a b

Fig. 2 MRINSPECT II (a) and its corresponding mechanism (b)

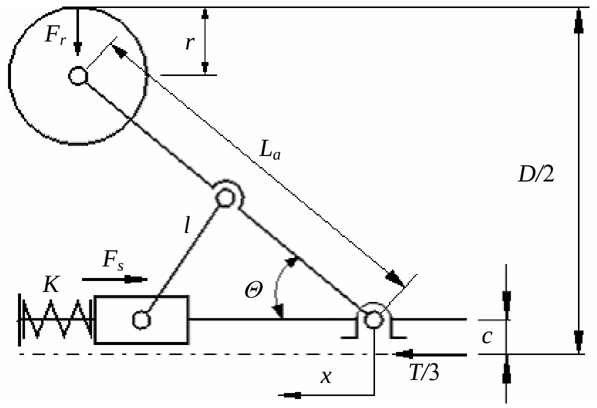
Another type of mechanism which can assure the adaptability of robots to different pipe diameters is the modified pantograph, used in the structure of the MRINSPECT II robot (Fig. 2) [2]. This mechanism allows the movement of the wheels along the radial direction. This aspect is very important, because distortion forces no longer appear, as the robot passes over the obstacles. For the control of the pushing force over the inner surface of the pipe, a linear actuator and two position sensors are used.

The in-pipe inspection robot *MRINSPECT IV*, presented in Fig. 3 contains a mechanism which allows it to adapt its structure to the pipes' diameter. This mechanism helps also to assure the direction of the robot, when it passes through elbows and *T* junctions [2].

Three types of pipe inspection robots, Thes-I, Thes-II and Thes-III, for the gas pipes of 50 mm and 150 mm in diameters are shown in Fig. 4 [3].

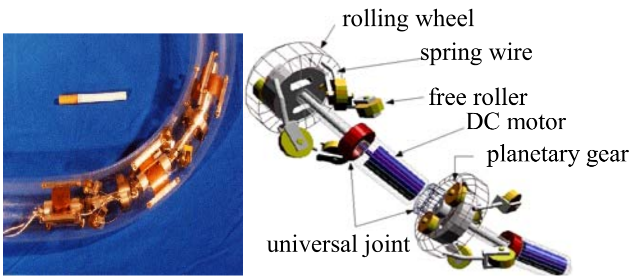


a

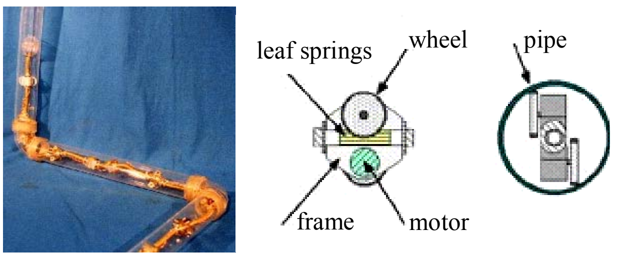


b

Fig. 3 MRINSPECT IV (a) and its corresponding mechanism (b)



a



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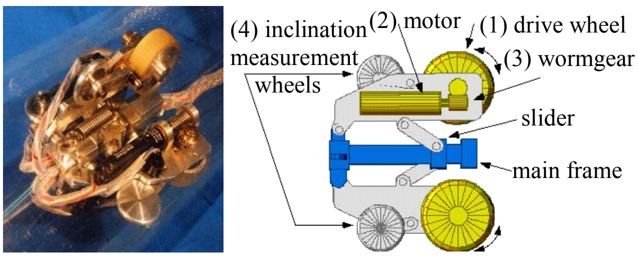


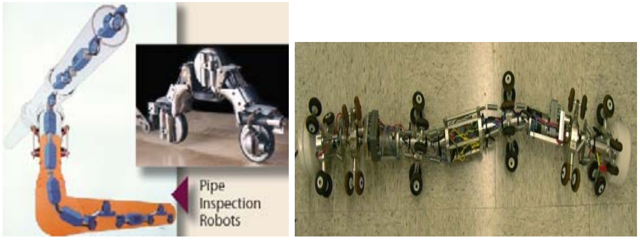
c

Fig. 4 Mobile Robots Thes-I (a) Thes-II (b), Thes-III (c) and their corresponding mechanisms

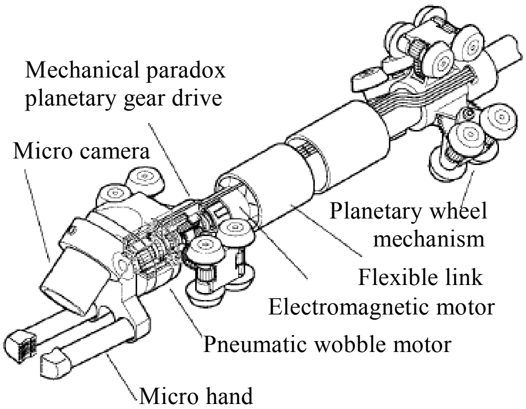
Other structures of this type of robots presented in the literature [3-5] are shown in the following Figs. 5-8.

3. The developed in-pipe minirobots

The first prototype - In Fig. 6, it is given the first constructive variant of an in-pipe inspection minirobot, which was designed, modelled and developed. The minirobot contains three linkages mechanisms, symmetrically disposed along the longitudinal axis of the robot [9, 10].



a b



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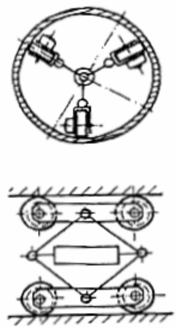
d



e f

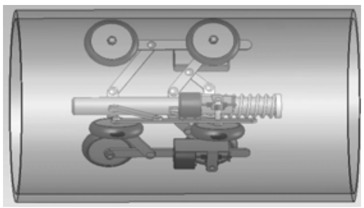
Fig. 5 In-pipe inspection robots with adaptable structure: RoboScan (a), Pipe Crawler (b), Robot for 1 inch pipes (c), Mogler (d), HELI-PIPE (e), Schemes of tried wheels robot (f)

The force that the minirobot mechanism exercises on the pipe walls is generated with the help of an extensible spring. The helical spring disposed on the central axis assures the repositioning of the structure, in the case of the pipe diameters' variation. The components of the minirobot are, (Fig. 6, c): *1* – helical spring, *2* – translational element, *3* – actuator support, *4* – worm wheel, *5* – worm gear, *6* – actuator, *7* – central axis, *8* – link, *9* – wheel.

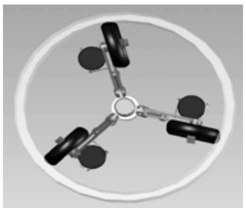
The wheels at the back are driven by three DC SANKO motors, through reduction transmissions. The weight of the minirobot (the weight of current feeding wires is also considered) is 987 g, and the wheels have the radius *r* = 25 mm and the length 17 mm; the component elements have the lengths: $h_1 = 30\text{ mm}$, $h_2 = 70\text{ mm}$, $h_3 = 105\text{ mm}$.

In the present paper, we proposed two wheeled type in-pipe minirobots characterized by an adaptable structure based on linkages mechanisms. Compared with the above-presented robots, our prototypes are characterized by a simple structure and kinematics, small number of actuators, light weight, low power consumption.

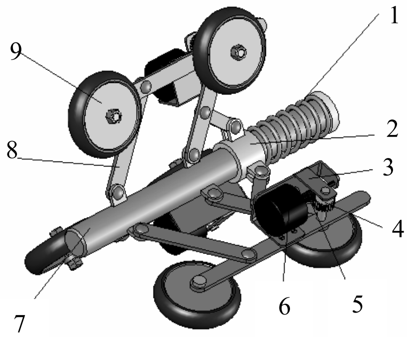
The actuation of the driver wheels is made through two worm gears with $z_1 = 1, z_2 = 52$. This minirobot has movement capacities for inspection in 140 - 200 mm diameter pipes in horizontal or vertical configuration.



a



b



c

Fig. 6 The 3D model of the minirobot in pipe (a, b), components of minirobot (c)

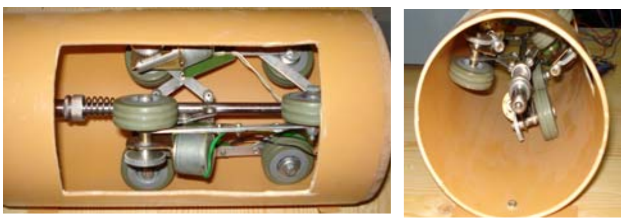
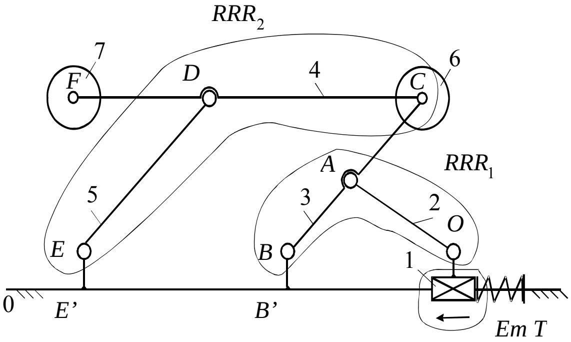


Fig. 7 Picture of the developed in-pipe minirobot

In the robot's structure, there is a mechanism (Fig. 8, a), composed of a translational input element, and two strutural (Assur) groups RRR, (EmT(1) + RRR(2,3) + RRR(4,5)).



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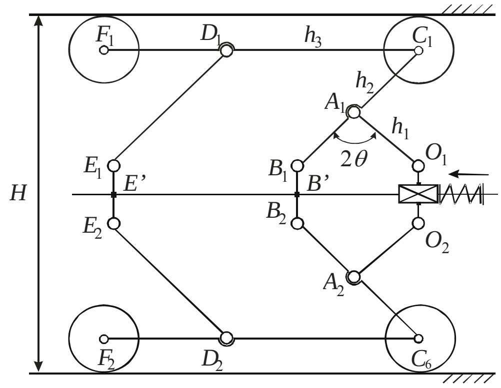


b

Fig. 8 Elementary mechanism (a) and the structural scheme of the minirobot (b)

The robot's height can be determined with the relation ($h_1 = OA, h_2 = BC = DE, h_3 = CF$)

$$H = 2r + 2d + 2h_2 \cos(\theta) \tag{1}$$

where *r* is the radius of the wheels and *d* is the distance EE' (EE'= *d* = 28 mm).

The maximum and minimum height of the robot can be determined based on the angle *θ*, ($\theta \in 15° \div 60°$) and on the lengths of the elements h_1, h_2, with the relation [4]

$$H_{min/max} = 2r + 2d + h_2 \cos(\theta_{max/min}) \tag{2}$$

where θ_{min} and θ_{max} are the maximum and minimum limits of the angle θ.

The minirobot is powered through wires and it is controlled with the aid of a microcontroller *ATMEL Atmega8535*. An interface realized in *Delphi* software was developed. The drive DC motors can be powered with the voltage between 3-12 V. The presented structure allows the usage of a CCD camera for pipe inspection or other devices needed in detecting of a malfunction in the pipes (remote-controlled laser measuring systems, sensors).

In Fig. 9 the 3D model of the minirobot in a curved pipe is illustrated.

For pipes with elbows (tubular network in T or L shape) we propose the usage of minirobot which is made of two modules connected with a spherical joint. The model of this structure, which will be developed in the near future, is presented in Fig. 10.

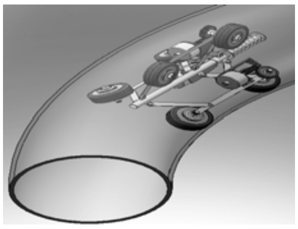
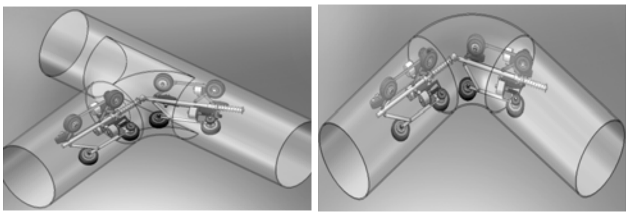


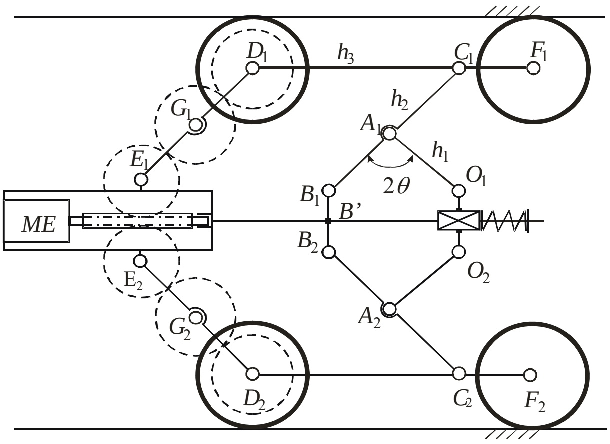
Fig. 9 3D model of the minirobot in a curved pipe



a b

Fig. 10 3D model of the minirobot in a tubular network pipe in T (a) or L (b) shape

The second prototype - Another constructive solution that uses a similar structure with the first prototype is presented in the Fig. 11.



a

b

Fig. 11 Structural scheme (a) and photograph of the minirobot (prototype 2) (b)

It is more compact from the constructive view point and uses a single DC motor for actuation, disposed on the main axis of the minirobot (module no. 1). Transmission of motion from the driving motor to the wheels of the minirobot is realized using three transmissions with gears (Fig. 12). The DC motors equipped with speed reducer can be powered with the voltage between 4-6 V. The maximum current is 50 mA and maximum torque is 220 Ncm.

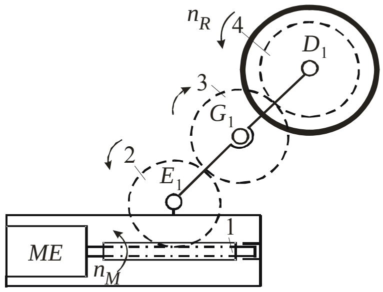


Fig. 12 Transmission with gears in the structure of the minirobot

One of the most important issues in the design of the mechanism from the structure of the robot is how to obtain the traction power enough to pull instrumentation and the robot itself. On the condition that the wheels do not slip over pipe surface, the traction force by wheel is proportional to the friction coefficient and pressing force between the wheel and the pipe surface. Since the friction coefficient depends on the wheel material and surface condition of pipe, the link mechanisms that are able to adjust the wall pressing force are to be designed.

We note: *1* – worm, *2*, *3*, *4* – gears, $z_1=1$ one thread, $z_4 = 44$ teeth.

Denoting with n_M the motor rotation frequency and with n_R motor wheel rotation frequency from the expression of gear ratio

$$i_{MR} = \frac{n_M}{n_R} = i_{12} i_{23} i_{34} \tag{3}$$

The angular speed of the driving wheels of the minirobot is obtained

$$n_R = \frac{z_1}{z_4} n_M \tag{4}$$

For the development of a modular robotic system a second module having in its structure the same mechanism (Fig. 13) was realized.

Fig. 13 Second module with the same structure

Using the two modules (Fig. 11 and Fig. 13) connected by a universal joint a prototype of a modular robotic system with adaptable structure, as is presented in Fig. 14, was developed. The first module (Fig. 11) generates traction force. The joint disposed by the two modules of the robot offers the capacity of orientation of this one.

The second module is necessary for the transportation of the necessary equipment for performing the in-pipe inspection.

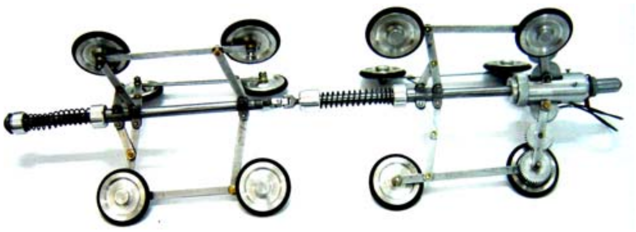


Fig. 14 The photograph of the modular robotic system

4. Conclusions

In this paper two wheeled-type in-pipe minirobots are proposed. A very important design goal of these robotic systems is the adaptability to the inner diameters of the pipes. Thus, the studied minirobots are characterized by an adaptable structure, based on linkage mechanisms.

The prototypes were designed in order to inspect pipes with variable diameters within 140 and 200 mm. The modular robotic system is still in the phase of development.

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MOBILIŲ MINIROBOTŲ, SKIRTŲ VAMZDYNŲ DIAGNOSTIKOS UŽDAVINIAMS, KŪRIMAS

R e z i u m ė

Nagrinėjamos miniatiūrinių robotizuotų sistemų panaudojimo galimybės vamzdynų diagnostikai, tyrimui ir aptarnavimui. Straipsnyje detaliai aptartas autorių indėlis šioje srityje. Apibūdinti du autorių sukurti vamzdynams skirti minirobotai. Pagrindinis dėmesys skiriamas mobilumui vamzdyno viduje ir atitinkamoms vykdymo sistemoms. Pateikiama keletas funkcinių charakteristikų (pvz.. maksimalus/minimalus vidinis vamzdžio skersmuo).

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DEVELOPMENT OF MOBILE MINIROBOTS FOR IN PIPE INSPECTION TASKS

S u m m a r y

The possibilities to use a miniaturized robotic system for inspection, exploration and maintenance of the pipes are highlighted. In this paper, the authors' contribution in this field is discussed. Two in-pipe minirobots developed by the authors are described. The efforts are focused on the in-pipe mobility and corresponding actuation systems. Several functional characteristics (e.g. the maximum /minimum inner pipe diameter) are given.

О. Татар, Д. Мандру, И. Арделеан

РАЗРАБОТКА МОБИЛЬНЫХ МИНИРОБОТОВ ДЛЯ ВНУТРЕННЕЙ ДИАГНОСТИКИ ТРУБОПРОВОДОВ

Р е з ю м е

Обсуждаются возможности использования миниатюрных роботизированных систем для диагностики, проверки и обслуживания трубопроводов. В статье подробно обсужден личный вклад авторов в этом направлении. Характеризованы два трубопроводных минировота, разработанные авторами. Особое внимание уделено вопросам мобильности внутри труб и соответствующим системам приводов. Представлены некоторые функциональные характеристики (например, максимальный/минимальный внутренний диаметр трубы).

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