

Design and construction of an inspection robot for the sewage pipes

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Abstract. Robotic systems are used wherever human limits are achieved. The inspection robots are used for securing the access to the manholes, pipes and sewage systems, for monitoring faults and for the eventual minor repairs. The paper presents the design, construction and assembly of a four-wheeled inspection robotic rover used in sewage pipes with diameters larger than 200 mm. We managed to design the robust, waterproof and dirt-resistant washable rover solution, which has been proved to be very functional and easy to produce.

1 Introduction

Robotics is one of the fastest developing branches of industry and robots are presently used wherever working conditions are difficult, unsafe, often recurring or otherwise limited. Attention is focused on the robotic systems capable of controlled movement and the inspection of inaccessible pipe systems. It is the only way how to inspect cleanliness, leakage, mechanical damage or the corrosion level and also to identify recovery spots [1-5] directly beneath the surface.

It is currently usual that piping systems are inspected by full autonomous robots or by cable-tethered robots with a remote control by human operator being on the ground [6-7]. Fully autonomous inspection robots are able to inspect vast area of sewage pipes. Moreover, fully autonomous robots depend on some form of intelligence [8-10] allowing them to move in various piping systems, where the only limitation is the battery capacity. In this case, a robot without a cable connection is difficult to be picked up from a pipeline. On the other hand, cable-tethered robot can be pulled by the cable out of the pipeline in case of failure. The length of the cable is the limiting factor for the distance to be inspected. The operator controls the robot from the outside of the piping system and monitors the area by an inspection camera placed on the robot.

In-pipe robots have long history and several mechanical concepts [11] were developed until now. The geometry and environment are the determining factors to which the robots are able to adapt. A wide-spread type is a wheeled robot with differential driving [12]. The caterpillar type is preferably used on uneven surfaces to overcome obstacles [13].

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Legged or snake robots are used for branched pipe systems [14], both are characteristic by their mobility. Further, the inchworm type of robot is able to move in curved pipes. The screw type robot has rather simple structure, nevertheless the control reacts slowly [15].

Recently, a number of developers are dedicated to the construction of more complex robots with hybrid locomotion [16-18].

In this paper, we focus on the design, development and construction of the in-pipe inspection robot intended to be used in the sewage pipes with diameters larger than 200 mm. The wheeled moving mechanism was considered in order to realize the inexpensive and robust inspection robot, equipped with an inspection camera at the front, and operated by the human operator on the ground surface. Following chapters describe the main construction units of the robot that were designed and assembled in Solid Edge software. Unless otherwise specified below, non-standard parts were fabricated on a CNC machine tool from duralumin work material.

2 Requirements

Following criteria that the inspection robot must meet were determined. The robot should consist of a small size inspection camera with a minimal viewing angle of 180°. The robot must have regulated movement back and forth at a constant speed. Cabling must include not only a power wire and wire for Ethernet communications, but also a string for towing in case of failure.

Wheels should be appropriate for the environment of sewage pipes both for tire tread design and material, and must ensure their interchangeability. An important condition is the ability to upgrade the entire control system, as well as individual elements and the CCD camera also for the reason of repair.

Water resistance is the next requirement for washing up after pulling out of sewage pipe, together with overpressure in the body of the robot, so that the external environment will not pervade inside, furthermore there is requirement for stiffness, LED lights for the camera system and easy portability.

3 Vision system

Structural arrangement of the whole camera (Fig. 1) has been designed to meet the demands of working in sewage polluted environments, and it has been done with the requirement to be leak-proof.

For the sensing of the area inside of the drain, the pipe camera Rasberry Pi has been used, which capable is of transferring the pixel data at extremely high speed. Lens OFISH-125MIR XtendLan with a range of 185 degrees have been used. A lens are attached to the camera holder, which we designed using CAD software and manufactured on a CNC milling machine.

The three LEDs (each with an output of 1 W) are attached to the surface of the camera holder. Camera housing was made of (spare parts for industrial camera) cover hemisphere and the ring of PMMA produced by CO₂ laser machining equipment. The two housing parts have been joined after assembly into a single unit sealed with silicon. The clamping ring keeps attached the cover hemisphere to the camera holder. Sealing rings have provided protection against intrusion of dirt.

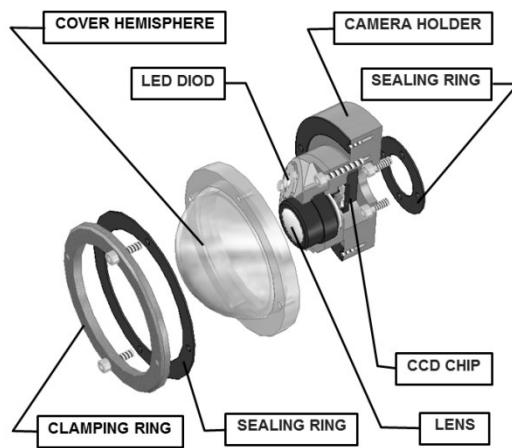


Fig. 1. Camera module.

4 Motion unit

The drive unit (Fig. 2) was designed to operate at speed of 0.2 ms^{-1} . It was made by the company Maxon (power rating 90W, speed 7270 rpm stall torque 966 m). The transfer of the drive torque to the front axle of the robot has been achieved through the transmission (Haberkorn 2 T20 / 20), the transfer ratio has been 1:1.

For more efficient movement of the rear axle gear we used a sprocket ($6 \times 2.8 \text{ T23}$) and chain. Wheels have been compiled from three parts of the hub, plates and tires. The hub and plates were manufactured using CNC milling. Similarly, a mold for vulcanizing the tires was made.

The modular design allows more solutions. We have chosen interchangeable wheels for a larger diameter waste pipe. Tires can be exchanged according to the surface of the pipe walls.

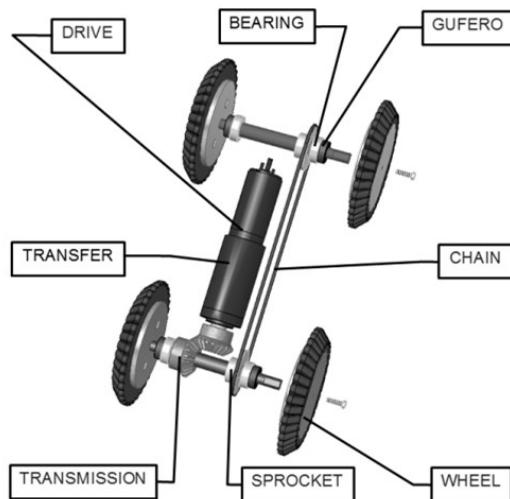


Fig. 2. Drive unit.

5 Electronics unit

Electronics unit (Fig. 3) includes a microcomputer (Raspberry PI), H-Bridge and Convertor. These were assembled by using the robot mounting board. The mounting board was modelled in 3D with CAD and CNC machining milling using polymer PA. Their interconnection is shown schematically in Fig. 4.

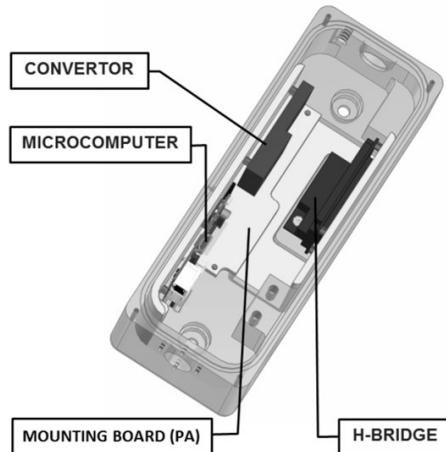


Fig. 3. Electronics arranged on plastic mounting board.

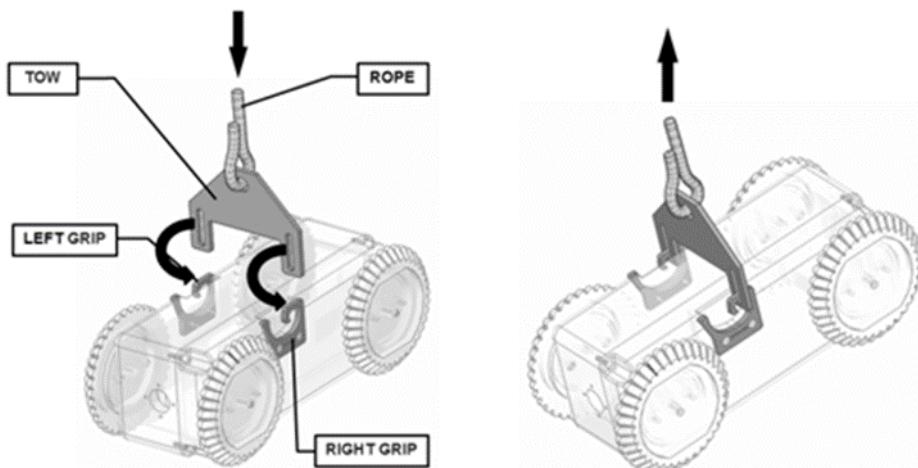


Fig. 4. Diagram of the electronic part of the robot.

6 Handling

Handling parts (Fig. 5) consist of the left and right grips for the location of the hinge for the rope, by which the robot is inserted into the waste pipe. Before the action the tow together with a rope are pulled out of the pipe. After the inspection the pipeline robot is removed by the same tow with a rope. Handling elements (left and right grip, tow) were created using CAD and produced using a CNC milling machine.

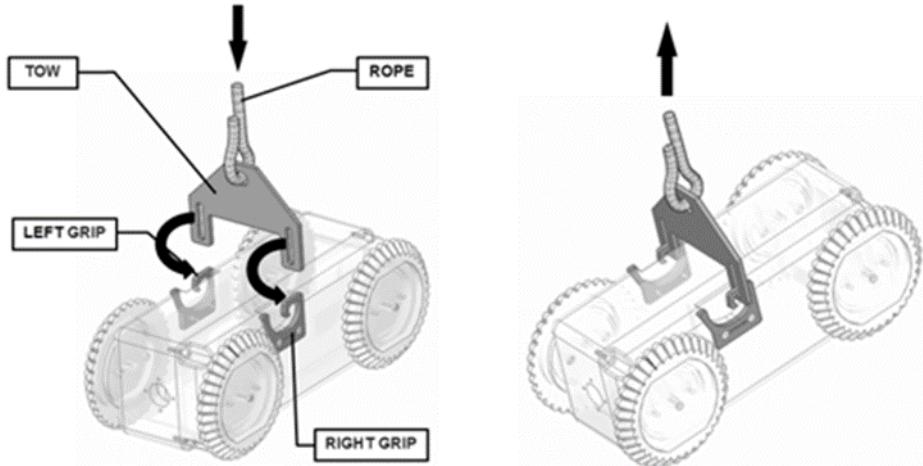


Fig. 5. Process of pulling out robot from the pipe.

7 Outer body

The outer body (Fig. 6) which we proposed is divided into the left and right section for easy assembly and disassembly. The design of the inside of the covers has been adapted to meet the requirements for placement of Motion unit (into mounting protrusion) and Electronics unit (pocket created for electronics). External surfaces of the body are manufactured so that the grips can be flush fixtured. The seal groove has been milled in the left cover. The seal is intended to prevent the intrusion of impurities inside the body. A hole has been created for insertion of a cycling valve in the left cover. The outer body was modelled using CAD and produced on CNC milling machine. Both parts of the outer body were manufactured from a single blank of aluminium alloy.

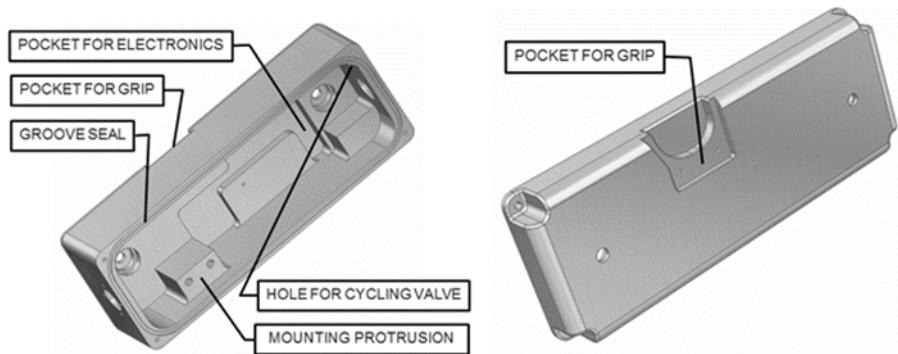


Fig. 6. Left and right cover of outer robot body.

8 Final robot assembly

The completed robot is shown in the figure in the CAD version (left) and the real rover (right) in Fig. 7. After assembling all the mechanical components of the robot, the sealing has been carried out, followed by pressurizing the air through the valve. Gauge air pressure ensures protection against intrusion of polluted wastewater into the robot body. Next, a leak

test was carried out by immersion in water (the extreme environment to which the robot should not be exposed). After the sealing test, testing of electronics and robot motion has been carried out. Moreover, software that controls the movement of the device there and back a controls lighting has been designed.

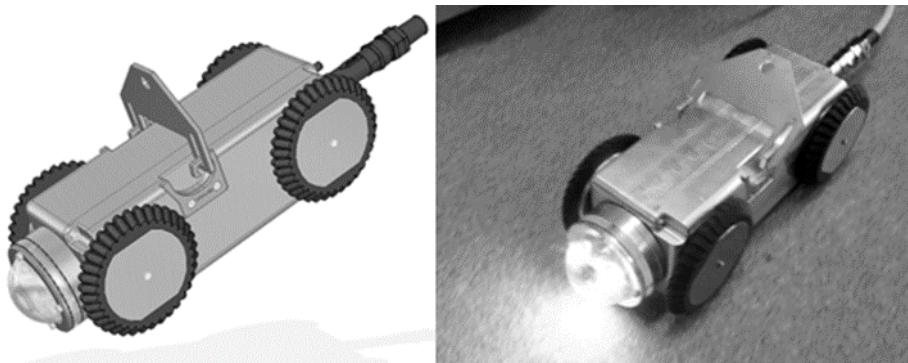


Fig. 7. Final CAD assembly and manufactured prototype.

9 Conclusions

A prototype of final design was created. The operating test was completed successfully; it demonstrated that:

- the robot moves forward and backward without slipping,
- the robot unit can be upgraded, malfunctioning parts can be replaced,
- the material and robot cover allow easy maintenance (washable) and sealing of the gas pressurized inside,
- the robot can be pulled out of sewage pipeline by the cable or by the tow on the rope.

References

1. R.R. Marangoni, R. Baron, The 58th Ilmenau Scientific Colloquium, 8 - 12 September 2014 at the Technische Universität Ilmenau (2014)
2. A. Nayak, S.K. Pradhan, Procedia Eng., **97**, 2081 (2014)
3. J. Novak-Marcincin, M. Janak, D. Takac, Manuf. Technol., **14** (2014)
4. P. Li, S. Ma, Y. Li, Proc. – IEEE Int. Conf. Robot. Autom. Pasadena, California (2008)
5. H. Lim, T. Ohki, ICROS-SICE International Joint Conference Fukuoka, Japan (2009)
6. F. Nassiraei, Y. Kawamura, A. Ahrary, Y. Mikuriya, K. Ishii, Proc. - IEEE Int. Conf. Robot., Angelicum University Roma, Italy (2007)
7. M. Bachratý, P. Hubinský, A. Vitko, Proceedings of the 14th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines, CLAWAR (2012)
8. C. Zhu, Ind. Robot Int. J., **34** (2000)
9. S. Hirose, H. Ohno, T. Mitsui, K. Suyama, IEEE Int. Conf. Robot. Autom. Detroit, MI, USA (1999)
10. Kawaguchi, I. Yoshida, H. Kurumatani, T. Kikuta, Y. Yamada, Proc. 1995 IEEE Int. Conf. Robot. Autom., Nagoya, Aichi, Japan, **1** (1995)
11. V. Kepplin, K.U. Scholl, and K. Berns, IEEE/ASME Int. Conf. Adv. Intell. Mechatronics September, GA, USA (1999)
12. S.G. Roh, H.R. Choi, IEEE Trans. Robot., **21**(1), 1 (2005)
13. S.G. Roh, D.W. Kim, J.S. Lee, H. Moon, H.R. Choi, Int. J. Control. Autom. Syst., **7**, 105 (2009)

14. O. Tătar, D. Mândru, I. Ardelean, *Mechanika*, **68**(6), 60 (2007)
15. N.A.B.H. Yahya, N. Ashrafi, A.H. Humod, *IOSR Journal of Mechanical and Civil Engineering*, **11**(4), 1 (2014)
16. N.S. Roslin, A. Anuar, M.F.A. Jalal, K.S.M. Sahari, *Procedia Eng.*, **41**, 1456 (2012)
17. M.R.A. M. Zin, K.S.M. Sahari, J.M. Saad, A. Anuar, A.T. Zulkarnain, *Procedia Eng.*, **41**, 1469 (2012)
18. J. Slamka, M. Jedinák, M. Tolnay, M. Bachratý, O. Staš, *Appl. Mech. Mater.*, **332**, 423 (2013)