Modeling and Simulation of In-pipe Inspection Robot Behavior through Pipeline Fittings

Krešimir Osman[1] and Zdenko Kovačić[2]

[1] *Termo Servis Ltd., Sales and Technical Department, Ulica grada Vukovara 72, 10000 Zagreb, Croatia, kresimir.osman@gmail.com*

[2] *University of Zagreb Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia zdenko.kovacic@fer.hr*

Due to their system complexity, because they are configured from different pipe fittings (elbows, T-pieces, narrowing and widening points), pipelines need robots with extraordinary mobility, including the relevant advanced control algorithms to be tested [1]. For the purposes of pipeline maintenance and inspection, in particular its interior walls, a number of researchers have developed quite of lot of robots that are able to move within a pipeline. It is the complexity of the pipeline that defines special conditions of moving through them, which is why there are few developed robots able to easily move within them [2]. Existing robots are normally able to successfully negotiate mainly horizontal pipeline sections, but only some of them are able to fully negotiate complex pipeline configurations, i.e. some of their fittings such as vertical sections, elbows and T-pieces [1]. All these researchers are driven by the idea of developing a robot system that will easily move irrespective of which pipeline fitting it is passing through.

The research presented in this article is an extension of the research presented in Osman and Kovačić, 2017 [3], and will generally be based on such presented architecture for an in-pipe inspection robot with a central motion system based on the screw principle and featuring an adaptive mechanism that provides the necessary pressure of its wheels against the pipeline walls. The motion principle for some of its parts, such as its legs, has been modified. We removed the hydraulic cylinders between its legs and installed electromechanical motion actuators on the leg joints, between its links. The authors believed this would facilitate resolving the issue of controlling the robot and improve its stability and adaptability to varying pipeline diameters and its ability to move through any pipeline fitting, thus also enhancing the overall efficiency of the robot system [3]. We propose a so-called hybrid pipeline inspection robot compliance control system, including its passive and active parts. Force sensors have been installed on the robot legs, which detect contact with the surface (interior pipeline wall) and actively control the robot actuators. Also, an actuator has been installed in the lower link of each robot leg, which allows for varying legs' passive compliance. As the pipeline interior is a curved 3-dimensional surface, it is very difficult to create a mathematical model, especially in pipeline fittings such as elbows, T-pieces or narrowing points. A crucial issue appearing here refers to the speeds of each wheel, or wheel pair as in [3], of going through the pipeline, as well as the wheels' pressures against the pipeline wall, which are different.

This paper aims to present and establish mathematical models for typical pipeline fittings such as elbows, T-pieces, and narrowing and widening points, which should result in kinematic and dynamic equations for the robot's movement through such fittings. Furthermore, we aim to present a control model based on the control of robot's contact force with the interior pipeline wall. It became obvious while modeling robot's motion through a T-piece that the geometry of this model makes it much more complex than the model designed for a pipeline elbow, requiring additional assumptions and considerations, depending on the direction in which the robot moves through this pipeline fitting. We intended to use the models so obtained to simulate robot motion through the pipeline and its fittings by using a combination of the MSC ADAMS © and MATLAB © computer tools. We expect such simulation would be of great help as a tool by allowing us to conduct a broader analysis of the robot system's behavior, detect any errors in the robot system and in its relevant model, and to optimize the robot's configuration and the mathematical behavior model parameters. If we were to apply both methods concurrently, it would be easier for us to evaluate the robot system, i.e. its architecture and behavior. A mathematical model may be developed by using different analytical methods subject to certain assumptions and approximations required by the complexity of the system, however, simulation is always recommendable as a method of testing a system's behavior and verifying it [4].

Based on the robot architecture presented in [3] and above described modifications in the robot structure, we provided CAD models for each component and assembly by using Solid Works ©. The robot CAD model was imported to the MSC ADAMS simulation program, where it creates a CAD model of a complex mechanical system including all necessary properties, kinematic connections and parameters for further kinematic and dynamic analysis. The ADAMS/Control interface connects MSC ADAMS and MATLAB Simulink, i.e. data are exchanged between them. In this case, it is the output based on the relevant robot motion equations - MATLAB Simulink creates a system control block scheme based on such data. During the kinematic and dynamic estimation process, data are exchanged between the virtual prototype and the system control program, where MSC ADAMS and MATLAB Simulink solve the mechanical and control system equations, respectively. A flowchart diagram presenting data exchange between these three computer programs is provided in Figure 1.

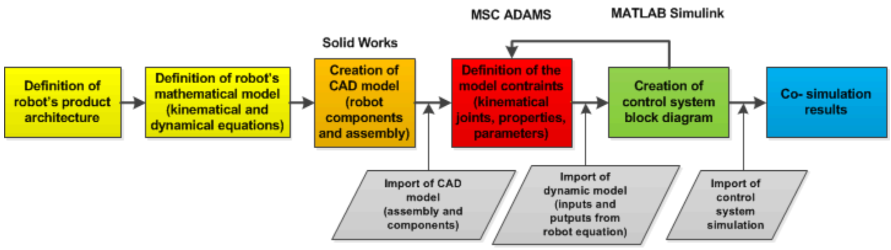

Fig. 1: Flowchart diagram of data exchange between the computer programs Solid Works, MSC ADAMS and MATLAB Simulink

In other words, it may be said that simulating a combination of the mechanical system and the control system uses the benefits of each computer program, which actually results in an electromechanical analysis of the robot's system. Taking advantage of such interaction between the computer programs reduces the time necessary to resolve problems and fix errors appearing during the design assessment iterations. The authors propose several directions for future research. The primary direction of future research would be to design a robot prototype to be used to conduct an experimental analysis and compare its results with the simulation results. Furthermore, building upon the previously reported compliance control methods [5] we propose to further elaborate the control method based on contact force control and active and variable passive compliance control parts.

References

[1] S. Roh and H. Ryeol Choi, "Differential-Drive In-Pipe Robot for Moving Inside Urban Gas Pipelines", *IEEE Transactions on Robotics*, Volume 21, Issue 1, pp. 1-17, 2005.

[2] A. Kakogawal, T. Nishimura and S. Ma, "Development of a Screw Drive In-pipe Robot for Passing through Bent and Branch Pipes", in *Proceedings of 44th International Symposium on Robotics (ISR)*, October 24-26, Seoul, South Korea, 2013.

[3] K. Osman and Z. Kovačić, "Development of Structure and Behavioral Model for Screw Driving In-pipe Inspection Robot based on Adaptive Mechanism on Legs", in *Proceedings of ECCOMAS Thematic Conference on Multibody Dynamics*, pp. 619-626, June 19 - 22, Prague, Czech Republic, 2017.

[4] L. Ángel, M. P. Pérez, C. Díaz-Quintero and C. Mendoza, "ADAMS/MATLAB CO-SIMULATION: Dynamic Systems Analysis and Control Tool", *Applied Mechanics and Materials*, Vol. 232, pp. 527-531, Trans Tech Publications, 2012.

[5] Kočo E.; Mutka A.; Kovačić Z.; New Variable Passive Compliant Element Design for Quadruped Adaptation to Stiffness-Varying Terrain, *International Journal of Advanced Robotic Systems*, Intech, Vol 13, No. 3, pp. 90-116, 2016 (on-line: doi:10.5772/63893).