SIMULATION OF THE GAS TRANSPORTATION THROUGH PIPES INSPECTED BY INTELLIGENT ROBOTS

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Abstract. In this paper the authors have created the visual images of transport gas nets, by using the Delphi visual programming medium, as qualitative simulation tool. The authors show that using this tool, one can obtain a priori, in the design stadium, the information about the state of the transport pipe. In a real environment these information must be confirmed using the physical measurements and by the examination of the state of transport pipe by the intelligent robots inspectors. During the inspection, the robot stays in contact with pipe's wall and the robot motion path will be imposed by the pipe profile and the pipe route. If the robot discovers the cracks in the pipe wall, this will signalize the defect zone. In this paper, for testing the robot motion control algorithms in the environment with constraints, the authors propose the using of the behavioural simulation method.

Keywords: Qualitative simulation, virtual aplications, leakage monitoring

1. Introduction

Gas distribution pipeline networks are systems with hundreds or thousands of kilometres of pipes and production, storage and distribution centres, compression stations, and many other devices like valves and regulators. These types of systems work at high pressures and use compression stations to supply to the gas enough energy to be moved along long distances.

When gas flows through the network, it suffers energy and pressure losses due to the friction between the gas and the inner walls of gas ducts but also due to the leaks of the gas in the environment. If demanded gas has to be supplied to delivery points with a specified pressure, the undesired pressure drops along the network must be periodically restored. This task is performed by compression stations installed on the network, but these usually consume over 3% or 5% of total gas transported [1].

On the other hand, if an increase of gas pressure takes place, certain safety limits could be exceeded. In these cases it is necessary to activate an emergency mechanism to avoid such contingency.

To cope with it the network has pressure regulators able to reduce the pressure until reaching values which are within these limits. As in the compressor stations case, these devices consume a fraction of the total gas transported by the network.

In literature, there are different models to describe the behaviour of gas dynamics inside a gas duct with constant circular section. In most cases they make reference to a horizontal gas duct.

The control and the diagnosis of process with the incomplete knowledge regarding the state of process make the analytical methods to be applied with difficulty. In this situation is the technical process, as the gas combustible transport.

The robot motion control supposes the motion path planning, step in which it needs the compromise between the time and precision of the positioning task. In the case of the inspector robot, both performances are essentials to perform with success a robotic task. The analysis of these performances has been realized at the virtual robot level and the results will be included into a real environment.

The virtual robot's movement inside virtual space has been researched trying to give them the capability to adaptation at specific conditions without human interference. To achieve this goal, in the real robot case, one can be use several strategies, including spatial cartography strategy, area sweeping strategy, iterative methods strategy, etc.

In the case of iterative methods, the planning algorithm of the motion path builds the path based on a set of spatial positions, and the intelligent control system transpose this path into space positions occupied by robot, who stay in contact with pipe' wall.

With iterative methods one can adjust the robot performances at a level such it allow to adapt at a new situation. A specific situation is when the robot is moving in a perpendicular direction on the pipe's wall. The adjusting process continues, conform the protocol established, till one obtain a new contact with the pipe wall unless strong impact.

2. Robots' movement simulation in the environment with constraints

A control structure for a mobile robot, which moves in the environment with constraints, must avoid the impact with the workspace' limits, during the motion. The information about the robot's operating environment is derived from its onboard sensors and external sensors, included in the external control loops. The sensorial information enables the steering of the robot, to the designated target and out of difficult areas.

The obstacles avoidance, in 3D-space, can be achieved with simple reactive control architectures. In the exploration missions, the intelligent inspector robots must identify the change the direction of pipe path [2]. At the points of change of direction, the pipe's wall is assimilated as horizontals and verticals obstacles.

Generally, the control systems of inspector robots require some means of detecting obstacles in its path, and a capability of manoeuvre, to avoid them and also to avoid the strong impact with pipe wall [3].

The virtual operating environment consists in a virtual space with horizontal and vertical corridor inside the pipes, used in virtual experiments. During the virtual experiments the robot has to avoid the impact with wall of pipe and follow a free corridor.

3. The intelligent robots' movement in the gas distribution pipelines

The objective of this research study is to present some considerations regarding the implementation of a gas distribution pipeline network simulator to evaluate different operation scenarios such as the inspection by intelligent robots, taking into account the previously mentioned features for such kind of systems.

Gas ducts are the most important components of such kind of systems since they define the major dynamic characteristics. Unidirectional flow is usually assumed when modelling the gas flow through a gas duct. This paper presents a simplified model derived from the set of equations governing the dynamics of the process. With this library it is possible to simulate the behaviour of a gas distribution network from the individual simulation of each component.

3.1 Modelling of the gas distribution system

It is known that one of the most interesting issues in a gas distribution system is the search of the pressure that should be applied to the gas from the compression stations to reach the consumption points with the required conditions by the client. The gas flow inside a gas pipe is governed by some dynamic laws, constituting a "hydrodynamic" system [4]. In this paper the qualitative aspects, of the hydrodynamic system, are analyze.

For qualitative simulation has been already introduced an important simplification for slow dynamic effects. Neglecting the friction of the non viscous gas classic dynamics in which pressure waves propagate through the gas at the speed of sound without any damping will be obtained. Neglecting the inertia terms it results in a creeping motion.

As an example, it is considered a gas duct for high pressure gas transmission, where the dynamic variations are stimulated by demand fluctuations, and it takes hours to complete a significant change [5]. The values given for the variables at these conditions, together with the estimated magnitude for the terms in the real time are proposed.

3.2 Behaviour simulation

Different models of the pipeline and their simulation are discussed. The proposed models can be used for different purposes, such as controller design, leakage monitoring etc. Observer-based leak detection and localisation with inspectors robots schemes, was realized. It describes the two-dimensional space the compressible fluid flow through the pipeline and is represented by a set of dynamic images. Also was realized examples of the pipeline model without a leak. The industrial applications must to demonstrate the performances of the observer-based on the inspector robots methods. No general solutions, of the active observer methods, are known yet [6].

The most common use of Delphi application is to create custom Simulation blocks, but they can be used for a variety of applications. An advantage of using Simulation code source is that it is possible to build a general purpose block that can be used many times in a model, varying parameters with each instance of the block.

As it can be seen the block implementation of a gas duct has two inputs robot ports and one output robot port. Figure 1 shows the internal implementation of such a block. Input ports specify the climbing robots demand in the inspection missions at the inlet of the gas duct (these are the necessary boundary conditions) to provide the mobile robots.

After integration the block gives the entrance of the robots in the inlet, the gas flow along the gas duct, the outing of the robots inside the pipe and the exit through output ports, the gas pressure at the outlet. Both input and output signals pass through a zero-order-hold to simulate an external data sampling each time period needed for future control applications.

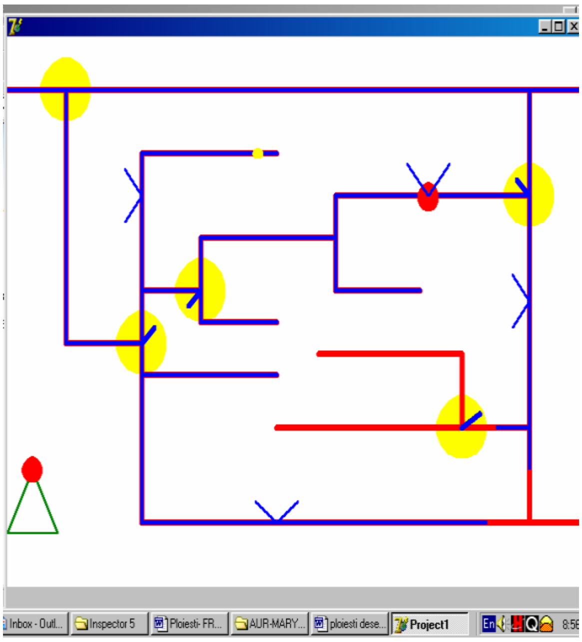

Figure 1. Virtual gas distribution system, populated with mobile robots

Figure 1 also shows how the internal implementation of a gas duct has been masked to customize the user interface. This window let the user specify the physical characteristic of a gas duct but also the desired parameters for the numerical schema to be used to obtain the visual model. It is possible to specify the length of path for each mobile robot and the initial conditions from which to start the simulation as example the speed of motion of each robot.

The use of the developed library to simulate different operating conditions is suggested with the purpose of acquiring deeper knowledge of such kind of inspector robots systems. Gas duct blocks can also be interconnected with other blocks like compressor station to form more complex networks. Finally, easy implementation of such gas pipeline networks is a very powerful tool to test different control strategies proposed for the system. For example, an optimal control could be implemented with the aim of reducing the cost of the distribution process in the network under certain operation conditions taking the discharge pressure at compressors and the flow distribution in bifurcations as the manipulated variables.

As an application example of the visual programming algorithms developed in our laboratory, the simulation of the temporal variation of flow rate in discrete zone of a gas pipe is possible. The initial conditions must be determined on the basis of the gas pipe state at the start time of the simulation.

3.3 Exemplification

The Delphi environment is a visual medium for applications development really oriented on objects and with methodical modulating, based on Windows platform. The Delphi visual programming medium uses a strong programming language, the language Object Pascal, in Borland Delphi vision.

The authors have created the visual image, obtained by using the Delphi visual programming, of the virtual transport pipe equipped with inspector robots.

For exemplification see also figure 1, presenting the virtual mobile systems which operate in the virtual environments with constraints. The virtual robot system operates in a 2-D virtual environment constrained by the pipe' wall.

A virtual system can be used to the exploration of the virtual environments and serve as working instruments, to establish the critical points of the movement path and of the critical distances between mobile robot system and obstacles [7].

The natural gas loss that appears due to the cracks that might appear in the pipe is even hard to identify. When there is a case of liquid fuel loss oil spots appear in the area of the broken pipe but in case of a gas fuel loss there aren't any obvious signs.

Actually methods are based on the surface inspection and detection of gas losses with the hep of specialized apparatus. Once localised the gas leak, the next step is executing the repairing work which imply cutting the pipe in the defect area.

The inspection methods through the interior of the pipes which includes, by case, repairing the defect, using intelligent robots is an original solution which simplifies the repairing technology, by eliminating the cut of the pipe.

In the proposed case the population of robots' flotilla is two. We note that, the two robots appear as the visible objects on the scene. The robots appear as yellow spots on the map. When the robot arrives at defect area with leak of gas, he changes her colour in red.

For the mobile robot the obstacles, as perpendicular tube on the movement' direction, appear in front of it, and show the evidence of an imminent collision.

Some exploration experimented strategies for the virtual environment can be usefully for the real work environment exploration as we can see in Figure 2.

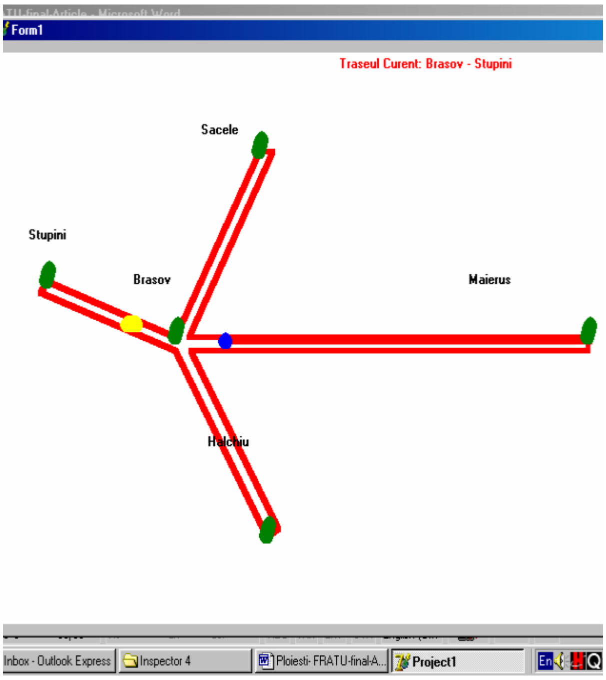

Figure 2. Virtual gas distribution local area network

4. Conclusions

The scenes described by the flotilla of robots led us to adapt classical robot navigation methods in order to use the results for the command algorithm.

The authors developed a simulator of a robot moving in a simplified environment, to test theoretically control methods using the impact avoid command algorithm. The simulator showed the possibility to build guidance methods based on the impact avoid command algorithm. Our current work consists in transferring and extending these control methods to real-world situations.

Configuration control must provide a convenient technique, to benefit of utilizing the redundancy in such situations. The robot working in the safety conditions, inside unknown environment supposes a high adaptability capacity.

The robot adaptability at real work conditions is possible if are activate the redundant degrees-of-freedom.

Real time obstacle avoidance is difficult to achieve, because of the vast amounts of data that would have to be communicated between the high level processing unit and the robot measurements systems. Also redundancy technique, used in the measurement process, is achieved by using multiple and diversified measurements.

The option for demanded redundancy also in the measurement systems depends on multiple factors and leads to the achievement of the reliability demands. Redundancy, in the measuring systems is necessary to increase the default tolerance.

Finally, easy implementation of such gas pipeline networks is a very powerful tool to test different inspector robots' control strategies proposed for the system. For example, an optimal control could be implemented with the aim of reducing the cost of the distribution process in the network under certain operation conditions taking the discharge pressure at leaks and also the flotilla robots distribution in bifurcations of the pipe.

5. References

1. Parker, L.E.: *Distributed Algorithms for Multi-Robot Observation of Multiple Moving Targets*. Journal Autonomous Robots, Vol. 2, No. 3, p. 231-255, ISSN 0929-5593, Springer Netherlands Publisher
2. Fratu, A., Fratu Mariana: *Artificial Intelligence and the appearance of Intelligent Robots*. Hermeneutica Historiae et Philosophiae Technicae, Liber III, Anno 2005, p. 150-154, ISBN 973-635-744-9, Romanian Academy Publisher, Brasov, Romania
3. Heejin, L. et al.: *Variable structure control of manipulator using linear time-varying sliding surfaces*. Proceeding of International Conferences on Intelligent Robots and Systems, Vol. 2, ISBN 0-7803-4465-0, p. 806-811, Victoria, BC, Canada
4. Matko, D., Geiger, G., Gregoritza, W.: *Pipeline simulation techniques*. Proceeding of the Mathematics and Computers in Simulation, Vol. 52, Issues 3-4, 30 June 2000, p. 211-230, IMACS. Published by Elsevier Science Ltd
5. Fratu, A., Fratu, M.: *Programarea vizuală în mediul Delphi cu Aplicații în Robotică* (*Visual programming in Delphi environment with Applications in Robotics*). “Transilvania” University Press, ISBN 978-973-598-315-4, Brasov, Romania, 2008 (in Romanian)
6. Wooldridge, M. et al.: *Model checking multi-agent systems with MABLE*. Proceedings of the First International Joint Conference on Autonomous Agents and Multi-agent Systems, Part 2, ISBN 1-58113-480-0, p. 952-959, 2002
7. Fernandez-Madrigal, J-A. et al.: *A software engineering approach for the development of heterogeneous robotic applications*. Proceeding of Robotics and Computer-Integrated Manufacturing, no. 24 (2008) p.150–166

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