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Development of a Decision Making Guide for Locomotion Design for In-pipe Inspection Robots - One Step towards Open Innovation in Robotics

Bahadur Ibrahimov, MSc*.

**Vienna University of Technology, Favoritenstrasse 9 - 11 1040 Vienna,*
Austria (Tel: 06766501388; e-mail: bahaduribrahimov@gmail.com).

Abstract: From the beginning of development of the pipeline inspection robots, different drive mechanisms have been proposed for distinctive purposes and specifications. Due to sensitive environment of oil pipelines and restrictions of innovations in petroleum industry in general, designing propelling system for robots are quiet cost-intensive and hard. In most cases, such innovations end up re-inventing existing systems and approaches. Therefore, guidelines of innovation in petroleum industry should begin to develop and an open innovation platform for oil industry should begin to be built. This paper intends to define the main points and variables of in-pipe inspection locomotion and build guidelines for decision making tool to help developers to define needs and requirements to design drive mechanisms for distinctive requisitions that fulfill predefined requirements and specifications of robotic developments. This work intends to take a novel approach of guideline formation of Pipeline Robotics for the sake of cost saving in robotics. This guidelines is the beginning of definition of a whole decision making tool for In-Pipe Inspection robot's drive systems designs and developments.

Keywords: Open Innovation, In-pipe Inspection Robots, Robot Navigation, Pipelines, in-pipe robots

1. INTRODUCTION

In petroleum industry it is very common to use in-pipe robotic systems for inspection and maintenance tasks, but it is hard to find the right robot for the different requirements robots are facing in various in-pipe environments. In fact these vehicles are used to find cracks and internal erosion problems which can occur for example from overheating or degeneration effects. (Mirats Tur, Garthwaithe, 2010) as well as (Roslin et al., 2012) mentioned the common types for the locomotion part of in-pipe robots which were used in the last decades. In general there is a distinction (Mirats Tur, Garthwaithe, 2010) between passive locomotion and the active one, which means that there is any kind of drive mechanic on the robot, like wheels, legs, inchworm, tracks, caterpillars, snake locomotion parts or a screwed system.

Another projection was made by Hirose et al. (Hirose et al., 1999), as they divided the possible locomotion types of in-pipe inspections robots into three general forms. Form 1 robots are using the pressure of the fluid inside a pipeline as power source for the locomotion; Form 2 transfers the propulsion where it is available through an elastic rod and creates the move and Form 3 has any kind of drive mechanism on its body to create locomotion. Those basic forms create 5 types of simple drive systems and they create a bunch of hybrid systems which connects simple drive mechanisms and forms more complex locomotion types (Roslin et al., 2012). All drive mechanisms developed so far rely on some variables but others were not been taken under consideration. Some locomotion types fit the diameter of the pipe, some of them are adjustable but not taking the flow into account, others are only theoretical designs and no real applications. So far a study on all possible major scenarios, with respect to all main variables and use cases does not exist. In this paper, we analyse and evaluate the variables, count the cases and build questions out of scenarios and finally propose a decision making tool for industrial users on pipeline robotic locomotion.

With this work, first time in the industry a tool for decision making in locomotion design is proposed which indents to decrease costs in research and development and value addition to cost-oriented robotics.

2. SCENARIOS

To be able to propose a decision making guidelines, all possible variables should be evaluated. In order to evaluate all main variables, first we should define some of them changing in small range or which creates scenarios for others to be applicable as well. We defined the situation of usage, the material that being transported and the pipeline material as main variables with so-called step changes and let them form the possible cases. Therefore the following table shows an overview of all different possibilities of the developed underlying model.

In total the model consists out of twelve cases which can be divided in three parts, structured by the situation of usage, which can be "in use", "before use" or "after use" setting as mentioned in Table 1. All of these three main settings of the pipe refer to the transported material which can on the one hand be gas and on the other hand liquid, therefore the transported material is in the model stated as the second

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question. If inspection robot will be used in “before use” or “after use” cases, the material that flowed does not matter for our model.

Table 1. Case overview of the model

Cases		Usage		Material		Pipeline
1.	=	In use	+	Gas	+	Metal
2.	=	In use	+	Gas	+	Plastic
3.	=	In use	+	Gas	+	Undefined
4.	=	In use	+	Liquid	+	Metal
5.	=	In use	+	Liquid	+	Plastic
6.	=	In use	+	Liquid	+	Undefined
7.	=	Before	+	All types	+	Metal
8.	=	Before	+	All types	+	Plastic
9.	=	Before	+	All types	+	Undefined
10.	=	After	+	All types	+	Metal
11.	=	After	+	All types	+	Plastic
12.	=	After	+	All types	+	Undefined

Another important factor and the third main question of the model, is the material of the pipe in addition with the material specification K which denotes the material characteristics of the pipe and can be found in the variable list down below.

The following twenty six ***variables*** are used as input factors in the developed model in addition to the three main questions mentioned above in the table as usage of the pipeline, flowing material and material of the pipeline.

Main variables

1. V = Robot´s velocity
2. P = pressure in pipeline
3. Ig = weight use factor
4. Ø = slope angle of the pipeline to ground
5. Ob = obstacles
6. R = radius of the pipeline
7. ∑F = sum of all forces
8. T = output torque of the adjusting motor, N.m
9. PS = Power supply
10. m = Payload

Specific variables

1. M = movement directions
2. Φf = velocity flow of the fluid inside the pipeline
3. C = temperature inside the pipeline
4. K = additional material specifications of the pipeline
5. μ = adhesion coefficient between driving wheels and pipe wall
6. RR = robots radius (can be diagonal in different shapes)
7. Fl = flexibility of connection / DOF
8. St = stiffness of connection
9. Θ = Wheel angle of the pipe base
10. L = length of the pipeline
11. ρf = density of the fluid inside the pipeline
12. α = curve angle (rx = curve radius)
13. #B = number of bodies / universal joints
14. S = safety or accessibility of a robot
15. B = degrees of freedom or turning angle of joints / wheels
16. Com = Communication port of the robot

3. QUESTIONS

Three defined main variables and other constraints forms questions of our model as:

<u>1: Situation of usage</u>: defines the usage situation of the pipeline if it is in use, already used or before usage. In the here mentioned case set the user selects the in use status. The following modes are possible for an in-pipe usage of a robot in petroleum industry.

- Before
- In Use
- After

The pipeline status in use means that it is being used for, either Gas carriage or Petroleum transportation – gas and liquid carriages respectively.

2: Aim of usage:

Defines the aim of usage regarding which product is transported inside the pipeline. Either the pipeline carries gas, petroleum or some other undefined or predefined products. Crude oil and other initial petroleum products should also be defined as petroleum. Other products are out of the scope of this model.

This question is the main decision making point of the IN Use case of the Q1, in which the external forces applications are changing due to the flowing material inside the pipeline. As mentioned above, it can have either Gas carriage or Liquid carriage.

In gas carriage phase, the robot inside the pipeline will be under pressure from the gas inside and can be affected due to the high flow rate of the gas inside. This should also be considered as external forces which plays major role in deciding the locomotion type of the robot.

In liquid carriage phase robot is under external forces due to the reaction of the flow rate of the liquid as well as pressure related to the mass of the flowing material per second.

3: Material of pipeline:

This is another main part of the technique to decide on Locomotion type of the robot. It defines the material’s construction type, magnetic attitude of the material, density, viscosity and as well as the size of the material. User should define the materials name and size in this question which