Design of a pipe climbing robot engineering essay

This technical paper explains the design process and simulation of a concept vehicle to drive inside a circular pipe of the desired configuration as shown in figure 1. The design is developed to facilitate; pipe climbing and carry an inspection of an inspection panel. This vehicle when operated will travel in a horizontal section of pipe initially, before entering the inclined part of the circular pipe. It then drives within 0. 2m of the inspection panel and starts inspecting it with the help of an on-board camera. Specific equations and assumptions are used to monitor vehicle motion and system controllers are designed to enforce there is enough traction applied by the vehicle to grip the pipe and move forward.

Figure 1 Pipe inspection Scenario

Index Terms-design, linear actuators, multi-wheel drive, proximity sensor, robots

Introduction

Inspection and maintenance are essential in all industries. Failure to conduct proper maintenance could result in potential danger to workers and machines. Carrying out these inspections impose rigours hurdles in case of various industries where the conditions are unsafe for human workers, for example, inspection and maintenance in a nuclear industry, where the environment poses serious risk for the humans. The most common way for conducting these inspections in hazardous conditions is to use long manipulators which could be expensive. The alternate way of carrying these inspections is by using walking/climbing robots.

Pipe climbing robots are advanced robots, which have the potential to climb inside/outside of a pipe to perform specific functions, where a normal operator cannot be used. The improvements in this sector have grown rapidly, since it's a cheap and effective way for investigating various properties inside a pipe.

An assignment has been assigned to design a concept vehicle to drive inside a circular pipe as in fig 1. This vehicle needs to enter the tunnel and drive to within 0. 2m of the inspection panel and inspect the panel at the end of pipe. The vehicle must also carry a wire which is tethered.

The climbing robots can be classified into four major categories based on their approach to climbing: adhesive, brute force fixture, spines and grasp. The robots with adhesive approach use a mechanism such as suction or an electromagnetic fixture on the climbing surfaces. The brute force robots use a mechanism to grab on to the structure and move forward. The spine group of robots use spines/multi-spines to attach themselves to the climbing surface so as to propel forwards. The last group of grasp robots use their own dynamic and kinematic state to grasp on to the engineering structure and moves forward.

The present conceptual design can be categorised under grasping group of climbing robots. These robots consist of mainly two mechanisms, one to power the robot to move and the other to grip the surface of the structure.

The mechanisms used to grip on to the surface can be facilitated by the usage of spring and v-shaped arm or longitudinal actuators. A v-shaped arm along with a compression spring is connected to the body of the robot. The compression springs tends to expand the arms, if the outer arm reaches the surface, it exerts a force normal to the contact of surface thus proving the traction for gripping the surface. In case of linear actuators various mechanisms are used to produce the linear motion of the arms to exert force onto the surface.

The present design employs a linear actuator. It has longitudinal arms connected to linear actuators. The linear actuator is a simple rack-pinion mechanism, but consists of three racks to synchronise the outward motion equally in all three directions, thus providing an equal amount of force on each surface of the structure.

A multi-wheel drive system is employed for the present case, as there is a need for requirement for more torque when the robot climbs the inclination part and to reduce the slip generated by the wheel. In the present case, the robot has five wheels and hence five individual motors, two on the bottom of the base, one on either side of robot and one at the top of the robot. When in operation the outer end of the wheels on all directions would be perfectly inscribed in a circle of 200cm when looked at front view. This mechanism coupled with linear actuators makes sure that at any instant all the wheels are in contact with the surface of the pipe thus providing maximum available traction for the robot.

Robot model and modelling assumptions

In the present concept of design the circular pipe is considered to be even and has a constant coefficient of friction throughout. Designing the robot requires a methodological approach to implement a professional structured robot is done by generating a CAD model of the robot. The components of the robot are selected with maximum care with feasible materials, since theoretical tests and scenarios can be modelled based on weight and dimension of the robot. After selection of optimum materials for robot, the design process is finished.

The weight of the vehicle including the power source (batteries), on-board camera and computer controller along with other drive motors and actuators will approximately be around 1. 8 kg. The dimensions of the robot while in operation are 0. 275m in length, 0. 2m in both width and height. The front part of the robot is designed in such a way that it gets inscribed in a circle perfectly during motion. To maintain perfect contact at all time the wheel positioning is very critical. Both the bottom wheels are place below the base of the robot to facilitate more space for other components such as power source, camera, controllers, sensors etc. The remaining three wheels are positioned perpendicular to each other on the actuator arm. The length of this arm can be varied using the linear actuator mechanism. In the present case this linear actuator mechanism is a simple rack-pinion mechanism. All the three arms are synchronised such that under operation the displacement of arms is equal in all directions. Four proximity sensors are used to calculate the distance between the surface of pipe and surface of the tyre. Three sensors are linked to one at each actuating arm in their respective direction. One sensor is linked to calculate the distance from surface of front tyre to the surface of the inspection panel. The three sensors on actuator arm are categorised into a single sensor unit (say sensor unit 1), while the other sensor (say sensor unit 2) is categorised separately.

The categorised bill of the materials used is as follows

Working of the robot

Initially when the robot is at rest, all the three linear actuating arms are in contracted position. When the system of the robot is started, the sensor unit 1 present on the linear actuator arms calculates the distance between wheel and surface of pipe and sends the feedback to the on-board CPU. The CPU then sends a signal to increment the step motor to one step. This whole process of increment of steps continues until the wheel touches the surface of pipe and thus exerts a small normal force to grip onto that surface. Once this process is completed, drive motors of the robot are actuated. These motors are controlled by on-board CPU with the help of feedback from the sensor unit 2. All the five motors through a gear box connected to the wheels are powered with equal force, hence powering robot equally in all directions and sensor unit 1 ensures there's maximum grip available at the end of the actuating arms. The power to the motor is stopped once the sensor unit 2 senses the distance between the front wheels and the inspection panel is 0. 2m, thus activating the camera to carry the inspection process. This whole process can be controlled using a manual operation panel or fully autonomous programmed GUI on-board.

Simulation of vehicle dynamics

The vehicle dynamics of the robot are established using specific equations for motion. This analysis is used to determine the performance capacity and capability of the robot. It also helps to calculate the velocity, force dynamics at any instance of time. Before using the equations a few assumptions are considered. The drag forces exerted on the body and wire are neglected. The drive force from the wheels is considered to be a constant ideal force, where wheel slip and wheel tyre deflection are neglected. The gravitational constant and the friction coefficient considered to remain constant throughout the process.

The simulation emphasises more on the vehicle motion along the entire length of pipe including the inclined part of pipe. The terminology used for the following calculaitons are as follows

Parameter

Description

Value

mb

Mass of robot

1. 8 kg

r

Radius of the wheel

0. 03m

mw|

mass of wire per unit length

0. 2 kg/m

Ub

Coefficient of friction of body

0. 5

Uw

Coeffient of friction of wire

0. 2

G

Gravitational constant

9. 81 m/s2

Ts

Stall torque of motor

0. 9 kg-m

Wn

No load speed of motor

38 rpm

O

Angle of inclination of pipe

40o

Straight path

A constant force is produced through five drive motors and is calculated as follows, where Fm is the force exerted by the motor,

But the torque generated by the motor changes with velocity of the body. Torque ™ at any time is given as

Where w is rotational speed at that instant of time. W can be written in terms of velocity v of the body

Since there are five motors present to power the robot, the net force exeterd by motors at any time is

The frictional force (Ffb) acting on the body due to its own weight

Frictional force (Ffw) due to mass of wire

Where mw is mass of wire carried at that time and is calculated by using length l of distance travelled by the robot

The resultant force(F) resulting in forward motion of the robot

Acceleration(a) of the body is given by

Velocity vf of the body is given by

Displacement lf of the body is given by

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••
••
••••

Inclined path

Consider the instance at which the robot just reaches the inclined path of the pipe. The force exerted by the motor remains constant as in eq().

When the robot is in inclined position weight gradient of body(Fgb) and weight gradient of wire (Fgw)opposes the motion of body. These are given as

The frictional forces acting opposite to motion also changes as follows

Where l is the total displacement along the pipe

The net force (Fi) acting on the body along the pipe is

Acceleration of the body along the pipe

Velocity (vi) of the robot at any instance is given by

Where vf is the velocity of the robot at the start of the inclination.

Abstract-These instructions are a guide to the assignments to be submitted for Mech5090 Mechatronics and Robotics Applications

[this section should contain a brief description of the task and outcomes]

The assignment must not exceed 6 sides of A4!!!!

Index Terms-About four key words or phrases in alphabetical order, separated by commas.

INTRODUCTION

THIS document is a template for Microsoft Word versions 6. 0 or later. Do not change the font sizes or line spacing to squeeze more text into a limited number of pages. Use italics for emphasis; do not underline.

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This section should contain a description of the problem and a critical discussion of the references used for the work.

System design…

Mechanical considerations…. eg

This section should contain the description of the system you propose including any specific hardware you are proposing to use.

You can be flexible how you use headings and divide the work up.

References

Number citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]-[3]. When citing a section in a book, please give the relevant page numbers [2]. In sentences, refer simply to the reference number, as in [3]. Do not use " Ref. [3]" or " reference [3]" except at the beginning of a sentence: "

Figures

The assignment should contain technical/non-technical illustrations of important aspects of the work.

Graphs

The assignment may contain graphs produced by a software package such as Matlab. They should have the correct axis/units. They must have a figure caption and be referenced in the text. Tables of information are also fine with the rules above adhered to.

Equations

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). First use the equation editor to create the equation. Then select the " Equation" markup style. Press the tab key and write the equation number in parentheses. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

(1)

Conclusion

A conclusion section is required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.