DESIGN AND ANALYSIS OF SMART WANDERER AUTONOMOUS PIPELINE INSPECTION ROBOT

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ABSTRACT

This articleprovides the design and analysis of calculated model of an autonomous Pipe Line Inspection Robot, called Smart Wanderer robot. The essential goal is to utilize this kind of robot for fuel and gas pipeline investigation, cleaning by using brushes attached to the wheel links and collecting the dust by using vacuum chamber on the rear of the robot, particularly for those pipelines in which the normal smart pigging frameworks couldn't be difficult to be sent. The Smart-wanderer, which is continuously guided by its own onboard MCU center and force provided by an embraced-up battery, is relied upon to execute pipeline examination automatically. An adaptable tool structure is implemented to recognize the wanderer's adaptability to adjust the various diameter of pipelines just to deal with some unpredictable circumstances, for example, to go through impediment territories or to move at a corner or cleans the line, junction to gather the residue in that and recognize the breaks inside the line. This conversion is naturally constrained by the MCU regulator dependent on the pressure sensors' input. The prepared gadgets, for example, the selected motors and battery packs, just as a human-and-machine interface is additionally examined in detail.

Keywords: Pipeline inspection, wanderer robot, automatic control, adaptable legs, HMI interface.

I. INTRODUCTION:

1.1 The Pipeline Domain

There are numerous zones where robots may be swapped for human; among them, pipelines are one of the maximum challenges able to change. Pipelines had been utilized in significant utilities for a long term. Greater than billions of spots from tremendous plants to a non public house, robots are used by individuals. Be that as it may, numerous difficulties like maturing, intake, decay, breaks, and bodily harms from outsiders, have passed off in pipelines. Subsequently, preservation of pipelines is simple to keep them beneficial, and except the continuation price for those exercises is being increased. Indeed, irrespective of the previously noted troubles in the pipeline, individuals despite everything incline in the direction of them. The explanation being, pipelines are implemented in moving substances through a simple channel. Extra often than not fluid and gases are dispatched.Pneumatic cylinders that transport robust bins utilizing packed air are additionally being used. Like gases and beverages, any artificially consistent substance may be dispatched via a pipeline. Therefore sewage, slurry, water, and even big pipelines exist. With these facts, we can setup pipelines concerning the substance that it conveys. We will take a gander at everyone in detail

1.1.1 Ethanol Pipelines

These pipelines are significantly utilized in Brazil and the United States. There are a few ethanol pipeline ventures in Brazil and the United States.

1.1.2 Water Pipelines

This is one of the most utilized pipelines all around the globe and an old strategy too. The main individuals to ship water were the Romans to ship enormous reservoir conduits water from higher heights by building the water channels in graduated fragments that permitted gravity to just push the hurrying water along until it arrived at its proposed objective.

1.1.3 Oil Pipelines

Dmitri Mendeleev in 1893 recommended pipelines for shipping Petroleum; most nations have utilized these pipelines. These funnels began to get broadly utilized far

And wide.

In this paper, the adaptable system structure is depicted in detail and depicts the automatic control system executed in MCU to constantly change the legs to various conditions depending on the weight minor departure from wheels. The execution of the proposed pipeline reviews the robot stage, including regulator, a few gadgets' determinations, and the 3d modelling and simulation are depicted and the end is followed. In this plan, we utilized the hub motor Omni wheel that will help the robot for the freehand development which can be guided by the client as indicated by their necessity and with a circled course development which is pre-introduced in the framework. The vacuum chamber likewise called the pull chamber is set by the focal point of gravity of the entire framework. This situation of the pull chamber helps in gathering the residue in the pipeline.

II. OBJECTIVE

This arrangement is made to research the underground even gas pipeline.

- This arrangement is helpful for the assessment group to inspect the overflow, blockage, or destruction.
- To decreases human endeavours, wastage of cash material taking care of the cost. Simple to connect with and recognize the breaks and deformity
- This plan blunt work costs and incidental cases. Look at the harmed parcel and effectively we recuperate from it by end relevant region.

III. METHODOLOGY OF WORK

Step-1: Literature survey on various existing mechanisms.

Step-2: Finalizing the model parts and dimensions.

Step-3: Designing the required parts for modeling in FUSION360.

Step-4: Collecting all the components and assembly into a 3D-model.

Step-5: Completing the analysis on the required parts.

Step-7: mathematical modeling

Step-8: Discussing the results.

IV. SYSTEMARCHITECTURE

Thisarchitecture of the system, all the parts used for modeling are in tabular form represented with part numbers and names.

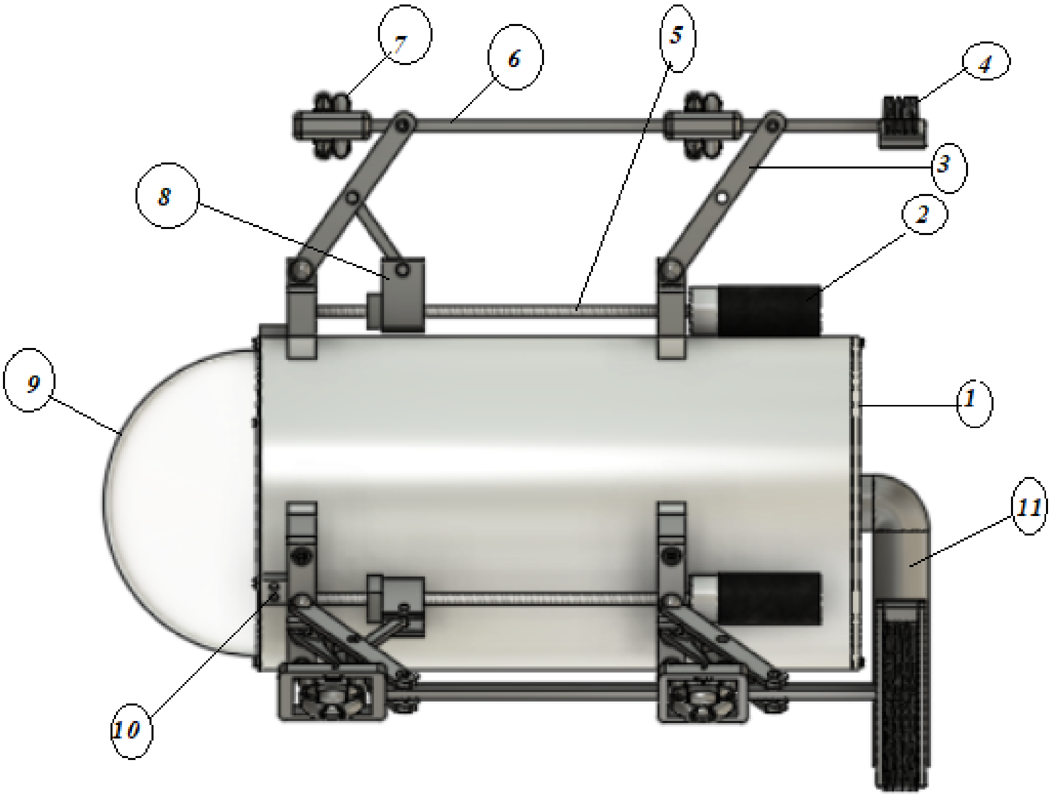

Fig 1:The 3d model of the smart wanderer robot.

Part .No	Part Name
1	Body of the robot
2	Stepper motor
3	Link
4	Brushes
5	Threading rod
6	Omni wheel link
7	Omni Wheel
8	Slider link on the threading road
9	Acrylic domes
10	Ultra sonic sensor
11	Vacuum tube

V. MODELLING AND CONSTRUCTION OF SMART WANDERER ROBOT:

Modelling:

The dimensions of the designed model i.e, Smart Wanderer robot is shown in the below fig 1(a):

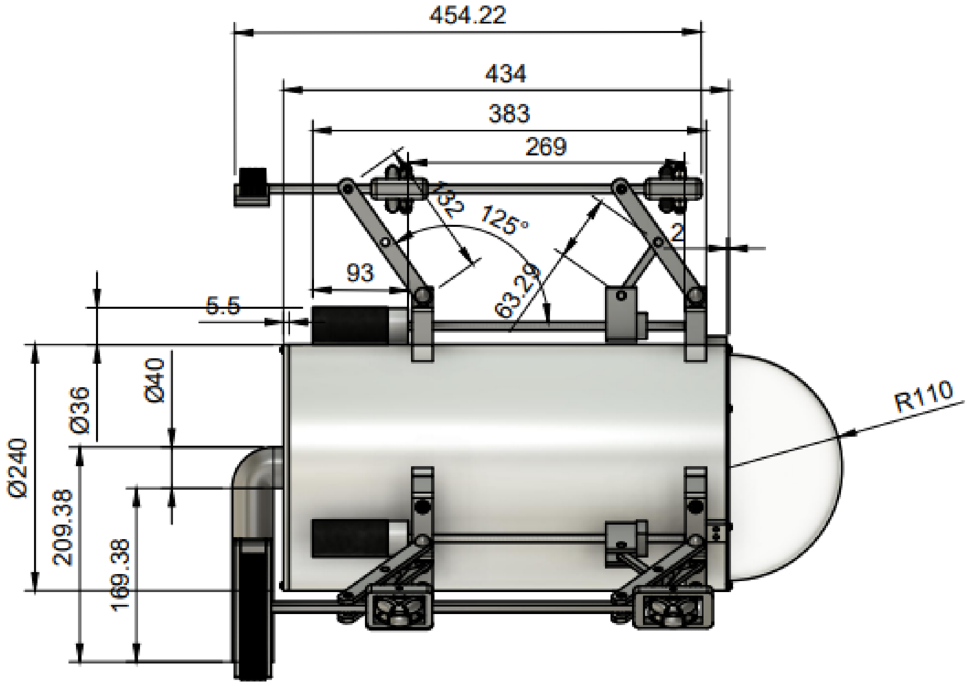

Fig 1(a):The 3d model with measurements of the smart wanderer robot.

Whole Smart Wanderer robot system:

The Smart-Spider framework is made out of the robot gadget and the workstation. The Smart Wanderer robot can move in line for playing out certain assignments consequently, with no ties or interfacing cables with the workstation. As to the Wanderer itself, the instrument structure comprises two sections: the primary body and the adaptable component. The electronic framework oversees movement control, information assortment, and capacity, and so forth on the aspect far away from the workstation, the graphical user interface is utilized basically for two purposes: (1) sending beginning and finish orders toward start and finish of one programmed review test; (2) monitoring the ongoing data in an exploratory stage, utilizing remote correspondence between the robot and workstation.

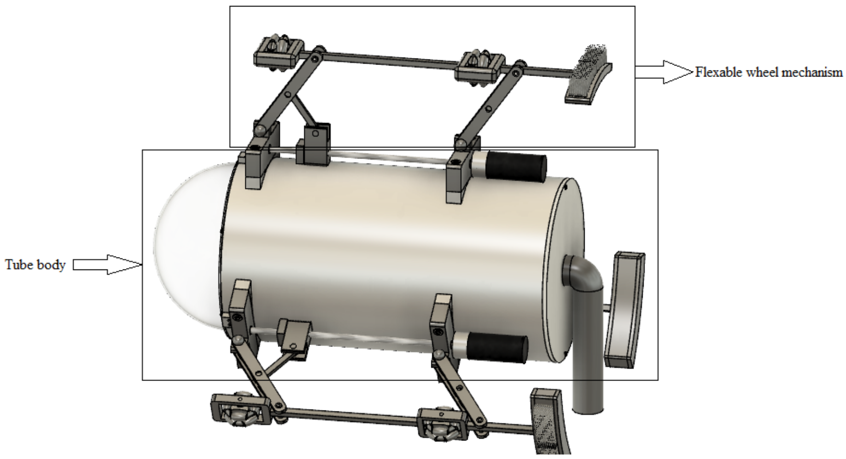

Fig 2:The fundamental component structure of the smart wanderer robot.

The basic structure of the part is represented in Fig.2, which is made of two sections: one is the body and the cylinder other is three adaptable flexible components. Both these two sections are made of aluminium. Inside the cylinder, the body is having a rack for an electronic framework and three adaptable clutch sets. The electronic framework, comprising of a battery and two layers of electronic PCB's and parts, is fixed on the cylinder inside. On the outsidecylindrical surface of the body, the three arrangements of adaptable grip systems are coordinated with 120 degrees span point, which makes the Smart-wanderer suit well for pipelines with the round cross area. Additionally, one acrylic arch is gathered at the front and the back sides of the cylinder body a vacuum chamber is assembled to collect the dust during cleaning the pipe.

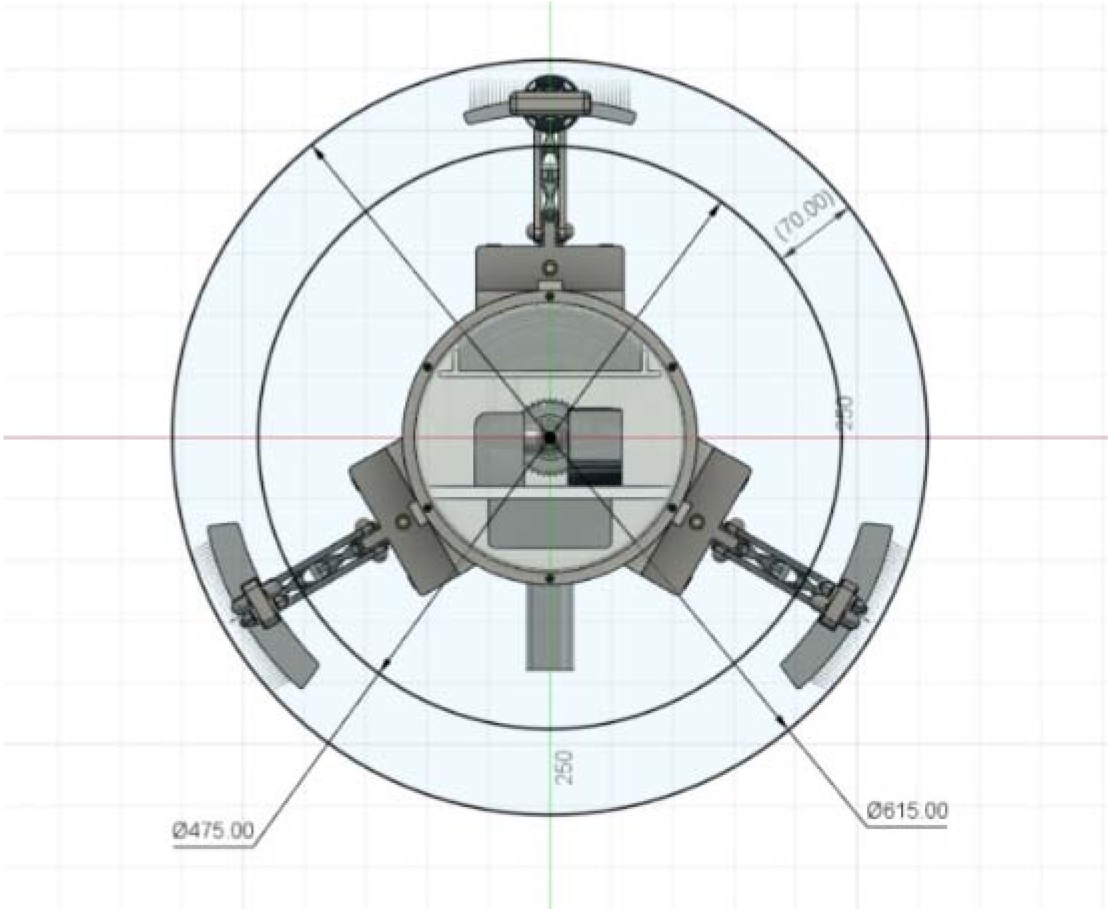

Fig 3:The diameter transmission scope of Smart-Wanderer

The length of the Smart-wanderer is 420 mm. Based on the adaptable component, the outside diameter of Smart Wanderer can change from 475 mm to 615 mm, which implies a variety of the adaptable systems can arrive at 70%. The diameter transmission scope of Smart-Wanderer is represented in Fig. 3. Accordingly, the Smart-Wanderer can be applied for review assignment in the pipelines with these measurements in this range.

VI. FLEXIBLE MECHANISM:

Three sets of adaptable Omni wheel components are incorporated in the Smart-wanderer, and every one of their structures is the same. Every one of these adaptable wheel components comprises of three units: the driving instrument, the linkage grasp component, and Omni wheel units, In request to be more minimal and then some adaptable, a screw bar is bidden to replace the conventional spring hatchet, and a 4-bar shape is intended for the linkage grip mechanism, Every wheel unit is made up of two arrangements of wheels set comprises a wheel, another end of the wheel set is having brushes attached to it so that the brushes will also able to change direction and also for cleaning. Each wheel set is driven by a hub motor inside the Omni wheel. As shown in fig:4

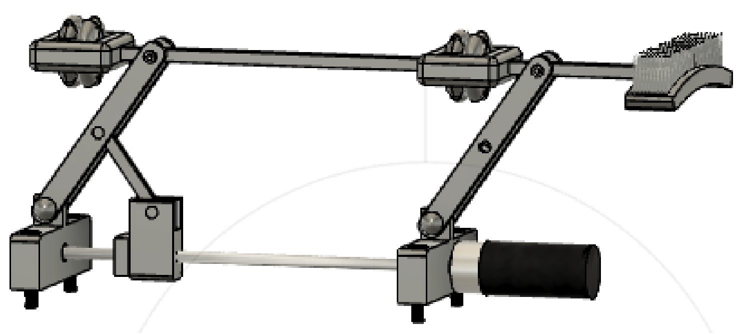

Fig 4: The view of the flexible mechanism of the smart wanderer.

The driving mechanism is liable for impelling the 4-bar linkage grasp components to broaden or contract, followed by the wheel units to acclimate to various pipeline diameter. The screw pole is driven by a stepper engine to spin clockwise or anticlockwise. Accordingly, the U-shape slider and the connector slider crossing on the screw pole can push ahead and in reverse separately. At that point, the point in the 4-bar linkage grip changes as indicated by the situation of the sliders, which decides the outside distance across of the Smart-wanderer. So that the brushes are attached to the wheel. The vacuum chamber is attached at the backside of the tube body it will rotate to collect the dust particles in the pipe. The ultrasonic sensor is placed on the front side of the tube body.

VII. FLEXIBLE MECHANISM MOVEMENT CONTROL METHODOLOGY:

Thebendable's movement mechanism is constrained through the MCU dependent on the pressure statistics between the pipeline and wheels internal floor, which can be identified with the pressures among the slider and the U-form slider. In an ordinary direct pipeline lacking diameter change, the pressures are inside the limit levels.

For a few exceptional pipelines, for example, oil pipelines, the grating among the wheels and pipelines internal floor, which is chosen by the pressure among them, need to be large sufficient to make sure the Smart-wanderer typical moving development. Nonetheless, when the inward pipeline measurement modifies, the pressures at the wheels will alternate, and the pressure among sliders will alternate likewise. The adaptable systems will make contract when the pressure surpasses the restrict stages while the pipeline internal diameter across modifies into small, as an instance, there's a deterrent or a nook. On the opposite, the flexible mechanism will expand while the pressure diminishes decreases than the limit levels.

The limit on the pressure variety for various adaptable components on various spots may be unique, this is, the pressure limit for the 2 bases adaptable mechanism are a lot better the best one if the robot actions principally in a forward manner. In certain circumstances, the disposition of the Smart-wanderer adjustments for the duration of transferring along the pipeline, and if the variety of the attitude is large sufficient, a moving movement can occur. Along these lines, the places of the past top and base adaptable instruments may trade. Within the MCU, the pressure restriction levels for every flexible system want to change as indicated by explicit specific directions, where the attitude is gathered by the attitude sensor. The movement system of the flexible mechanism in the MCU and is for one manipulate-cycle length. From the start, the places of the 3 flexible systems are assessed depending at the proposed robot's attitude measurement and the limits for everyone maybe chosen, in which the mentality information is gathered by the attitude sensor. Because of the positive edge goes, the pressure information for every flexible component is contrasted and the reach. If at least one pressure surpasses better or decrease than the limit goes, the MCU won't drive the motors to change the Smart wanderer diameter quickly, however will save the pressure circumstances till a few examining durations later. If every one of these weights is past the edge runs, the MCU will manage the stepper by imparting a PWM signal to the driving force boards behind the PI controller. All the three flexible components contracting or stretching out simultaneously can guarantee the symmetrical triangle mechanical shape of the 3 flexible mechanisms, that's a steady shape for the Smart-wanderer to in shape movement prerequisites. The ultrasonic sensors will generate the acoustic waves to detect the cracks.

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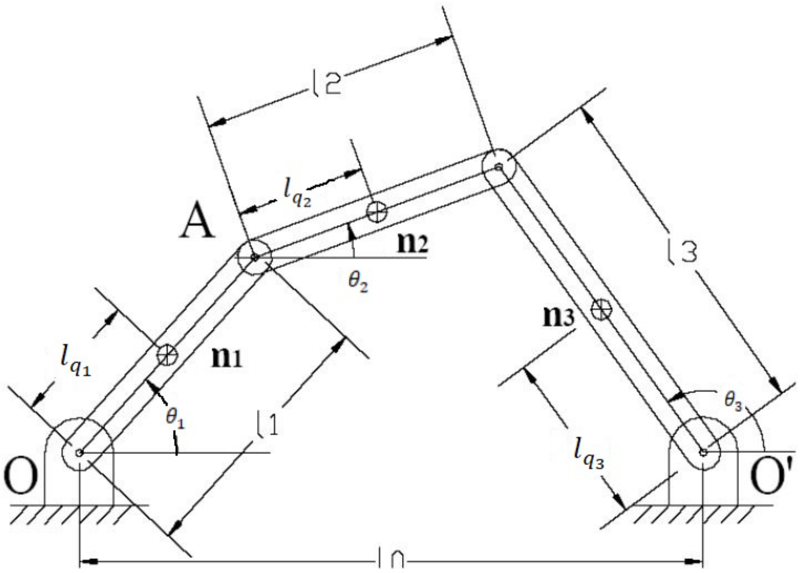
VIII. MATHEMATICAL ANALYSIS OF ROBOT



The four bar consist of 3 moving links of length l_1, l_2, l_3 with angle $\theta_1, \theta_2, \theta_3$

The ground is measured from O toO' of length of l_0

Position analysis

$-l_1 cos\theta_1 - l_2 cos\theta_2 + l_0 + l_3 cos\theta_3$=0 --------- ----> (1)

$-l_1 sin\theta_1 - l_2 sin\theta_2 + l_3 sin\theta_3$=0 -------------- ----> (2)

Equation (1) & (2) are theconstraints loop closure in x & y coordinates

We expressθ_2&θ_3 in terms of θ_1 . So first rearrange the equation above into the following way to eliminateθ_2:

$l_2 cos\theta_2 = -l_1 cos\theta_1 + l_0 + l_3 cos\theta_3$ ------------ ----> (4)

$l_2 sin\theta_2 = -l_1 sin\theta_1 + l_3 sin\theta_3$ -------------- ----> (3)

The sum of square of above (3) & (4) equation

$k_1(\theta_1) sin\theta_3 + k_2(\theta_1) cos\theta_3 + k_3(\theta_1) = 0$ ----------- -----> (5)

k_i(1,2,3)are functions of θ_1

$k_1(\theta_1) = -2 l_1 l_3 sin\theta_1$

$k_2(\theta_1) = -2 l_3 (l_0 - l_1 cos\theta_1)$

$k_3(\theta_1) = l_0^2 + l_1^2 - l_2^2 + l_3^2 - 2 l_0 l_1 cos\theta_1$

Dividing equation (4) by equation (3) we can then arrive at

$\theta_2(\theta_1, \theta_3) = arc \tan 2(-l_1 sin\theta_1 + l_3 sin\theta_3, l_0 - l_1 cos\theta_1 + l_3 cos\theta_3)$ -----------------> (6)

At this stage, we express θ_2& θ_3 completely in terms of θ_1

Velocity Analysis:

In velocity analysis, trying to differentiate the loop closure limts in equation (1) & (2) with respect to time and expressing them in matrix form yield:

$$\underbrace{\begin{bmatrix} l_1 sin\theta_1 & l_2 sin\theta_2 & -l_3 sin\theta_3 \\ -l_1 cos\theta_1 & -l_2 cos\theta_2 & -l_3 cos\theta_3 \end{bmatrix}}_{A} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \text{-----------------> (7)}$$

Since we have choose θ_1 as the independent variable, we arrange equation (7) in

$$\begin{bmatrix} l_2 sin\theta_2 & -l_3 sin\theta_3 \\ -l_2 cos\theta_2 & l_3 cos\theta_3 \end{bmatrix} \begin{bmatrix} \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = \begin{bmatrix} -l_1 sin\theta_1 \\ l_1 cos\theta_1 \end{bmatrix} \dot{\theta}_1 \text{ --------------------------> (8)}$$

$$\begin{bmatrix} \dot{\theta}_2 \\ \dot{\theta}_3 \end{bmatrix} = \begin{bmatrix} s_1(\theta_1, \theta_2, \theta_3) \\ s_2(\theta_1, \theta_2, \theta_3 \end{bmatrix} \dot{\theta}_1 \text{ ------------------------- ----> (9)}$$

Where $S = \begin{bmatrix} s_1(\theta_1, \theta_2, \theta_3) \\ s_2(\theta_1, \theta_2, \theta_3 \end{bmatrix}$ is the null space of matrix A

$$s_1(\theta_1, \theta_2, \theta_3) = \frac{\partial\theta_2}{\partial\theta_1} = \frac{l_1 \sin(\theta_3 - \theta_1)}{l_2 \sin(\theta_2 - \theta_3} \text{-----------------------------> (10)}$$

$$s_2(\theta_1, \theta_2, \theta_3) = \frac{\partial\theta_3}{\partial\theta_1} = \frac{l_1 \sin(\theta_2 - \theta_1)}{l_3 \sin(\theta_2 - \theta_3} \text{-----------------------------> (11)}$$

Lagrangian Formulation:

Lagrangian of the entire system is defined by the overall kinetic energy less overall potential energy.

Total kinetic energy of the system as:

$$T = \underbrace{\frac{1}{2}\left(n_1 \left|\left|v_{q_1}\right|\right|^2 + I_1\dot{\theta}_1^2\right)}_{T_1} + \underbrace{\frac{1}{2}\left(n_2 \left|\left|v_{q_2}\right|\right|^2 + I_2\dot{\theta}_2^2\right)}_{T_2} + \underbrace{\frac{1}{2}\left(n_3 \left|\left|v_{q_3}\right|\right|^2 + I_3\dot{\theta}_1^2\right)}_{T_3} \text{ -----------------> (12)}$$

Where

$$||v_{q_1}||^2 = l_{q_1}^2 \dot{\theta}_1^2$$

$$||v_{q_2}||^2 = l_1^2 \dot{\theta}_1^2 + l_{q_2}^2 \dot{\theta}_2^2 + 2 l_1 l_{q_2} \cos(\theta_1 - \theta_2)\dot{\theta}_1 \dot{\theta}_2$$

$$||v_{q_3}||^2 = l_{q_3}^2 \dot{\theta}_3^2$$

T_i ------------> Kinetic energy of link i.

Potential energy of the system as:

$$V = n_1 g y_{q_1} + n_2 g y_{q_2} + n_3 g y_{q_3} \text{ -----------------------------> (13)}$$

$$\underbrace{\qquad}_{v_1}\ \underbrace{\qquad}_{v_2}\ \underbrace{\qquad}_{v_3}$$

g--> gravitational acceleration

$$y_{q_1} = l_{q_1} sin\theta_1$$

$$y_{q_2} = l_1 sin\theta_1 + l_{q_2} sin\theta_2$$

$$y_{q_3} = l_{q_3} sin\theta_3$$

Lagrangian of the entire system is given by

L=T-V --> (14)

$$L(\theta_1,\theta_2,\theta_3,\dot{\theta}_1,\dot{\theta}_2,\dot{\theta}_3) = J_1\dot{\theta}_1^2 + J_2\dot{\theta}_2^2 + J_3\dot{\theta}_3^2 + P_1 C_1(\theta_1,\theta_2)\dot{\theta}_1\dot{\theta}_2 + G(\theta_1,\theta_2,\theta_3) \text{ ---------->(15)}$$

Where

$$J_1 = \frac{1}{2}(n_1 l_{q_1^2} + I_1 + n_2 l_1^2)$$

$$J_2 = \frac{1}{2}(n_2 l_{q_2^2} + I_2)$$

$$J_3 = \frac{1}{2}(n_3 l_{q_3^2} + I_3)$$

$$P_1 = n_2 l_1 l_{q_2}$$

$$c_1(\theta_1,\theta_2) = \cos(\theta_1 - \theta_2)$$

$$G(\theta_1,\theta_2,\theta_3) = \left(-n_1 g l_{q_1} - n_2 g l_1\right) sin\theta - n_2 g l_{q_2} sin\theta_2 - n_3 g l_{q_3} sin\theta_3$$

We eliminate the velocity terms of $\dot{\theta}_2, \dot{\theta}_3$ from equation (15) by using the linear relationship in equation (9) and get :

$$L\left(\theta_1,\theta_2,\theta_3,\dot{\theta}_1,\dot{\theta}_2,\dot{\theta}_3\right) = [J_1 + J_2 s_1^2(\theta_1,\theta_2,\theta_3) + J_3 s_2^2(\theta_1,\theta_2,\theta_3) + P_1 C_1(\theta_1,\theta_2) s_1(\theta_1,\theta_2,\theta_3)]\dot{\theta}_1^2 + G(\theta_1,\theta_2,\theta_3)$$

------------------> (16)

Although θ_2 *and* θ_3 are still remain in the equation .they can be said in terms of θ_1 and the Lagrangian is considered completely written in terms of θ_1

IX. ANALYSIS:

Body analysis: Displacement **Total** [mm] 0 4.901E-05

Omni wheel: Displacement **Total** [mm] 0 1.568E-04

Wheel link: Displacement **Total** [mm] 0 0.04787

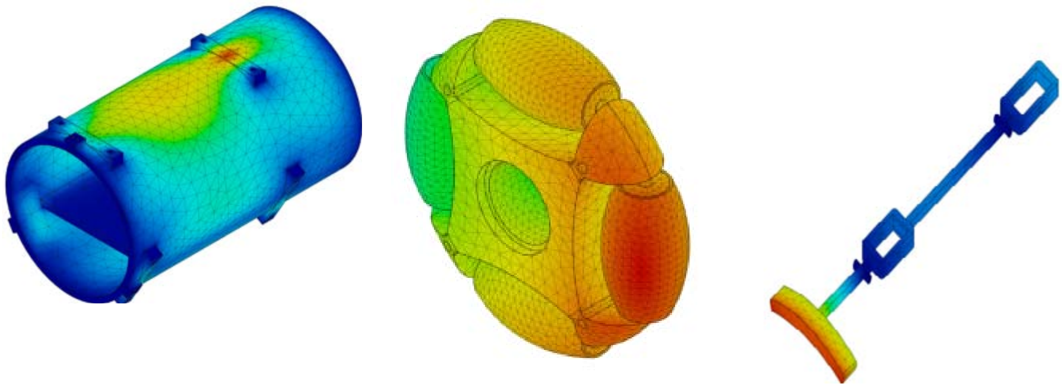


Fig 5: simulation of body ,Omni wheel, wheel link

This Smart Wanderer Autonomous Pipe Line Inspection Robot is designed and simulated in Auto desk fusion 360. In the simulation study (Static Stress, Deformation) fixed constraints are given for tube body, Omni wheel, wheel link. These are studied considering Steel and Aluminum material. A load is applied to these components taking into account the motor weight and assembles Sensors, and outer body. In this simulation study, it shows a deformation because we use aluminum and steel material and an optimized design. For minimum deformation, a blue is shown on the frame and for maximum deformation shows a red. In this deformation, red and green in colors are shown in the places on about the various components and it is negligible deformation when compared to other regions the components here show more information.

X. CONCLUSION:

On this paper, an autonomous inline assessment robot model, called Smart-wanderer, is planned and created. It could circulate along the pipeline to actualize a few undertakings furthermore, handle some particular conditions, for example, an obstacle, cracks, cleaning consequently, which dues to the utilization of the MCU regulator and the adaptable components. Moreover, without the restriction of ties or links, the proposed robot's movement may be extra adaptable farther far off, which of significant highlights for the review of a few complex mechanical pipelines. the 3d design effects are provided and analyzed.

For the later Smart-wanderer ages, numerous upgrades might be implemented:

(1) Onboard calculations for programmed way acknowledgment and anticipating unpredictable or obscure pipeline conditions;

(2) Integration with investigation instruments for explicit applications;

(3) Smart forces the executives to plan from data assortment and energy productivity angles.

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