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Dynamic Modelling and Obstacle Avoidance for Cable Maneuvering Robot

In application to Transmission line Inspection robots

[1]Narrendar.R.C, [2]Prof.S.Denis Ashok
[1]Gaduate Student, [2]Professor,
[1]Department of Mechatronics Engineering,
[1]VIT University, Vellore, India

***Abstract* - Power transmission involves the crucial part power supply over a country. Continues assessment and inspection can effectively promote the overall productivity of these energy systems. Deployment of mobile robots can provide an effective solution to this problem. In this paper inspection tasks performed by the robot carrying detection instruments and rolling/crawling along the overhead ground wires are considered. There are different uncertainties involved with the inertial aspects of transmission line and the robot, achieving an accurate mathematical model of the system is difficult, which in turn increases the complexity over control. But coupling the dynamic aspects between the robot and its moving path can give better control over motion precision. This paper involves the dynamic modelling of cable maneuvering robot enabling traction control and centroid compensation. The scope of these analysis will help in understanding the system's stability and achieving its control effectively. Path planning and obstacle avoidance schemes are developed based on the former results.**

***Index Terms* - Mobile Robot, Dynamic Control, Path planning, Obstacle Avoidance**

I. INTRODUCTION

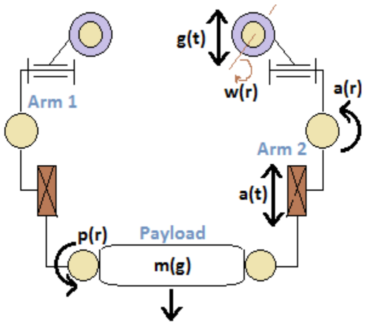
Current pace of power line inspection using mobile robot involves the robot's maneuver over the line and identify any defects under the supervision of a ground based crew. However the next technological advancement has focus to autonomous inspection. Survey of Existing Robotic Systems including the works of *Sawada et al., 1991* involving a robot with an obstacle avoidance mechanism that is able to negotiate towers as well and transfer to the next span to inspect rest of the power line. Another robot developed by *Tsujimura and Morimitsu in 1997* created gait trajectories kinematically which had both stability and simplicity in control. Moreover, with some minor modifications in the gripper design a similar approach by *Zhu et al., 2006* enabled the robot will be even more stable in windy climates. The *Chinese Academy of Sciences* in *Shenyang* developed a complex robot mechanism with a special gripper combined with a driving wheel, the obstacles avoidance strategy needed only two degrees of freedom that could overcome all standard obstacles over the phase transmission lines. Apart from academic research *Hydro Quebec's Line Scout*, *LineROVer* and Hibot's *EXPLINER* are commercially deployed line inspection robots. The main research problem with climbing robots is therefore the development of a robot mechanism and its control system for obstacle crossing.

II. MECHANICAL DESIGN

The design framework involved with these kind of robot must enable them, by adapting to different geometrical environments to avoid obstacles, slope traversing and inertial compensation. Which is achieved by intelligent traction control and centroid recovery. Simple pendulum analogy for the robot and its effect by wind drag are modelled and its parameters are defined. The drag force due to the effect of the wind, with ρ as the air density, A- the projected area of the fluid drain, C_d the coefficient of hydrodynamic drag, U - maximum speed of the wind with the frequency ω, enumerates the drag force F_D exerted on the robot suspended over the transmission line. In order to stabilize the robot against this perturbation it has to provide a controlling force τ_i that compensates the wind drag F_D as represented by *equation 1*.

$$I_o\left(\frac{d^2\theta}{dt^2}\right)(t) + mgL\theta(t) = \frac{1}{2}\left(\rho A C_d U^2\right)\sin\omega t \qquad (1)$$

The equation of motion for the robot with mass m is derived from its moment of inertia I_o, angular acceleration $\frac{d^2\theta}{dt^2}$, the length of the connecting rod L that suspends the robot over the transmission line. The influence of wind on the robot oscillation indicated that the hydrodynamic shape is directly proportional to amplitude of oscillation of the robot.



Symbol	Parameter Description
g(t)	Compressive force exerted by gripper
w(r)	Torque required to rotate the gripper wheel
a(r)	Gripper rotation normal to p(r)
a(t)	Arm translating payload up and down
p(r)	Arm rotating payload for COG balance
m(g)	Weight of the robot acting downwards

Figure 1: Motion Parameters of the Robot

III. Traction Control

Mechanical Components of gripper include the mechanism for controlling the traction of the robot on the wire and the gripper wheel. The wheel design is conical with a tint of the rubber to provide the necessary traction. The traction force on the wheel is proportional to the cosine of the cone angle ($\emptyset$) from the normal coefficient of friction μ.

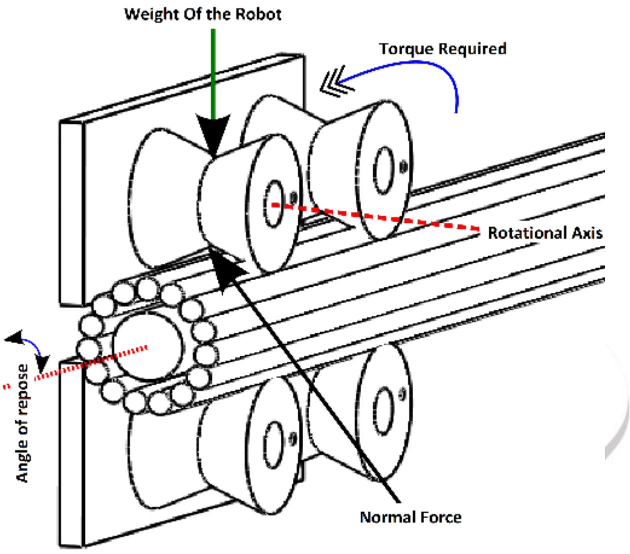


Figure 2: Forces acting on the gripper wheel while traversing along the power line

The reaction forces $F_{N1} + F_{N2}$ acting on the conical section of wheel in contact with the base is proportional to the normal force (F_N) given by the *equation 2*

$$F_{N1} + F_{N2} = \mu \, \frac{F_N}{\cos \emptyset} \qquad (2)$$

Therefore, the acuteness of the angle is optimized to accommodate more cable diameters and the traction force. The nature of wheel radius and the maximum torque for the motors can be calculated by the *equation 3*

$$\boldsymbol{\tau}_{\text{Torque}} = \mathrm{F}_{\text{Net}} * \mathrm{R}_{\text{wheel}} \qquad (3)$$

Robot traversing over the wire can accelerate or decelerate based on the nature of slope, in these scenarios control of acceleration can be achieved either by torque input from the motor or by applying pressure over the wire initiating controlled traction. The mechanism involves a movable platform and a stationary one. A lead screw type actuation from a micro-motor can effectively vary the force exerted by gripper wheels on the wire. The necessary tractive force can be achieved as a linear relation with the coefficient of friction μ and the reaction force N_v exerted between the gripped wheel and the transmission line.

$$F_t = \mu \, (\lambda) N_v \qquad (4)$$

In order for the robot to move without slipping, joint torques τ_i must be smaller than the moment due to static friction μ_k

$$\tau_i < [\mu_k] \qquad (5)$$

IV. MODELLING THE TRANSMISSION LINE

Environment modelling is a crucial factor in case of mobile robot design. As the maximum contribution to non-linearity comes from the external factors- understanding the environment can help in designing the robot better and to achieve effective control. The analysis of dynamic behavior is based on the wave equations. The simulation conditions are depicted as the wire strained between two towers. The model is constrained as a string, which can move between the fixed points in horizontal and vertical directions and can also rotate.

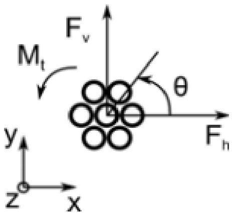


Figure 3: Various forces acting on the Transmission line

The dynamics of the wire movement is described by three partial differential equations. The first equation describes the motion of wires in the vertical direction depending on the longitudinal position (variable z) and time t. The second equation describes the wire motion in the horizontal direction. The third equation then adds rotation (torsion) θ.

$$m\frac{\delta^2 y}{\delta t^2} + C_y\frac{\delta y}{\delta t} - T\frac{\delta^2 y}{\delta^2 z} = F_V(z) \qquad (4)$$

$$m\frac{\delta^2 x}{\delta t^2} + C_x\frac{\delta x}{\delta t} - T\frac{\delta^2 x}{\delta^2 z} = F_h(z) \qquad (5)$$

$$I\frac{\delta^2 \theta}{\delta t^2} + C_\theta\frac{\delta \theta}{\delta t} - GJ\frac{\delta^2 \theta}{\delta^2 z} = M_t(z) \qquad (6)$$

V. DYNAMIC MODELLING OF THE ROBOT

As the robots design parameters are defined the dynamic analysis is developed using Lagrangian equations. Where the Lagrangian is the difference between the kinetic and potential energies of the system. The formulation helps in determining the equations of motion for the robot from which, the joint torque can be estimated for inverse dynamics or robot's motion can be determined for a given joint torque for forward dynamics.

$$\frac{d}{dt}\left(\frac{\delta L}{\delta \dot{q}_j}\right) + \frac{\delta}{\delta q_i} = Q_i \qquad (7)$$

Using MATLAB SimMechanics module, the intended system is realized in a virtual environment. As the robot generally has lots of joints and mechanical elements; combining all elements for the dynamic analysis may complicate the simulation. For this reason only vital elements of the system are considered and are imported into MATLAB that actually represents the real system in action. The Simulink model and the output of the system for an obstacle avoidance scheme was simulated.

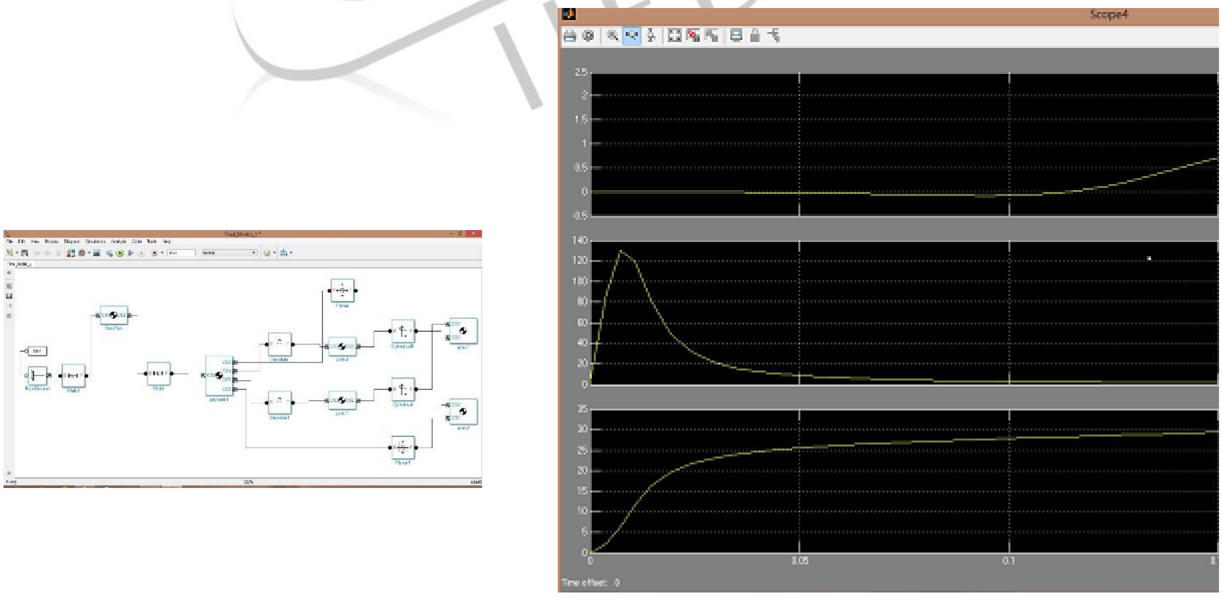


Figure 4: Equivalent MATLAB model showing the Center of Mass Displacement for Two arms and body

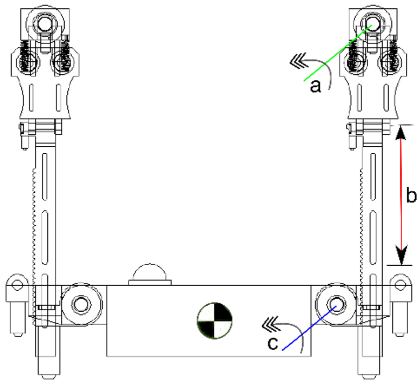


Figure 5: Robot showing 3DOF arm and its COM

VI. MANEUVER ALONG TRANSMISSION LINES

The robot's mechanical structure is designed as a cable car for navigating on the wires. The robot has two arms and a set of wheel claw mechanism is mounted on the end of each arm to climb on the wires. The control system and the inspection devices are installed in the control module which is suspended under the body of the robot. Each arm has 3 DOF. The rotary joint on the arm can regulate the claws for grasping object accurately. The rack and pinion mechanisms are applied to drive the claws and wheels upward and downward. The worm and worm gear mechanisms are applied to drive the arms upward and downward.The control module can move along the body of the robot which can balance the robot and improve the stability. Mounting the robot on a cable with the slope, the center of mass has to be maintained first. Initially the sensors helps to identify the nature of slope, from which a prediction of Centre of mass is calculated. Based on the deviation of COM and correction required- the joints are controlled achieving stability.

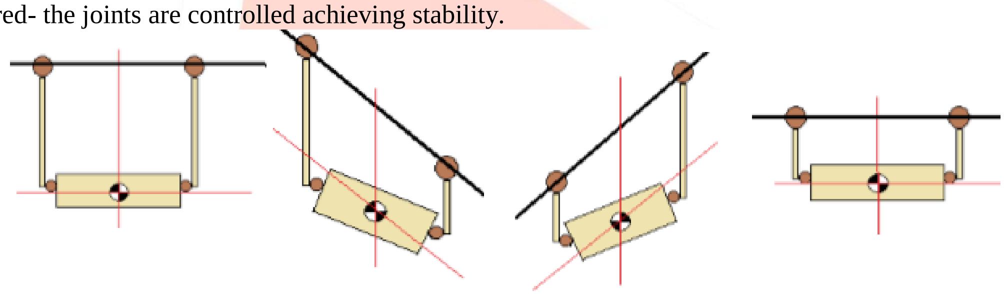


Fig: 5 Different Slope traversing strategies

VII. OBSTACLE AVOIDANCE SCHEME

The warning balloon obstacle is one of the most complicated obstacles in power line cable, which requires sufficient attention on the robot stability while passing. The robot is designed in such a way to pass the obstacle. As the obstacles and their nature are previously known they are considered to be constrained. And their models are linearized for achieving easy and effective control. The obstacle avoidance scheme is divided into three kinematic entities where the de-proximitation of the robot from wire takes place followed by Forward traverse of arm1 and Reverse traverse of arm. This process completes a cycle for avoiding an obstacle.

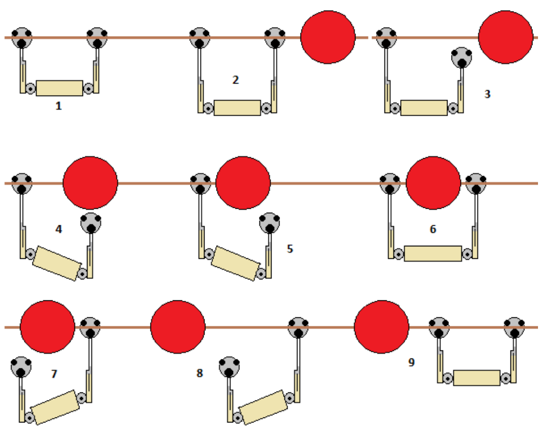


Figure: 6 Obstacle avoidance scheme

VIII. CONCLUSION

The objective of developing a virtual prototype for analyzing and optimizing its functionality are achieved. All the design and control parameters are made from actual analysis of the modelled system. Also the dynamic analysis presented provides a valuable insight over its stability and control, the proposed model, its navigation and obstacle avoidance schemes are simulated in the transmission line environment. Based on the acquired results the proposed design proved to be reliable and more complex maneuvers were able to perform with lesser Degrees of freedom and the motion study clearly indicated that the indented obstacle passing scheme was effective and stable.

REFERENCES

[1] Mostafa Nayyerloo, XiaoQi Chen, Wenhui Wang and J Geoffrey Chase (2009). Cable-Climbing Robots for Power Transmission Lines Inspection, Mobile Robots - State of the Art in Land, Sea, Air, and Collaborative Missions, XiaoQiChen (Ed.), ISBN: 978-953-307-001-8, InTech,

[2] Fu S. F.; Wang H. G.; Fang L. J. & Jiang Y. (2005). On obstacle-navigation control of inspection robot for the extra-high voltage power transmission line. Robot, Vol.27 No. 4, pp. 341-345+366, 1002-0446

[3] Xiao X. H.; Wu G. P.; Du E.; & Li S. P. (2008). The impacts of flexible obstructive working environment on the dynamic performances of an inspection robot for power transmission line. Journal of Central South University of Technology, Vol.15, No.3, pp: 525-530, 1005-9784

[4] Wang L. D.; Fang L. J.; Wang H. G.; et al. (2006). Development and control of an autonomously obstacle-navigation inspection robot for extra-high voltage power transmission line, Proceedings of the International Joint Conference of SICE-ICASE, pp. 5400-5405, 89-950038-5-5, Busan, March, 2006, Publisher, Busan

[5] Wu G. P.; Xiao X. H.; Xiao H.; Dai J. C.; Bao W. J. & Hu J. (2006). Development of a Mobile Inspection Robot for High Voltage Transmission Lines. Automation of Electric Power System, Vol.30, No.13, pp. 91-93+107, 1004-1026

[6] Wu G. P.; Xiao X. H.; Guo Y.L. & Hu J. C. (2006). Development of a Crawling Robot for Overhead High-Voltage Transmission Line. China Mechanical Engineering, Vol.17, No.2, pp. 237-240, 1004-132X

[7] Peungsungwal S., Pungsiri B. & Chamnongthai K. (2001).Autonomous robot for a power transmission line inspection. Proceedings of 2001 IEEE International Symposium on Circuits and Systems, pp. 121-124, 0-7803-6685-9, Sydney, NSW, Australia, May 2001, Institute of Electrical and Electronics Engineers, Sydney

[8] Xiao X. H.; Wu G. P.; Du E. & Shi T. L. (2005). Dynamics simulation and experimental study of inspection robot for high-voltage transmission-line. Journal of Central South University of Technology (English Edition), Vol.12, No.6, pp: 726-731, 1005-9784.