INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: **Design and Development of a Pipe Climbing Robot with a Compliant Bistable Gripping Mechanism**

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SHORT ABSTRACT

Rigid pipes are used in almost every walks of life, starting from industries to domestic household for the transportation of fluids. All these pipes are subjected to wear and tear after a period of time. Any such wear and tear of the pipes leads to the disruption of supply lines in residential areas and may lead to a major accident in industries. Hence, the structural health of the pipes, especially in industries, is to be inspected on a periodic basis for any flaws or cracks. Apart from the dangers associated with the inspection of the toxic fluid carrying pipes, many a time some portion of the pipelines are situated at such remote locations or at heights where the human workers are unable to reach. Hence, there is a need to develop a pipe climbing robot to suit the industrial needs, with a payload to weight ratio greater than 0.5 and the overall load bearing capacity greater than 1 kg. Also, it should have a structure similar to a parallel manipulator so that industrial equipment can be kept or mounted on it.

The pipe climbing robot considered in this work has a motion similar to that of an inchworm as inchworm type pipe climbing robots have a better load carrying capacity as compared to their wheeled counterparts. The gripper in the proposed robot uses a bistable buckled beam, which is one of the types of bistable compliant mechanism. A bistable buckled beam is chosen as the gripping mechanism as it has two stable equilibrium states and no power or energy is required to maintain the stable states. The bistable buckled beam in the gripper of the proposed robot is alternately actuated between its two stable equilibrium states by a mechanical drive system involving cams and lever. The values of the design parameters of the bistable buckled beam are obtained both experimentally and numerically. Depending on the dimensions of the bistable buckled beam and the pre-stress it is subjected to, the cam profiles are also designed following the standard procedures. The proposed robot is modelled and the working and simulation of its different parts are checked in Solidworks.

After designing the gripper, two climbing mechanisms are proposed both of which are compatible to the designed grippers. One is based on a prismatic (or lead-screw based) joint for climbing straight vertical pipes and the other is based on a revolute-revolute-revolute-prismatic (RRRP) climbing mechanism having a three dimensional workspace, for climbing any bend pipe including ninety-degree bend pipes. The working of both the mechanisms is discussed. The end-effector positions of the RRRP climbing mechanism are generated by making use of its workspace. Then, a soft computing technique, namely, adaptive neuro-fuzzy inference system (ANFIS) is used to obtain the joint angles corresponding to the different end-effector positions of the climbing mechanism. The trajectory between the two points is planned in joint space using the method of modified linear function with parabolic blends. After that, the Euler-Lagrange equations of motion of the climbing mechanism are derived. These equations are evaluated to obtain the nominal torques acting at the joints.

After the dynamic analysis of the climbing mechanism, a proportional-integral-derivative (PID) control law is used in a RRRP serial pick and place robot for trajectory tracking of the joints of the robot. The feedback gains of the PID control law are tuned using Floquet theory. The advantage of using Floquet theory for RP class of serial manipulators is that no information is required on the bounds of the inertia matrix and the Jacobian of the gravity vector. The successful demonstration of Floquet theory for a RRRP pick and place robot shows that it can also be used for accurate trajectory tracking in the proposed RRRP climbing mechanism.

After designing the grippers and the climbing mechanism, the parts of the robot are fabricated and assembled. The pipe climbing robot for straight vertical climbing is only fabricated. The working of the pipe climbing robot is successfully demonstrated on a polyvinyl chloride (PVC) pipe of 110 mm diameter. The designed and developed pipe climbing robot has a payload to weight ratio of 0.52, overall load bearing capacity of 11.69 kg, a power consumption of 18.58 W and a speed of 0.2 m min^{-1}.

The thesis has five chapters. Chapter 1 gives a brief introduction on pipe climbing robots and the motivation behind the design and development of a pipe climbing robot. This chapter also carries out the scientific and comprehensive analysis of literature. Chapter 2 discusses the model and the design process of the gripping mechanism. The model of the climbing mechanism and its dynamic analysis are given in chapter 3. After the design of the mechanisms, chapter 4 discusses the development of the pipe climbing robot, which includes the fabrication, materials used and electronics. Lastly, chapter 5 concludes the thesis with a scope for future work.