Mechatronics 21 (2011) 48–62

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

3DCLIMBER: Climbing and manipulation over 3D structures ☆

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ARTICLE INFO

Article history:
Received 8 September 2009
Accepted 22 August 2010
Available online 28 September 2010

Keywords:
Pole
Pipe
Climbing
Robot
NDT
Fine manipulation
3D structure
Accelerometer
Inspection
Inclinometer
Mobile arm

ABSTRACT

This paper describes the development of a novel pole climbing robot with the ability of climbing and manipulating across 3D structures, like petrochemical pipelines. The robot consists of a 4-DOF serial climbing mechanism and two grippers. Unlike many other developed pole climbing robots, 3DCLIMBER can overcome bends, T-junctions, flanges, and sharp changes on the pole's diameter. With the current gripper, the robot can operate on circular profiles with diameters ranging from 200 mm to 350 mm and is able to scan the exterior surface of the pole. Existence of separate gripping and climbing modules allows application of various grippers for different profile shapes and sizes without any change on the climbing mechanism. In case of power failure the robot maintains its status without slipping on the structure. Furthermore, some nondestructive test operations require fine manipulation over the structure. Fine manipulation with an industrial arm encounters many well known difficulties. Such difficulties become even more problematic when the base of the robot's arm is mobile. This problem was addressed by a robotic proprioception solution embedded into the robot by integration of inclinometers and range finder sensors as well as error compensation and self calibration algorithms. The proposed algorithms and sensors significantly improved the manipulation accuracy of the robot.

1. Introduction

Pole climbing robots have many applications in the inspection of human made 3D tubular structures. One of the most important applications is performing periodical inspections with nondestructive test (NDT) devices in order to asses the progression of material degradation and the detection of welding defects. Nowadays, NDT methods are performed by dextrous technicians across high level pipes, frequently carrying dangerous chemicals. This task is extremely difficult and can be categorized as a Dirty, Dangerous and Difficult (DDD job). In the United States, wages for DDD occupations can be over 70,000 USD annually and even though there are lack of workers for these jobs since they are dangerous for human life. Climbing robots with the ability of climbing across 3D tubular structures with bends and branches and scanning the whole or part of the pipe's surface, may be equipped with NDT probes and be used to do such inspections automatically. The user requirement of the 3DCLIMBER project defined two main objectives:

(1) Ability to autonomously climb industrial pipes with bends and T-junctions.
(2) Ability of fine manipulation on the structure without the need of an extra arm.

As a result of the increasing interest on climbing robots all around the world, different types of climbing robots were developed for climbing across flat or curved surfaces. For holding robot attached to a smooth surface, suction cups [10,20,26,35] or attraction force generated by propeller [22,23] or magnets [12,14] were used. Robots whose end-effectors match engineered features of the environment like fences or porous materials or bars [6,36,37,2] were developed. Robots for climbing inside pipes or ducts [21,25] or climbing across poles [5,1,24,31,3,34,13] were also developed. The later group is called Pole Climbing Robots (PCRs). None of the already developed robots could fulfill the requirements of this project. They were either not able to pass bent sections of up to 90° [3,15,24,34] or were not able to pass branches [1]. The most recently reported PCR is a quadrupedal robot which can rapidly climb across straight poles [13], but the ability of passing the bent sections and T-junctions was not reported. Furthermore this robot may not be able to climb from metallic surfaces due to the claws-like grippers which are designed for soft materials, like wood.

Design of the climbing configuration depends on the applications considered for the robot. Almonacid et al. have developed a 6-DOF parallel robot with pneumatic actuators [1]. Balaguer et al.

☆ This project is partially financed by Foundation of Science and Technology (FCT) of Portugal under the Contract SFRH/BD/29883/2006.

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doi:10.1016/j.mechatronics.2010.08.006