Robot Applications Against Gravity

Carlos Balaguer, University Carlos III of Madrid, Spain
Gurvinder Virk, University of Leeds, United Kingdom
Manuel Armada, Institute of Industrial Automation, Spain

Mobile robotics has seen tremendous growth in recent years, and several types of locomotion systems have been investigated as robotics migrates from traditional fixed-base systems, which are used essentially for manufacturing, to mobile systems designed to provide much more flexible services. The mobility has been designed using wheeled and tracked designs for moving on office and domestic environments or even terrains, legged machines for moving in three dimensional (3-D) unstructured environments, swimming and underwater robots for subsea exploration, etc.

Climbing robots form a specialized area of mobile robots, the main feature being mobility against gravity. Unlike wheeled and legged robots, which move in ground environments, the climbing robots move in complex 3-D environments and need to be self-supported, keeping in mind the gravity force. They are able to work in many spatial conditions and move along walls, ceilings, floors, roofs, etc. Climbing robots are, in general, also able to climb vertical natural or artificial terrains like an alpinist or mountaineer. These robots transit from one spatial plane to another without difficulties by using complex 3-D kinematics configurations and special safe grasping devices.

An important aspect to consider in the design of such robots is that they need to be lightweight and powerful enough to not only move around but also to support their own weight. Therefore, the design must consider not only locomotion, as in all mobile robot systems, but also adhesion and/or attachment aspects, i.e., how does the machine stick to the surface it is meant to be climbing? There are several forms of adhesion, the main ones include: 1) magnetic solutions for climbing on ferrous surfaces via electromagnets or permanent magnets; 2) vacuum suction technologies for nonporous surfaces by fans, vacuum pumps, or venture pumps supplied by compressed air; 3) specific attachment devices for the structure being climbed, such as rails or pegs or other obtrusions allowing the machine to support itself; and 4) grippers or pressure-loaded mechanisms that attach to some parts of the structure like beams, columns, pipes, and ducts.

From the design point of view, the climbing robots' locomotion ability can be classified into three main classes: 1) wheel-driven machines that climb the vertical planes by combining wheels for translation and rotation and magnets or vacuum pumps for surface attachment; 2) legged locomotion consists commonly of four or six legs, each of them with magnets, and a vacuum pump for good attachment but with limited maneuverability; and 3) locomotion based on arms with grippers or similar devices that provide the robot with a high level of mobility. The first class of climbing robot has "1-D mobility" for walking along flat or quasi-flat tracks or surfaces, the second class has "2-D mobility," which permits them to transit from one plane to another, and finally, the arm-based locomotion permits full "3-D mobility" for transitioning, for example, from one face of the column to the opposite one.

Other important aspects are the power supply and robots' payload. The limitations of the umbilical power connection due to distance and the wire's roll up make it necessary to install the power supply on board. The actual batteries' life and the air pressure reservoir's size and weight have big limitations. This is why the kinematics and dynamics design of the autonomous robots must optimize the overall robot weight, making them as lightweight as possible. For this purpose, the "loop" iterative process is established: the reduction of 1 kg of the overall robot weight generates the possibility to reduce the actuators (motors) torque and their weight and consequently reduce the robot's overall weight. At the same time, reducing the weight means that the same battery has more life time. This process is applied iteratively to reach the desired optimum design for specific applications as other research has demonstrated.

The climbing robots are commonly equipped with all the necessary systems for autonomous navigation: battery, computers, and sensors. The internal sensory feedback, using cameras and laser telemeters, helps the robot in the selection of the best grasping position and also helps avoid collisions. At the same time, these and other sensors (X ray, ultrasound, etc.) are used to inspect and transmit the status of the surface of the structure being climbed to the ground computer. An autonomous navigation capability is also needed in many cases to control the stability of the robot attachments during each gait operation: before releasing one leg/arm/gripper it is necessary to be sure that the robot will continue to be stable. The dynamics during the various gait transitions is crucial.

Many applications exist where climbing machines can be usefully deployed either to reduce the danger for humans or for carrying out tasks which otherwise would be impossible. Application areas include the inspection of tall buildings and structures (walls, roofs, windows, overhangs, etc); the cleaning and maintenance of industrial structures (electrical, conventional, and nuclear plants and towers); civil engineering infrastructure inspection (bridges, dams, ports), petrochemical plants (including off-shore platforms); tank and pipe monitoring, repair, and inspection; big transportation systems inspection (ships, aircrafts); natural landscape inspection and maintenance, etc. The requirements for these (and other) applications can be extensive. For example (as well as for more complicated 3-D environments), machines need to move around on flat and curved surfaces, prepare and clean the surfaces, and perform various operations such as nondestructive testing to assess structural integrity and overall condition.

This special issue focuses on the area of climbing robots design and applications and how the technology has developed. In this issue, five articles were selected that describe different types of applications, robot design, and control strategies. All the articles have experimental parts which make them very valuable. The first deals with the climbing parallel robot (CPR) for the inspection of palm trees and tubular structures like oil pipes and bridge steel cables. The second article describes the Roboclimber, which is able to perform consolidation on steep natural walls by climbing rocks and reaching the position indicated by geologists and then drilling the mountain. The third focuses on the climbing robot Sky Cleaner, which cleans the glass curtain walls of high-rise buildings using a vacuum suckers system. The fourth one presents the low-cost Alicia family of climbing robots for the automatic inspection of concrete walls by using nondesctructive inspection. And finally, the fifth article describes the climbing robot MATS for the personal assistance of elderly and disabled people; this robot is able to climb in domestic and office environments.

We hope you will enjoy the articles of this special issue and the efforts of the researchers.

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