Autonomous Robotic Systems for Mars Exploration

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Robotic spacecraft that land on and rove over the surface of Mars must be designed to overcome many challenges due to the hostile and uncertain environment. Winds and dust buffet landers as they descend rapidly to the surface. Rocks, scarps, dunes and slopes must be avoided during landing and rover traverse. Temperature extremes, radiation, shock and vibration stress mechanical designs and computing must recover gracefully from hardware and software failures. The round-trip light time precludes direct tele-operation so all vehicle motion is executed autonomously on-board given high level commands from earth. Autonomous robotic systems are increasingly used to mitigate these challenges while also extending the capabilities of the spacecraft.

The objective of robotic Mars missions is to advance scientific discovery. Science return is greater when there is geological diversity and stratigraphy near the landing site, but these create terrain that is risky for landing. To mitigate these risks autonomous robotic systems are being developed for safe landing in these hazardous terrains. Algorithms have been developed that estimate the pose of the lander relative to known landmarks and automatically detect and avoid landing hazards. These algorithms are being combined with sensors and high performance computing to create bolt-on systems for safe and pin-point landing. Landing is fully autonomous and failure is not recoverable, so these systems are designed to be self-checking and as simple as possible while also dealing with environmental factors like illumination variations, dust and terrain relief. System robustness is demonstrated though extensive testing in the field and in simulation.

Safe and precise landing technologies enable landing at scientifically rich sites, but there is still a need to bring a mobile science platform to sample multiple sites in different geological contexts. Roving on Mars is semi-autonomous; high-level commands are uplinked to the rover and then the rover executes them without the controllers in the loop. Simple blind drive commands are used when the terrain is benign and long distances need to be covered. When the terrain is more challenging autonomous robotic systems are needed. The basic functions are stereovision based hazard detection and avoidance and visual odometry. Hazard avoidance detects obstacles that cannot be driven over, computes a short trajectory to avoid the obstacles and then drives around them. Visual odometry uses the stereo imagery to compute the change in pose of the vehicle so that precise trajectories can be followed and slip in loose soil can be detected. Other technologies tested on Mars include visual target tracking for precise instrument placement and global path planning to guide the rover to a desired goal while avoidance obstacles.

Autonomous robotic systems for Mars exploration have been developed gradually over the last two decades. Mars Pathfinder (MPF) landed blindly and then deployed the small Sojourner rover, which had stereo cameras to produce images for processing on the ground. Mars Exploration Rover (MER) landed two moderate sized rovers with a vision system that estimated velocity during landing. The rovers had multiple stereo pairs for on-board hazard avoidance and visual odometry. Visual target tracking and global planning were uploaded later as a technology demonstration. The Mars Science Laboratory (MSL) is a large rover that lands on its wheels in August of 2012 using a Doppler radar for velocity and altitude estimation. The MSL rover has the core capabilities of the MER rovers and can operate them at a higher rate. The next planned lander mission to Mars will launch in 2018 and will be the first in a sequence of missions to return samples from Mars. Technology is being developed for this mission to detect hazards and estimate position during landing so that the best possible landing site can be selected for sample return. Rover fast traverse technology is also being developed that provides sub-second hazard avoidance and visual odometry to increase the number of sites can be sampled in the mission lifetime. This presentation will describe the arc of robotic system development for Mars exploration and then focus in on the technology under development now.