Curiouser and Curiouser: Surface Robotic Technology Driving Mars Rover Curiosity's Exploration of Gale Crater

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ABSTRACT

NASA's newest Mars Rover, Curiosity, has been exploring Gale Crater under the aegis of the Mars Science Laboratory (MSL) mission since August 5, 2012 PDT. Its prime mission will encompass one Martian year, lasting into the summer of 2014. As of March 1, 2013, after more than 200 Martian Solar days (sols) on Mars, the Curiosity science team is unraveling some of Mars' secrets, and the engineering team continues to demonstrate more and more of the rover's extensive onboard capabilities.

Curiosity inherited many capabilities from the Mars Exploration Rover (MER) mission; its rocker/bogie suspension system [Harrington and Voorhees, 2004], Inertial Measurement Unit (IMU) attitude estimation framework [Ali et al., 2005], hazard detection and navigation cameras [Maki et al., 2003], [Maki et al., 2012], and much of its onboard autonomous surface operations software all trace back to the MER primary and extended missions [Maimone et al., 2007b].

But Curiosity also needed to incorporate more (and more complex) science instruments, which led to a whole new class of Mars Rover. Weighing in at 900 kg, its arm alone has as much mass as a whole MER vehicle. At 3 meters long, 2.7 meters wide and 2.2 meters tall, and with 50 cm diameter wheels, Curiosity is twice as big as MER in each dimension. Its 200 MHz CPU is 10 times faster than MER. This bigger and more complex system design led to new challenges.

One of the important changes made to the onboard autonomy was an evolutionary update to the MER Visual Odometry software [Maimone et al., 2007a]. These changes [Johnson et al., 2008] improved the robustness of the system, enabled multiresolution tracking, and (coupled with the faster CPU) have reduced the onboard processing time to under 40 seconds per step. This has enabled the human Rover Drivers to employ it much more frequently than MER did during their prime missions; Curiosity has used Visual Odometry (VO) on 34 of 40 drive sols so far, either in "slip check" mode (once every 10+ meters) or in "every step" mode, and it has converged successfully during 499 updates so far. Three planned updates intentionally failed due to poor image overlap (60% overlap is recommended, but these had less than 25%), and three more updates converged properly but were incorrectly rejected onboard due to a more than 1 degree mismatch with the onboard IMU attitude estimate. Those last three actually exposed a misconfiguration in surface IMU parameters which was quickly corrected.

Curiosity has been on relatively level ground so far during 724 meters of driving toward the Glenelg location in Gale Crater. It has not experienced large amounts of slip yet, Visual Odometry has measured about 4% on average so far (with a one-time peak of 19%). If Curiosity detects an excessive discrepancy between idealized and actual motions, it can be commanded to stop the drive autonomously to avoid potentially becoming embedded in loose soil.

Another autonomous robotic technology Curiosity has is the ability to detect and reason about geometric terrain hazards. Combining stereo vision data from multiple sources, it evaluates nearby terrain out to just over 7 meters away looking for Step, Tilt, or Roughness hazards using updated MER-heritage GESTALT terrain assessment software [Biesiadecki and Maimone, 2006]. It can then drive through the terrain making its own steering decisions using full hazard-avoidance mode, or it can be asked to follow a particular path in "Guarded" mode, where it will simply stop if it spots a nearby obstacle rather than drive around it autonomously.

The benign terrain experienced so far has meant that autonomous hazard detection has only been demonstrated, not yet used routinely. Onboard terrain assessment occurred on sols 24, 45, 127 and 133, and has been cleared for use, but so far the sampling and drilling campaigns have kept the team from wanting to drive the rover long distances.

Additional autonomous capabilities first shown on MER like Visual Target Tracking [Kim et al., 2005] and D-star path planning [Carsten et al., 2007] are also being readied for deployment on Curiosity. And Curiosity improves upon MER, whose architecture did not support easy execution of multiple simultaneous autonomous capabilities. Curiosity's design strategy makes it easier for Rover Drivers to employ as many (or few) autonomous capabilities as needed for a given drive.

Curiosity's exploration of Mars has just begun. And future software updates hold the potential of delivering even more autonomous capabilities to this next generation of Mars Rover.

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***Index Terms*— Mars rover, planetary rover, surface navigation, robotic autonomy, visual odometry**

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