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# THE CYBORG ASTROBIOLOGIST: LEARNING HOW TO AUGMENT SCIENTIFIC EXPLORATION BY ROBOTS AND ASTRONAUTS

**Abstract**

During the Apollo era, the space-exploration community debated about how astronauts should be chosen. Some thought that one or more geologists should be trained to become astronauts, in order to properly explore the Moon, through the first-hand eyes of a geologist. Others thought that astronauts, who at that time were normally pilots, should receive training to be geologists. Mirroring the Apollo-era debate, there is currently a different debate in the Mars exploration and robotics community concerning the degree to which scientific autonomy should be developed and implemented for such missions as MSL'2009 and its successors. Indeed, the autonomy of the MER missions in 2004-2005 has been limited to hazard avoidance. Yet, with this limited autonomy, together with the direction of a large team of human roboticists and planetary scientists on the Earth, these missions have been highly successful.

Nonetheless, we believe that continued development of autonomy measures is worthwhile, especially to augment:

- the scientific-discovery capabilities of remote robotic explorers on Mars,
- the decision-making skills of the human control team here on the Earth, and
- the scientific production by astronaut explorers on the Moon and on Mars (through 'augmented reality').

In 2004, we tested the 'Cyborg Astrobiologist' (CA) at a gypsum-bearing outcrop near Rivas Vaciamadrid in central Spain. The Cyborg Astrobiologist is a wearable computer and robotic video camcorder system that we are using to test and train a computer-vision system towards having some of the autonomous decision-making capabilities of a field-geologist. The CA platform has thus far been used for testing and development of these algorithms and systems: robotic acquisition of quasi-mosaics of images, real-time image segmentation, and real-time determination of interesting points in the image mosaics. The Cyborg Astrobiologist has demonstrated its ability of finding genuinely interesting points in real-time in the geological scenery, and then gathering more information about these interest points in an automated manner(**). Particularly, the system was able to autonomously identify as unusual, and then proceed to study further, two mid-sized dark regions on the outcrop. These two dark regions were caused by water leaking out of the outcrop.

In 2005, we have completed further field tests of the Cyborg Astrobiologist, at a field site containing layered outcrops of red-colored sandstones from the Triassic period, near Riba de Santiuste, in the province of Guadalajara in central Spain. With the CA system, we studied three outcrops at Riba de Santiuste. At the first outcrop, the CA's computer vision system found several white-colored "reduction spherules" (3-10 cm diameter) to be interesting, as well as finding several small dark-burgundy-colored concretions/nodules (0.1-0.3 cm diameter) to be interesting. One hypothesis for the formation of the reduction spherules is through the bleaching of the red sandstone by biological agents. The concretions are different from the "blueberries" observed by MER Opportunity in Meridiani Planum on Mars; these concretions bear somewhat more resemblence to the less-spherical "popcorn" concretions also observed by Opportunity. The two other outcrops studied by the Cyborg Astrobiologist at Riba de Santiuste include an outcrop with white-textured mineral deposits and an outcrop with paleosoils containing fossilized plant-root structures.

With the NEO graphical-programming language (developed in Bielefeld, Germany), we are also further developing our algorithms for semi-autonomous (sub)surface exploration at a "Mars Analog" site in the Rio Tinto region of Andalucia in SW Spain. Later this year, we also plan to upgrade the Cyborg Astrobiologist, so that it uses more-advanced image-segmentation algorithms that are capable of simultaneously segmenting color and texture.

(**)McGuire et al., "The Cyborg Astrobiologist: First Field Experience", *International Journal of Astrobiology*, vol 3, issue 3 (2004).