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LUNAR EXPLORATION VIA MANNED-UNMANNED TEAMING WITH AUTONOMOUS ROBOTIC SWARMS

Abstract

The effective exploration of the Moon, Mars, and other celestial bodies will be possible through robotic exploration assets such as rovers, satellites, and atmospheric vehicles. The communications time delay to Earth and limited human presence near these assets means that they must be able to function with collaborative autonomy to ensure effectiveness and minimize the burden on human operators. However, such autonomy poses unique challenges at the individual asset level – to deliver mission utility while being attentive to the how onboard resources (subsystems, sensors, processors, and transceivers) must be employed along with their energy costs, at the "swarm" level – to employ multiple assets in a coordinated manner to ensure mission completion and limit redundant tasking, and for human-machine teaming – to enable interactions with astronauts-in-the-loop when possible.

Orbit Logic is developing the Intelligent Navigation, Planning, and Awareness for Swarm Systems (IN-PASS) solution for NASA – an autonomous planning architecture supporting collaborative lunar exploration via teaming between astronauts and heterogeneous swarms of orbital (satellite) and surface (rover) assets. IN-PASS is built on Orbit Logic's existing Autonomous Planning System (APS) architecture and, through collaboration with CU Boulder, leverages advanced algorithms for data fusion and multi-objective decision making.

An instance of APS will operate onboard each swarm asset to provide asset level resource planning and independence as well as to enable collaborative autonomy between assets over intermittently available communication links. Assets can replan in reaction to encountered events; e.g., if a rover finds something

its onboard processing deems interesting, it can request follow-up observation from a satellite. Astronauts or mission operators can interact with IN-PASS to provide guidance, shape mission objectives, and perform tasks uniquely suited to human dexterity or cognition. IN-PASS will allow humans to leverage the full capabilities of a heterogeneous robotic swarm without micromanaging the actions of each individual asset.

CU's Event-Triggered Decentralized Data Fusion (ET-DDF) algorithm will maintain a common relevant operations picture (CROP) with minimal data exchange. Linear Temporal Logic (LTL) will be used for task specification and multi-objective control policies will be used to tradeoff navigation performance and resource use. In future research, CU's ASPEN lab will provide an environment for mixed-mode hardware testing with wheeled robotic rovers.

APS can be leveraged for autonomous planning in any domain. Beyond Lunar exploration, Orbit Logic has deployed APS Low Earth Orbit (LEO) constellations with DARPA and AFRL, unmanned underwater/surface/aerial vehicles (UUVs/USVs/UAVs) with the Navy, and robotic Mars exploration with NASA.