TIER-SCALABLE RECONNAISSANCE MISSION TEST BED: IMPLEMENTATION OF GROUND-TIER

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Introduction: Robotic reconnaissance operations are called for in extreme environments such as space, including planetary atmospheres, surfaces, and subsurfaces, as well as in potentially hazardous or inaccessible operational areas on Earth. Real time reconnaissance enables identification and characterization of transient events. We reported earlier on a fundamentally new planetary exploration mission concept, termed *tier-scalable reconnaissance* [1-6], which is aimed at replacing engineering and safety constrained mission designs of the past. The tier-scalable paradigm integrates multi-tier (orbit⇔atmosphere⇔surface/subsurface) and multi-agent (satellite(s)⇔blimps⇔ground agents/sensors) hierarchical mission architectures. It not only introduces mission redundancy and safety, but enables distributed, science-driven, and less constrained reconnaissance (both spatially and temporally) in real time on a global, regional, and local scale of prime locations on Titan, Mars, Venus, Europa, Ganymede, and elsewhere, allowing for increased science return, and paving the way towards fully autonomous robotic missions.

A typical operations scenario for a tier-scalable reconnaissance system is illustrated schematically in Fig. 1. Multi-tiered, multi-agent hierarchical integrated mission architectures allow for varying degrees of independence from human intervention, and also permit manual override at any level. A human operator may communicate to the orbiter(s), as well as command the airborne agents via the orbiters (and thereby command the ground-tier reconnaissance agents via the airborne agents). Or, a highly automated operation mode may be used, enabling autonomous reconnaissance missions as they are necessary, when the communication time lag prohibits meaningful teleoperation, or, e.g., on the rear side of the Moon.

In the highly automated scenario, the satellites command and control the airborne agents autonomously, and the airborne agents autonomously command and control the ground-tier reconnaissance agents (Fig. 1). This system integrates satellites with balloons/blimps (airships) and ground-tier agents (rovers, fixed landers, e.g., Beagle 2, and sensors). The airborne and ground-tier agents can be inexpensive enough (in terms of capital cost and operational resources) to allow for the deployment of numerous, expendable agents (i.e., from the point of view of successfully achieving the mission objective(s)) that collectively can address specific science-driven questions within the operational areas of particular interest. Examples of “inexpensive” agents are Micro-Electro-Mechanical-Systems (MEMS)-based sensors, and mini-rovers akin to Minerva, the lander/mini-rover of the Japanese asteroid sample-return mission Hayabusa. Multiple ground-tier and airborne agents collectively can explore the same science target(s) with a complementary suite of instruments.

A multi-tier, hierarchical mission architecture would overcome the inherent challenge of geologic planetary surface exploration [1-3]: airborne agents (orbiters in conjunction with balloons/blimps) possess overhead perspectives at different length scales/resolutions, which could provide guidance and control to ground-based agents (e.g., mobile rover units). Such airborne agents would map out operational areas of interest (e.g., prime sites) and acquire terrain images that subsequently could be processed through automated feature-extraction software packages, such as the *Automated Geologic Field Analyzer (AGFA)* [7]. The feature data would be analyzed by science prioritization algorithms (e.g., [7-10]) to choose potential targets for close examination by subsequently deployed sensors or rovers and for determining safe passages to their designated targets. At the respective targets, the rovers would conduct in situ science experiments and thereby gather data that complement the remote sensing data obtained by the airborne units. In addition, such a system could help direct rovers equipped with a driller for in-situ sampling.

We report on the implementation of the ground-tier of an Earth-based (outdoors) test bed for tier-scalable reconnaissance. Such a test bed opens up the opportunity for a wide scientific target audience (planetary geologists, hydrologists, astrobiologists, mission architects, physicists, roboticists, etc.) to develop and field-test remote planetary exploration strategies and tools, ranging from algorithms to hardware.

Technical Approach: A 4WD remote controllable robotic platform is utilized as a representative mobile ground-tier agent (Fig. 2). To enable remote user control of the ground-tier agent, an Internet TCP/IP connection is first established between the CPU aboard the mobile platform (via its wireless LAN) and the computer hosting the front-end control software. Once this is accomplished, the mobile platform transmits video frames, in a packetized and compressed format, from its on-board camera to the front-end for display. The mobile platform also transmits its housekeeping data (battery level, sensor data, etc.) and awaits camera and wheel commands from the front-end software.

For the purpose of commanding the ground-tier agent interactively (later autonomously), the front-end software has an integrated video panel for displaying the transmitted video frames from the mobile platform's on-board camera; it is also outfitted with a USB-based joystick device. The user's movements of the joystick are translated into camera orientation and wheel rotation commands, and are sent to the mobile platform. As the mobile platform begins to move, it also sends back video frames and housekeeping data, which are displayed on the front-end. With this feedback information, a user (or automated control software for autonomous operation) is able to control the ground-tier agent interactively (or automatically) from anywhere in the world, in near real-time.

Implications and Outlook: A ground-tier test bed by itself already enables the development, implementation, field-testing, and validation of exploration/navigation, feature extraction (e.g., [7]), and science goal prioritization (e.g., [7-10]) algorithms/software and strategies. Furthermore, the ground-tier agents may act as ideal (mobile) platforms for field-testing (novel) instrument and sensor equipment (e.g., intelligently reconfigurable snapshot hyperspectral imager [11], and digital camera with adapter-based microscopic and wide-angle imaging capability [12]). With the near-term advent of the airborne tier, a full-fledged Earth-based test bed for tier-scalable reconnaissance will eventually become available, as some of the airborne agents can take on the role of the space-borne agents (e.g., orbiters) at higher altitudes above the operational area. This test bed will then allow the development, implementation, field-testing, and validation of software packages for both intra-tier and inter-tier operations, allowing all agents to communicate with one another and to navigate and explore operational areas with greatly reduced (and ultimately without) help from ground operators, thus affording more mission autonomy/flexibility and increased science return.

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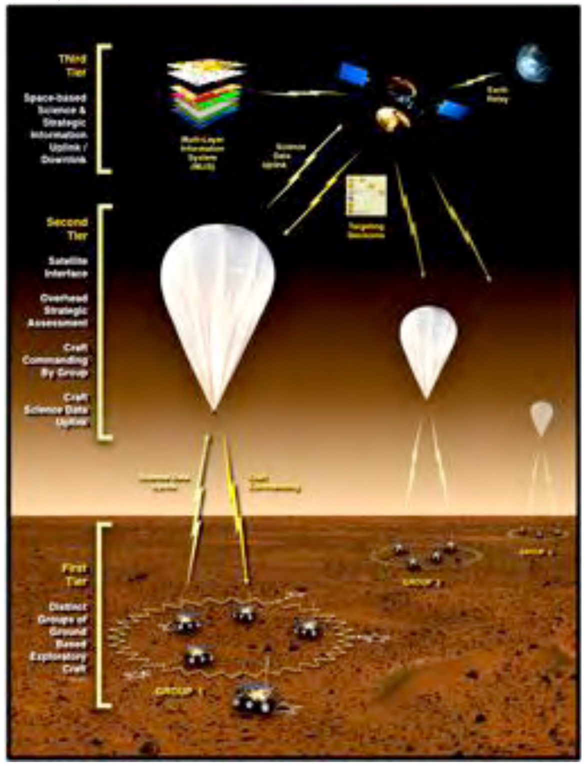

Fig. 1. Tier-scalable reconnaissance mission paradigm for autonomous planetary exploration [1].

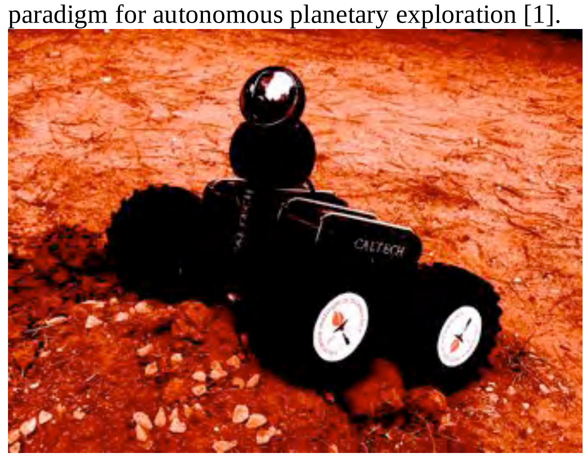

Fig. 2. 4WD remote controllable robotic platform as a representative mobile ground-tier agent of the tier-scalable reconnaissance mission test bed.