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# COOPERATION OF A TEAM OF HETEROGENEOUS SWARM ROBOTS FOR SPACE EXPLORATION

**Abstract**

As we move into the era of establishing a sustainable human presence on the Moon and Mars, robotic missions will also expand in both complexity and servicing scope. Employing a team of distributed heterogeneous robots will allow for increased synergy, efficiency, scalability, and resilience through capability complementation, equipment/function redundancy, team cooperation, and information sharing. One of the key strategies to reaping these potential benefits is effective cooperation or collaboration between the team of robots. Defining a metric for effective cooperation is a difficult task that will depend on the composition of the team, tasks being performed, and the environment. This work establishes a method for determining the reward criteria (figures of merit) that can be used for training the robots through reinforcement learning techniques. A hierarchical framework of rewards is used which at the lowest level measures the success of an individual robot in performing its task. The success of all robots performing different subtasks is then measured using the Quantified Cooperation Assessment metric which was introduced in our previous research of multi-robot collaboration. Finally, the mission-level success and overall reward is determined by weighting each task using its priority within the overall mission context. A common reward for each of the robotic teammates is then applied within the learning process, which emphasizes group performance over that of an individual and encourages cooperative behavior. To test this cooperation framework, an example mission of exploration of a central peak of a lunar crater was used to illustrate the enhanced operational benefits of a coordinated team versus a single robot. The mission is performed with a heterogenous team of robots consisting of orbiting satellites, landing craft, traditional rovers, simple and agile robots. Tasks performed and evaluated as part of the reward criteria include: traveling to specific regions of interest over unstructured terrain, gathering data for detailed local mapping, detecting the presence of lunar volatiles, and obtaining a simple sample. The mission is executed and evaluated through an event-based simulation where in place of a detailed dynamic model of each robot's action, statistical models are used to determine the probability of success for each robot based on the task complexity, robot's proficiency awareness, and environmental conditions. Using the presented technique, the overall mission performance can be improved through the behavior of individual teammates' intelligent decision making which is trained through a Deep-Q learning algorithm aiming at maximizing the reward of the team.