Multi-Robot 3D Coverage Path Planning for Inspecting Space Structures. B. Kwon[1] and J. Thangavelautham[1],

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Abstract: Demand exists for space infrastructure, ranging from communication relays to refueling depots and on-orbit service/repair facilities. Current methods for on-orbit inspection, service and repair depend upon one monolithic robotic spacecraft teleoperated from a base station. While this lessens risks associated with a human spacewalk, teleoperation can lead to operator fatigue and errors. A promising alternative is the use of multiple robots operating like a coordinated crew at a racing car pitstop. This alterntive enables parallelism and redundancy that reduces time and increases efficiency. To achieve this goal, we propose an autonomous, multi-robot controller for three-dimensional (3D) complete, coverage path planning (CPP) for space applications.

Although many algorithms exist for 2-dimensional (2D) complete CPP, these algorithms require substantial human intervention, and/or rely on hardwired path planning. Furthermore, these algorithms are not practical for space applications because they do not incorporate real-world constraints of limited on-board power, computing, memory and communications. Complete CPP for the 3D case is less studied and more complex than the 2D case. Among other things, the 3D problem has a greater possibility of collisions between robots, or between the inspection target and robots.

Recently, we showed in small scale, computer simulations that an autonomous, multi-robot team can completely, or near completely, cover 2D open grid, basic geometric shapes (see example Figure 1) in linear, or near-linear time, where time complexity is measured by the total number of open grid cells to cover and robot time steps [1]. This computer simulation used a decentralized, multi-robot controller, the Artificial Neural Tissue (ANT), with limited on-board power, computing, memory and communications. Inspired by neuromodulation in the brain, ANT is an artificial neural network-based robotic controller that employs an adaptive activation function and sparse, variable network topology [2].

In this current paper, we present computer simulations of an autonomous, multi-robot team employing the ANT robotic controller to cover 3D geometric shapes and a 3D mesh grid model of the International Space Station (Figure 2). We compare the performance of the ANT robotic controller against circular (decomposition) and sampling-based path planning for 3D complete CPP.
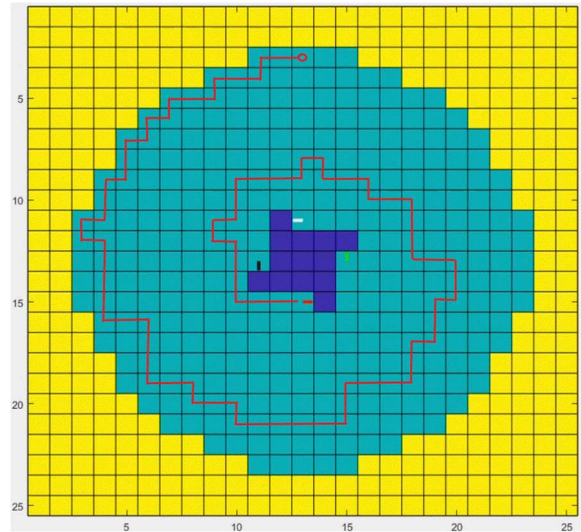

Figure 1. Four autonomous ANT robots (colored quivers) starting at 12, 3, 6 and 9 o'clock positions, spiraling-in to cover 2D open grid area, where blue cells are uncovered cells. Red line shows path of red robot starting at 12 o'clock (red circle) and now at row 15, column 13, pointing east
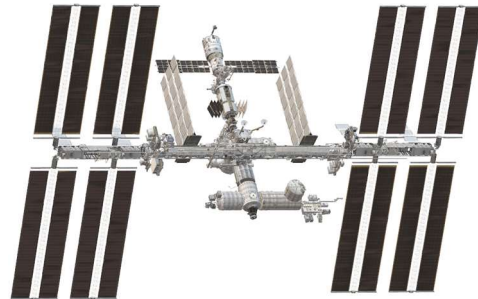

Figure 2. Animation of International Space Station (Image Credit: NASA Visualization Technology Applications and Development)

References: [1] B. Kwon and J. Thangavelautham (2020) "Autonomous Coverage Path Planning Using Artificial Neural Tissue for Aerospace Applications", IEEE Aerospace Conference Proceedings, Big Sky, Montana, March 13, 2020. [2] J. Thangavelautham and G.M.T. D'Eleuterio, G.M.T. (2012) "Tackling Learning Intractability Through Topological Organization and Regulation of Cortical Networks," IEEE Trans. Neural Netw. Learn. Syst.,Vol. 23, No. 4, pp. 552-564.