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An autonomous system to assemble reconfigurable robotic structures in space

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Credit: NASA

Large space structures, such as telescopes and spacecraft, should ideally be assembled directly in space, as they are difficult or impossible to launch from Earth as a single piece. In several cases, however, assembling these technologies manually in space is either highly expensive or unfeasible.

In recent years, roboticists have thus been trying to develop systems that could be used to automatically assemble structures in space. To simplify this assembly process, space structures could have a modular design, which essentially means that they are comprised of different building blocks or modules that can be shifted to create different shapes or forms.

Researchers at the German Aerospace Center (DLR) and Technische Universität München (TUM) have recently developed an autonomous planner that could be used to assemble reconfigurable structures directly in space. This system, introduced in a paper presented at the *2021 IEEE Aerospace Conference*, could allow aerospace engineers and astronauts to assemble large structures in space and adapt them for specific use cases, reconfiguring them when necessary.

"Our paper was inspired by the MOSAR project," Ismael Rodriguez, Adrian Bauer and Maximo Roa, three of the researchers who carried out the study, told TechXplore via email. "In this project, we study modular assemblies for creating the next generation of satellites. Imagine that a satellite can be created as an array of cubic modules (just like Lego pieces) and the satellite can easily be reconfigured in space for maintenance or to update its hardware."

The assembly or reconfiguration of satellites on-orbit should be performed by a robotic arm. In their paper, Rodriguez, Bauer, Roa and their colleagues introduced a planner that could plan the movements of this robotic arm. They specifically utilized a hybrid planner, a type of planner that has often been used to achieve autonomous robot-based manufacturing.

"The system we created consists of two layers, a symbolic one and a physical one," the authors said. "Given the exponential number of all possible solutions, it is very costly to verify the kinematics for each one of them. To quickly rule out unfeasible solutions, the symbolic layer verifies that possible solutions fulfill certain conditions such as connectivity of the satellite before passing them to the physical layer."

The 'symbolic layer' of the planner developed by the researchers also sets a series of rules that are acquired by the physical layer. For instance, if the system tries to perform an action that fails in the physical layer, it stores this information and avoids symbolic solutions that involve the same action.

The system's physical layer, on the other hand, utilizes kinematic simulations to execute a given symbolic solution. This allows the system to verify that individual assembly steps are actually executable by the robotic arm, while also considering its unique features and characteristics (e.g., its reachability, dexterity, payload and motion constraints).

"In our opinion, the biggest achievement of this work is the development of the system that generates symbolic rules from experience in the physical layer," Rodriguez, Bauer and Roa said. "We used different techniques, including a binary prediction tool, to predict which symbolic actions were kinematically feasible in the given environment."

The binary prediction tool used by the researchers cuts the time necessary to plan the robotic arm's movements, in some cases reducing it by almost 50%. Moreover, by simulating different scenarios, it ensures that specific movements are kinematically executable.

"This tool also simplifies the planning process, which would be painstakingly difficult for a human, especially for manually checking the validity of a given sequence of motions," Rodriguez, Bauer and Roa said.

The researchers verified their planner in a series of tests, specifically evaluating its ability to disassemble parts of a modular structure and reassemble them into a new configuration. In these tests, their system achieved remarkable results and was also found to be highly adaptable, as it enabled the assembly of robots with different sets of skills, in scenarios with simulated hardware failures.

In the future, the autonomous planning system developed by Rodriguez, Bauer, Roa and their colleagues could simplify the assembly and reconfiguration of large-scale structures in space. Meanwhile, the team would like to extend the scope of their system's physical layer, by considering both kinematic and dynamic restrictions.

"For instance, some optimizations could be included to reduce the disturbances experienced by a satellite when the robotic arm is moving a cube around," Rodriguez, Bauer and Roa explained. "Another research direction we would like to explore in the future is the use of a pattern recognition algorithm, which could identify sub-structures that have already been considered, so that we can reuse the already computed subplans to save time during the generation of a new plan."

More information: Ismael Rodriguez et al, Autonomous Robot Planning System for In-Space Assembly of Reconfigurable Structures, *2021 IEEE Aerospace Conference (50100)* (2021). DOI: 10.1109/AERO50100.2021.9438257