Starshade Analog Robotic Assembly Demonstration

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I. Introduction

The science drive for utilizing occulters to nullify the bright light of stars to allow observation of their orbiting planets is well established. [1] Starshades are a type of external occulter designed to fly in tandem with space telescopes and reduce the target star's brightness by having its large flower-like shaped structure between the telescope and the star. All current hardware experimentation of starshades involve complex deployment mechanisms and sequences to achieve a single launch requirement. [2] While this deployable method might be achievable for smaller diameter starshades, such as the 30-meter diameter class proposed for rendezvous with the WFIRST telescope [3], the need for larger starshades on the order of 150-meters has been expressed and with it the desire to have the ability to assemble starshades on-orbit. [4] [5] The *In-Space Assembly of a Starshade as an External Occulter for Direct Exoplanet Observations* white paper for the Astro2020 Decadal Survey [6] proposed that assembling starshades might be the preferable method, even for smaller diameters, due to the potential to lower cost and risk. The concept of operations (CONOPS) outlined in that white paper was used as inspiration for this autonomous robotic assembly of a 2.5-meter starshade analog. This demonstration focused on proving the robotic feasibility of the CONOPS and did not use accurate structural test articles or tolerancing joints for assembly. The robotic assembly testbed was set up as shown in Fig. 1 and the robotic arm removed six petal analogs from storage and assembled a single ringed starshade analog around a center hexagon.

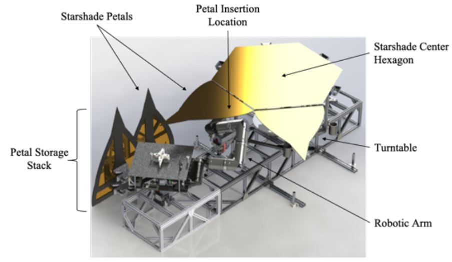

Fig. 1. Experimental setup for 2.5-meter starshade analog robotic assembly.

II. Robotic Assembly Demonstration

A seven degree of freedom arm with a one degree of freedom end effector was used to perform the robotic manipulation for the assembly, with corresponding petal grapple interfaces. The starshade analog was assembled around a center hexagon with existing female ratcheting mechanisms to capture the male plug interfaces mounted to each petal. [7] This demonstration utlilized a turtable under the center hexagon of the starshade to rotate the structure between petal insertion sequences, differeing from the white paper's CONOPS where the robotic arm moved around the structure. End over end walking is a proven capability of this robotic arm [8] but the turntable was chosen for this demonstration due to it simplifying robotic pick and place operation. The robotic arm was programmed to autonomously complete the entire end to end assembly sequence, without operator interferance, of the six petals to complete the 2.5-meter starshade analog, as shown in Fig. 2.

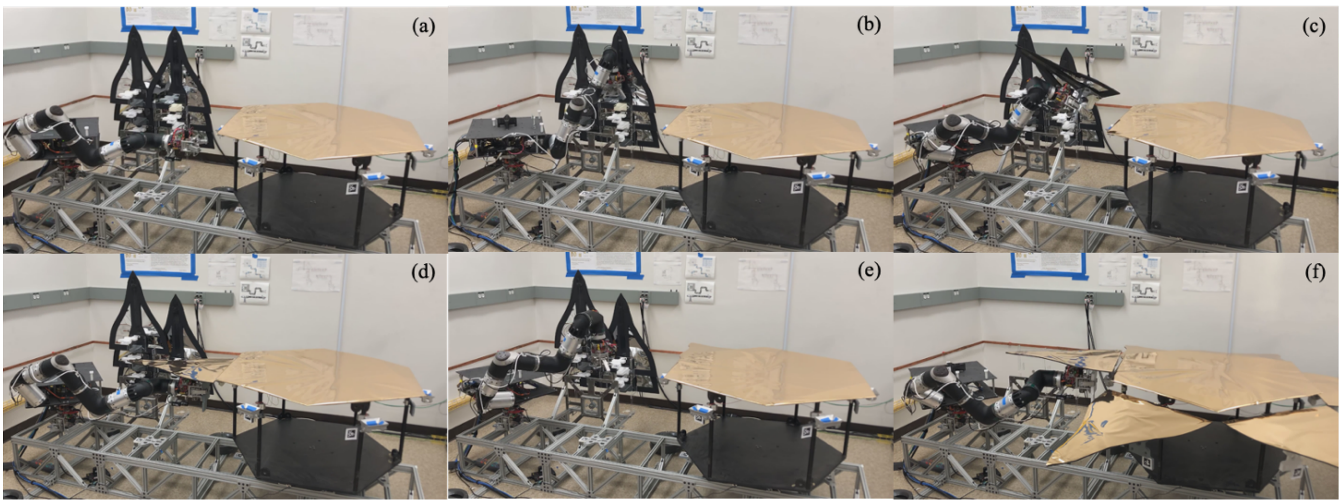

Fig. 2. The sequence of images shows the steps that must be repeated by the robotic arm six times to assembly the 2.5-meter starshade analog. The robotic arm (a) moves to a predefined teachpoint position above the petal storage stack, (b) runs petal retrieval from storage stack sequence, (c) follows teachpoints to transit from the petal storage stack to the starshade analog construction area ending at predefined position where fiducials on center hexagon are visible, (d) runs petal insertion sequence, (e) moves to teachpoint between the assembly and storage area and commands turntable to complete a 60 degree rotation of the central hexagon, pointing an open corner to the petal insertion location, and repeats until the full starshade analog is assembled, shown in (f).

The steps in the petal retrieval from the storage stack sequence are detailed in Fig. 3.

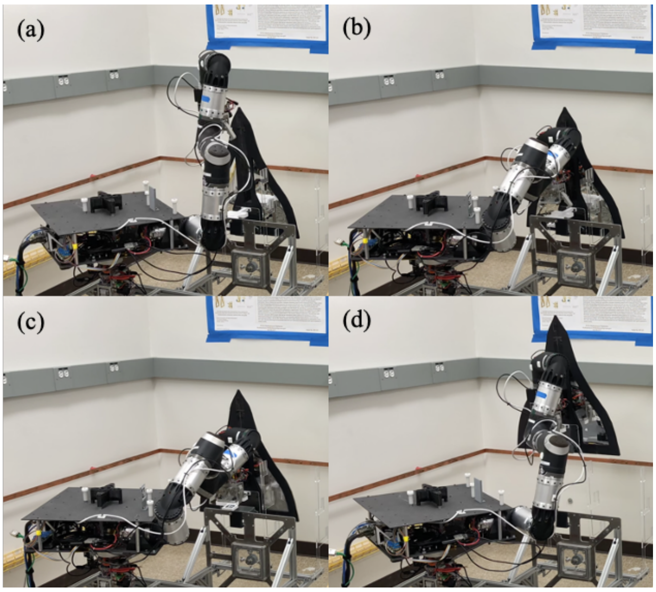

Fig. 3. The petal retrieval from storage stack sequence begins at a predefined teachpoint position above the petal storage stack, then the robotic arm (a) approaches the grapple of the petal using visual servoing, (b) moves into contact with petal grapple under force control, (c) closes the gripper end effector and latches around the petal grapple, and (d) moves arm in upward in cartesian motion to remove the petal from the storage stack.

The steps in the petal insertion into the center hexagon sequence are detailed in Fig. 4.

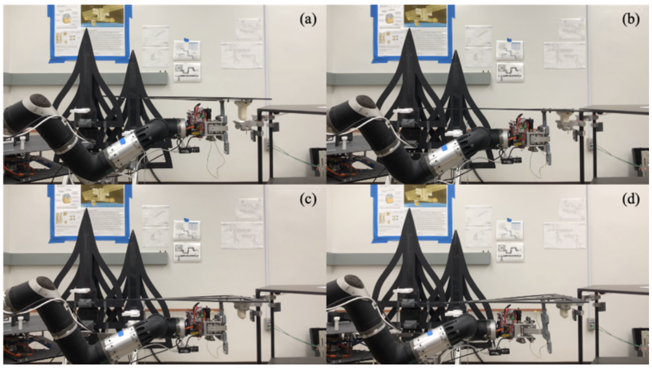

Fig. 4. The petal insertion sequence starts at a predefined position where the fiducials on the center hexagon are visible, the robotic arm (a) uses visual servoing to move the petal down until it begins to seat into connector, (b) force moves until the petal's male plug bottoms out after ratcheting into the center hexagon's female connector, and (c) opens the end effector to release petal grapple and move robotic arm back to allow turntable to rotate starshade analog.

CONCLUSIONS

The Starshade Rendezvous Probe Study Report [9] outlined in great detail specifics such as the schedule, cost, risk, technology gaps, etc. involved in flying a starshade with the WFIRST mission. Other studies are further investigating the potential cost, risk, and science benefits of in-space assembly. [10] This robotic demonstration took a step toward showing that it is robotically feasible to assemble a starshade by completing a 2.5-meter analog version, shown in Fig. 5.

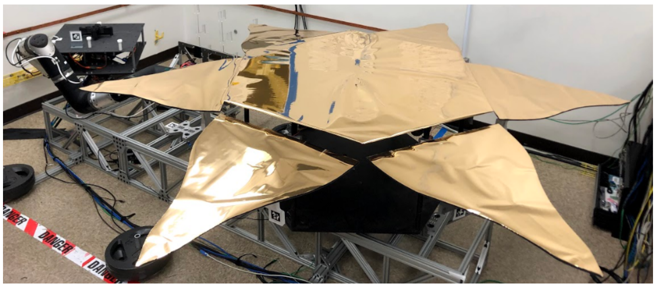

Fig. 5. Completed robotically assembled 2.5-meter starshade analog.

Since the robotic assembly behaviors of positioning petals are unlikely to vary with the improvement of the hardware's structural stiffness accuracy, and similarly the joints could be swapped out for those of higher tolerancing, this robotic demonstration succeeded in a proof of concept of the CONOPS. Future demonstration with higher Technical Readiness Level technology and future trade studies of starshade deployment versus assembly techniques are required to determine the best path forward for starshade technology.

ACKNOWLEDGMENT

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