Materials Research Proceedings 37 (2023) 508-512 https://doi.org/10.21741/9781644902813-111

AUTOMA project: technologies for autonomous in orbit assembly operations

Alex Caon[1,a*], Martina Imperatrice[2,b], Mattia Peruffo[1,c], Francesco Branz[2,d], Alessandro Francesconi[2,e]

[1]C.I.S.A.S. - Centre of Studies and Activities for Space "G. Colombo", Via Venezia 15, Padova (Italy)

[2]Department of Industrial Engineering, University of Padova, via Venezia, 1, Padova (Italy)

[a]alex.caon@unipd.it, [b]martina.imperatrice@studenti.unipd.it, [c]mattia.peruffo@unipd.it, [d]francesco.branz@unipd.it, [e]alessandro.francesceoni@unipd.it

Keywords: In-Orbit Servicing, Space Robots, Capture Tool, Autonomous System

Abstract. The possibility of manipulating objects in space is at the basis of the In-Orbit Servicing missions with the purpose to extend or improve the life of existing satellites. This can be obtained by equipping a target satellite with additional modules capable of providing additional basic functions, like power, thrust or communication. One of the most promising technologies to accomplish to these purposes is presented by space robots (satellites with one or more robotic manipulators) equipped with dedicated tool. The manipulators have the dual purposes to capture the additional module and to manipulate and attach it to the target satellite. In order to advance in IOS technologies, the Department of Industrial Engineer has funded the AUTOMA (AUtonomous Technologies for Orbital servicing and Modular Assembly) project[1]. The project aims to (1) upgrade an autonomous capture tool, (2) develop the additional module (EAU), and (3) execute tests in relevant laboratory scenarios. The autonomous tool is represented by SMACK (SMArt Capture Kit). SMACK is a capture system equipped with (1) different types of sensors to measure the relative pose during the entire approach for the capture and for the assembly; (2) a set of actuators to capture the module and keep a rigid connection during the manipulation; (3) a computer to execute locally the required software like guidance and navigation algorithms. The external module (Elementary Assembly Unit, EAU) is equipped with three features to be captured and manipulated by SMACK and a docking system to allow the assembly on the target structure. In order to test the assembly phase, SMACK has been mounted on the end-effector of a 6 degrees of freedom robotic arm in laboratory environment, while the target has been fixed on a frame. These tests proved the ability of SMACK to manage assembly tasks such as the control of a robotic arm with sufficient accuracy.

Introduction

In-Orbit Assembly missions have the purpose of assembling large structures in space such as telescopes or antennas [1]. Another fast-growing area is the possibility to install small building blocks onto existing satellites in order to provide additional functionalities such as communication, propulsion, power, etc. [2]. Both the objectives are achieved by the employment of small building blocks that are assembled by means of connecting ports. The assembly phase can be either performed by space robots that handle the blocks or executed autonomously by the blocks themselves.

The AUTOMA project has been funded in order to develop and test IOS technologies. In particular, the project focuses on the possibility to upgrade a capture tool, equipped with a set of

[1] This work was partially funded by Università degli Studi di Padova in the framework of the BIRD 2021 programme (BRAN_BIRD2121_01).

sensors, actuators and algorithms, able to autonomously perform different assembly tasks. To this aim, two main systems have been developed (see Fig. 1): the SMArt Capture Kit (SMACK) [3] and the Elementary Assembly Unit (EAU): the first has the purpose to catch and handle the second and assemble it on a target structure through a docking port.

The two systems have undergone a series of tests in order to evaluate their capabilities in terms of holding force of the gripper and the docking port, of the measurement error of each sensor, of the state estimation error and of the tolerated misalignment of both the gripper and of the docking port. A final functional system test consisted in letting SMACK to control the movements of the robot to perform the capture and the assembly of the EAU on the target structure. The use of the robotic arm ensures a positioning precision of 2 mm, which is lower than the errors of the sensors and algorithms of SMACK [4].

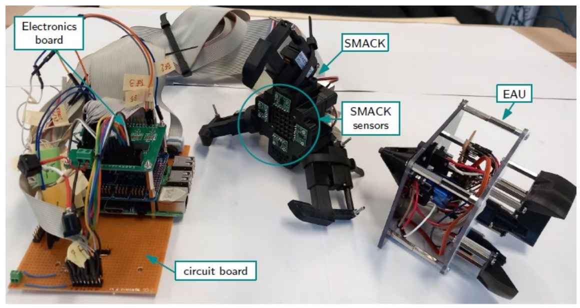

Figure 1: SMACK with its electronics and computer and the EAU.

SMArt Capture Kit (SMACK)

The SMArt Capture Kit (SMACK) has the purpose to identify, move and manage the assembly of the EAU on the target structure (or satellite). SMACK is equipped with a set of sensors, actuators and an integrated computer that renders it independent from the rest of the robotic arm on which it is mounted. The mechanical connection with the EAU is established by a gripper with three fingers. Each finger is individually actuated so that SMACK is able to capture the EAU even in case of relative misalignments by elongating differently each finger.

The sensors, coupled with the estimation algorithm, are employed to estimate the pose and the relative rates of the target. To this purpose, there are three types of sensors:

1. A NavCam that reconstructs the pose of a pattern of fiducial LED mounted on the target [5]. Measurement errors: 2.0 mm for the position and 1.5 deg for the attitude.
2. A set of four Time-of-Flight sensors that are employed to retrieve the distance and the relative yaw and pitch angles. In fact, if the target is tilted, the ToF sensors measure different distances, and allowing to indirectly measure the relative orientation, as illustrated in Fig. 2 [5]. They are coupled with a Kalman filter in order to improve their estimation capabilities. Estimation errors: 1.5 mm along the x axis and 1.5 deg for the yaw and pitch.
3. An in-plane matrix sensor that measures the position of the EAU along the x, y and z axes. The sensor is composed by a matrix of phototransistors activated by an infrared LED mounted on the EAU. The relative measure is computed based on the number of active phototransistors (second picture of Fig. 2) [6]. Measurement errors: 3.5 mm along the y and z axes.
4. A roll matrix to measure the relative roll angle. The sensors share the same working principle of the in-plane matrix (third picture of Fig. 2), but the active phototransistors are employed to measure the roll angle. Measurement error: 3.1 deg around the roll axis.

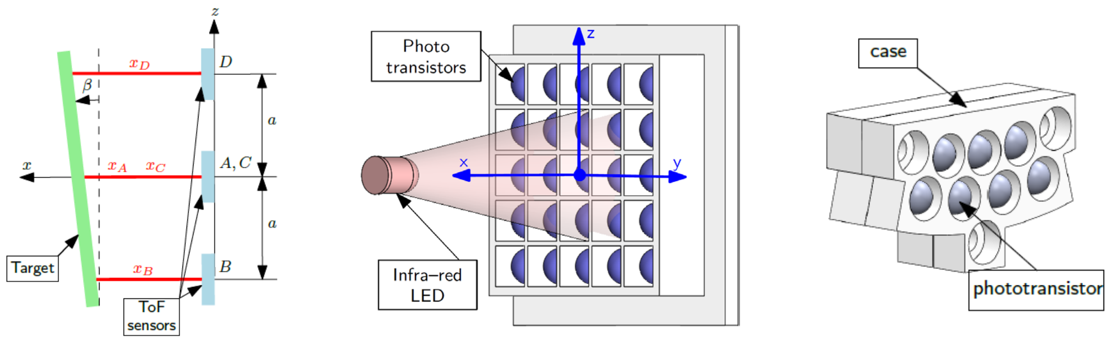

Figure 2: The measurement of a tilted object with the ToF sensors he in-plane matrix sensor, the roll matrix sensor and.

Elementary Assembly Unit (EAU)

The main purpose of the Elementary Assembly Unit (EAU) is to provide basic functionalities to the target interface, for example, additional power, communication, and thruster capabilities, etc. The EAU developed for this first stage is a box of size 100 mm by 100 mm by 50 mm, whose capabilities are limited to the mechanical connection by the means of a probe-drogue docking mechanism [8]. The tip of the probe can rotate in order to provide a rigid connection between the parts. The EAU is also equipped with three features to allow SMACK to catch it, a pattern of LEDs employed by the NavCam and two infrared LED beacons employed by the matrix sensors.

Assembly experiments

Both SMACK and the EAU have passed a series of tests to validate their capabilities in terms of (1) measurement and estimation capabilities; (2) holding force for both the gripper and the docking port; and (3) misalignment tolerance for the gripper and self-alignment management for the docking port. Then, a functional system test on the assembly procedure is required, to validate the involved mechanisms and the assembly procedure.

To execute the test, SMACK has been mounted on the end-effector of the robotic arm, the target frame has been mounted on a fixed frame, while the EAU has been placed in a known position. The procedure from the capture of the EAU to its assembly on the target frame has been divided into four main waypoints, which are transmitted to the robotic arm by SMACK, they are (referring to Fig. 3):

1. *Pre-capture*: in front of the EAU and aligned with it, but at a distance of 100 mm.
2. *Capture*: aligned with the EAU, in order to close the fingers and capture it.
3. *Post-capture*: after the capture, SMACK and the EAU are placed in front of the docking port at a distance of 100 mm.
4. *Docking*: the position where the docking mechanism can be activated.

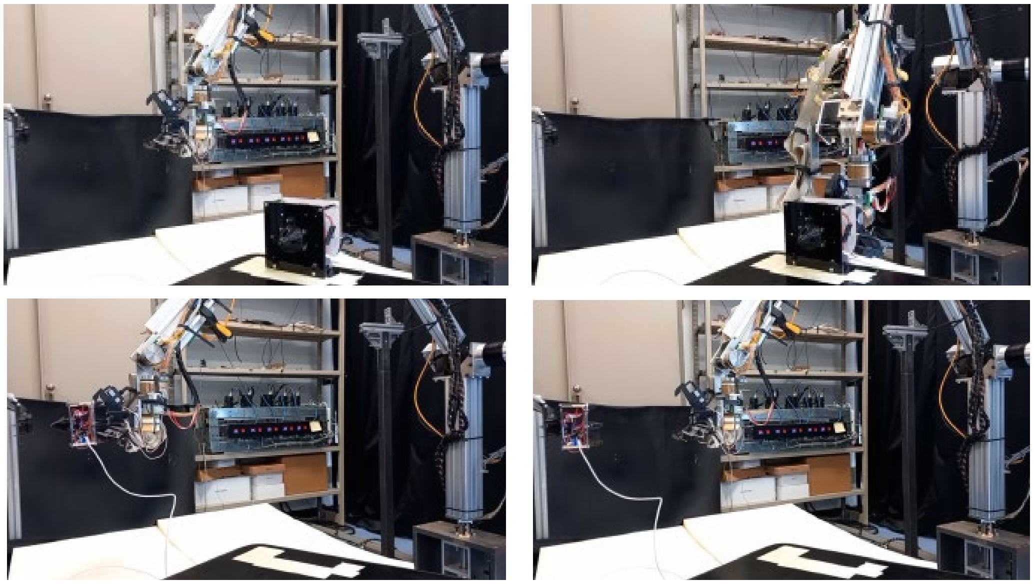

Figure 3: The waypoints of the phase.

Conclusions

This paper presents a brief overview of the AUTOMA project, that has the purpose to develop technologies in order to perform experiments on In-Orbit Assembly. Both the systems proved their capabilities through dedicated tests campaign. In particular, the relative state is estimated with an error lower than the tolerated misalignments, allowing SMACK to capture, handle and assemble the EAU to the target structure, as proved by the assembly experiment. The assembly phase and the involved mechanisms have been tested with a dedicated test which proved the abilities of the mechanisms to provide a rigid mechanical connection between the parts.

The next phase will focus on a closed-loop test in which SMACK has to perform an assembly with the use of its sensors and algorithms.

References

[1] W. R. Oegerle, L. R. Purves, J. G. Budinoff, R. V. Moe, T. M. Carnahan, D. Evans and C. K. Kim, "Concept for a large scalable space telescope: in-space assembly," *SPIE,* 2006. https://doi.org/10.1117/12.672244

[2] Northrop Grumman, "Space Logistics," 16 06 2023. [Online]. Available: https://www.northropgrumman.com/space/space-logistics-services/.

[3] A. Caon, F. Branz and A. Francesconi, "Smart capture tool for space robots," *Acta Astronautica,* 2023. https://doi.org/10.1016/j.actaastro.2023.05.014

[4] A. Caon, F. Branz and A. Francesconi, "Development and test of a robotic arm for experiments on close proximity operations," *Acta Astronautica, 195,* pp. 287-294, 2022. https://doi.org/10.1016/j.actaastro.2022.03.006

[5] A. Caon, M. Peruffo, F. Branz and A. Francesconi, "Consensus sensor fusion to estimate the relative attitude during space capture operations," in *IEEE 9 International Workshop onMetrology for AeroSpace (MetroAeroSpace)*, 2022. https://doi.org/10.1109/MetroAeroSpace54187.2022.9856096

[6] A. Caon, F. Branz and A. Francesconi, "Characterization of a new positioning senosr for space capture," in *IEEE 8 International Workshop on Metrology for AeroSpace (MetroAeroSpace)*, 2021. https://doi.org/10.1109/MetroAeroSpace51421.2021.9511704

[7] F. Sansone, F. Banz and A. Francesconi, "A relative sensor for CubeSat based on LED fiducial markers," *Acta Astronautica,* 2018. https://doi.org/10.1016/j.actaastro.2018.02.028

[8] F. Branz, L. Olivieri, F. Sansone and A. Francesconi, "Miniature docking mechanism for CubeSats," *Acta Astronautica,* pp. 510-519, 2020. https://doi.org/10.1016/j.actaastro.2020.06.042