PX4Space and ATMOS: Towards Open-source, Replicable Space Robotics

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***Abstract*— With the rising interest in space robotics, both from an academic and industrial perspective, the need for standardization of testing facilities is growing ever greater. Providing an open-source solution that multiple parties can use and share improvements on becomes pivotal for supporting research and technology transfer roles, accelerating the progress in autonomy for this field. In this short note, we present the Autonomy Testbed for Multipurpose Orbiting Systems (ATMOS) open-hardware platform, along with PX4Space - open-source PX4 modules for space systems. We conclude with a summary of our results.**

I. INTRODUCTION

Space robotics has recently become popular to augment space systems with recent progress in decision-making capabilities developed for terrestrial systems. Due to the challenges in sending hardware to orbital environments, ground experiment testbeds such as CAST Spacecraft Simulator [1], ESTEC's Orbital Robotics Lab [2], and University of Luxembougs's Zero-G laboratory [3] are vital for space research. However, conducting experiments is still challenging due to the use of custom-built software or inaccessible hardware.

Providing an open-source solution for space robotics would be pivotal for supporting research and technology transfer roles. MIT SPHERES [4] and NASA Astrobee [5] have paved the way for the space robotics community to make space-deployed hardware more accessible. Particularly, the Astrobee provides open-source software and simulation tools, making it easier to develop software for this platform. However, such software is developed for a specific hardware, making it hard to use on other spacecraft analogues.

In the aerial robotics community, open-source hardware [6] and software [7] have efficiently supported research by sharing hardware and software infrastructure, leading to lower maintenance effort.

In this work, we present an adaptation of the PX4 Autopilot [7] for space robotics, as well as ATMOS [8], an open-hardware spacecraft analog platform. We take advantage of the generic architecture of PX4, to create a hardware-agnostic software framework for space robotics. We showcase the proposed framework both in a software-in-the-loop (SITL) simulation, as well as on ATMOS at KTH's Space Robotics Laboratory. Our key contributions are i) the addition of interfaces for thruster-based control allocation; ii) custom spacecraft modules; iii) a development environment using SITL for testing control systems; and iv) open-source hardware, complete with a bill-of-materials and step-by-step instructions, for easy replication. The remainder of the paper is organized as follows: an overview of the system architecture is provided in Section II; results are shown in Section III; and concluding remarks are discussed in Section IV.

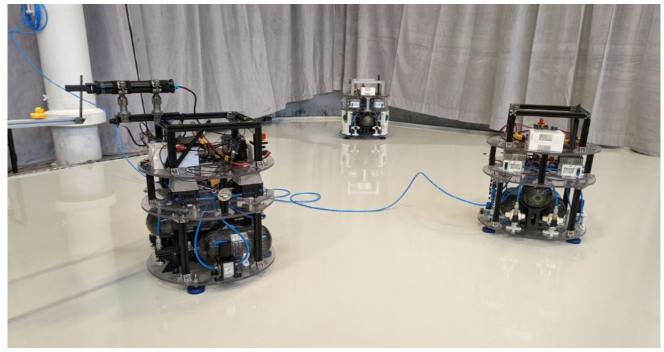

Fig. 1: The KTH Space Robotics Laboratory, with three ATMOS free-flyers operating on a flat floor. One free-flyer is equipped with a manipulator payload, while another is connected to a low-pressure tether system.

II. ARCHITECTURE

In this section, we provide an overview of PX4Space and the ATMOS platform. All the information is available at https://atmos.discower.io.

A. Hardware

The free-flyers developed for the laboratory have the following design goals: i) modularity, allowing for easy module substitution and template designing without significant changes to the platform; ii) cost-efficiency, allowing for an economical replication of these units, and iii) guest science support, providing a facility that external researchers or industry partners can use as a payload bearer to test hardware or software in the laboratory. With these goals in mind, the final design of our platform is shown in Fig. 1. All details are available in [8]. Briefly, ATMOS has a wet mass of 16.8kg and an inertia of $0.297\,\mathrm{kg\,m^2}$. The maximum thrust on each axis is approximately 3.0N, and maximum torque is $0.51\,\mathrm{N\,m}$.

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This work was supported by the H2020 ERC Grant LEAFHOUND, the Swedish Research Council (VR), the Knut och Alice Wallenberg Foundation (KAW), and the Wallenberg AI, Autonomous Systems and Software Program (WASP) DISCOWER funded by KAW.

B. Control

We show the control scheme implemented in the *PX4Space* Firmware in Fig. 2. The control system is composed of three cascaded PI and PID controllers. The cascaded loop structure allows using *PX4Space* as a low-level controller of multiple levels to evaluate different control methods. The Position controller receives a position setpoint $\boldsymbol{p}$ and regulates it through a PI controller, generating an internal velocity setpoint tracked by a PID for the velocity error. An attitude setpoint $\boldsymbol{\beta} = \{\mathbf{f}_{ref}, \mathbf{q}_{ref}\}$ is generated, corresponding to a body-frame thrust and a target attitude setpoint, respectively. The attitude controller implements a P-controller to regulate the attitude reference, generating an angular rate setpoint $\boldsymbol{\gamma} = \{\mathbf{f}_{ref}, \boldsymbol{\omega}_{ref}\}$. Lastly, the rate controller generates a wrench setpoint $\delta = \{\mathbf{f}_{ref}, \tau_{ref}\}$, through a PID to converge the angular velocity to the target.

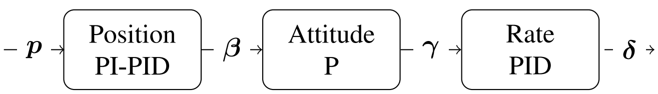


Fig. 2: Cascaded control scheme implemented in *PX4Space*. The references $\boldsymbol{p}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta}$ represent position, attitude, rate, and thrust/torque setpoints, respectively.

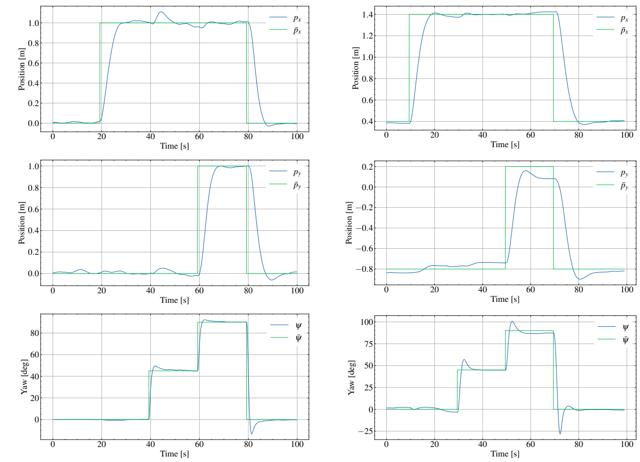
To actuate each thruster on the platform, the wrench setpoint $\boldsymbol{\delta}$ is processed by the control allocator (CA) module. The CA then sends a normalized thrust to each actuator i, $\boldsymbol{f}_i \in [0, 1]$, as a PWM signal, referred to as direct control allocation (DAC). The platform geometry is defined by configuring the location of each thruster, along with its effectiveness. For details, we refer the reader to the airframe 71002_gz_spacecraft_2d in the codebase. It is worth noting that the above setpoints are specific to the implementation of the cascaded loop structure. Due to the modular structure of PX4, it is easy to add custom modules or control schemes. Moreover, these setpoints can be generated not only from a module or through manual inputs, but also via external entities such as an onboard computer.

III. RESULTS

We present a comparison between SITL and hardware ATMOS versions using DAC. We encourage the reader to test these and more modules on the provided codebase. Control inputs are generated from a nonlinear model predictive control scheme. The performance of the system is shown in Fig. 3, with dashed lines representing setpoints and solid lines the measured state. The setpoints are appropriately tracked during the entire motion, with the hardware showing an offset error due to floor disturbances/unevenness. The controller, as well as other examples of MPC schemes, are available at https://github.com/DISCOWER/px4-mpc.

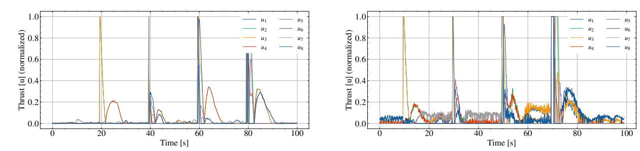
IV. CONCLUSIONS AND FUTURE WORK

In this work, we proposed *PX4Space* and ATMOS for an open-source hardware and software stack for space robotics. The solution enables testing in SITL simulation and a seamless transition to hardware testing. The results show the proposed software both in simulation and hardware. For future work, compatibility with other infrastructure in the PX4 ecosystem, such as QGroundControl would provide even more opportunities for development.



(a) ATMOS SITL performance with DAC.

(b) ATMOS hardware performance with DAC.



(c) ATMOS SITL control inputs with DAC.

(d) ATMOS hardware control inputs with DAC.

Fig. 3: ATMOS SITL and hardware performance when using an NMPC scheme and Direct Control Allocation (DAC).

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