Developed AprilNav, an Indoor Navigation and Localization System for Autonomous Testing of Electric Sail Dynamics

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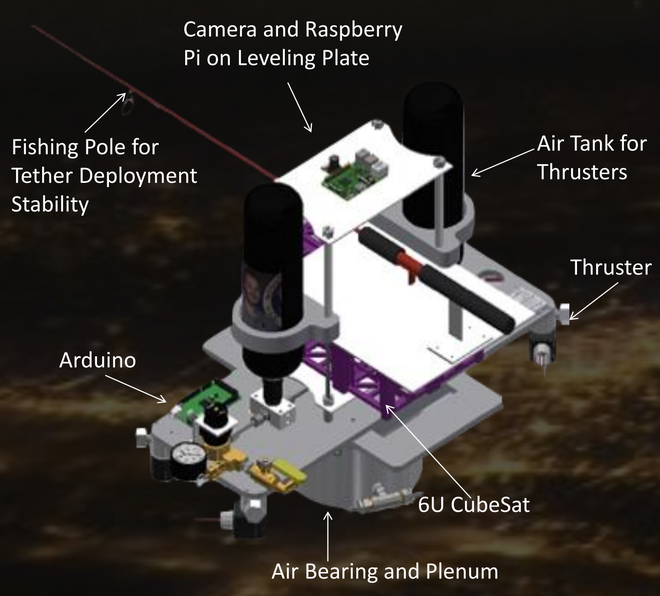
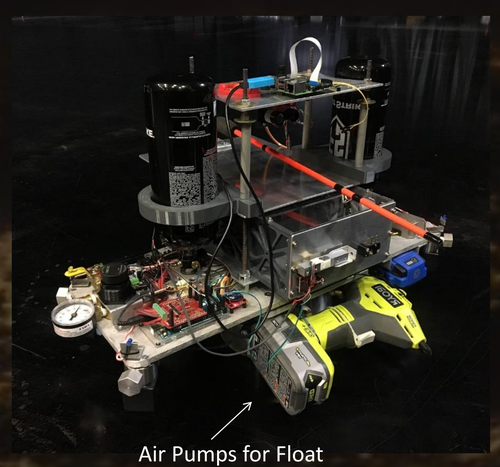
ABSTRACT

An electrostatic sail (E-sail) is a new type of propulsion which harnesses the Sun's solar wind to propel a spacecraft. Voyager I took about 40 years to reach interstellar space using solid rocket propellant, whereas electrostatic sails can travel the same distance in 6-10 years by using small but constant acceleration. As part of Marshall Space Flight Center's (MSFC) Space Systems Department and Advanced Concepts Office, we are continuing research for the HERTS (Heliopause Electrostatic Rapid Transit System) E-sail project. Previous researchers developed a Nano Air-bearing Simulator (NAS) prototype for initial testing of E-sails; this prototype was properly documented in CAD in order to build a second improved NAS. MSFC's Robotic Lab (Flat Floor) allows for 2-dimensional simulations of spacecraft dynamics by attaching air bearings to a system. An indoor navigation system, AprilNav, was developed and has been implemented on the ceiling of the flat floor for localization and autonomous testing of the two bearing-equipped NAS. With two NAS, tether dynamics between the two simulators as well as steering control algorithms are being tested on the flat floor using AprilNav.

BACKGROUND

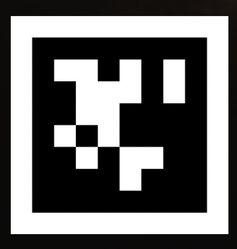
- The NAS was developed at MSFC to physically simulate space in 2-dimensions. The NAS is equipped with an air bearing pressurized to approx. 20 psi to enable float on Marshall's epoxy flat floor with minimal drag (approx. 2 oz).





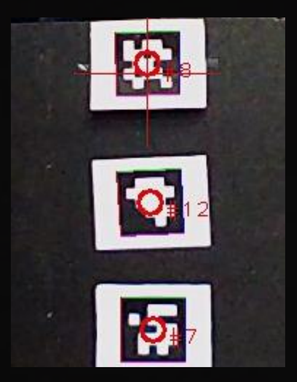
- In order to conduct accurate tests with the NAS, autonomous navigation and localization are needed. An indoor navigation system, which we titled AprilNav, was developed to pinpoint the NAS location on the flat floor for autonomous navigation. Current off the shelf indoor localization systems do not function at high ceiling heights, thus AprilNav was created.

- University of Michigan designed a scalable visual fiducial system, entitled AprilTags, for detecting 3D position of tags relative to a camera. By updating their algorithms, camera pose can be determined rather than tag position, and a scalable indoor navigation system can be implemented. A 2D AprilTag barcode (or tag) is shown to the right.



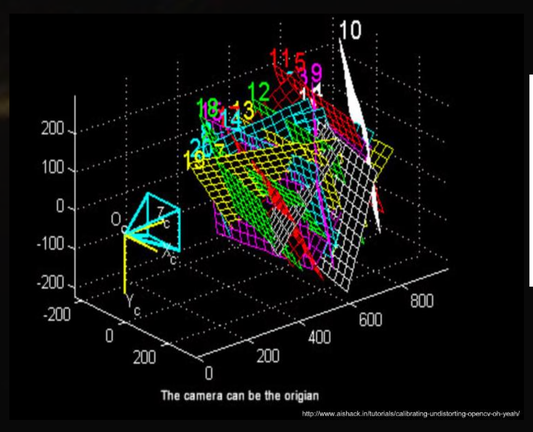
METHODOLOGY: Accuracy

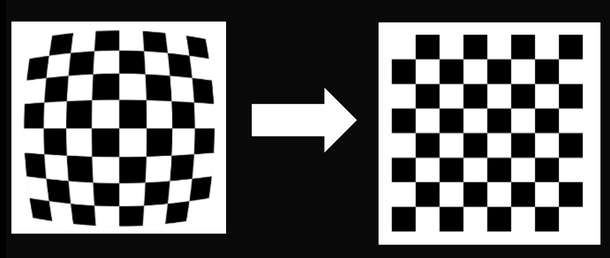
- Testing was conducted to determine if the AprilTags system was accurate enough for indoor localization.
- A precisely measured grid of 5 tags was mounted to a wall and the true measurements were compared to AprilTags output measurements.
- X and Y are accurate to approx. 5cm. Yaw is arcuate to approx. 1°. The Z direction, pitch and roll were not tested for accuracy because our system does not require them.



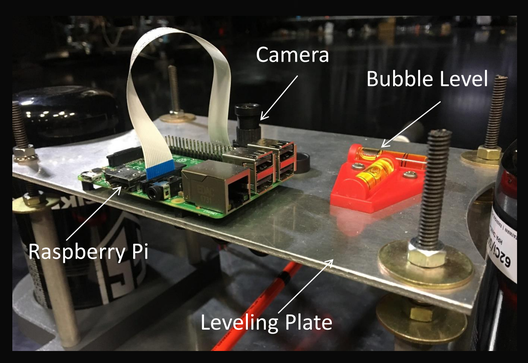
METHODOLOGY: Camera Calibration

- Camera calibration is extremely important to achieve accurate results. Digital calibration involves removing radial distortion from the image:





- Physical calibration requires orienting the lens of the camera perpendicular with the ceiling. Physical calibration was achieved by mounting the camera on a leveling plate with a bubble level, shown to the right.



INSTALLATION AND RESULTS

- Physical installation of the 2D barcodes on the Flat Floor ceiling ensued after accuracy and scalability were verified. Shown below on the left is a map of the 2D barcodes on the ceiling. Our system returns camera pose on the Flat Floor; the more tags in view, the more accurate the system gets.
- Autonomous navigation research using AprilNav began once the 2D barcodes were installed and precisely measured on the ceiling.

AprilNav was created for autonomous control and localization of the NAS on MSFC's Flat Floor. After measuring the tag locations and calibrating the camera, AprilNav has an accuracy of ~5cm. This system is cheap, accurate, scalable, and works with any visual camera. In addition to creating a command line version of AprilNav, a GUI was also created for Linux and Mac OS operating systems. The bulk of AprilNav was written in C++, with a few python scripts for conducting accurate measurement tests of the 2D barcodes. The system runs on a single board computer (Raspberry PI) on the NAS and sends commands over serial to an Arduino to autonomously control the robot.

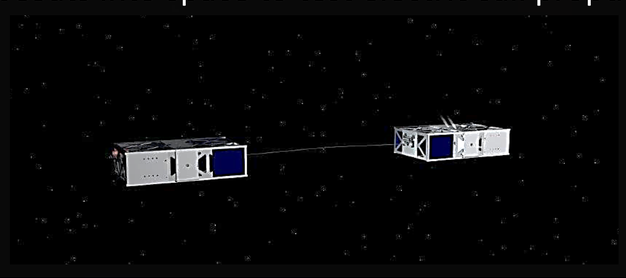
CONCLUSION

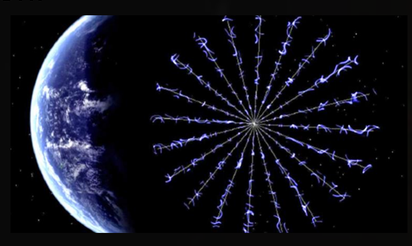
Several tasks were accomplished for the HERTS E-Sail project:

- A CAD model of the NAS has been created, along with initial manufacturing of a second improved NAS.
- AprilNav has been implemented and installed on the ceiling of the Flat Floor for localization and autonomous navigation of the NAS using AprilTags. A GUI implementation of AprilNAV has also been create.
- Initial autonomous navigation testing of NAS using AprilNav on Flat Floor.

FUTURE GOALS

Future goals for the project include development of tether deployment dynamics between the two NAS, along with spin-up deployment testing on the Flat Floor. The current end goal for the HERTS E-Sail project is to put 6U CubeSats into space to test electric sail propulsion.





ACKOWLEDGMENT

Special thanks to Tom Bryan (ES35) and Charles Cowen (ET20) For their guidance, mentorship, and facilitation on this project. Thank you also to NASA and USRA for making this research opportunity possible.