National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

Bias Compensated Inertial Navigation

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Strategic Focus Area: Localization and Mobility

Objectives: The objective of this research is to understand and improve JPL experience in inertial navigation. More specifically:

- Generate algorithms that can simulate an IMU system suspended in a gondola under a Venus Balloon
- Conduct a field test to acquire inertial navigation data
- Understand the achievable accuracy improvement by mechanically rotating an IMU to null out biases in the IMU

Background: Many methods exist for position determination. These methods include GPS, celestial navigation, correlation to a terrain image, digital elevation mapping, magnetic maps, inertial navigation, and pulsar navigation. In two environments position determination is very difficult: On a balloon inside a cloud or in a submarine. This is because external optical measurements are not possible. Also, position determination on places other than Earth is difficult because the magnetic field may not be strong or stable and no GPS satellites are available. Under these circumstances only one means of navigation is feasible: Inertial navigation. Within the last years, Phosphine has been discovered in the atmosphere of Venus. Some scientists believe it could be a biomarker. This discovery has initiated a massive interest in missions to Venus. In-situ analysis of the Venus atmosphere will require an airship/balloon/ballute type mission. A Venus balloon will be without communications for periods of up to 12 hours. Position estimation of such an airship/balloon/ballute will primary be based on inertial navigation. It is likely that JPL will propose a Venus balloon mission to NASA in the future and this will require that JPL has a creditable solution for position estimation.

Approach and Results: The following results were achieved during this last year's research: Algorithms for inertial navigation were developed. A specially formulated Kalman filter to provide attitude observability using a stochastic wind model was generated. The following navigation error compensation methods were included:

Method **A** – Perform rotation of the accelerometer to average/null out accel bias
Method **G** – Perform rotation of the gyro to average/null out gyro bias
Method **T** – Perform tip/tilt correction of gravity by using the projected gravity vector in the local accelerometer frame to estimate (tip/tilt) attitude error

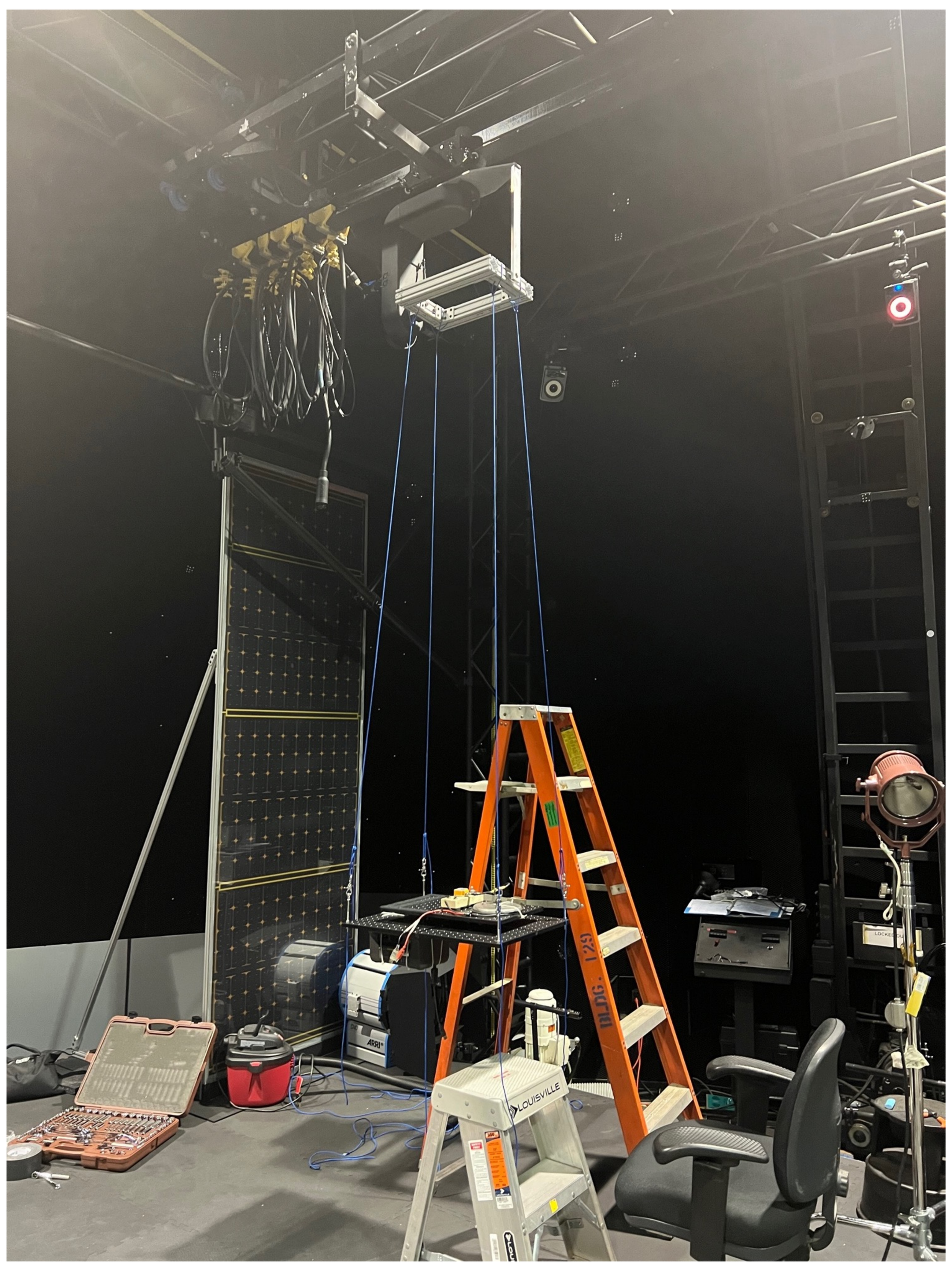
The detail of the algorithmic implementation is discussed in: S. Ploen *et al.*, "Bias Compensated Inertia Navigation for Venus Balloon Missions," *2023 IEEE Aerospace Conference*, Big Sky, MT, USA, 2023, pp. 1-13, doi: 10.1109/AERO55745.2023.10115888. The paper was presented this year and received a best paper award. The results of the bias compensated inertial navigation algorithms are shown to the right. It is observed that rotating an IMU to achieve bias compensation will result in a 10 – 100 times improvement in the accuracy.

Summary of 2-Sigma Knowledge Errors Resulting from Various Compensation Methods (1 Hr)

Knowledge Error (2-sigma)	Compensation Method			
	None	T	T+A	T+A+G
Position Error (km)	614.12	32.9	8.2	7.7
Velocity Error (m/s)	402.38	60.1	15.2	14.1
Attitude Error (deg)	0.81	0.1	0.07	0.068

Monte Carlo simulation of the achievable accuracy utilizing a STIM300 IMU and the improvement of rotating the IMU. It is observed that a factor 10-100 improvement can be realized.

Also, a Venus balloon simulator facility was built. It is based on a big gantry that is mounted in 199-101. An experimental setup can be suspended in 12 feet strings under the gantry. The gantry can move in different patterns that mimics a Venus Balloon suspended in the Venus atmosphere. Data from the experimental setup has been acquired with a rotating IMU. Unfortunately, a delay due to safety, resulted in data not being available before a few days before the end of this task. Therefore, real data from the facility was not used with the algorithms and the algorithms were verified by Monte Carlo simulations only.



Venus Balloon Simulator Facility

Significance/Benefits to JPL and NASA: Inertial navigation will be used for position determination for future balloon missions to Venus and future missions to the ocean of Europa. JPL does not have a lot of experience in inertial position determination. The RTD increases the experience level of several GNC analysts in section 343. Due to the discovery of phosphine in the atmosphere of Venus, it is expected that a solicitation for a Venus Balloon type mission will come out within a few years. This type of mission will require position estimation for the science payload. Utilizing, low mass technology will result in a system with very poor performance. Therefore, this RTD investigates the idea of mechanically rotating the IMU to increase the accuracy. This work will make it possible to confidently make a system design for position estimation and make reference to a JPL published paper. This will avoid JPL getting a weakness in a future proposal and increase JPL chance of winning the project. Also, this research may become relevant for position determination for Lunar rovers for future mission to the Moon.

Publications:

S. Ploen *et al.*, "Bias Compensated Inertial Navigation for Venus Balloon Missions," *2023 IEEE Aerospace Conference*, Big Sky, MT, USA, 2023, pp. 1-13, doi: 10.1109/AERO55745.2023.10115888.

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