NASA EPSCoR
Research Performance Progress Report (RPPR)
Seed Award

I. Collaborating Organizations

A. Academic Collaborators *(do not include names of minors)*

Name	Academic Affiliation	RID Project Role	Nearest person month worked	Contribution to Project	Funding Support
Guoquan Huang	University of Delaware	PI	1	Advise grad and undergrad students, oversee the project, and design new visual-inertial estimation algorithms for the project.	University of Delaware
Yuxiang Peng	University of Delaware	Graduate Student	9	Develop and implement the square-root and quantized VINS algorithms.	NASA EPSCoR RID
Woosik Lee	University of Delaware	Graduate Student	3	Develop the MINS algorithm	Google
Chuchu Chen	University of Delaware	Graduate Student	6	Develop the fast covariance recovery algorithm.	Google
Jayden Thomas	University of Delaware	Undergrad Student	3	Build the aerial vehicle as the test platform	DE Space Grant Summer Internship

B. NASA Collaborators

Name	Title	NASA Center	Nature of the Collaboration

C. Industry Collaborators

Name	Title	Industry/Company Name	Nature of the Collaboration

D. New non-EPSCoR grants

Funding Entity	Award Name	Value of New Grant
NSF	Ultrafast Visual-Inertial 3D Perception for Micro Aerial Vehicles	$447,276 (recommended)

E. Other Organizations Involved as Partners

Organization	Nature of the Partnership	Benefit of the Partnership

II. Products

A. List Journal publications – Please only list papers that have been published.

Date Published	Published Paper (APA format)
Feb., 2024	Yang, Y., Geneva, P., & Huang, G. (2024). Multi-Visual-Inertial System: Analysis, Calibration and Estimation. International Journal of Robotics Research (IJRR). In Press.
April, 2024	Lee, W., Geneva, P., Chen, C., & Huang, G. (2023). MINS: Efficient and Robust Multisensor-aided Inertial Navigation System. arXiv: https://arxiv.org/abs/2309.15390. (Submitted to JFR).
July, 2024	Merrill N, Geneva P, Katragadda S, Chen C, Huang G. Fast and robust learned single-view depth-aided monocular visual-inertial initialization. *The International Journal of Robotics Research*. 2024. doi:10.1177/02783649241262452

B. List Conference Papers – Please only list papers that are included in conference proceeding.

Conference Date	Conference Paper (APA format)
May 13-17, 2024	Peng, Y., Chen, C., & Huang, G. (2024). Ultrafast Square-Root Filter-based VINS. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Peng, Y., Chen, C., & Huang, G. (2024). Quantized Visual-Inertial Odometry. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Chen, C., Peng, Y., & Huang, G. (2024). Fast and Consistent Covariance Recovery for Sliding-window Optimization-based VINS. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Katragadda, S., Lee, W., Peng, Y., Geneva, P., Chen, C., Guo, C., Li, M., & Huang, G. (2024). NeRF-VINS: A Real-time Neural Radiance Field Map-based Visual-Inertial Navigation System. In 2024 IEEE International Conference on Robotics and Automation (ICRA).

C. List Conference Presentation – Please list conference presentation.

Conference Date	Presentation Topic (APA format)
May 13-17, 2024	Peng, Y. (2024). Ultrafast Square-Root Filter-based VINS. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Peng, Y. (2024). Quantized Visual-Inertial Odometry. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Huang, G. (2024). Fast and Consistent Covariance Recovery for Sliding-window Optimization-based VINS. In 2024 IEEE International Conference on Robotics and Automation (ICRA).
May 13-17, 2024	Peng, Y. (2024). NeRF-VINS: A Real-time Neural Radiance Field Map-based Visual-Inertial Navigation System. In 2024 IEEE International Conference on Robotics and Automation (ICRA).

D. List Books and/or other Publications – Please include explanations, help us to learn about your accomplishments.

Date	Explanations (APA format -Book, Newspaper Op-Ed, …)

E. List talk/presentation/event/outreach activity – Please include explanations, help us to learn about your accomplishments.

Date	List talk/presentation/event/outreach activity (APA format if applicable)
March 13, 2024	Huang, G. (2024). Visual-Inertial Sensing, Estimation and Learning. University of Delaware, BIOMS Seminar.
2023 -- 2024	Huang, G. (2024). Mentor for the FIRST Tech Challenge (Team: Green Lemons, PA)

F. List of new or updated Website(s) or other Internet site(s).

URL	Short description of purpose of site
https://github.com/rpng	PI's group open sources
https://www.youtube.com/c/rpng-ud	PI's group Youtube channel

G. Technology/Technique

Technology/Technique	Short description of technologies or techniques

H. List patent – Please include Patent Number/Patent Title/ Patent Abstract (or link to it).

Date Patent Issued	Patent Number/Patent Title/ Patent Abstract (or link to it)

I. List Inventions – Please include Invention Title, List of Inventor(s) and Description.

Invention Title	List Inventor(s)	Invention Description

J. List Licenses – Please include license issued, Invention Title, List of Inventor(s) and Description.

Date License Issued	License Assignees	License Title

K. List New/Revised Courses – Please include new/revised courses.

Course Number	Course Name/Title	Offering Institution
MEEG 677	Estimation I	University of Delaware

L. Others: List Databases, Physical collections, Audio or video products, Software or NetWare, Models, Instruments or equipment, Data & Research Material (e.g., cell lines, DNA probes, animal models) related to your EPSCoR research.

Accomplishments title	Short Description of accomplishments
MINS Open Source	https://github.com/rpng/MINS An efficient, robust, and tightly-coupled Multisensor-aided Inertial Navigation System (MINS) which is capable of flexibly fusing all five sensing modalities (IMU, wheel encoders, camera, GNSS, and LiDAR) in a filtering fashion by overcoming the hurdles of computational complexity, sensor asynchronicity, and intra-sensor calibration.

III. Changes/Problems

A. Actual or anticipated problems or delays and actions or plans to resolve them

B. Changes that have a significant impact on expenditures

NA.

IV. Impact

Include article and photo w/caption (see instructions). Obtain permission to publish photo from any recognizable person. Do not include photos of minors.

To enable robust hazard detection during autonomous landing of a spacecraft on hazardous terrain, robust and efficient multisensor fusion of multi-modal measurements such as IMUs, cameras, and LiDARs, for navigation and perception is essential. To this end, in this project, we have thus far developed a consistent tightly-coupled Multisensor-aided Inertial Navigation System (MINS) that is capable of fusing the most common navigation sensors in an efficient filtering framework, by addressing the particular challenges of computational complexity, sensor asynchronicity, and intra-sensor calibration. In particular, we have designed a consistent high-order on-manifold interpolation scheme to enable efficient asynchronous sensor fusion and state management strategy (i.e. dynamic cloning). We also enable online intrinsic and extrinsic (spatiotemporal) calibration of all onboard sensors to compensate for poor prior calibration and/or degraded calibration varying over time. We have extensively validated our MINS technology in challenging real-world environments on UD campus, both indoor and outdoor (see Figure 1), outperforming the state-of-the-art methods, in terms of navigation accuracy, consistency, and computation efficiency. Importantly, to broadly impact the robotics community, we have also open-sourced our algorithm, simulator, and evaluation toolbox: https://github.com/rpng/mins.

Figure 1: We validate our navigation and perception algorithms in different indoor and outdoor environments on UD campus with a Husky vehicle equipped with low-cost, low-fidelity LiDAR, camera and inertial sensors. These technologies can be translated to autonomous landing of a spacecraft in planetary exploration missions.