Fiscal Year:	FY 2019	**Task Last Updated:**	FY 04/22/2020
PI Name:	Duda, Kevin R Ph.D.		
Project Title:	Wearable Kinematic Systems for Quantifying 3-D Space Utilization in the Microgravity Environment		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Space Human Factors Engineering		
Joint Agency Name:		**TechPort:**	Yes
Human Research Program Elements:	(1) **HFBP**:Human Factors & Behavioral Performance (IRP Rev H)		
Human Research Program Risks:	(1) **HSIA**:Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	kduda@draper.com	**Fax:**	FY 617-258-2772
PI Organization Type:	NON-PROFIT	**Phone:**	617-258-4385
Organization Name:	The Charles Stark Draper Laboratory, Inc.		
PI Address 1:	555 Technology Sq		
PI Address 2:	MS 27		
PI Web Page:			
City:	Cambridge	**State:**	MA
Zip Code:	02139-3539	**Congressional District:**	7
Comments:			
Project Type:	Flight,Ground	**Solicitation / Funding Source:**	2013-14 HERO NNJ13ZSA002N-ILSRA. International Life Sciences Research Announcement
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No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:	Williams, Thomas	**Contact Phone:**	281-483-8773
Contact Email:	thomas.j.will1@nasa.gov		
Flight Program:	PostFlight		
Flight Assignment:	NOTE: End date changed to 3/31/2019 per NSSC information (Ed., 2/12/19) NOTE: End date change to 8/26/2018 per E. Connell/JSC HRP (Ed., 3/22/18) NOTE: Element change to Human Factors & Behavioral Performance; previously Space Human Factors & Habitability (Ed., 1/18/17)		
Key Personnel Changes/Previous PI:	PI: Kevin R. Duda, Ph.D., Co-I: Ted J. Steiner, III, Ph.D., Program Manager: John J. West		
COI Name (Institution):	Steiner 3rd, Theodore J. Ph.D. (Draper Laboratory)		
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Task Description:	Astronauts living and working onboard the International Space Station (ISS) provide a unique opportunity to capture and quantify the “architectural layout and 3-D space utilization” in a microgravity environment. As NASA looks to design and build future space exploration vehicles, information gathered on the human-system operational environment on-board the ISS will provide critical data on the minimum net habitable volume (NHV) for these systems. This proposed research aims to produce a validated wearable kinematic system to unobtrusively and continuously determine an ISS crewmember’s navigation state vector as a function of time for characterizing vehicle habitability to reduce the risk of incompatible vehicle/habitat design for future deep space exploration missions. We aim to leverage extensively the wearable kinematic and positioning systems that have been developed at Draper Laboratory under prior NASA and U.S. Army Programs. In addition, we aim to leverage Draper’s decades of guidance, navigation and control, and perceptual systems experience for navigation in complex environments as well as our human-systems integration and engineering capabilities. The overall goal of this project is to develop the concept of operations, high-level architecture, and requirements (crew/hardware/software) for ISS transition of a wearable kinematic system to be used for quantifying 3-D space utilization in the microgravity environment. This will be accomplished by demonstrating the vision-aided inertial navigation algorithms for net habitable volume (NHV) metrics on a COTS (commercial off-the-shelf)/existing device in a ground based analog environment. The specific aims of this project are: (1) Definition of ISS Integration, Flight Definition, and NHV Model Requirements. This includes the specification of the technical, performance, functional, and operational requirements for the wearable kinematic system associated with ISS integration and analytics for NHV metrics calculation, as well as Flight Experiment Definition planning. (2) Wearable Kinematic System Design, Development & Verification. A system architecture trade study and detailed design for the wearable module development, testing to verify the performance in ground-based analog scenarios, and the requirements for transitioning the equipment for ISS spaceflight operations will be completed. (3) Quantification of ISS NHV Metrics. This aim develops the infrastructure and algorithms for calculating the relevant NHV metrics from the wearable module navigation state vector, including automating the process and providing intuitive visualizations of the data. This research will address the NASA Human Research Program (HRP) Program Requirements Document (PRD) Risk of Incompatible Vehicle/Habitat Design. The development and implementation of the proposed wearable kinematic system will provide a capability for the Integrated Research Plan (IRP) Gap SHFE-HAB-09 to collect data for the design and assessment of vehicles/habitats. Subsequently, this data will then address Gaps SHFE-HAB-03/05/07 for understanding how astronauts interact with the vehicle/habitat and informing guidelines for determining net habitable volume.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Knowing your location within an enclosed, or confined environment enables algorithms, technologies and systems to quantify the net habitable volume, analyze habitat/work environment geometry and task efficiencies, and improve safety through route and egress planning and guidance. This project developed algorithms that take advantage of a wearable camera and inertial measurement unit (IMU) to continually estimate position and orientation – a key technology that benefits life on Earth for soldiers, submariners, maintenance personnel, first responders, and oil rig workers to name a few. This project also demonstrated the ability to time, and location tag carbon dioxide measurements within an enclosed habitat – critical for environmental monitoring and mapping. Fundamentally, this system has the potential to be a location services provider in environments where GPS or other radio frequency-based systems are not available.
Task Progress:	The International Space Station (ISS) provides a unique opportunity to capture and quantify the architectural layout and 3-D space utilization in a microgravity environment from the astronauts living and working there. Information gathered will provide critical insight on the minimum net habitable volume (NHV) required for future spacecraft, as well as architectural layout and task designs and efficiencies. This project developed a small, wearable system to estimate a crewmember’s navigation state vector – position and orientation – as a function of time during the course of their normal daily activities. The device does not require any special infrastructure, and includes completely passive vision and inertial sensors to bound long-term drift in position and orientation estimates, thus providing a location service within the ISS (or any confined environment) that can integrate with astronauts or moveable equipment. Throughout the course of this project, we made a preliminary definition of the system architecture, concept of operations (CONOPS), data processing pipeline, integrated a carbon dioxide sensor with our navigation system, and the development and integration of an algorithm to enable self-initialization and periodically correct accumulated drift through loop closures. Additionally, we prototyped a self-contained portable system for technology demonstration and algorithmic testing in a variety of representative environments including the ISS mockups within NASA’s Space Vehicle Mockup Facility, NASA’s Human Exploration Research Analog (HERA) facility, and the Aquarius Reef Base during NASA Extreme Environment Mission Operations (NEEMO) 23. With the goal of providing ISS astronauts with navigation state vector information that can both be visualized by engineers and used in net habitable volume (NHV) modeling and analysis efforts, we have drafted a CONOPS for the use of the system. This CONOPS takes into account the required interactions by the astronauts as well as the required hardware and software functions to complete the required activities. This has resulted in the definition of key system and functional requirements that were used to guide the development of the prototype wearable kinematic system. Additionally, we worked with collaborators at Johnson Space Center (JSC) who support flight integration of technologies to understand the constraints of the ISS operational environment, as well as with our consultant (who is a former ISS crewmember) to ensure the design and operations will be accepted by the crew. Our team collaborated with the JSC Wearables Lab regarding integration with their wearable carbon dioxide (CO_2) system to provide append a location estimate with each measurement. The principal output of the wearable kinematic system is a time-stamped estimate of the astronaut’s navigation state vector (e.g., position and orientation) when the device is attached to their body. Through discussions with our NASA Space Human Factors and Habitability partners, we identified required performance metrics of the system (e.g., navigation accuracy) that will enable the definition and validation of ongoing net habitable volume modeling efforts. The specification of these performance metrics enabled the definition of a set of criteria to measure navigation performance

against when testing the Draper-developed vision-inertial navigation system in the ground-based analog environments. Additionally, we used Draper's optical motion tracking facility to validate the vision+inertial position and orientation estimate against a "ground truth" estimate. The vision+inertial estimate was extremely close to the "ground truth" estimate during the length of the testing.

Prior to the development of the prototype system, we used a self-contained set of trade study hardware that was previously developed for the U.S. Army, which simultaneously recorded time synchronized data from two cameras and three inertial measurement units (IMUs), was used during various waking routes within the Human Exploration Research Analog (HERA) and the International Space Station (ISS) mockup facility at the NASA Johnson Space Center. The data from a walking route within the ISS mockups and analyzed using Draper Laboratory's Multi-State Constrained Kalman Filter ("Mischief") for visual-inertial odometry can be seen on YouTube here: https:// . We subsequently re-analyzed that same data set using our next-generation algorithm, smoothing and mapping with inertial state estimation (SAMWISE) and were able to repeat the performance, and in many cases show that we had less final position error as a percentage of the estimated route distance. SAMWISE is the baseline algorithm going forward to enable online initialization and periodic accumulated drift correction using "loop closures."

Under Draper Laboratory internal research and development funding, we extended the use of the wearable kinematic system to include the integration of a carbon dioxide sensor for time and location stamping of environmental monitoring data. This was demonstrated with success during NEEMO 23 where the Wearable Kinematic Systems (WKS) identified trends in increases in CO2 over time, as well as the identification of pockets of CO2 within the habitat where there is known to be reduced airflow. This is a key demonstration of the technology that has direct applicability to operations within the ISS. Lastly, we have been in discussions with the EVA (extravehicular activity) Management Office regarding the extension of the technology for tracking ISS EVA astronauts as well as during operations on the lunar surface.

Bibliography Type:	Description: (Last Updated: 09/04/2023)
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