Fiscal Year:	FY 2016	**Task Last Updated:**	FY 05/19/2016
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		
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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 PhD Candidates:	0	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:		**Contact Phone:**	
Contact Email:			
Flight Program:	PostFlight		
Flight Assignment:	NOTE: Element change to Human Factors & Behavioral Performance; previously Space Human Factors & Habitability (Ed., 1/18/17)		
Key Personnel Changes/Previous PI:			
COI Name (Institution):	Jacobs, Shane Ph.D. (David Clark Company, Inc.) DeBitetto, Paul (The Charles Stark Draper Laboratory, Inc.)		
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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 of complex systems 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 is developing 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. Fundamentally, this eventual 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 aims to develop a small, unobtrusive wearable kinematic 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 proposed device will 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 that can integrate with astronauts or moveable equipment. In this project year, we have made significant progress in the definition of the system architecture, concept of operations, data processing pipeline, and initial testing of an off-the-shelf vision-aided inertial navigation system in two ground-based analog environments. With the goal of providing ISS astronaut 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 concept of operations (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 subsequently resulted in the definition of key system and functional requirements that will be used to guide the development of an eventual wearable kinematic system. Additionally, we have worked with collaborators at Johnson Space Center 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. 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 a Draper-developed vision-inertial navigation system in the ground-based analog environments. 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. Data was collected from 14 ISS mockup routes where the system traversed more than 1,943 m total (1.2 miles) over the course of more than 60 minutes. The average ISS mockup

walking route was 139 m (455 ft) and took 4.3 minutes. Similarly, 19 HERA mockup routes were traversed totaling more than 769 m traversed (0.48 miles) over the course of more than 40 minutes. The average HERA walking route was 40 m (133 ft) and took 2.1 minutes. The analysis of the data using the six camera and IMU combinations enables a trade study of hardware configuration (e.g., camera and IMU fidelity pairs) and visual-inertial odometry algorithms. The data from a walking route within the ISS mockups using data from the uEye imager and ADIS 16448 IMU and analyzed using Draper Laboratory's Multi-State Constrained Kalman Filter ("Mischief") for visual-inertial odometry can be seen on YouTube here: https:// . The initial position and orientation were manually specified, and the subsequent navigation state estimates during the 5 minute, 550 foot traverse were made via visual-inertial odometry. The total error was estimated at approximately 2.5 feet (0.4%). We typically found final position errors of less than 1% of the estimated route distance across all of the routes analyzed. Future work will include the analysis of alternate routes within the facilities, and collection of data from tasking that is representative of a "day-in-the-life" of an ISS astronaut.

Project plans for the subsequent year of the program are to continue the development of the concept of operations and specification of the requirements of the system to enable both the science objectives of modeling and analysis of net habitable volume (NHV) as well as ensuring crew acceptance and use of the device during ISS expeditions. We are continuing our development of the vision-aided inertial navigation estimate algorithms to increase performance during extended duration routes by correcting for navigation estimate drift, as well as automatically initializing the position/orientation estimate to increase ease of use. Lastly, we have identified several additional routes and motions that we would like to collect in the ISS mockup facility to test our system and algorithms to give us greater confidence in the performance during a representative ISS mission.

Bibliography Type:	Description: (Last Updated: 09/04/2023)
Abstracts for Journals and Proceedings	Duda KR, Steiner TJ, DeBitetto PA, West JJ. "Wearable Kinematic Systems for Quantifying 3-D Space Utilization in the Microgravity Environment." Abstract and Poster at the 2016 NASA Human Research Program Investigators' Workshop, Galveston, TX, February 8-11, 2016. 2016 NASA Human Research Program Investigators' Workshop, Galveston, TX, February 8-11, 2016. , Feb-2016