Fiscal Year:	FY 2020	**Task Last Updated:**	FY 07/30/2019
PI Name:	Feigh, Karen Ph.D.		
Project Title:	Objective Function Allocation Method for Human-Automation/Robotic Interaction using Work Models that Compute		
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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Comments:			
Project Type:	GROUND	**Solicitation / Funding Source:**	2015-16 HERO NNJ15ZSA001N-Crew Health (FLAGSHIP, NSBRI, OMNIBUS). Appendix A-Crew Health, Appendix B-NSBRI, Appendix C-Omnibus
Start Date:	10/07/2016	**End Date:**	10/06/2020
No. of Post Docs:	0	**No. of PhD Degrees:**	2
No. of PhD Candidates:	1	**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:	Williams, Thomas	**Contact Phone:**	281-483-8773
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Flight Program:			
Flight Assignment:	NOTE: Changed end date to 10/06/2020 per NSSC information (Ed., 10/4/19)		
Key Personnel Changes/Previous PI:	July 2019 report: We added an additional PhD student and graduated the two previous PhD students.		
COI Name (Institution):	Pritchett, Amy Sc.D. (Pennsylvania State University)		
Grant/Contract No.:	NNX17AB08G		
Performance Goal No.:			
Performance Goal Text:			

Task Description:	To develop effective Human-Automation/Robotic (HAR) systems, NASA requires the development of methods and tools to inform the decisions regarding function allocation between robots and crew members that are able to objectively assess the implications of the assignment of these roles for the human-system performance trade space. This research will establish a validated method for the evaluation of function allocation between robots and automated systems and their human crew mates for use in deep space exploration missions. It will further produce computational models of different possible combinations of a three person human crew and various classes of robots for a variety of tasks which can be used as-is for additional analysis or modified for future concepts of operation. The method for function allocation will apply fast-time simulation, which will be validated by ground-based human-in-the-loop experimentation. It may also include human-in-the-loop simulation in an analog environment. The proposed research addresses three main research questions: First, how should roles and responsibilities be optimally assigned to robots and humans based on a combination of task demands, robotic capabilities, and available crew resources, with special attention to the capabilities inherent to classes of robots? Second, what is the human-robot system performance trade-space that serves as the basis for the allocation? Third, how can this function allocation method be validated as creating appropriate function allocation for both nominal and off-nominal operations? We propose a three year effort to address these questions. In the first year we propose to model the function allocation design space that exists between humans and robots in deep space exploration missions. We will use a computational framework called Work Models that Compute (WMC), which allows us to model dynamical systems (such as space vehicles and robots), automated systems (such as the automated rendezvous and docking system), and human agents working together to achieve common goals. WMC was custom designed to model function allocation and to measure eight metrics of function allocation previously established by the proposers. In the second year we will explore the design space, deeply investigating each metric such as taskload, authority-responsibility mismatch, coherency, etc., while beginning the validation process through the use of human-in-the-loop experiments with simulated robots. In the final year we will move from exploring each metric individually to looking at their combined effects as we vary the design space constraints, the tasks, crew stress levels, and function allocation options. We will continue our validation efforts using human-in-the-loop experiments using a combination of simulated robots and/or real robots. These experiments will systematically explore a large number of conditions such that they serve not only to demonstrate the function allocation chosen by the method, but also to validate the method.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	This research has the potential to impact several fields including computational modeling of function allocation, cognitive engineering methods, and the field human-robot teaming. First, this project uses current-day computational methods to model and simulate the human-robot teams at work. We are expanding on existing methods used in aeronautics to advance the field of computational simulation of function allocation for the improvement of crewed space exploration where we encounter additional challenges of agents with differential capabilities, time delay of communication, and the need to represent limitations in resources which might be both physical (say a wrench or oxygen) as well as informational (say the current CO_2 levels). The capability to simulate how human-robot teams work together will help systems designers understand the interaction between humans and space robotics to allow for robust and effective as well as efficient teamwork across missions and different crew-robot complements. In turn, human-robot teams not only become better at doing their taskwork, but also expand the capacity of what human-robot teams can accomplish. Human-robot teams may then go on to accomplish the numerous tasks that will expand humanity's knowledge of space exploration. Second, our research also impacts the growing field of human-robot teaming, as robots continue to advance technically and become less like tools for humans and more like peers and teammates. The computational framework and capabilities we are creating and demonstrating advance the field of cognitive engineering to investigate robot-human teaming, which is a research area applicable to domains beyond space exploration including manufacturing, healthcare, transportation, and agriculture.
Task Progress:	In the first year of performance we have modelled the function allocation design space that exists between humans and robots in future space exploration missions. We have extended a computational framework called Work Models that Compute (WMC), which allows us to model dynamical systems (such as space vehicles and robots), automated systems (such as the automated rendezvous and docking system), and human agents working together to achieve common goals. WMC was custom designed to model function allocation and to measure eight metrics of function allocation previously established by the proposers. In the second year of performance we created models of representative multi-human/multi-robot function allocations for prototypical EVA (extravehicular activity) missions. We then applied these models to demonstrate key implications in how various modes of human-robot interaction, including the implicit requirements for monitoring inherent to leaving human agents responsible for the outcome of tasks performed by robots, the implications of different human-robot control modes, and the idling time resulting from different distribution of tasks. In this past year, we validated our simulation results by conducting a human-in-the-loop experiment of an on-orbit maintenance scenario. We then further modeled an additional case study involving an autonomous lunar rover with kinematic and dynamic motion. Finally, we applied work strategies to both these scenarios to identify how to select function allocations.
Bibliography Type:	Description: (Last Updated: 02/11/2021)
Articles in Peer-reviewed Journals	IJtsma M, Ma LM, Feigh KM, Pritchett AR. "Demonstration of the “Work Models that Compute” simulation framework for objective function allocation." Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2018 Sep;62(1):321-4. (62nd Annual Meeting of the Human Factors and Ergonomics Society, Philadelphia, Pennsylvania, October 1–5, 2018.) https://doi.org/10.1177/1541931218621074 , Sep-2018

Articles in Peer-reviewed Journals	IJtsma M, Ma LM, Pritchett AR, Feigh KM. "Computational methodology for the allocation of work and interaction in human-robot teams." Journal of Cognitive Engineering and Decision Making. First published online August 30, 2019. https://doi.org/10.1177/1555343419869484 [note will be part of Special Issue on Human-Machine Teaming] , Aug-2019
Papers from Meeting Proceedings	IJtsma M, Ye S, Feigh KM, Pritchett AR. "Simulating Human-Robot Teamwork Dynamics for Evaluation of Work Strategies in Human-Robot Teams." Paper presented at the 20th International Symposium on Aviation Psychology, Dayton, OH, May 7-10, 2019. 20th International Symposium on Aviation Psychology, Dayton, OH, May 7-10, 2019. , May-2019