Fiscal Year:	FY 2018	**Task Last Updated:**	FY 08/08/2017
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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Zip Code:	30332-0150	**Congressional District:**	5
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
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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
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Flight Program:			
Flight Assignment:			
Key Personnel Changes/Previous PI:	August 2017 report: No changes to personnel. One of the Co-PIs, Amy Pritchett, has relocated from Georgia Tech to Penn State where she will serve as the Head of their Aerospace Engineering Department.		
COI Name (Institution):	Pritchett, Amy Sc.D. (Georgia Institute of Technology)		
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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 manned 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 CO2 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 to 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 humanities 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.
	In this 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 this year of performance we have created models of representative multi-human/multi-robot function allocations for prototypical EVA (extravehicular activity) missions. We have 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. As a case study, consider an on-orbit maintenance scenario in which three panels exterior to the spacecraft need to be inspected and – if in bad condition – replaced. The aim of this case study is to illustrate the use of our simulation framework for modeling and analyzing human-robot interaction in function allocation, including the metrics it can assess and the resulting insights that it can provide. The scenario includes six agents that can be deployed to execute the work: two human astronauts, one extra-vehicular (EV) and one intra-vehicular (IV), an RMS, two humanoid robots (Hum) that can operate inside and – at a more notional level – outside the spacecraft, and the Mission Control Center (MCC). The robotic agents might need to be controlled by a human operator, depending on their capabilities per action, as well as the desired specifications of the function allocation. The IV astronaut has access to a datalink with the humanoid robot, a datalink with RMS, and a radio-connection with the EV astronaut and the MCC. The EV astronaut has access to the same radio-link, and can additionally directly interact with the humanoid when they are working shoulder-to-shoulder. The RMS is in connection with the IV astronaut, as well as with the humanoid. Finally, MCC can talk directly to the both astronauts over the radio link. Depending on which agents are involved in the function allocation and the required information transfer, communication needs to occur over these channels. The taskwork for the scenario includes actions associated with overhead tasks, locomotion outside the vehicle,

Task Progress:	inspection, replacement of a broken panel, and tool handling. We tested three potential function allocations, each with different distributions of the work and different requirements for control modes and monitoring and confirmation needs. FA1 is a function allocation in which the EV astronaut directly controls a humanoid robot, the two of them working shoulder-to-shoulder to conduct the inspection and replacement of broken panels. This human-robot team is assisted by the RMS, which is being manually controlled by the IV astronaut. For FA2, the humanoid takes over the tasks of the EV astronaut. Most actions need humans to tele-operate the robots, either through direct tele-operation or command sequencing. MCC directs the humanoid, whereas the IV astronaut can directly operate the RMS. Furthermore, we have denoted five critical actions that need to be confirmed instead of monitored: the “apply inspection tools” and the four actions associated with the replacement of a broken panel. Finally, FA3 is a more notional function allocation, in which it is assumed that the humanoid is capable of executing tasks more independently from human operators. Thus, two humanoids, one performing the inspection and one doing the replacement of bad panels, are intermittently commanded by the IV astronaut and MCC, respectively. Humanoid I is continuously being monitored by the IV astronaut. MCC is responsible for Humanoid II, but because there might not be real-time data available for MCC, all actions of the Humanoid II are confirmed as opposed to monitored. Results from FA1: Here we have an EV astronaut who is working shoulder-to-shoulder with a humanoid. The astronaut at times needs to directly control this humanoid to execute inspection tasks. Replacement of broken panels is conducted by the astronaut, in collaboration with the RMS, which is being controlled and monitored by an IV astronaut. The time traces show that the RMS, IV astronaut, and humanoid often need to wait for the EV astronaut to complete his/her task before they can continue their own operations. Results from FA2: It shows MCC has a high taskload in controlling, monitoring, and confirming the operations of the humanoid. Furthermore, the IV astronaut has long periods of idling time and only occasionally needs to control and confirm the operations of the RMS. We additionally observe that the humanoid needs to occasionally wait for the MCC to provide commands. Likewise, the RMS is sometimes idling while the intra-vehicular astronaut is confirming the correct execution of the previous action. Results from FA3: Here, two humanoids are together performing the mission, and are assumed to only occasionally need commands from human operators. The IV astronaut is responsible for the actions of Humanoid I and thus has a continuous monitoring load. MCC is confirming every action of Humanoid II, and together with the waiting for commands, this causes long idling times. Additionally, because the replacement of panels is now only executed by a single agent, the mission duration is extended. The total number of information transfer requirements increases when moving from FA1 to FA3. The use of different communication channels is seen for the direct interaction between the EV astronaut and the humanoid, the Datalink1 for the humanoid, and Datalink2 for RMS. For FA1 we see some of the interaction associated with control and monitoring takes place through direct interaction between EV astronaut and the humanoid. For FA3, all communication takes place over the datalink channel with the two humanoids on it.
Bibliography Type:	Description: (Last Updated: 02/11/2021)
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