Objective Function Allocation Method for Human-Robot Interaction using Work Models that Compute

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Introduction

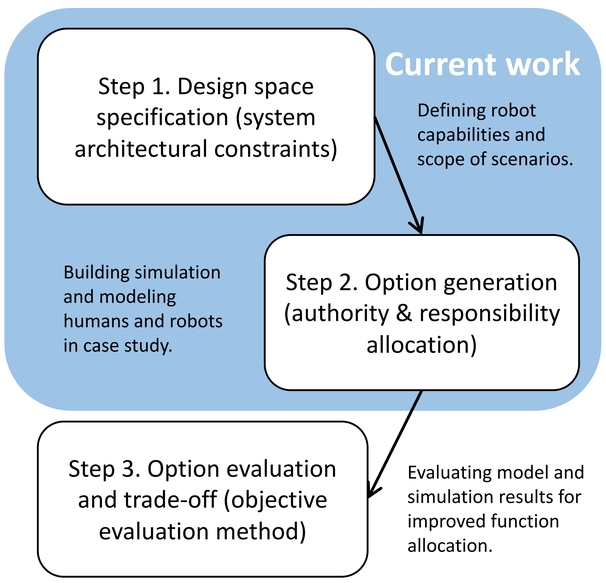
Future manned space missions will require astronauts to work with a variety of robotic systems. To develop effective human-robot teams, NASA needs objective methods for function allocation between humans and robots.

Some problems that need to be addressed in function allocation are:

- Monitoring of agents
- Agents waiting on other agents (idle time)
- High task load of agents
- Excessive amount of communication required

This study develops an objective method for function allocation between humans and robots for future manned space missions.

Methodology



Defining Agent Capabilities

Robotic and human capabilities constrain the available design space for function allocation: capabilities determine whether an agent can or cannot execute a certain action, and whether or not an action can be allocated to that agent.

- We classify capabilities of each agent based on physical and cognitive capabilities.
  - Taking into account both current and future (reasonably expected) capabilities.
- Physical capabilities include *manipulation of objects, locomotion* and *interaction* with other agents.
- Cognitive capabilities include *perception, judgment* and *decision-making* at three different levels of abstraction.
- Robots that we are currently analyzing include
  - Remotely Operated Vehicles (RMS)
  - Remote Manipulator Systems
  - Humanoids
  - Inspection robots.
- Agent capabilities are compared to required capabilities for each to-be-allocated action.

Capabilities for the Robonaut Agent

Robonaut (future)			Capability: Taskwork: Manipulation of objects: Movement of objects	Manipulation of objects: Dexterity	Locomotion: Surface	Locomotion: Space
Do we have the capability?			1	1	1	1
Intelligence	**Perception** (receive and recognize what it sees/feels)	Low-level behavior	1	1	1	1
		Mid-level behavior	1	1	1	1
		High-level behavior	1	0	1	1
	Judging (assess correctness of current behavior)	Low-level behavior	1	1	1	1
		Mid-level behavior	1	1	1	1
		High-level behavior	0	0	1	1
	Decision-making (determining new behavior)	Low-level behavior	1	1	1	1
		Mid-level behavior	1	1	1	1
		High-level behavior	0	0	1	1

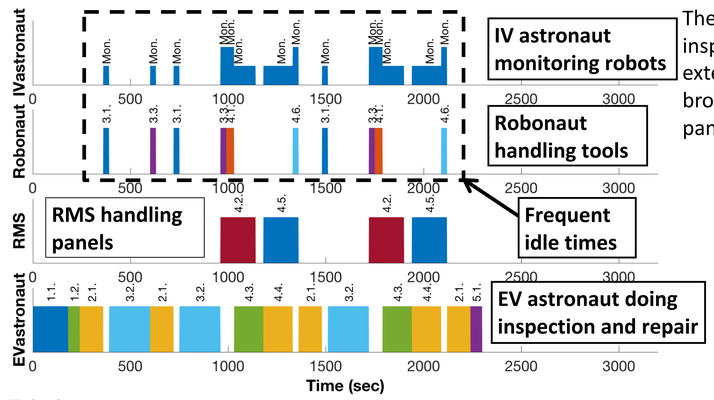
- 1 = the robot has the ability to make judgments/decisions at this level, no human required.
- 0 = the human needs to be involved in decision-making that involve (re-)organization of actions at this level.

Mapping Capabilities to WMC

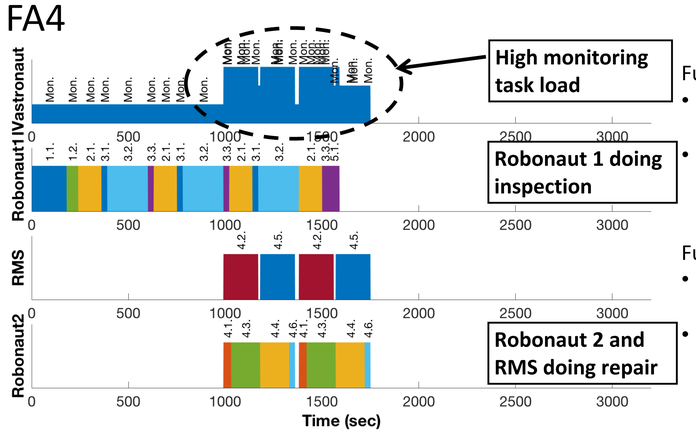
Functional blocks	Action	Cognitive Capabilities: Perception	Judgment	Decision-making	Physical capabilities: Dexterity	Movement of objects	Space locomotion	Current capabilities: Humans	Robonaut	Camera	Fetching	RMS	Future capabilities: Humans	Robonaut	Camera	Fetching	RMS
1. Exit dock	1.1. Prepare	1	1	0	1	1 or 0	0	1	0	1	0	0	1	1	1	1	0
	1.2. Leave dock	1	1	0	0	0	1	1	0	1	0	0	1	1	1	1	0
2. Traverse	2.1. Traverse	1	1	1	0	0	1	1	0	1	0	1	1	1	1	1	1
3. Inspect panel	3.1. Get inspection tools	1	1	1	0	1	0	1	0	0	0	0	1	1	0	1	0
	3.2. Apply inspection tools	1	1	0	1	0	0	1	0	0	0	0	1	1	1	0	0
	3.3. Store inspection tools	1	1	0	0	1	0	1	0	0	0	0	1	1	0	1	0
4. Repair panel	4.1. Get repair tools	1	1	1	0	0	1	1	0	0	0	1	1	1	1	1	1
	4.2. Get new panel	1	1	1	0	1	0	1	0	0	0	1	1	0	0	1	1
	4.3. Remove broken panel	1	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0
	4.4. Emplace new panel	1	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0
	4.5. Dispose of broken panel	1	1	0	0	1	0	1	0	0	0	1	1	0	0	1	1
5. Enter dock	5.1. Enter dock	1	1	0	0	0	1	1	0	1	0	0	1	1	1	1	0

Case Study: On-orbit Maintenance

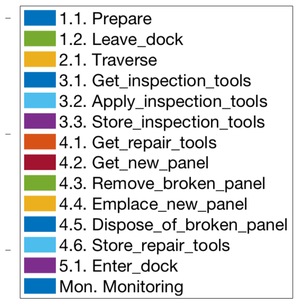
FA3



FA4



The on-orbit maintenance scenario involves inspection of panel on the spacecraft's exterior. Whenever panels turn out to be broken, a replacement procedure of these panels begins.



Function allocation 3 (FA3):

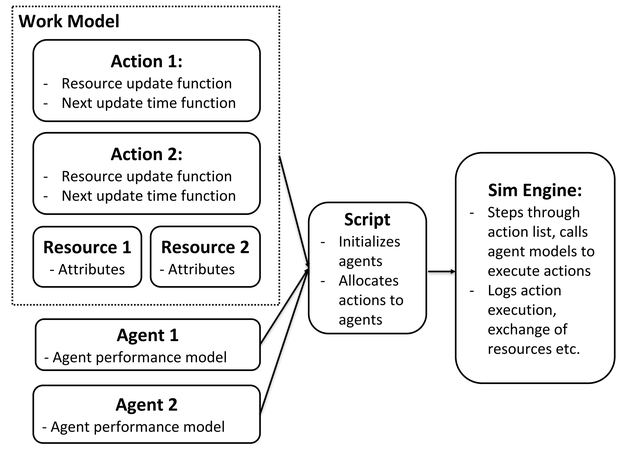
- Frequent idle times for the IV astronaut, Robonaut and RMS.
- IV astronauts required to monitor Robonaut and RMS because of authority-responsibility mismatches.

Function allocation 4 (FA4):

- Fewer idle times and a shorter mission duration
- IV astronaut has a high monitoring task load, at times monitoring three robots at once.

Computational Simulation Work Models that Compute (WMC)

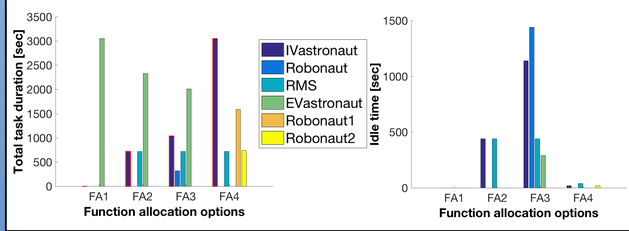
WMC is a scenario-based computational simulation framework for evaluation function allocations. Work is modeled in the form of actions that can be allocated to agents with a single line of code, representing a particular function allocation.



Case Study Early Results

Actions	Current capabilities: FA1: EV only	FA2: EV, RMS	Future day capabilities: FA3: EV, RMS, Robo	FA4: Robo1, Robo2/RMS
1.1 Prepare	EV	EV	EV	Robonaut1
1.2 Leave dock	EV	EV	EV	Robonaut1
2.1 Traverse	EV	EV	EV	Robonaut1
3.1 Get inspection tools	EV	EV	Robonaut	Robonaut1
3.2 Apply inspection tools	EV	EV	EV	Robonaut1
3.3 Store inspection tools	EV	EV	Robonaut	Robonaut1
4.1 Get repair tools	EV	EV	Robonaut	Robonaut2
4.2 Get new panel	EV	RMS	RMS	RMS
4.3 Remove broken panel	EV	EV	EV	Robonaut2
4.4 Emplace new panel	EV	EV	EV	Robonaut2
4.5 Dispose of broken panel	EV	RMS	RMS	RMS
4.6 Store repair tools	EV	EV	Robonaut	Robonaut2
5.1 Enter dock	EV	EV	EV	Robonaut1

- **Current capabilities** (FA1 vs. FA2): FA2 has balanced task load, shorter mission time, but longer idle time.
- **Future capabilities** (FA3 vs. FA4): FA3 has long idle times for all agents, FA4 much shorter mission time, but IV astronaut possibly overloaded with monitoring.



Future Work

We will continue our work to model robotic capabilities and human-robot teams for NASA's use while extending the capabilities of the WMC.

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