Shared Mental Models to Support Distributed Human-Robot Teaming in Space

Felix Gervits* Terry Fong† and Matthias Scheutz*

*Tufts University, Medford, MA

†NASA Ames Research Center, Mountain View, CA

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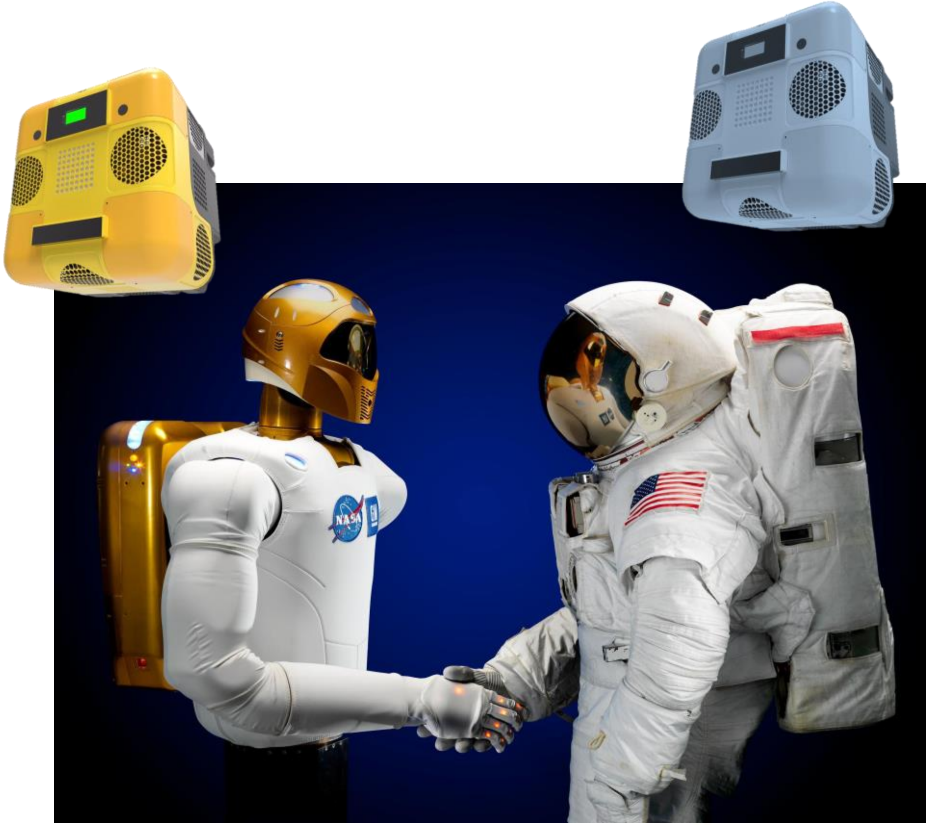
Human-Robot Teaming in Space



Robots as teammates

- ➢ Robots perform dull, dirty, dangerous tasks
- ➢ HRI can offset limitations in autonomy
- ➢ Many different kinds of human-robot teams:
  - Supervised remote teleoperation
  - Co-located peer-to-peer interaction
  - Limited interaction
- ➢ Need to coordinate activity in these different teams

Previous Work

- Approaches to coordinating HRI
  - Collaborative framework - Hoffman & Breazeal (2004)
  - P2P HRI; HRI O/S - Fong et al. (2005; 2006)
  - ACT-R/E - Trafton et al. (2013)

+ Core focus includes robot-as-teammate, maintaining shared goals, and using dialogue to establish common ground

- Not easily extensible to multiple robots and different team configurations

Present Work

Shared Mental Models (SMMs)

Task Model		Team Model	
Equipment	**Task**	**Team Interaction**	**Team (Teammates')**
Equipment Functioning	Task Procedures	Roles/Responsibilities	Knowledge
Operating Procedures	Likely Contingencies	Information Sources	Skills
Equipment/System Limitations	Likely Scenarios	Role Interdependencies	Attitudes
Likely Failures	Task Component Relationships	Communication Channels	Preferences
	Environmental Constraints	Interaction Patterns	Performance History
	Task Strategies	Information Flow	Tendencies

- Effective human teams build and use SMMs (e.g., Cannon-Bowers et al., 1993; Mathieu et al., 2000)

Shared Mental Model (SMM) Framework

- Computational framework that implements shared mental models (Scheutz et al., 2017):
  - Data Structures: *Capable(A, scan-room), Goal(A,scanned(room2)), etc.*
  - Update Processes: *Goal(A, visited(A, room2))* ⇒ *GoingTo(A, room2)*
  - Control Processes: *Goal(A, scanned(room2))* ∧ ¬*Capable(A, scan-room)* ⇒ *ChangeRole(A)*
- Information is synchronized between all robots on the team

Overview of Present Work

- Goal: test the potential of the SMM framework to improve human-robot coordination and team performance

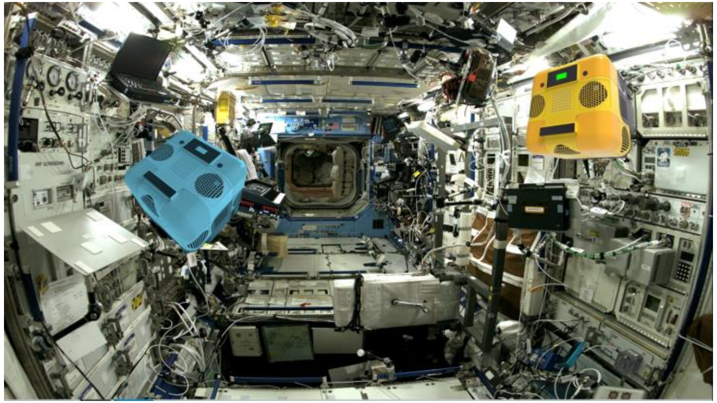
- Formalize task domain
- Apply it to virtual environment with simulated agents
  - Agents behave as if they have SMMs
- Run crowd-sourced human-subjects experiment

Task Domain

Shaping the Future of Aerospace

Supervised Emergency Maintenance Task

- Ground-based human operator supervising 2 semi-autonomous robots on a spacecraft orbiting the moon
- Tool search / Panel repair task
- Actions involve navigating, scanning room, shutting off panel, and searching toolbox
- Team roles
- Equipment failure
- Loss of Signal
- Robot autonomy



Domain Formalization in SMM Framework - 1

- **Domain Knowledge** - Agents, Object Types, Activities, etc.
  - *Agent(R1); Object(wrench); Activity(search-toolbox)*
  - *located(A, room)* $\Rightarrow$ *isOccupied(room)*
- **Agent Capabilities** - *Capable(A,X,σ), Perceivable(A,X,σ), etc.*
  - *Perceivable(R1, toolbox2, {located(R1, room2)})*
- **Agent and Task States** – *Knows-Of(A,X), Goal(A,γ), etc.*
  - *Knows-Of(R1, isScanned(R1, room5))*

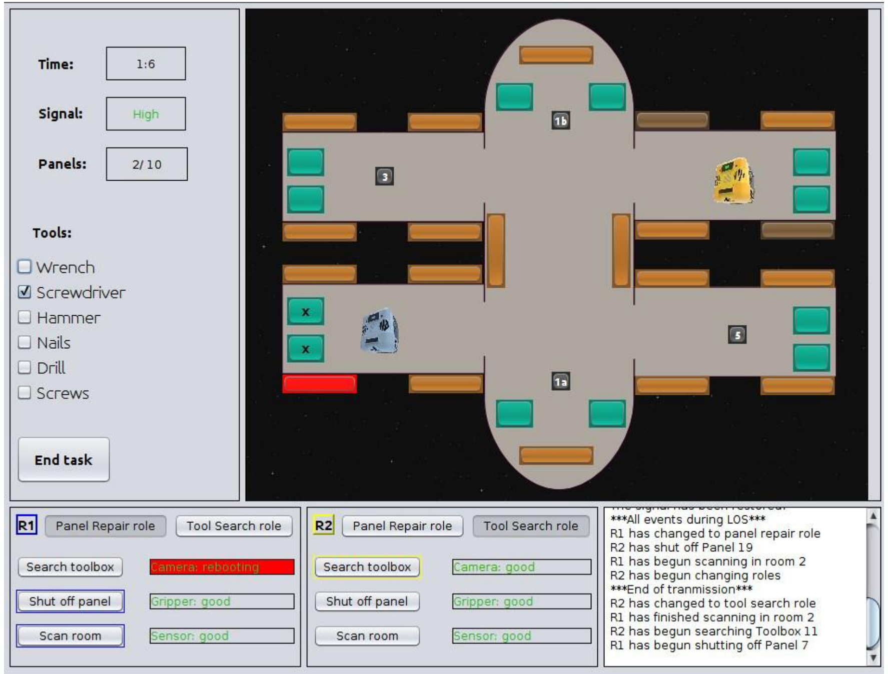
Domain Formalization in SMM Framework - 2

- **Plans and Autonomy** – *Adopted(A,π,σ), Achieves(π,φ,σ), etc.*
  - *located(A, room) ∧ ¬scanned(A, room) ⇒ STI(A,scanned(A,room))*
- **Obligations and Norms** – *Superior(A1, A2), Proposes(A1,A2,X)*
  - *Proposes(O, R1, X) ∧ Superior(O, R1) ⇒ Accepts(R1, O, X)*
  - *Accepts(R1, O, X) ⇒ Goal(R1, X)*
- **Role requirements** – *Required(e,φ),Requires(A,e)*
  - *Required(gripper,shutoff(panel)); Requires(R1,gripper)*

Preliminary Study

Study Overview

- Simulated task environment
  - Simulated agents that behave as if they have SMMs
- Crowd-sourced MTurk study
- Two experimental conditions - Baseline vs SMM
  - SMM agents share information
  - *Common-Goal(γ), Common-Knowledge(φ)*



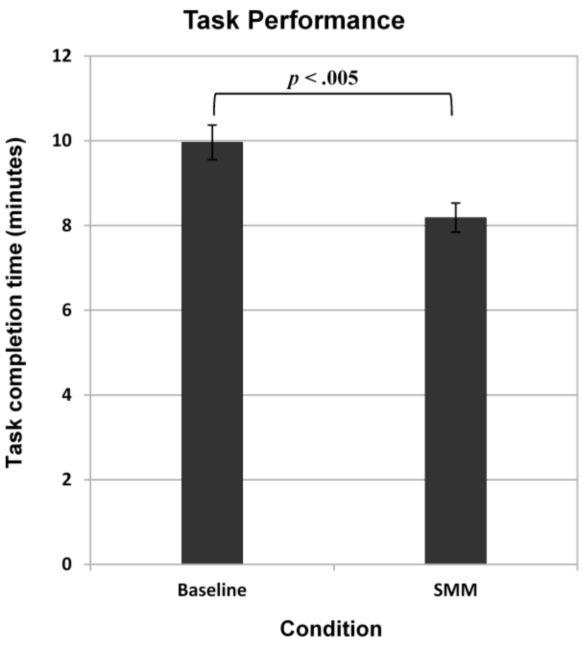
https://vimeo.com/284638484

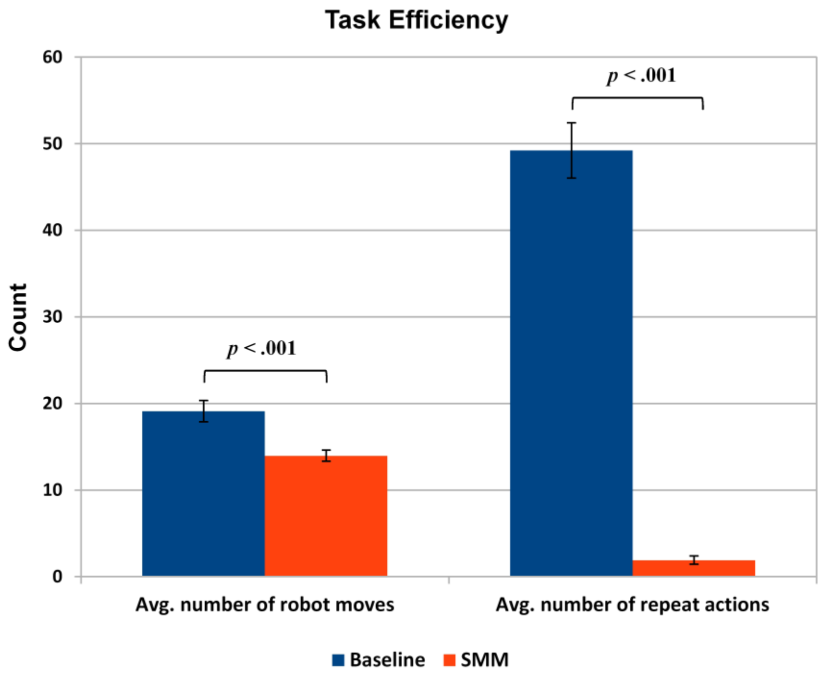
Metrics and Hypotheses

- **Objective:**
  - Completion Time (-)
  - Robot Movements (-)
  - Action Repetitions (-)
  - Operator Interventions (-)
  - LOS productivity (+)
- **Subjective:**
  - Workload (NASA-TLX) (-)
  - Team Workload (TWLQ) (-)
  - Situational Awareness (SART) (+)

- **Hypotheses:**
  - SMMs will allow the task to be performed faster and more efficiently
  - SMMs will reduce operator workload and improve SA

Results (N=70)


Task Performance
$p < .005$
Task completion time (minutes)
0
2
4
6
8
10
12
Baseline
SMM
Condition


Task Efficiency
$p < .001$
$p < .001$
Count
0
10
20
30
40
50
60
Avg. number of robot moves
Avg. number of repeat actions
Baseline
SMM

Future Work

- Implementation and evaluation of SMM framework
- Explore different team configurations and tasks
- Resolving inconsistencies in synchronization and handling uncertainty

Conclusion

- Extended our SMM framework to a space robotics domain
- Formalized and implemented the task domain in an environment with simulated agents
- Ran preliminary study showing the benefit of applying our coordination framework to space robotics teams

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Tufts Human-Robot Interaction Lab: hrilab.tufts.edu

NASA Intelligent Robotics Group: https://ti.arc.nasa.gov/tech/asr/groups/intelligent-robotics/

Email: Felix.Gervits@tufts.edu