How Autonomous Intelligent Systems Can Facilitate Earth-Independent Medical Care: Going Beyond Telepresence

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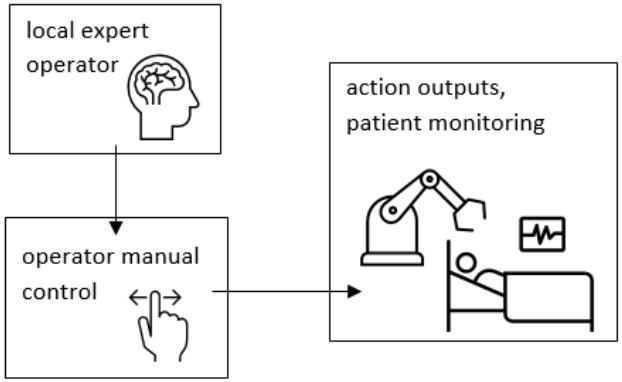
Teleoperated Robotic Systems

- Teleoperated robotic systems have extended humans' sensorimotor competence to digitally fly beyond the physical barrier of distance and scale
  - Sensorimotor skills of the human are transmitted through direct communication
- Telepresence capabilities have enabled tele-physical remote access at small scales
- These technologies have expanded into the medical domain and resulted in teleoperated medical robots, including telerobotic surgical systems
  - Necessary technological advancement remains to be realized, yet system development can enable manual control at the microscale (Das et al., 2001)
  - There is much yet to be determined around medical robotics and increasing levels of autonomy (Yang et al., 2017)



Basic architecture of a teleoperated robotic system

Direct Telepresence for Exploration Spaceflight Missions far from Earth

- Effective telepresence fundamentally depends on an agile, reliable, and secure communication medium
  - Transmits real-time information between the operator and a remote device
- Direct telepresence may not be achievable for exploration spaceflight missions far from Earth
  - If not blocked, minutes of latency can be expected
- Yet, some form of support is necessary to maintain clinical outcomes during exploration when Earth-based ground support is unavailable (Yule et al., 2022)
- Potential solutions:
  - Fully Autonomous Systems
  - Partial Automation, Augmenting a Local Operator

Learning from Pre-captured Inputs of a Skilled Human Operator: Technical Skills

- Demonstration systems may employ the pre-captured inputs of a skilled human operator
  - Computationally modeled and probabilistically replicated manual skill profiles toward the completion of remote physical tasks
  - Trained autonomous systems (e.g., robots) can perform remote operations that mimic the physical performance of experts during remote operations/training
  - Autonomous agents can make decisions or can be used to support human decision-making
- Using an autonomous system, pre-trained cognitive and manipulation-based skills can be leveraged (acquired during pre-mission events) to produce digital twins of an intelligent operator
- Skill Transfer Learning (STL)

Learning from Pre-captured Inputs of a Skilled Human Operator: Non-Technical Skills

- Non-Technical skills, and thus Neuroscience technology, are important as well
  - Non-technical cognitive skills are important to clinical outcomes, and additional studies are needed in this area (Nagyné Elek and Haidegger, 2021)
  - An *observational* tool for non-technical skill assessment specific to robot-assisted surgery recently has been developed (Schreyer et al., 2022)
  - Neuroscientific *monitoring* to gauge levels of Non-Technical skills such as cognitive focus and and cognitive / human performance via wearable sensors for the quantification of:
    - Workload (Miyake, 2001; Singh et al., 2018)
    - Attentional state (Harrivel et al., 2017)
    - Situation awareness (Memar and Esfahani, 2018)
    - Brain activity monitoring (Singh et al., 2018; Uchitel et al., 2021)
    - Expertise level (Hannah et al., 2022)
    - Skill acquisition (Izzetoglu et al., 2021)
    - Possibly even action prediction (Vecchiato, 2021)
  - *Neuroaugmentation* via stimulation (Patel et al., 2020)

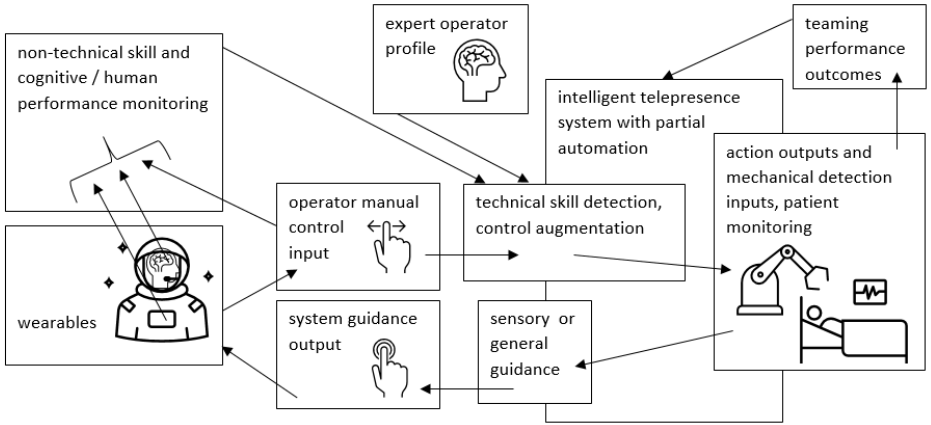
Partial Automation with a Local Operator

- Here we describe an Intelligent Telepresence System vision that is relevant to enabling Earth independence (beyond the reach of telementoring), involving:
  - Partial Automation and cooperative robotics
    - “[A] modular human–robot system design with versatile access to cooperative functions with varying degrees of automation on demand is desirable” (Schleer et al., 2019)
  - Augmented Control and Sensory Awareness
  - Wearable Systems
  - A local operator
    - The local operator conducts delicate tasks while guided using sensory augmentation
    - Such a system closes the loop (Stephens et al., 2018) through the local operator
- An expert operator profile is compiled based on control input and operator state data collected from skilled operators, and made available to the system
- The envisioned system augments the control inputs of the local human to match those of a skilled expert operator (or an amalgam of a set of expert operators) who is not accessible locally nor in real-time
- This approach to intelligent telepresence goes beyond classic telepresence (Haidegger et al., 2011), and reduces needed skill and training

Partial Automation with a Local Operator

- System inputs:
  - Local manual control
  - Technical skill monitoring
  - Non-Technical skill monitoring, Crew State
  - Expert operator profile
  - Patient mechanical sensing and monitoring

- System outputs:
  - Sensory guidance, haptic feedback to crew
  - Manipulation-based technical skill detection
  - Actions on the patient based on crew input augmented toward that of a skilled operator
  - General guidance from the system such as spatial or temporal pacing cues, or other job aids



An overview of a partial automation system with a local operator

- The performance *of the crew and the system as a team* is measured and fed back to the system to enable controlled adaptability, optimal crew state, and progress toward positive patient outcomes

Conclusion

- Effective telepresence fundamentally depends on an agile, reliable, and secure communication medium

- Direct telepresence may not be achievable for long-duration exploration spaceflight missions
- Autonomous systems and local intelligence represent potential solutions to this issue

- Trained autonomous systems (e.g., robots) can perform remote operations that mimic the physical performance of experts during remote operations/training

- Partial-automation using remote intelligence and remote sensing is possible

- Autonomous agents will eventually enable the safe, consistent, and efficient delivery of complex, remote, and smart medical care during space exploration across operators in an Earth-independent fashion

Questions

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