Breakout 2.1: Challenges for Telelabor as Digital Transportation – ARPA-E Questions

Wednesday, April 27, 11:00-12:30

<u>Objective</u>: The goal is to introduce new tele-operation technology that enables manual laborers and technicians to work remotely. We've identified several thrust areas to focus our developments on for maximum adoption and energy impact:

- Low-cost (< $5k) arm and manipulator systems
- Intuitive, "transparent" user interfaces
- Teleoperation over high-latency (> 100ms) networks
- Developing relevant and meaningful user studies for telelabor systems

The purpose of this breakout session is to identify and discuss the key technological challenges that must be overcome to realize a telelabor system with the necessary energy impact.

Core Technological Capabilities

ARPA-E has identified a number of use cases for telelabor technology that would reduce travel energy with a relatively low bar for adoption. These use cases include:

- **Production**, including fabrication, assembly, inspection, and packaging. This could be end-to-end production at a single station, or as part of an assembly-line. Typical applications include factories and fulfillment centers.
- **Maintenance**. This includes performing remote maintenance on general machinery, HVAC systems, automobiles, plumbing, etc. in both commercial and residential applications. Replaces a repairman having to travel to a site/home.
- **Food Service**, including cooking, packaging, and cleaning. This primarily applies to kitchen staff for restaurants and laborers at food manufacturing plants.

What are the required core technology capabilities that are common to these use cases?

Low-Cost Arms and Manipulators

Today's commercially available robotic arms and end effectors are too costly for appreciable adoption in our target use cases. We have identified that actuators, gearboxes, and motor controllers are the primary cost drivers in state-of-the-art systems.

1. Are there ways to reduce the cost of these components aside from higher volume production?
2. What is the trade-off between precision, reliability, and cost?
3. Can acceptable teleoperation be achieved without harmonic/cycloidal drives or high DOF arms?

4. Can we define an appropriate set of tasks that allows teams to properly size their actuators and define hand DOFs?

Dealing with High Latency

High latency (>100ms) and unreliable network connections are still very much a reality in today's commercial network technology. Although speed and reliability improvements are expected to improve (1Gb/s internet coming to homes within 5 years), we expect a large portion of our use case population will remain with sub-optimal network connections far into the future.

1. What complications will an unreliable, high-latency (>100ms) network introduce for today's teleoperation technology?
2. What existing and/or new methods are needed to enable robust teleoperation in unreliable and/or high latency environments?

High-Quality, Transparent User Interfaces

For high adoption rates, the user interface needs to be intuitive and relatively transparent to the task. Similarly to the teleoperation arm itself, the user interface must also be cost-efficient for our target use cases.

1. What do today's teleoperation interfaces look like, and what are their primary issues? What do we need to achieve to make them more transparent?
2. Is convincing haptic feedback achievable? If not, what limitations must be overcome?
3. What are the driving costs behind today's teleoperation interfaces? Are there ways to reduce cost?
4. Does the controller need to be a physically held device? Can we imagine some other modality, such as gesture-based control or voice recognition?

Autonomous Manipulation

Poor network latency and non-intuitive interfaces introduce a possible requirement for autonomy in a teleoperation solution. Sliding autonomy would allow the operator to adjust their level of control based on the task or network quality.

1. What is the state of the art capable of when it comes to autonomous manipulation and grasping? What are the issues? What still needs to be solved?
2. What are notable solutions in the current state of the art that implement sliding autonomy in teleoperation? What are their issues? What is the community still trying to solve?
3. What are the present and future limitations of machine vision and perception when it comes to object manipulation? How can these be overcome?

User Performance and Acceptance Studies

A critical factor for achieving widespread adoption involves designing a system towards specific user performance and acceptance goals. Given the core technologies and requirements discussed in the above questions:

1. Are there community-standard user study methods for evaluating the performance of a human/teleoperation system, even if particular to a specific application/market?
2. How are user studies typically conducted for teleoperation systems (e.g. quantitative vs qualitative methods)? How can they be improved?
3. What would the ideal user studies be able to tell us about performance and acceptance? Why don't we have this capability now?

Breakout Session 2.1: Feedback

Low-Cost Arms and Manipulators

- Bill of materials is not the significant cost driver.
- Transmissions are the best place to save cost and efficiency.
- Soft robotics would be game changer; power, weight, compliance, and efficiency are all great, but lifetime issues are hard.
- Human in the loop will assist with lower reliability/accurate manipulators.
- Can build low cost ($1k) arm - tradeoff of accuracy/repeatability
    - Tying knots would be tough at that cheap price point
- Metric needed – reliability. (5 days vs 8 years). Reliability in terms of the task, not just lifetime
- Keep in mind that when you know the robot will be there, the environment can/will be designed differently to accommodate it and may alleviate the need for specialized capabilities
- Most sensors are probably not a barrier - could leverage automotive components
- Think of hand and arm separately. Some tasks need just the arm. Some tasks where hand are more critical

Dealing with High Latency

- Local autonomy.
- Consider network redundancy.
- 100ms latency is limit of what you can tolerate – person can adapt quickly and intuitive control. Once you cross 100ms threshold, impossible. Basically have to bring in automation. Operators would be drained.

Autonomous Manipulation

- A lot of work is being done in autonomous manipulation but it's very much in the research stage.
    - A lot of work in grasp optimization, machine learning for grasping in the future.
- Autonomy would help greatly in cases where high latency or poor haptics.
- Tough to see reflective or transparent objects, and is not studied well in machine vision community.
- The robot can also suggest grasps and the operator can ok them (or not). Shared autonomy can also be a, say, linear blending, for motion. Gripping an object—can be discrete choices.
- If you have a video of plumbers, etc. can you just train robots? And then if it fails then the user can help.
- Might not need that many sensors based on the autonomy capabilities.

High-Quality, Transparent User Interfaces

- VR headsets aren't good at giving you any kind of 3D sense of the space and situational awareness.
- Stereo vision with a sense of depth is really important.
- Need more user studies to see what people need and can use.
- A person interacting with an environment. A slave is a substitute for the person, so the master is the substitute for the environment. Not a master being the same as the slave, a matter of the master being the same as the environment.
- Intuitiveness of interface is important. Interpreting signals we naturally understand into signals we do NOT understand is problematic. Are you willing to retrain people on a new interface to do their jobs? Expensive. Not impossible
- Illustrative example - hand transplants. Anatomy of hands can be quite different. Even if a surgery is perfect, it doesn't mean that one mind is prepared to compare other's hand. Also related to this task—this will affect the cognitive load that will be applied to tele labor operators. If we have really good visual feedback we can do impressive hand-eye manipulation tasks. Really good haptic sensing. If we add some extra sensors—really good off-the-shelf robot hands. Friction can kill the experiment.

User Performance and Acceptance Studies

- How much time it takes you to complete a task, accuracy.
- Need to consider long term studies, but there isn't enough telelabor going on right now to get enough data.

Other People in the Community to Engage:

- Hacker Spaces
- Cognitive Psychologists
- User Base for our use cases
- Gamers (to discuss interfaces)
- Teachers and Developmental Psychologists to learn how people learn.