Student questions: Terry Fong colloquium on "Human-robot teaming for space exploration"
10/11/17

Question 1: When teaming robots with humans at the same time, has any consideration been given to using the robots in part for some kind of medical/safety assistance in order for humans to gain access to more dangerous but more scientifically interesting targets?

Some thought has been given to using robots to retrieve/transport injured astronauts, both in-space and on planetary surfaces. However, I do not know of any consideration for gaining access to more dangerous targets.

Question 2: Of the three examples given: robots before humans, robots after humans, and robots and humans, which seems to be the most cost effective and or most promising so far?

Robots before humans seems to be the most promising, given that we already have experience in using robots to explore planetary surfaces. In addition, some missions, such as Resource Prospector, are now being designed to explicitly inform subsequent human missions by collecting data that is needed to close "strategic knowledge gaps".

Question 1: How soon do you see humans and robots working alongside each other on a single planetary mission?

I am sure that the next time humans set foot on another planetary body, they will be accompanied by robots of various forms.

Question 2: With the current rate at which technology is progressing, what is the best time frame/schedule to be sending out robotic missions to get the most use out of state-of-the-art technology? Every five years? Every ten years?

All times! The key question, however, is: what can we do to reduce the increasing gap between what is possible with robots on Earth and robots in space.

Question 1: Have you thought about using drones in your research?

Yes, we are starting to do so. Our primary concern, however, is that drones (and aerial robots in general) have limited relevance for most planetary targets given the need for suitable atmosphere.

Question 2: What are the benefits of having a space station orbiting a planet with scientists controlling robots on land?

Some people hypothesize that allowing robots to be operated in a fully interactive manner, with high-bandwidth communication and low-latency, might improve the scientific return. I, myself, am skeptical of this given that it seems to be more useful to increase the on-board autonomy of robot systems and to allow humans to function at a supervisory level (rather than manual control).

Question 1: Could these robots be economically viable to collect data in remote places on Earth or are they exclusively for non-terrestrial applications?

They could definitely be used on Earth! In fact, we have used robots to explore active volcanos, lava tubes, and underwater (including beneath the sea ice in Antarctica).

Question 2: With the recent announcement from the government expressing support for future manned lunar missions , how does this affect your research direction/focus?

We are hopeful that lunar mission concepts, such as Resource Prospector, will be given the opportunity to gather new scientific and engineering data about the Moon.

Question 1: During the evaluation of the Lunar Libration Point mission ops, did you find substantial benefit from having astronauts able to operate the robots real time as compared to operations with a relativistic time delay, and does that benefit justify the added cost of sending a human mission as opposed to a purely robotic one?

No, not in terms of robot utilization or productivity. That said, a key benefit of operating from an orbiting spacecraft might be the opportunity to make use of the computing (processing and storage) carried by such a spacecraft.

Question 2: I am aware of efforts at NASA Goddard in Maryland to develop instruments for astronauts to use for surface exploration featuring static instruments that can be deployed by astronauts during one EVA and retrieved during another. Has there been any consideration for how robotic operations might interface with these human-deployed static systems?

Within the robotics community, there has long been disagreement about whether it is better to create custom, “robot friendly” interfaces/devices vs. enabling robots to work with artifacts designed for humans. My personal opinion is that the former is far simpler and more effective, though there is obvious associated cost.

Question 1: Has this human-robotic teamwork been successfully deployed for exploration in extreme earth environments (deep sea, underwater caves, tar pits/volcanic zones)?

Yes, there have been a number of such projects with underwater robots.

Question 2: What are the main limitations on planetary exploration by drones that currently make exploration by rovers more favorable?

Atmospheric density (for places that have atmosphere) and power (required for flight).

Question 1: In the creation of geologic maps with robots, how were the strikes and dips of units taken?

All instrument data (monocular images, stereo images, lidar data, etc.) is time-stamped and tagged with full geospatial information. This allows quantitative analysis (in terms of location and orientation) of units.

Question 2: As robotic exploration technology is developed, what level of priority is given to "robotic curiosity", or the ability for a robot to notice something out of place or interesting, and then investigate it?

"Science Autonomy" is an active area of research of robotics. We would very much like robots to be able to detect "anomalous" features and to make (some) exploration decisions autonomously.

Question 1: What are the current challenges to have robots choose specific samples for chemical analyses of interest automatically (without human interference)?

Automated sample selection continues to be a very challenging research area, primarily due to the difficulty of specifying what combinations of attributes (intrinsic and extrinsic) make a "good" sample.

Question 2: What other aspects were decisive to choose Black Point Lava Flow as a site similar to Straight Wall for robot testing other than climate characteristics?

Accesibility, prior field work, scale, and logistics.

Question 1: Why would we still send astronauts to space for exploration if robots are cheaper and safer?

For performing tasks that cannot be (easily or cost-effectively) performed by robots.

Question 2: Could we equip robots with more analytical equipment like mass spectrometers, electron microprobes, etc?

Definitely! It really just depends on whether we are able to reduce the size, weight, and power of these instruments to be compatible with robots.

Question 1: Has there been any estimation made as to how much money can be saved by using robots either before or after human exploration in terms of cost relative to scientific return?

Not as far as I am aware. This is, of course, a very difficult thing to estimate given all of the factors that are involved.

Question 2: Are there any specific upcoming missions with which your robotic approch, either pre or post manned mission, is scheduled to be used?

The Resource Prospector mission is designed to answer questions that NASA has regarding the distribution, quantity, and exploitability of lunar volatiles. Answering these questions is essential to planning subsequent human missions, including surface infrastructure and the extent to which in-situ resources can be used.

Question 1: Was the k10 robot ever used in a mission after its testing in Arizona?

Not in a flight mission. However, we used K10 in 2013 for a series of experiments with the Space Station. During these experiments, astronauts on the Space Station remotely operated K10 in California to perform a simulated lunar surface mission.

Question 2: What's the next mission planned for a recon robot team?

Nothing at present.

Question 1: You mentioned that recon robots can be used not only on the moon, but also on Mars or asteroids. Does the performance of robots change depending on which planets/moons (i.e., what kind of landscape) we are running them?

Yes, definitely. In particular, the topography, surface composition, etc. of a given area has significant implications for traversability. At present, for example, it is difficult to imagine how a planetary rover could traverse ejecta blankets or penitentes.

Question 2: You mentioned the interaction between humans and robots is still not fast enough. What has been the bottle necks to make it faster?

Humans communicate best with natural language. Robots do not.

Question 1: Moving into the future, what types of tasks might planetary robots be suited to perform autonomously?

Surveys, site preparation, instrument and infrastructure deployment, sample return, to name a few.

Question 2: You mentioned that the poles of the moon might be suitable for resource exploration/extraction. What types of resources would be found and would they be enough to justify more permanent human ventures on the moon?

The primary resource of interest are volatiles, particularly various species of hydrogen. If there are sufficient amounts of hydrogen, and they can be effectively "mined", then this would radically change how human exploration is carried out.

Question 1: Can one vehicle/robot be used for pre-, concurrent, and post- reconnaissance with humans or do they require entirely different instruments/capabilities?

Yes, one vehicle/robot could be used for all those activities. However, it is likely that different activites will require different capabilities (locomotion, instrumentation, range, etc)

Question 2: What kind of scientific experiments of other 'planetary' bodies can, as of now, only be run by humans and not these semi-autonomous robots?

Studies of dynamic, emphemeral, and/or transient phenomena that occur more rapidly than the communication delays to/from Earth are difficult to study with current robots. For example, it is not clear how best to observe plumes on Enceladeus or Europa with a purely robotic mission and it is impractical for humans to be "in the loop" from Earth.

Question 1: Do you think that the upcoming New Frontiers proposal mission Dragonfly (a quadcopter on Titan) is a viable mission given the current state of "AI robotics"?

I am not familiar with Dragonfly.

Question 2: Are there plans to integrate things like neuro-networks (finding interesting anomalies) into the partial-AI robotics programs being developed at NASA in order to add a component of science based inquiry?

Yes, this is an active area of research. See, for example, work by Akash Arora (Univ. of Sydney), P. Michael Furlong (NASA Ames), and David Thompson (JPL).

Question 1: How close are we to robots/AI that can adapt to unexpected situations completely on their own?

Not very, but this an active area of research. For example, the National Science Foundation's "Smart and Autonomous Systems" program is addressing this specific topic.

Question 2: Do you think we will eventually have completely robot led exploration and if so, how soon do you think this would happen?

Yes, I do! I would not be surprised to see this happen within the next 25 years, given the extremely rapid pace of autonomy technology development in many fields.

Question 1: What are the anomalies or edge cases that we can help support robots with?

Any time a robot operates at the limits of its capabilities, human assistance can be invaluable. For example, vision-based obstacle detection generally only works within a particular performance envelope (dynamic range, speed, depth, etc) and for obstacles that are expected. A robot that is designed to work well in daylight likely will have tremendous difficulties at sunrise and sunset.

Question 2: After you complete the field experiments, did you make any adjustments to the robots?

Yes, all the time! We conduct field experiments specifically to learn what is not possible in just laboratory settings. The real world has so much complexity and variability that we are always making adjustments.

Question 1: What is the most important aspect of mission planing that will help increase the efficiency of the robotic mission in completing its science objectives?

Developing plans at an appropriate level of detail and accuracy that they can be carried out.

Question 2: Is there research being conducted on how robotics impacts social interactions/behavior amongst crew members?

Not at the current time. However, the NASA Human Research Program is studying the risk of inadequate design of human and automation/robotic integration, which may result in flight and ground crew errors and inefficiencies, failed mission and program objectives, and an increase in crew injuries due to increased use of robotics:

https://humanresearchroadmap.nasa.gov/risks/risk.aspx?i=163

Question 1: With a smarter pathing system, could we begin to place more sophisticated movement systems, such as robotic legs demonstrated with the Boston Dynamics group, to replace the wheels we see on most rovers/robots, and would this system be less useful because of weight restrictions on the robot (every leg has to support weight like a wheel does now)?

Legged locomotion is often more effective than wheeled locomotion for traversing rough or uneven terrain. However, legged robots are generally more complex and less reliable.

Question 2: As the robots begin to work in more of a human time-frame and are able to make these decisions with much more calculations than a human, would programming this 'intuition' become more realistic and eventually lead to the human interfering actually hindering the robot?

Interesting question… I have no idea!

Question 1: Has there been work with using robotics to mule samples or supplies back and forth to research stations?

NASA has performed some limited field tests of these scenarios. However, the US military (DARPA, US Marine Corps, etc) has done much more work in this area.

Question 2: How much work have you done in using robotics to setup structures or facilities in advance of human arrival?

During the 2013 "Surface Telerobotics" test, we had astronauts on the Space Station remotely operate a rover to perform a simulated lunar mission: survey a site, partly deploy a radio telescope, and inspect the deployed components.

Question 1: I noticed that all rovers have wheels instead of other means of getting around. Why is that and what are some limitations that wheels have?

Wheels are highly reliable, have a high strength-to-weight ratio, and can (with proper suspension) negotiate a wide range of terrain. Wheels, however, have difficulty with rough, steep, or uneven terrain, as well as when face with high obstacle density.

Question 2: Say we want to explore other planets using rovers. How are typical landing sites selected, and do criteria change depending on the types of rovers you send?

Site selection involves considering many factors, including scientific interest, ease of safe landing, topography, illumination, etc. Rover capability, particularly traverse limitations (range, maximum slope, maximum step obstacle clearance, etc.), often has a major impact.

Question 1: What was the most surprising thing to you, that came from the Real Time Human-Robotic Collaboration test on the ISS?

We were pleasantly surprised that all the astronauts were able to gain high proficiency with rover operations after only a short amount of training.

Question 2: Because of the different time scales that humans and current robots work on, is it better to focus on just robotic missions that occur before and after human missions, for now?

Yes, that is what we contend.

Question 1: Do you think we will ever reach a point where everything that needs to be done on these missions can be done with only robots or will there always be that aspect of human presence needed?

I think that there will always be a need for human involvement in planetary exploration. The activities performed by both humans and robots will likely continue to evolve over time.

Question 2: I believe you mentioned that what the people who guide the robots are doing is "high-level guidance" and not "low-level control". Why is this such an important distinction to make?

Low-level control, such as "joysticking", is fatiguing and usually requires high-bandwidth and low-latency. In addition, performance is highly correlated to the operator's experience, skill, training, health, etc. With "high-level guidance" (supervisory control), the variation in performance due to the operator is significantly reduced.

Question 1: What type of scenarios would an astonaut have to take control of the robot?

Whenever the robot has problems, or difficulty performing some aspect of a task.

Question 2: Are there any plans to send astronauts back to the moon or would the scouting robots be used more for a mission to mars?

There are no new human missions currently planned for the lunar surface. However, this may change over the next few months.

Question 1: Why don't we use robots before, during, and after crews?

At present, the only human space missions taking place are to the Space Station. Once we start developing human missions to the Moon or Mars, I fully expect to see robots used before, during, and after these missions.

Question 2: Would we be using robots on the moon for simply practicing for when we go to other planets or would we be doing actual science with them?

We would likely be using the robots to perform scientific field work on the Moon.

Question 1: In the Robot Mission (June 2009), what is the difference between laser scanner and the actual camera taking the pictures?

The "laser scanner" is a surveying lidar, which provides 3D measurements. The cameras only provide 2D images.

Question 2: In the Crew Mission (September 2009), what kind of tools or equipment does the rover carry?

The types of tools that were used during the Apollo mission: rock hammer, shovel, sample collection bags. In addition, the vehicle had a GigaPan panoramic imager mounted on a mast, which allowed our simulated mission control team to remotely observe the traverse stations.

Question 1: Can you discuss real-world examples of advantages and pitfalls experienced during your field tests by allowing robots to have more autonomy?

A significant advantage of autonomy is that the robot can continue to operate even when communications are poor (not available, low bandwidth, high latency, etc). For planetary missions, maximizing "uptime" is essential given that all equipment will eventually fail.

A significant disadvantage of autonomy is that it can be difficult to predict when limitations will be reached, or when failure is likely to occur.

Question 2: Are there practical applications of human-robot teaming in the near future outside of the Moon and Mars?

Yes, in fact, the Space Station provides ample opportunity for human-robot teaming. Robots can assist astronauts to perform inspection, maintenance, surveys, etc. both inside the Space Station and outside.

Question 1: Why is there a need to have astronauts orbiting the body where robots are deployed instead of transmitting and operating from Earth?

This is a topic of active discussion and debate. There are some who contend that having humans "in proximity" (particularly in terms of communications) is advantageous because humans can more easily operate robots with low-latency and can more easily using robots as "avatars" to explore.

Question 2: Do you program the robots, that determine their own route between points, to never back-track the same topography in order to optimize coverage?

We usually emphasize traversability of routes vs. coverage optimization.

Question 1: How are you incorporating human-centered machine learning into your human-robotic interactions both remotely and in tandem missions?

We are not currently incorporating machine learning.

Question 2: How might this sort of interaction between humans and robots expand to planetary missions that are strictly robotic?

Yes, definitely. Human-robot teaming does not require that both be co-located.

Question 1: You talked a lot about lunar missions. Are there any Mars missions planned that would use human/robotic interaction?

Everything that I described for the Moon would also be applicable to Mars. That said, NASA does not currently have any near-terms plans for human missions to Mars.

Question 2: Is there any plan to test autonomy on future Mars or other planetary rovers?

The Curiosity rover already has some autonomy capabilities. For example, the "AutoNav" system enables the rover to make its own decisions on how to drive from point to point while avoiding obstacles.

Question 1: What is the state of the art of robot mobility designs? i.e., the design best at overcoming obstacles while still protecting onboard equipment

NASA is actively studying a wide range of robot mobility designs: wheeled rovers with active suspension, wheeled rovers with actively deformable wheels, dynamic tensegrity robots (such as the "SuperBall" at NASA Ames), "wheel on limb" walking/rolling robots, humanoid robots, etc. No single design is best for all environments or all missions.

Question 2: When do you predict robots with machine-learning capabilities will be used in missions?

Great question! I wish I knew…

Question 1: What kind of unusual anomalies could develop with human-robot collaboration?

Larry Bond once wrote "There's an old saying that collaborations succeed only if each partner does 60% of the work. It's funny and a little true, but even if it's entirely true, it's still a lot better than doing 100% of the work." I think one unusual anomaly would be that both humans and robots end up working less by collaborating!

Question 2: What kind of tools will robots use to make decisions on what kind of observations are notable to be made?

Very likely the same things that humans use: instruments and prior knowledge. However, the way (i.e, algorithms) in which robots reach decisions will likely be very different than humans.

Question 1: What are the key instruments needed for robots that are scouting?

Cameras, lidars, ground penetrating radar, penetrometers, etc. It all depends on what type of scouting is being performed.

Question 2: What are the major difficulties of continuing a human mission with robotic exploration after humans have left?

In general, robots cannot do the "same" things that humans can. Thus, terrain that is easy for a human to walk or climb over, might be very difficult (or impossible) for a robot. So, it is important when planning "follow-up" work for robots that consideration be given for the capabilities and limitations of the robots.

Question 1: You mentioned that robots can be sent to a site before humans arrive. Does NASA have plans to make robots capable of building some sort of infrastructure that can sustain us humans or would we have to build it ourselves?

I believe it is very likely that we will eventually send “pre-cursor” robot missions ahead of human missions to do exactly that. However, when this will occur is not clear.

Question 2: It may be some time before it happens, but how likely would it be to send humans to assist in mining an asteroid after sending robots for reconnaissance?

I think that depends on how difficult it would be to send humans to the same asteroid. If it takes several years for a robotic spacecraft to travel to an asteroid, we likely would not be able to send humans there (due to the problem of keeping humans alive for extended periods in space).

Question 1: As a ratio between robotic device autonomy and human user input, what percentage would you say current mission capabilities are at: 1%, 5%, or are we talking about fractions of a percent?

It depends on the specific task and the mission environment. On Mars, the Curiousity rover is fully capable of navigating from point to point by itself (i.e., without any human input). However, it does this very slowly (due to limited on-board computing). Thus, NASA generally does not operate the rover in this manner.

Question 2: What sort of timescale (how many more years) are we looking at in regards to having robotic missions that are ~80% autonomous of human-user input? I would define this as the craft/device could do short-timescale mission planning, navigation w/obstacle detection and route surveying, determining areas of scientific interest and collecting samples while monitoring time and resources. Human input would include initial site placement, large-timescale mission objectives, unforeseen maintenance needs, etc..

Developing these capabilities on Earth likely will require another 15-20 years. After that, it may take an addition 10-15 years to integrate the capabilities into a mission.

Question 1: It appears that your work has focused primarily on human-robot teaming efforts for land surface based operations. Are there any concepts being developed at Ames that might explore human-robot teaming efforts to explore aquatic-based environments?

We used to work with Remotely Operated Vehicles (ROVs) in places like Antarctica, and we also used to work with robot boats in Chile, but we currently do not have any active projects.

Question 2: How might you envision future generations, (or evolution in general), of the K-10 robot series at Ames, in terms of advances in machine learning programming and advances in robot structural design?

I would really like to see the successors of K10 be able to carry out fully autonomous exploration missions in a variety of environments, both surface and subsurface (e.g., lava tubes) on the Moon or Mars. A key part of this will be to develop better on-board (radiation hard) computing, better sensors (particularly navigation), and autonomy software.