Kaylen (00:14):

Terry Fong is NASA's senior scientist for autonomous systems and the deputy rover lead for NASA's VIPER, lunar rover mission. He's also chief roboticist and former director of the Intelligent Robotics Group at the Ames Research Center. Terry previously led development for the Astrobee free-flying robot, which was installed on the space station in 2019. Terry has published more than 150 papers in space and field robotics, human robot interaction, virtual reality and planet mapping. Terry received his BS and Ms in aeronautics and astronautics from MIT and his PhD in robotics from Carnegie Mellon University. Today, Terry Fong will be talking about the autonomous systems and robotics used during space exploration.

Terry Fong (01:07):

It's my great pleasure to speak today. As Kaylen said, I am an Illinois native, having spent my entire youth just pretty close to NIU, and it's actually really great to be able to speak and share with you some of what I do today. So first off, just a little bit more about me. I have two main jobs at NASA. One is I work at NASA headquarters in the Space Technology Mission Directorate, and that's what I'm going to start by talking about is some of the work that we are doing to plan for the development of new technologies for exploration.

Then the second half, actually, it was really just great timing, we totally did not coordinate this in any way, shape or form, is that I am the deputy rover lead for a mission that NASA is currently developing called VIPER. VIPER is intended to go to the Moon in about three years, supposed to launch at the end of 2023 to actually go prospect for some of these resources that we might try to mine in the future. So Leslie's talk was actually a perfect lead in to what I will end up talking about today, which is a bit about the VIPER mission.

But to start with, let's talk about space technologies. Those of you who were listening in, I think three weeks ago, heard a talk from Mark McDonald, from NASA headquarters who talked about the way that we think about space technology. In particular, right now we are focused on developing technology in four primary areas. And these are under these themes of go, land, live and explore. Where go of course is how you get from point A to point B, landing is how you land, especially on different planets and living has to do with anything that helps sustain a system or humans.

Then today, what I'm going to talk to you about is this last one, explore, which is anything and everything needed to make these transformative missions and discoveries. In particular, if we're thinking about exploration, there are technologies in several areas that NASA has been doing development of for many years, and is now focused on trying to extend and go beyond what we've done to date. For example, technology in the area of high performance computing. We know today that every single thing that we do as humans, requires high performance computing.

Whether this is for processing data onboard or robot, or for actually collecting information that is sent down for analysis for use by scientists. That's a big part of what NASA focuses on. Another thing which is near and dear to my heart, has to do with everything involving robotics. We use robotics to extend our reach in the solar system. And hopefully beyond. A lot of that has to do with our ability right now to reach places that we can't send humans. So we're trying to develop robotic technology to really get to those places, which we just cannot at the moment send people. S we use these robots as our proxies for exploring different planetary environments and frankly, a whole host of places in the solar system.

There are other things we're doing of course, closer to earth, and that has to do with things like satellites. We depend upon satellites obviously today for communications. A lot of the way that we send

information back and forth around the world would not be possible without satellites. One of the questions of course is how can do better to launch these, to maintain these, just to make sure that they can operate and perform the job that we need them to perform? Along the lines of that is been an interesting small push area for a number of years within NASA.

And that's the creation of what we call a small spacecraft. So these are typically satellites that are much smaller than the traditional ones. They might be the size of frankly a half gallon carton of milk, as a CubeSat. And these are things that a lot of universities in particular have been developing and testing. For us, I think it's interesting to see what these smaller, cheaper systems can do than the past could only be done by very large, very expensive spacecraft. So, let me start by just telling a little bit more detail about a couple of these areas, and then we'll dive into the primary focus, which is robotics.

In terms of satellite servicing, traditionally, when space agencies or companies launch satellites into orbit, they are one-time things. You basically launch it, you deploy it, you might open up a solar array, communications, antenna, and then that's it. They operate until they reach the end of their lifetime, which is governed not by how well they're functioning, but by believe it or not really the amount of fuel they carry on board, because of course in space, there are some disturbances and you need to basically use fuel to help reposition and maintain position.

So one of the big challenges that we've seen in space is the question of, well, if we have a satellite that still has useful life into it, how do we keep it going? Can we reposition it? Can we refuel that? If we have new technology, like a new transmitter that gives us higher bandwidth, how do we do that? How do we install that? So one of the things that NASA and other agencies have been working on in recent years is this whole idea of doing satellite servicing. That you would basically send up a robot and do on-orbit maintenance, on-orbit repair.

So some of the work that is going on right now with NASA are missions focused on this idea where on the next couple of years, we actually expect to see some of these missions that will fly up to existing satellites and basically do servicing, while they're in space. Now, of course, servicing is only part of that. Of course, that means that you can take care of things that you've already managed to deploy. But, what if you want to do more than that? What if you want to for example, build things that are larger than you can launch? Well, that turns into this other area, which is on-orbit assembly or on-orbit manufacturing.

One of the interesting projects that we're doing is one called Archinaut, let's see if this video will play here. Is this idea that we can try to do 3D printing in space. So this is a concept that comes from a company called, Made In Space, very appropriate name. Where they will basically 3D print this long beam that is extending out a solar array. The idea being that you can create a solar array for power that is much, much larger than you could try to fit in to a launch vehicle, into a rocket. This has a lot of great implications because this means if you can do this, if you can build this beam and extrude this beam, that you can create larger structures in space.

It's not just solar arrays, you can create observatories, you can create larger structures, and then be able to take advantage of all these interesting new shapes that are at large scales, that in the past we've just not been able to be able to launch into space. Now that's on the large side. Again, really enabled by the idea that you can manufacture things in space. On the other extreme is this whole revolution that has taken place over the past ... maybe 20 years or so, in terms of small spacecraft.

Now, traditionally we've launched satellites in orbit that are large, they're fairly custom, they're very expensive. They carry large instruments, and that has been totally fine for a lot of things that we've done, but they of course do cost a lot and it takes a long time to actually build and then launch them. Over the past 20 years has been this whole emergence of small spacecraft and especially ones that are

in the area of CubeSats. So these very small systems that we can build cheaply and we can launch them, they may only exist in space for a few hours or a few days, but they're small, they're cheap and we can just keep launching them over and over again.

So NASA has invested very heavily over the past several decades, in technologies that can enable these small spacecraft. Over the next couple years we're launching a number of these things to try to demonstrate how you could for example, use multiple small spacecraft together. So the idea that instead of just a single satellite, you might have cooperating multiple satellites just like you might have a sports team where all the different players are working together. And we've also been trying to look at how we could take these very small systems, which you would think, well, if it's only about this big, how could it do anything?

But actually carry out useful, deeper emissions. Recently, there was a pair of these CubeSats that went to make measurements above Mars. We have a mission coming up in 2021 called Lunar Flashlight, where we're going to be measuring the surface ice on the Moon using a small scale, basically a CubeSat-like system here. So, we talked a little bit about the idea that you could surface satellites in space and the idea that you could actually use smaller spacecraft to do things, but then we get to the area that really is near and dear to my heart, which is space robotics.

And this is all about how do we use robots to extend and do things in space beyond what humans currently can do? There are a lot of reasons to think about space robotics, and you can use these for exploration activities, such as us helping to do assembly, maintenance, things around human spacecraft. And we clearly have done that on the space station, and before that, on the space shuttle, where we use these large robot arms to actually do these activities in space. Of course, robots are used very widely for performing science. All of our deep space planetary missions are enabled by these planetary rovers.

I'm sure a lot of you just like us at NASA followed the landing of the Perseverance rover recently. Perseverance is just the latest in a long line of rovers that we've been using to explore Mars and to acquire primary scientific measurements of different things on the surface of the planet, and there's also a lot of work that we've been doing in terms of research and development. Onboard places like the International Space Station, robots like Robonaut 2 which is a humanoid robot that we had on the space station for several years, and currently the Astrobee robots.

If you saw in the news, the vice president recently talked with two of the astronauts on the space stations and they demonstrated as part of what they're doing, how they're working with these small scale robots called Astrobee. And I'll talk about that a little bit more in a minute here. In particular, I think it's interesting to look at how we can conceive of using robots to help take care of human spacecraft. One of the things that's not widely known, is that being on board the space station, isn't all, "Hey, let's go into space and do research and we'll do things that could be done only in say microgravity."

but rather, what happens is the astronauts spend a tremendous amount of their time taking care of their living environment. Because it's not like you can say, "Hey, I'll have the housekeepers come by and take care of the space station." The astronauts have to do everything themselves. And that includes things as menial as wiping down surfaces. Because, we as humans tend to shed a lot of skin cells and it leads to becoming a biologic hazard. And so what we actually require the astronauts to do is to basically take hand wipes and they have to wipe down handrails.

Of course, this is not something that anybody looks forward to doing. And so, one of the questions is, can we use other things such as robots to take care of these basic spacecraft care, taking kinds of functions, these kinds of activities that really are very repetitive, very menial, and frankly should

not be done by humans. And so for the past few years, we've been looking at how robots can do that. As I mentioned, Robonaut 2 was previously on the space station and we looked at how we could use a humanoid robot to do the kinds of dextrous manipulation work that we as humans do with our arms and our hands.

We've also had free-flying robots, such as the SPHERES free-flyers which were originally inspired by Star Wars, the Jedi lights, they were a trainer. If you remember that, and then more recently, these Astrobee robots, which are free-flying robots that we use for conducting experiments inside the space station. Astrobee in particular is an interesting robot because it's designed to be upgradeable. It has these three payload base that we can install new kinds of equipment, new sensors, new mechanisms.

It runs open-source software. All the software inside is open source, which means people can download it and extend it and they can work with it. We've had great fun over the past couple years, really just getting these robots installed and operational and this video here is going to show you, this was back in 2019, where Anne McClain had fun ... it was an early Christmas for her, this was actually back in April, unboxing a new robot to work with on the space station. This was the Bumble robot. You might guess that is, because they're called Astrobees, they're actually ... all have these interesting nicknames.

We have Bumblebee and Honeybee ... and Killerbee as well. This was the first wake up. The first time we turned on Astrobee on the space station here. The robot itself has three processors inside, there's smartphone class processors. Just like what you'd find in your favorite smartphone. It uses these controllable fans to push itself around. And so part of the early checkout work was to go through and help calibrate all the sensors needed to operate this, including what we would consider to be the robot torture session, where you spin the robot around to help calibrate its internal sensors.

And we then move beyond that to testing out how the robot could fly around inside of the space station. So you see here, Astrobee just navigating, flying through a portion of the space station. We've also designed it to just your favorite robot vacuuming cleaner, to be able to go back and dock and charge itself. And so there is a docking station on board the space station that supports two of these. We actually have three Astrobees on board right now. But they're being used for a variety of activities.

Thanks for the applause there. Anyway, let's move on and talk a little bit more about robots. Of course, for many years now, we've used robots to explore Mars. We had a pair of robots for many years called the Mars Exploration Rovers. This was Spirit and Opportunity. And then they were succeeded by the Curiosity rover, which landed back in 2015. Of course, this year the excitement is about the Perseverance robot and the Ingenuity helicopter that it carries. Ingenuity is actually scheduled to fly within the next couple weeks or so.

It'll be the first robotic flying vehicle on another planet. And we're very excited to actually have it fly. It does actually carry if you didn't pick this up on the news, it actually carries a fragment from the Wright Brother's aircraft on board there. So we have a little bit of material that flew on earth, and now it's going to fly on Mars. But of course, we use these rovers to take primary measurements for scientific purposes on other planets. We've done a lot of work on Mars. We've had a whole series of rovers from Sojourner to Spirit to Opportunity to Curiosity, and now Perseverance.

NASA in looking in the future is now turning its attention towards the Moon as well. I mentioned the start that I'm working on this mission called VIPER. VIPER like everything at NASA is an acronym. It stands for Volatiles Investigating Polar Exploration Rover, but you can think of this as basically the way that we will understand what kind of materials are available to mine on the Moon. The Moon of course has a variety of different materials. As Leslie talked about, one thing that we're really interested in though is the volatiles, these are various forms of hydrogen, including things like water ice.

Because of course hydrogen is a very important element for making everything from fuel to just helping support astronauts. One of the things that we're trying to do is to figure out how much material is located in the Moon and where it is and how is it accessible and all that. So the VIPER mission is intended to do that.

Speaker 3 (17:05):

We know from decades of study that the Moon has water, but where and how much? In 2023, a robotic rover will explore the Moon surface in search of water ice. NASA's VIPER Moon rover will perform the first resource mapping mission on another world, using advanced instruments and tools to determine the location and concentration of water on the Moon.

Speaker 4 (17:27):

To send VIPER to the Moon, we're leveraging industry as part of our commercial lunar payload services program, a program designed to send science instruments and technology payloads to the surface of the room. VIPER represents a very different development paradigm. We are developing each instrument for launch on a CLPS ahead of VIPER, totally flipping on its head how we normally do this. This is truly creative. An industry partner will launch VIPER to the Moon's south pole. This is a place where no human or rover has ever been before.

Speaker 3 (18:02):

The Rover survey will provide scientists with the most detailed view of the Moon's water to date, and point to spots where water could be harvested by future astronauts.

Speaker 5 (18:13):

VIPER will be the first resource-mapping mission on the surface of another celestial body. It represents a new kind of mission for NASA in which the objectives of advancing science and human exploration are closer than ever. The measurements that VIPER's instruments will make, can help us understand the source and distribution of the water and other volatiles on the Moon, giving us insight into the evolution of the Moon and the Earth-Moon system. The Moon's water is also a precious resource that could be extracted to support human exploration of the Moon and beyond.

Terry Fong (18:48):

So, one of the interesting things about VIPER of course, is that it's going to the Moon rather than Mars, which means it's very close ... in terms of distance, but even closer in terms of communications time. One of the things that we've always been limited when we operate robots on Mars is the fact that it takes a long time, 20 to 40 minutes for communication signals to go round trip from the earth to Mars and back, which means if we want to control a robot on Mars, we have to give it commands, and then it carries those commands out. And then we wait to find out what happens. That's not the case in the Moon of course.

The Moon is much, much closer, and if you look at the roundtrip communications, the amount of time it takes to send a signal from mission control to the robot and come back and go through all the various ground stations, it's only a matter of seconds. One of the things that we are now trying to do for the VIPER mission is look at how do we interactively control the robot? So let me just show you here. This is a simulation of the way we will be operating VIPER in a couple years. On the left here, you see a 3D interface and someone's just dragging out a little target that says where to drive the robot to.

On the right side is a 3D simulation of the Moon, including a rover on the Moon. And you can see that the commanding is fairly interactive, that you would send a command on the left there saying drive from the current location to a target point. And then a few seconds later, the robot will operate. And it's very interactive. Of course, we'll have continuous stream of information that comes from the robot back to the earth, and that allows us to monitor what's going on in essentially real-time. VIPER for us is a very different mission as well. It's going to places that are very, very dark.

The areas that we target are called permanently shadowed regions. These are places that are cold enough to actually maintain, we believe subsurface water ice, and it's going to be a very exciting, interesting mission when it launches in, like I said, in 2023. But with that, why don't I just go ahead and stop and ... I'm happy to take questions, feel free to put questions in the chat, or if you'd like to unmute and speak up, I'd be happy to answer your questions that way too.

Kaylen (21:02):

Yes. Thank you very much Dr. Terry Fong for delivering that speech. If anyone does have questions like you said, you should be able to unmute yourselves now.

Heidi (21:12):

Dr. Fong this is Heidi from Illinois Space Grant Consortium. Could you talk a little bit more about the interface that they're using? That's quite an advance from what I've seen from years ago when I was studying.

Terry Fong (21:25):

Yeah. It's a very interesting thing that of course, everybody who's working on VIPER grew up in an era of video games. So of course, we think of commanding and operating these robots not in terms of, well, let me try to send out a little command that's in some very specific text type interface. We really think more graphically, more interactively, and we want to use interfaces that allow us to reason about the 3D world, not just because we are trying to control a robot in the 3D world, but because we want to represent all the information that we have about the environment, about the rover's location, the path it takes.

So we try to use the 3D interfaces as a way of collecting all this information into a really nice focused way. Again, like I said, a lot of the inspiration does come from, frankly the video games that we've played over the years.

Heidi (22:25):

Thank you. Yeah. So, computer scientists definitely have a large part to play in these programs for development and things.

Terry Fong (22:36):

Oh, absolutely. Sometimes I'm asked by people who are interested in robotics, what should I study? And I tell them, "Well, you should learn everything possible about computer science, because every robot that's out there today, requires software." And it's not to say that the electronics and the mechanics are not important, they are as well. But the reality is that so much of what robots are able to do, especially as they become more capable, is driven by software.

Heidi (23:06):

Thank you. Yes. It's really interesting to see how much those have changed over the years.

Danielle (23:12):

Hi, my name is Danielle [inaudible 00:23:14] NIU. I do have a question. I don't know if you covered this earlier, but I was just wondering, so if robots were sent up into space and if there was a robot failure, if you couldn't like ... would there be data loss? Is there a way to retrieve any of that?

Terry Fong (23:37):

That's a great question. Thanks for that Danielle. We actually worry about the robots breaking all the time, and this is not even a complete loss of a robot. Even if you lose a wheel, if a wheel gets stuck and the robot then can't drive, that can be a big problem, because that means that the data that we want to acquire, the science that we might want to carry out, also becomes either difficult or impossible. So a lot of what we do when we build these systems for space, these space robotic systems ... we do a tremendous amount of testing, and we try to plan ahead for, "Well, if this breaks, is there a workaround?"

Or is there something that we can do because maybe we have a redundant system? It's something that I think ... until we get to a place where we can also send robots to fix other robots, or we can send humans and robots together and they can support one another, is always going to be a challenge. But it is something that we do think about a lot.

Heidi (24:38):

Amanda has a question. It seems like there have been more robotic research on Mars than on the Moon. Is that the case? And why is that?

Terry Fong (24:46):

So that's a complicated question. It is true, we've had a lot more exploration on Mars robotically for a couple reasons. I think one is that, we have not been able to send humans to Mars and it is of course, the planet and the solar system that is most Earth-like in terms of size and in terms of the question of whether or not life could have been possible on Mars or basically any place other than the earth. And so I think from a science point of view, there's been a huge focus on using robots to learn more about Mars. It's also the case too that for many years, we humans thought, "Oh, we know everything there is to know about the Moon."

We had Apollo, we learned a lot about it. It seemed like a dead ... dull place. And it's only in recent years that we've discovered, "Oh, well, actually the Moon has a lot more." It's interesting. There's a lot more still not known about it. The fact that we might be able to mine for resources has opened up this whole new discussion of, "Well, we should actually go back to learn more about the Moon." But for those reasons, the focus I think is starting to shift away from Mars to other places, including the Moon.

Heidi (25:58):

Thank you.