About Research

Space Environment System
Professor MACHIDA, Kazuo

Robotization and Artificial Intelligence Toward Realization of a Space Environment Preservation System

IInterviewer: Takashi Mikuriya, professor

——Professor Machida, I understand you graduated from the Department of Precision Engineering, Faculty of Engineering at Hokkaido University. Were you interested from the beginning in pursuing research on outer space?

Well, no. It was sheer chance, actually. I originally wanted to get into the National Institute of Radiological Sciences, but there were no slots open that year. So I went into the Electrotechnical Laboratory instead, and because of my background in precision engineering I conducted research on adaptive control for precision processing of electronic materials. I later took up somebody's suggestion that I start "doing space", and that's when I made the transition.

——How did you feel at the time about "doing space"?

There are always dreams and hopes in space, of course, but it was also a time when Japan was just beginning to work on space development with its own technology. There weren't any established systems in place, and I started research on space development because I saw an opportunity in that situation to do some innovative work. My theme at the time was "ion engines". It's the kind of thing you see in science fiction - turn propellant into plasma, extract ions with high voltage, accelerate them to get thrust. Seeing a jet of blue flash when it fired up in the vacuum chamber simulating space environment, I honestly got excited visualizing something like that flying through space.

——So the"allure of the blue flash"captured your imagination?

Yes, it did. I kept researching on it for about fifteen years. We were able to take it from absolute fundamentals to flight demonstrations in space, and eventually prove its practical applicability.

——Is fifteen years a short time-frame in the world of science and technology?

It is very short in space research, since you have to do flight demonstrations. When I sat down to think about what to do next after those fifteen years of research, I imagined what outer space would be like in twenty years and tried to come up with an idea for technological research that would be needed during that time span. The space shuttle had just gone operational at the time, and the infrastructure was beginning to develop in space. I started look into robotics based on the thought that we would need services, construction, and maintenance for the infrastructure.

Many new component technologies are required for robots that work in the extreme environment like in outer space, and it felt like a worthwhile technological endeavor to make such robots. I considered it a challenging theme from the standpoint both of component technologies and of integrated technologies, because those component technologies have to come together in some way as systems to function independently. This was why I went into the field, and also because I felt that putting robots and space together could give people dreams and hopes even more (laughter). Looking ahead, in my opinion the space development is going to continue as a collaborative effort between robots and human beings.

——Are robots that work in space greatly different from the ones that work here on Earth?

I'd say it's about fifty-fifty between similarities and differences. Robots that work in orbit, for example, can be big robots like cranes, ones for precise works, or free flying robots that fly to their jobs. The crane type is built to be able to walk with its arms like an inchworm in zero gravity; the flying type is sort of a hybrid between a robot and a satellite. So there are some morphological differences. There can also be considerable internal differences, even in robots that might otherwise look quite conventional. For instance we cover them with a white insulation called beta cloth, or use solid lubricants instead of ordinary oil to lubricate parts since oil will evaporate immediately out in space. One has to take various measures to enhance the reliability and safety of robots that work out in the harsh environment of space, and drastically different materials are used on the inside. Because it works in zero gravity, a robot that weighs only 100 kilograms can handle objects weighing ten tons or a hundred tons; that's something you couldn't do here on Earth, isn't it? Control methods are different, too, because there aren't any stable footholds. They can take a spacewalk, like the astronauts. Since their own weight isn't a hindrance, you can make robots that could modify themselves by adding another robot on the end of a robot arm or creating branched elements, something you wouldn't see on Earth.

――When robots like that go into space, are they all remotely controlled from the ground?

No, actually it doesn't work that way. If you try to teleoperate through inter-satellite communication networks, for instance, you get communication time lags that make it very difficult to control by force feedback. There are also problems with visualization and visibility, as when camera images are degraded by things like solar shadows, obstructing objects, or limits on communication capacity. Under those conditions, you run into a lot of practical difficulties if you try to do everything by remote control.

――So, do you build them to work autonomously in space?

It's not realistic to make everything autonomous, so you might say they're partially autonomous. How autonomous you can make them depends on the nature of the mission. You can probably get things done autonomously if the mission is simple enough, but that is difficult to do on a complicated mission. You have to augment with teleoperation what you can't accomplish through autonomous operation. What's important is to get the teleoperation and the autonomous operation to cooperate, which means getting humans and robots to cooperate and work efficiently by coordinating their intelligence and skills; we've been doing the research on telerobotics and space demonstrations to find a way to realize that.

"Space Environment Preservation" and "Recyclable Space System" Mainstays of Future Space Development

――You joined RCAST in 2002. Is your current mission a departure from the extension of your previous research?

I wanted to study space robots from the very basics all the way to space experiments, and beyond - linking them to actual utilization in space. Technology for development of robots has reached a respectable level, but technology for their utilization is lagging behind. I want to package my research in conjunction with utilization technologies, because space robots are important tools for space activities and their utilization is indispensable. My ongoing research since joining RCAST has focused on two themes: utilization of robots for space environment preservation, and the recyclable/reconfigurable space system.

――What kind of activity is "space environment preservation?"

Outer space is littered with space debris, detritus from the multitude of artificial objects that mankind has launched. This space debris is whirling around at high speed. The big pieces alone number nearly ten thousand, and we are still adding about three hundred pieces a year. If things keep up at this rate, there is likely to be chain collisions of debris and if the condition continues to worsen there is a concern that it will jeopardize future space activities. Thinking there ought to be a way to use robots to achieve coexistence between the continually growing number of space satellites and the protection of the space environment, I came up with the concept of "space environment preservation systems" and am currently carrying on research in that area.

――How do those robots work?

The basic concept is to care for satellite groups throughout their lives by space robots and not to produce debris. Specifically, I am researching on the robotization of orbit maintenance vehicle, which can be launched with multiple satellite kits, assemble the satellites in orbit, and position them in designated orbits. The robot also inspects satellites periodically and captures them as necessary for diagnosis and maintenance to extend their life spans. Finally, at the end of the mission the robot retrieves, disassembles, and deorbits satellites. This is the lifecycle of the system that I am working on. A nice feature of this research is that it offers a chance to develop nearly all of the component technologies necessary for future services in orbit.

―― Was it not anticipated at the outset of space development that a lot of "debris" would be generated in outer space?

Well, there was more or less a tendency back then to look at a lot of things as being disposable. Beyond that, though, the fact was that it would have cost a lot of money to manage every part that separated and drifted off after launch or to recover every satellite that failed. Nevertheless, the problem is now coming into close focus because of recent accidents and reported near-misses involving space debris.

If we continue to leave things the way they are, for instance when someday space tourism really gets going, there could be some very dangerous situations. The average speed of a piece of space debris is ten kilometers per second. For example, there are tiny particles of metal embedded in the paint coating on equipment in space to improve thermal conductivity. If some of this coating comes off and one of these half-millimeter particles hits a window on the space shuttle, it can cause a crack; so there's a high probability th at it would also penetrate the space suit on a person engaging in extravehicular activity.

——It's a task for humanity, just like trash pollution in the oceans and the industrial waste problem, isn't it? Is research on space environment preservation something that's going on only in Japan, or are you collaborating internationally?

Right now I'm working on it alone, but there's global awareness of the problem and research is now going on in places like Europe and the United States that includes satellite rescue with robots, so I imagine there will be increasing collaboration in the future.

——We've been talking about the space environment so far, but could you also say something about the subject of "recyclable space systems"?

This is an extension on the theme of "space environment preservation". People are looking forward to the realization of a recycling society based on sustainable development here on earth, too, but the extremely high costs of transportation in space make it even more critical that we evolve from the "disposable" model toward the "recyclable/reconfigurable" one, and I think robots can play a significant role in that process.

As an example of the recyclable/reconfigurable system, I've proposed a concept that I call cellular satellites. A cellular satellite would be one made up of discrete cells or elements that can be assembled in different ways as required for the satellite's function. A failed cell could be replaced and recycled. Earth observation satellites, for instance, have a lot of problems with maneuverability, flexibility, and operating life. With a cellular satellite, you could reassemble observation systems on demand in a timely way. Since failed cells can be replaced and recycled, I'd like to think that this idea would make maneuverable and sustainable earth observation possible. With that in mind, I'm conducting research into the cells' mechanisms and the technologies for reassembly of cells by robots.

The Next Phase: From Research Centered on Hardware Technology Toward Applications of Intelligent Information Processing Technology

——The environment in outer space is understood to be totally different from that here on earth. Are experiments performed primarily through computer simulations, or is there specialized experimental apparatus?

I'd say computer simulation is essential, of course, but interaction with the external environment is very important with robots and the issue is to verify how they respond to and work within that environment. The typical process therefore advances from computer simulation to experiments with apparatus using terrestrial models, similar to the actual mechanisms, in partially zero gravity conditions. There is gravity on earth, however, and many other environmental conditions are different, so it doesn't provide complete proof; it's only after technical demonstration experiments in space that a robot actually becomes operational.

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——What types of specialist currently form the mainstay of space research?

Since we can't very well call them space robots if they won't work in space, space-robot hardware technology has been the main emphasis up until now. Starting with materials and mechanisms capable of withstanding ultra-high vacuum, heat, and radiation, we've been studying motion control technology for robots in zero gravity and remote control technology for robots in ultra-remote environments. The general direction of our work here at RCAST is now shifting toward "intelligence" technologies, such as those required for autonomous execution of precise tasks based on the designer's intentions, even in uncertain conditions, and for diagnosis of equipment status in space by robots. We are now in a phase where the researchers working in the artificial intelligence (AI) are taking center stage.

——Specifically, what kind of research are the students in your laboratory doing?

The mission of our laboratory is to combine space systems engineering, space robotics, and AI, aiming to develop new applications of space technology. Our keywords are "robotization and the application of AI to space systems". We're therefore researching the application of robotics and AI to space in a broad sense, and our students are working with such subjects as diagnosis of satellites through the application of AI technology, localization and map construction of mobile robots, rotating motion estimation of malfunctioning satellites, and active diagnosis of satellites by robots including determination of the causes of malfunction.

——In others words, could we say there is research going on toward even broader ranges of application through robotization and the application of AI?

Yes, we could. Our lecturer, Doctor Yairi, concentrates on the field of AI technology while my own studies are related to space robots. If we divide things up vertically, though, it becomes detrimental to sharing of knowledge and information so we tend to do our teaching in cross-over fashion. We keep it flexible: for instance one of us might see an interesting potential in applying AI to some aspect of robotics, or vice versa.

Exchange of research information with other fields and with industry

promotes the development of "New Ideas"

——RCAST is actively engaged in collaborative research and exchange with other laboratories. Are there other laboratories with which the Machida Laboratory collaborates?

Of the numerous fields of research at RCAST, AI tends to be the one most closely integrated with the work we're doing, so we interact regularly with "Professor Hori's AI laboratory.

——What is your opinion of the research environment at RCAST?

The main mission at the National Institute of Advanced Industrial Science and Technology, where I used to work, has turned into research toward creation of markets for technology since it became an independent administrative institution. A unique merit of RCAST is that the emphasis here is on new concepts, and I think that's very significant.

——Does your group engage in industry-academia collaboration

Nothing is firm at this time, but there has been some interest in applying Japanese robotic technologies in the aerospace industry. We're at the stage now where we're having study group meetings at which industry representatives sit with us to discuss the possibilities.

——What sort of collaborative relationships do you have with other areas of space research, for example the "Nakasuka laboratory?*2"

Well, of course. Our labs are like brothers, after all. When the students in Professor Nakasuka's lab led the development and launch of their "nano-satellite, "CubeSat",*3" students from our lab actively participated

——Have you ever wanted to go into space yourself?

I did, back when I was young (laughter). Now I'd be happy just to see the space robots, which are my alter egos, do their work. Space robots by one definition are an extension of human feelings and actions into outer space; in that sense, they're a part of me.

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Links

RCAST
http://www.rcast.u-tokyo.ac.jp

Machida and Yairi Laboratory
http://www.space.rcast.u-tokyo.ac.jp/index.php?lang=en

*1:Professor Hori's AI laboratory.:
http://www.ai.rcast.u-tokyo.ac.jp/index.html
=Professor Hori's AI laboratory.

*2:Nakasuka laboratory?:
http://www.space.t.u-tokyo.ac.jp/nlab/index-e.html
=Nakasuka laboratory?

*3:nano-satellite, "CubeSat:
http://www.space.t.u-tokyo.ac.jp/cubesat/index-e.html
=nano-satellite, "CubeSat