The latest bulletin features Associate Professor Genya Ishigami, who develops robots exploring in space, volcanoes, and at the sites of natural disasters.

Development of robots for use in extreme environments through research in diverse domains

Including robots which will be of service for natural disasters, agriculture, and logistics chains based on research outcomes

"I want to make robots which help people," says our subject Ishigami-san, who is also developing robots to take on traditionally human tasks, with a particular emphasis on robots conducting surveys and other manual tasks, as well as carrying heavy loads, for use at locations such as the moon, Mars, and the sites of natural disasters, which cannot easily be accessed by humans.

The four basic fields of robot research

Technologies from various disciplines, such as mechanical engineering, electronic engineering, control engineering, and computer science, are encapsulated in a single robot. While most researchers specialize within either of these particular domains, Ishigami-san is engaged in research and development on the diverse aspects which relate to robots.

"I started out doing terramechanics, which is a critical concern when a mobile robot travels on rough terrain," says Ishigami-san. When robots move over the surface of the moon, the terrain surface is loose and non-uniform. A dynamic approach is required to investigate how a wheel would perform on the surface of the moon, scattered as it is with a mixture of sands and rocks.

Having grasped the terrain, the robot dynamics came to attract his attention. He also tackled questions as to how the bodywork of a robot would dynamically move as it attempted to climb over particular obstacles, or whether it would in fact overturn, in the field of multibody dynamics using analyses and computer simulations. This is also used in simulations for probes touching down on the surface of planetary bodies.

Following the body, his interest would turn to robot intelligence. He moved on to the field of "autonomous mobility systems," hoping to find out how to: "Facilitate a robot in making its own decisions on how it should move." This kind of research leads in to autonomous driving, including questions of how to control the wheels of a vehicle and what would be the safest potential routes. Computer science deals with this research topic; however, his knowledge and experience of mechanics has served him well and enabled effective analyses and accurate interpretations of results.

This experience of diverse fields will bear fruit in the development of a "sensor wheel." A sensor wheel is essentially a vehicle wheel equipped with artificial intelligence, similar to sensible skin on the sole of foot. The wheel itself can detect the terrain stiffness, the extent to which it has sunk, as well as the degree of traction beneath the wheel. In addition, the wheel stores test data and improves its traction via machine learning. This has been heralded as an epoch-making outcome in the field of terramechanics.

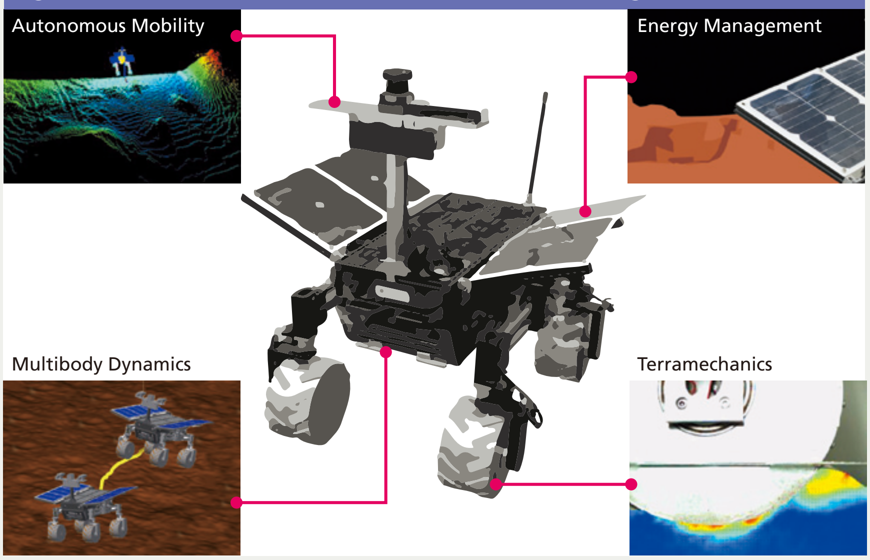
Another critical issue is "energy management." Streamlining movement while limiting a robot's energy consumption are imperatives when operating in extreme environments such as on the surface of the moon. "We use a machine learning algorithm to derive an optimum protocol for power generation control in robots equipped with solar panels, and to plan a robot motion which takes into account of quantity of energy generation, energy consumption, and related factors." Ishigami-san's transdisciplinary research experience has been leveraged to realize locomotion which minimizes energy loss, an undertaking that also requires terramechanics know-how.

Robots making their mark on Mars, the moon, and volcanoes

Ishigami-san is putting these four basic research areas to use in a variety of applied fields. He says that he is currently involved in three space-related projects. The first is a Mars exploration project led by the Japan Aerospace Exploration Agency (JAXA), which plans to take samples of the Martian surface and subsurface (underground) for a variety of proposed scientific surveys, including searching for traces of life. Ishigami-san has been participating in the capacity of system design and specification for a mobile robot equipped with a scientific probe.

The second project is the Martian Moons eXploration (MMX) project, also being led by JAXA, which aims to launch a space probe in the early part of the 2020s. Like Hayabusa, the project is an asteroid sample-return mission, which will bring back samples from the two

Fig. 1: Four basic research fields for robot technologies



Martian satellites of Phobos and Deimos to earth. Ishigami-san tells us that his team is conducting a landing dynamic simulation of the probe.

The third project is for exploration of an underground cavity called a vertical hole, which has been discovered on the moon's surface. There is a large cavern resembling the caves, or *lave tube*, at the base of Mount Fuji directly beneath the moon's surface. There is expectation that this could be exploited as a shelter from solar radiation in future manned exploration on the moon. He also says they are in the process of exploring a miniature robot to be deployed into this vertical hole, and that they have meanwhile conducted a volcano monitoring experiment using a mobile robot on Mounts Mihara and Aso.

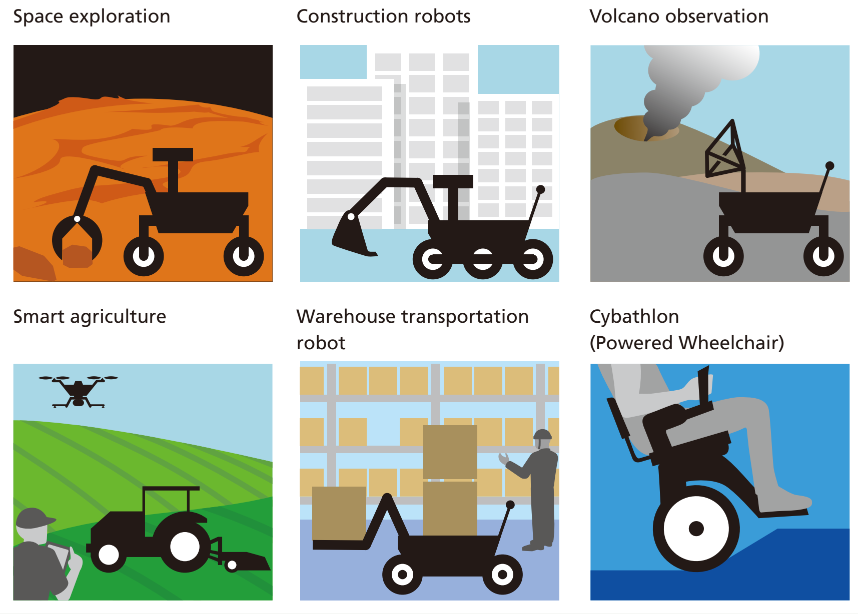
Ishigami's team are presently equipping robots with observational muography devices for surveying cavities inside volcanoes. Muography is a method to observe elementary cosmic particles called muons, which is now in the spotlight as a means to survey volcanoes, and has the potential to facilitate predictions on the size of phreatic eruptions.

Robots to contribute to load reduction at natural disaster sites and during transportation operations

Teleoperation technologies for robots come into their own at locations such as natural disasters sites. Tough Robotics Challenges (TRC) is a project which aims to realize tough robots for deployment at sites of natural disasters that involves in a part of the Cabinet Office's "Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT)." Ishigami-san is responsible for dynamic simulations, including those for removal operations of large volumes of rubble piles at the sites of natural disasters using construction vehicles; lifting the roofs off houses which have collapsed due to earthquakes; and rescue operations for any persons trapped inside such buildings.

He is also working with robots to assist with the harvesting of farm produce and the spreading of pesticides using autonomous mobility systems. For example, robots can detect agricultural workers with a mounted camera and follow behind them at a fixed distance such that the robots transport harvested heavy crops instead of the workers. "I would like to be entrusted with [developing] technologies for stable locomotion over soft and uneven agricultural terrain," says Ishigami-san. It appears that the basic technologies which he has researched can be exploited in this context as well.

Fig. 2: Six applied research fields



All of the research in these six applied fields is supported by research in the four basic research domains.

He says that, "A similar approach could also be used in a distribution warehouse." In a warehouse in which a single operator transports several tons in a single day, the assistance of a robot in picking up and transporting cargo would allow for load reductions and the mitigation of personnel shortages. These kinds of robotization have occasionally been met by protests that "robots will take people's jobs." To this Ishigami-san replies, "Rather than robots completely taking over the work of people, this would ideally be a question of a set-up whereby robots help to realize the coordination and streamlining to allow people to do what people can do and robots to do what robots can do."

Participation in powered wheelchair race at international competition

The development of powered wheelchairs is research to actively assist people further. Ishigami-san mentions that one day he happened to be riding the same train as Professor Kohei Ito, Dean of the Faculty of Science and Technology. The original inducement was being asked by the professor, "Ishigami-san, wouldn't you like to compete in the Cybathlon?" The Powered Wheelchair Race is one event at the Cybathlon, an international competition which aims to put robotics to use for persons with disabilities.

The race involves battling it out against the clock over an obstacle course which includes six obstacles typically encountered by wheelchair users in everyday life. These include negotiating slalom and hills, opening doors using robot arms while seated, and mounting slanting pavements. Ishigami-san made a snap decision to take part and will appear in the Japan leg of the Powered Wheelchair Series set to be held in May 2019.

You cannot leave it at "research for research's sake"

According to Ishigami-san, "What researchers working on robots must keep in mind is that their research should never be for its own sake." Although emphasizing the importance of basic research, he says that it is necessary to keep a keen eye on how this research might actually be used on practical real situation, while his guidance to his lab students also encourages a continual awareness of the background to research.

What brought this home to him most strongly was the Great East Japan Earthquake. When the accident at the Fukushima No. 1 Nuclear Power Plant occurred, the first robot dispatched for exploration was a military robot made in the United States, despite the fact that it would have been possible to immediately dispatch a Japanese-made probe robot. While Japanese technology is actually superior to that of the United States, the many people involved with robots in Japan missed out on the chance to contribute immediately and ended up just watching impatiently from the sidelines.

Ishigami-san's underlying aspiration is to create robots which are useful to and help people at real-world sites.

(Interview and text writer : Yuko Hiratsuka)