By Danielle DeLatte

The Day After Fukushima
Interview with Prof. Satoshi Tadokoro

When you have just been hit by a massive earthquake and tsunami, and your country is facing a serious emergency in one of its biggest nuclear power plants, the last thing you would think about is your research project. But when the earthquake and tsunami hit the Tohoku area on March 11, 2011, Prof. Satoshi Tadokoro realized that the project he was working on with several colleagues at Tohoku University and the Chiba Institute of Technology could be exactly what was needed to address the nuclear crisis at the Fukushima reactor.

Space Safety Magazine recently had the opportunity to sit down with Tadokoro, President of the International Rescue System Institute, professor of Information Science at Tohoku University in Sendai, and primary investigator for the Quince project. Quince is a tread robot that can climb stairs and provide human operators with video and sensor data. Its narrow frame, HD camera, 2D/3D map generation, semi-autonomy, and climbing ability made it uniquely suited to climb the stairs of the five-story Fukushima reactor and carry out a series of scouting missions.

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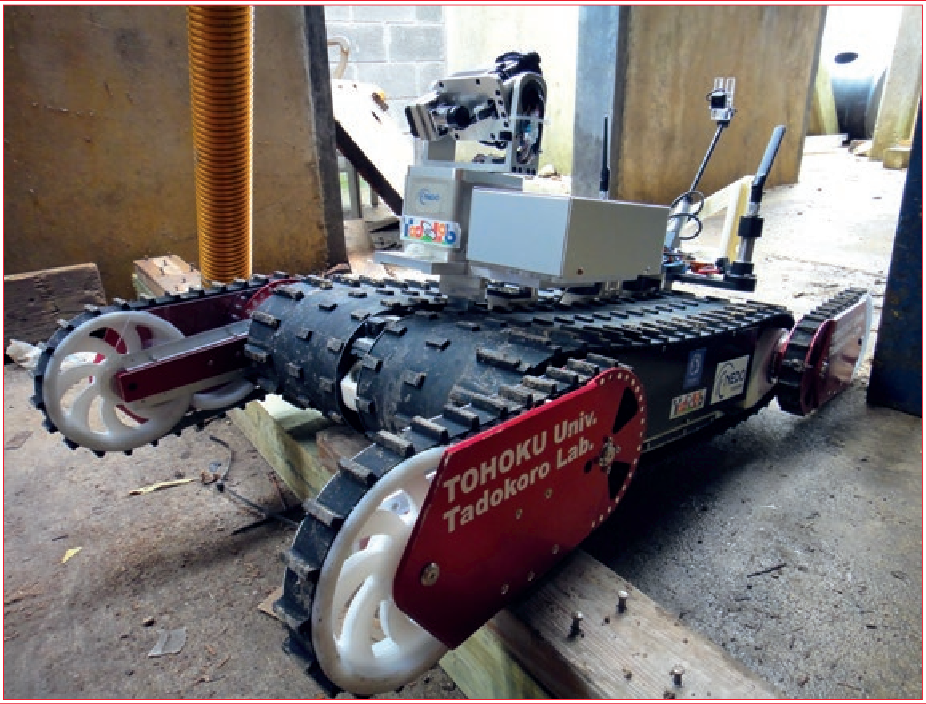
The nuclear power plant of Fukushima right after the earthquake and tsunami that struck Japan on March 11, 2011. – Credits: DigitalGlobe

Born for Mission Impossible

Quince developed from a NEDO (New Energy and Industrial Technology Development Organization) funded project as a joint program between the International Rescue System Institute, that worked on the hardware aspects, and Tohoku University, that handled systems integration, software, and artificial intelligence. The purpose of the project was to develop a robot that could investigate confined spaces possibly containing chemical agents. This research was conceived following the 1995 Subway Sarin Incident when a religious cult released a chemical agent in Tokyo’s subway system that killed 13 people and injured nearly a thousand, so a response to this type of attack was on people’s minds. “Quince would investigate situations by entering subway, buildings, or underground areas where responders are at risk from chemical agents,” Tadokoro explains. The class of incidents to which Quince would respond is known as CBRNE for chemical, biological, radioactive, nuclear, explosion.

Quince was not developed to respond to nuclear plant accidents. After the 1999 Tokaimura JCO accident at the nuclear fuel manufacturing company, the Japanese government made development of response robots a priority. That priority didn’t last long, however. “Specialists in nuclear power plants said such robotic systems are not necessary, because such accidents would never happen,” Tadokoro explains. Tadokoro finds such naiveté regarding the perfection of nuclear technology disappointing. “The engineer should not believe that type of thing: it is not scientific." According to Tadokoro, the statement was politically rooted, as nuclear lobbyists were trying to



Tohoku University's Quince model is designed for mobility. - Credit: International Rescue System Institute

Search and rescue is just starting to come into its own – much like space robotics

silence concerns raised by anti-nuclear activists. As a result, nuclear reactors were not considered dangerous and little research was done for that type of disaster scenario.

The Aftermath of a Nuclear Emergency

When the Fukushima reactor was damaged by the earthquake of March 2011, it was impossible to know how bad the damage was or what the radiation levels were without measuring them in person. Such a task would be incredibly dangerous for a human, and readings were needed from a five-story building with narrow metal stairs. On the International Nuclear Event Scale, Fukushima was rated maximum severity.

The first robot to enter Fukushima after the incident was Packbot, a military robot series manufactured by iRobot. Packbot was "thought of as a specialist of response robots," says Tadokoro. "I really appreciate iRobot's donation of Packbots to TEPCO. If they did not have Packbot, the cool shutdown of the plant would have [been] delayed significantly." But Packbot had a problem: stairs. The stairs were steep, at 42-45 degrees, and slippery with water. "Packbot could not go up to the 2^{nd} floor," says Tadokoro. "Packbot is really a good robot, but [it] was not designed for steep steps nor rubble piles." Then, Prof Eiji Koyanagi of the Chiba Institute of Technology immediately proposed using Quince, whose design had focused on difficult terrain. "We found this area of disaster had no information because every avenue of communication was cut," Tadokoro recalls. The team spent a week trying to track down someone in an official position, but with communications down, the situation was complete chaos. After a week, they gave up trying to find an authority and just started working.

First, the team tried to construct the scenario Quince would face. "Our starting point was the 1995 Great Hanshin/Kobe earthquake, a huge earthquake in which more than 6000 people died," recalls Tadokoro. In that disaster, though, 90% of the deaths were due to the earthquake itself. The later Hanshin-Awaji earthquake was next considered, in which over 80% of the deaths were caused by people being buried by collapsed buildings. In this type of situation, mobility in confined spaces is the priority. "Quince has very high mobility – that is the reason that we thought Quince would be a very nice solution," said Tadokoro.

In mid-March 2011 Tadokoro finally got a hold of the Economic Trade Ministry and insisted that Japanese robots would be critical to managing the disaster and suggested a demonstration of the technology. On April 4^{th}, Quince was demonstrated for the ministry. Koyanagi began remodeling Quince on March 18^{th}, in collaboration with many researchers. On June 24^{th}, Quince received his first mission.

Winning over the Skeptics

There was skepticism at first. Quince was only a research robot, not a fully developed search and rescue instrument like iRobot's Packbot. And at first, the skeptics seemed to be right. On his first mission, Quince got stuck on the stairs while ascending due to a mistake in the building's blueprints. Learning from that event, the Quince researchers were later able to successfully maneuver Quince so he could travel to all the upper floors for his next five missions.

Quince's July 4^{th} mission was particularly successful. Quince was assigned to check the status of the water spray cooling system. "Quince went to [the] 2^{nd} floor and checked the pipes and valves." Takodoro recalls the excitement as Quince confirmed: "the cooling system is alive!" While there, Quince also measured radiation levels so plans could be made for workers to perform repairs for safe time durations. After that, there were few skeptics left.

Lessons Learned from Space Radiation

Although industrial robotics is a well-developed field, the area of search and rescue is just starting to come into its own – much like space robotics. The fields share similarities in that flex- ▶▶

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ibility and autonomy have increased importance when searching through a rubble field or scouting a planetary surface. In the case of nuclear accident response, they share one more commonality: radiation.

Quince wasn’t designed to operate in a nuclear environment, so one of Tadokoro’s priorities during the remodeling phase was to find out exactly how much of a problem radiation was going to be. For answers, he turned to his colleagues at Tohoku University. Space radiation can cause two types of damage to electronic boards: component damage and bit flips. Only the former is caused by gamma radiation, the type that is present in a nuclear reactor. The researchers were able to save a lot of time by focusing on mitigating only a specific type of hazard.

Shielding vital components on Quince would require much more weight than was available. “If it becomes such a heavy creature, the mobility is seriously lost,” Tadokoro remarks. The increased weight would greatly reduce the mobility of the robot, and would make it impossible for it to climb Fukushima’s stairs. Luckily, Tadokoro reported, “Quince has enough tolerance.” Through a series of experiments testing component failure, the research group determined that Quince would survive for 400 hours with its non-radiation hardened components. This meant that Quince would be able to complete his mission without needing expensive radiation hardened components. This approach of using “good enough” off the shelf components is on the rise for short term, low cost space applications as well.

Quince’s great success proved that search and rescue robots and even research robots are able to significantly contribute in disaster scenarios and keep humans from danger. Robots working together with humans produce incredible results when each is given the proper tasks. Quince, Packbot, and other search and rescue robots have an important role to play in future disaster management, as human-robotic cooperation does in future space exploration.

Quince benefited from space radiation research, and robots being designed to work with astronauts will benefit from insights gleaned from the search and rescue robots that work with rescuers. Research in this field is great for the space industry and greater partnership would benefit both.

Quince and the Future of Disaster Robotics

What next for Quince? After six missions, the original Quince unit got stranded in Fukushima, where he still sits, due to a worker accidentally severing his communication cable. But Quince is now a series of rescue robots. In the second and third iterations, the team focused on improving worker-robot and robot-robot interactions, so, for example, one Quince could save another Quince unit that encountered difficulty. “If one Quince stuck somewhere, another will come there and start communication,” explains Takodoro, potentially saving the troubled unit.

The stranded Quince is now too radioactive to be recovered, but he has served his purpose and more. “The Tohoku earthquake was the first case where so much robotics were used,” says Tokadoro. Given their success, disaster robotics is sure to become a popular field of research. One sign of such popularity is the newly created International Research Institute of Disaster Sciences within Tohoku University, of which Tadokoro is a member. “There were so many problems where robots could have helped,” says Tokodoro. “It is important for responder agencies to have and use them every day through training and exercise.”

The development of disaster robotics has continued in Fukushima’s aftermath with the recent announcement of a robot that uses dry ice to “vacuum” radioactive material. This robot joins a suite of disaster robots coming out of Japan. These and future developments will enable rescuers in the next disaster to respond more effectively and with less personal injury.

This type of debris-strewn room is exactly what Quince was designed to navigate.
Credit: International Rescue System Institute

Los Alamos National Laboratory Muon Radiography team assess the use of cosmic ray radiography to image locations of nuclear materials in the Fukushima Daiichi reactor complex.
Credits: US Department of Energy