A SHORT HISTORY OF CONSTRUCTION ROBOTS RESEARCH & DEVELOPMENT IN A JAPANESE COMPANY

Tetsuji Yoshida
Space And Robot System Group
Institute of Technology, Shimizu Corporation
4-17, Etchujima 3-Chome, Koto-ku, Tokyo 135-8530 Japan
yoshida.tetsuji@shimz.co.jp

Abstract. The starting of the business was a development of a robotic machine for construction site workers, utilizing advanced technologies of computer, sensor and mechanism. The author wanted to realize a modern construction sites less 3K (Dangerous, Dirty, Heavy, in Japanese; Kiken, Kitanai, Kitsui), developing and introducing robots workable continuously for 24 hours a day. He developed fireproofing spray robots (SSR-1 to 3) to set human workers out of dirty and dusty environment. In Japan, many prototype robots were developed after his introduction. He did not continue developments of construction robots, but took his way to the applications of robotics under hazardous and challenging environments, and finally has reached space robots on the moon. Continuing space robotics, he is now shearing his effort to the robotics on the ground and space. For the ground use, he is planning to realize an intelligent buildings and habitation environment that is more comfortable and secured by robots. His ideal robots are not sophisticated like a humanoid and not for entertainment, but just a useful one. His targets are just machines workable in human territory with minimum components, minimum intelligence, minimum sensors and some capability of communication. His major works on robotics through 30 years are detailed and the lessons he learned are showed.

Keywords: construction robot, space robot, research and development, history

1. INTRODUCTION

34 years ago, the author joined Shimizu Corporation, and started his research and development (R&D) in its research institute on a mechanical construction system for a slip-form system for tall towers and chimneys. While searching technology and advanced components for the system improvement, he encountered with active people working on robotics in Japan. Mid `70s was a time before daybreak of industrial robots in Japan, and was the first term for the author to be involved in robotics.

Big question was “What the robot? What is the difference with autonomous system with some flexibility?” Robots were living in scientific fiction and cartoon. His first research on robotics was to find what “Robot” means. In the drama; “Rossum’s Universal Robots (RUR)” by Karel Capek in 1920, there was the name of “Robot”. The drama seemed to be appearing problems on modern materialism. The author got a strong impression that robots could corrupt human life and culture so badly and he should not take part of this kind of robotics. [1]

The authors have continuously questioned himself for these 30 years pursuits that he might develop robots and to make human idle or unhappy losing their motivation. Avoiding negative aspects of robot appeared by Capek, he began to work on sound robotics R&D that he could believe.

2. ROBOTS FOR CONSTRUCTION SITES

2.1 Construction Robots Development in Japan

More than 200 prototypes have produced and made trials at the Japanese construction sites in `80s. Several of them are still alive and contributing to modernize construction, but others were ruined or stored “frozen” in laboratories. Japanese engineers working for construction companies and construction machine manufacturers paid so much effort for the R&D, and looks to be failed to get enough return from their investment. The peak of the boom construction robots development took place in `80s through `90s in Japan. The beginning of the boom started like below. [2] [3] [4]

2.2 Robots for Hazardous Environment

The motivation for the first robot development was to release human workers from hazardous environment. Generally speaking in Japanese, construction site works are symbolizes in “3K” (Kiken=Dangerous, Kitanai=Dirty, Kitsui=Hard) and not recommended to younger generations as their life work.

The author picked up concrete spray work at NATM (New Austrian Tunneling Method) tunneling working face. Sprayed concrete supports inside and front face of wall naked to the tunneled space. Air blower transfers dry-mixed mortal (mixture of cement and sand) through flexible tube and water with chemical solution is also pumped to the nozzle through another tube. As cement, sand and solution are sprayed at the same time at the tunnel deadend, work environment is really bad with dust, humidity, high temperature and low visibility. Skilled spray workers must wear heavy protections such as goggle, helmet, gloves and suites protecting them form dusty materials and dirty splash to make thin and uniform concrete layer,.

Special spray machine powered by hydraulics was imported and available, but was expensive for contractors for the small market of NATM tunnel. There were not easy to make worker well-experienced for spraying using it. The machine was not welcomed by spray workers also, as the machine could not perform well enough for their delicate action that spray workers wanted.

The author had got an idea develop a robotic machine producing it by himself domestically to overcome both of aspects of performance and economic. The very first experimental robot prototype with master-slave control system by electric servo was appeared in 1979.

2.3 R&D Resources Needed

The NATM spray robot development was not successful as R&D resources below were in short.

1) Capability of commercial robot design and production

Practical system for construction must be designed and produced in cooperation with construction machine manufacturer utilizing their experience and technology for site application. General contractors could not have enough experience and data for each site work and machine.

2) Availability of dependable robot system component

Construction robots will be built by materials components and technology with higher specifications like MIL-Standards etc. Such components are not familiar in Japanese market and too expensive for industrial use. To develop the market of construction or field robotics industry, engineered on robotics and automation should communicate each other internationally.

3) Design and Analytical tools for developing robots

Historical approach focused on machine performance and economy did not work well for robotic systems design as their performances are not fixed but flexible. And construction work process was not well examined by general contractors, as site works were subcontracted.

2.4 Development of Fireproofing Spray Robots (SSR-1)

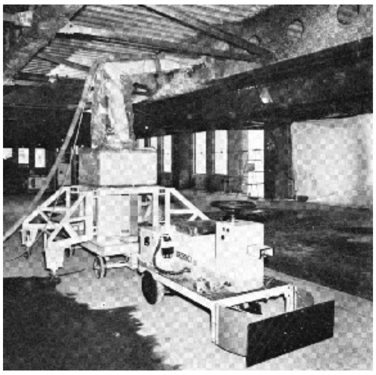

Fig.1 SSR-1

The second target was fireproofing material spray to steel girders and beams of building's structure. This work environment was not so bad like NATM tunnel spray work, but had the same problem of dusty environment.

Fireproofing layer must cover the exposed surface of the steel structure at all and its quality is evaluated by uniform thickness (30, 45, 60mm) and enough density. Two kinds of materials, rockwool and cement milk, were supplied from material supply plant. Spray experts handle the nozzle combined for two materials and form the layer mixing them on the surface of girder and beam. The performance of the feeder and the pump were poor to reduce the cost, and the spray experts could manage the machine problems by their skill. In humid and warm summer season in Japan, spray work becomes so hard wearing heavily to protect their skin, eyes and breathing against fine and irritating rock-wool fiver.

The fireproofing spray robot SSR-1 (Shimizu Spray Robot No.1) was developed that is composed from an industrial spray robot for automobile production line (KOBELCO-TRALLFA Spray Robot KTR-3000F), a wheeled base the robot sit on and an induction guided tractor towing the wheeled base. (Fig.1) The spray robot accompanies with a hydraulic unit and electric control consoles. These two components followed the SSR-1 moving and cables and hydraulic tubes connecting each other were dragged on the floor. These cable and tube was contaminated and damaged so easily and disturbed the robot mobility. Human worker was teaching nozzle movement to the robot (teaching and playback), and supported the robot work managing these cables and tubes. The first robot system could not realize higher performance than human worker however, was successfully impressed the people showing one of the future construction sites images. (Fig.2) [5] [6]

Fig.2 Fireproofing Spray by SSR-1

2.5 SSR-2

The SSR-1 could successfully appeal the beginning of the future construction age, awarded one of the "Man of the Year" from Engineering News Record (McGraw-Hill).

SSR-2 was the improved system based on the SSR-1, introducing brand-new self-mobile wheeled base. Traction system for SSR-1 was abandoned for poor mobility and its induction wire for the guiding system was troublesome. Mobile base for SSR-2 facilitated rotation axis and travel distance measuring system, obtained good performance of accessibility and travel belong girders and beams. A new motion plan programming that can be prepared before the robot works at site, was developed. This

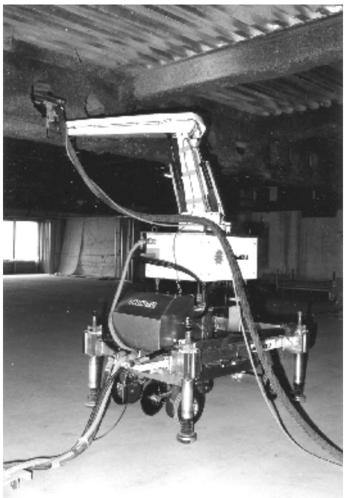

Fig.3 SSR-2

program was operated on a personal computer which was the most advanced system at that time. (Fig.3)

But the spray robot was the same as before, robot teaching process by human experts was still needed adjusting each shape of the fabricated steel girders and beams. It has happened so frequently that number of teaching programs developed was almost the same with the number of steel elements sprayed at a site. This meant that a modern design approach such as modular design was not recognized and applied at that time, just pursuing to minimize the weight of steel used only. An aspect of old construction production lacking rationalization was clarified by the robot.

SSR-2 was improved in mobility but not enough other performances. The winter season operation at north area in Japan was suffered low temperature below 0drgree in C getting higher viscosity of hydraulic oil for the manipulator. Normal automobile assembly line was set not so cold when it works to spray automobiles. Then, the next robot, SSR-3 development was started introducing totally new machine and software design applicable for various construction sites.

2.6 SSR-3

SSR-3 was a bland new construction robot in every performance and components, and became good for hazardous environment and facilitated sensing system to be able to apply almost all sites. The robot arm was replaced by an originally designed one powered by electric DC motors, from TRALLFA Spray Robot. Every control and programming component prepared in smaller size was packed into a box and placed on the omni directional mobility. The performance for spray position adjustment was highly improved and finishing process to keep the density of the fireproofing layer could be done by this arm. The dragged cables and tubes were decreased to two for electric power and fireproofing materials tubes electric power. (Fig.4)

Fig.4 SSR-3

The robot teaching process was also changed introducing analytical approach and software for SSR-3, not depending on human experts. The software could prepare all of the robot movement and manipulation on the PC screen, tracing its nozzle cover the steel element surface completely by continuous line. This method is based on the material quantity poured out form the nozzle is constant. Using this program, almost all spray programs was prepared before the site work getting the data form the building structure design. Not only the robot system but fireproofing material feeder and pumps must be improved in reliability and uniformity to complete the system development. Before remodeling these supporting equipments, the SSR-3 development was terminated.

The reason for the termination was small market for the SSR-3. Only 60 units could process all of the fireproofing construction in Japan. This number knocked down company management to give up further development of SSR, as they had plan in mind to put the robots on sale to make one of business. Current fireproofing work and process is still the same with the period of SSR series were developed in `80s. Fireproofing layer forming method is now changing into formed like a blanket, form spray method. Wet process with spray work will be replaced by dry method in the near future, realizing more comfortable working environment. [7][8]

3. DECOMMISSIONING ROBOT FOR NUCLEAR POWER PLANTS

3.1 Nuclear Power Plant Dismantlement

In 1980, a project for remote-operating robot system design has started for a retired nuclear power plant demolishment for Japan Power Demonstration Reactor (JPDR) in JAERI (Japan Atomic Energy Research Institute). Activated interior surface of the reactor biological shield wall is cut off activated parts separately form non-activated concrete, to decrease the quantity of activated wastes.

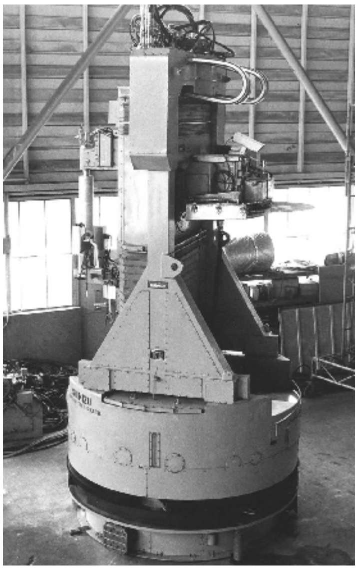

Fig.5 Robot for Demolish

For the future replacement of commercial nuclear power facilities, the decommissioning technology on remote operation and robotic systems had to be established and demonstrated in advance.

3.2 Activated Biological Shield Wall Dismantling Robot

The biological shield wall of the JPDR is composed of heavy concrete with 2meter in thickness. (Fig.5,6) Robot cut the concrete using diamond core drilling and diamond sawing. The cut concrete brocks are pinched up and transferred to the containers for high level waste by their handling system totally operated in remote. To confirm the system performance, biological shield wall mockup of

Fig.6 Cut Wall Mockup

JPDR was prepared and demonstrated the cutting concrete from inside of the wall. The system and technology are now waiting for the project for commercial nuclear plants decommissioning in the near future. [9]

4. ROBOTS FOR SPACE PROGRAMS

4.1 Construction in Space

In 1987, a study program on construction in space using robots had started in Shimizu. The author got a chance to research on robotics under the challenging environment. Large scale space facilities such as space hotel and lunar base on the Moon were assumed to be a kind of dream in the far future. So many scientific fiction, movies and cartoons took care of space travel and lunar development without any serious study on engineering. Serious study by construction engineers was invisible in Japan and other countries. (Fig.7)

The authors' team get started to build up a future target for space construction, and examined approaches to apply technologies on robotics and automation. There were several US space industries that were still interested in lunar programs continuing from Apollo program in `60s. A few US universities had been working on lunar and Mars exploration and working on space robotics as a tool for exploration. An international cooperative research programs joined with an US space industry started on the moon colony development as a real business.

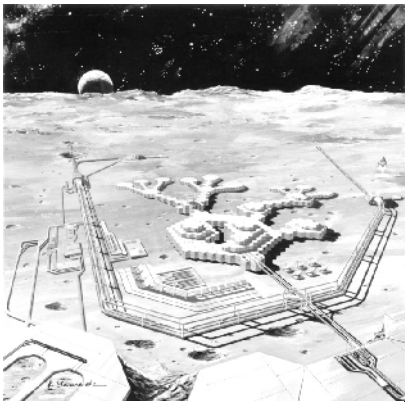

Fig.7 Moon Colony as a Target

4.2 Orbital Robot Research

Before arriving on the robotics on the lunar surface, there was a step for orbital robots. One of them was orbital infrastructure development for space logistics such as space hotels and space stations. Robotics was a key technology for space system development and the authors committed on an orbital space robotics research in Japan and in the US. (Fig.8) [10] [11]

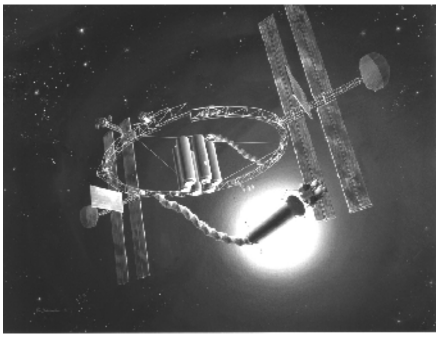

Fig.8 Image of a Robotic Factory on Orbit (Research Forum on Space Robotics and Automation 1990, NASDA)

4.3 Space Manipulator Development in CMU

From 1989, the author launched cooperative R&D on "Self-mobile Space Manipulator (SM^2)" at the Robotics Institute of Carnegie-Mellon University (CMU) in Pittsburgh. (Fig.9) The robot was designed to walk on large space structures for assembly and maintenance work reducing EVA (Extravehicular Activity) by astronauts.

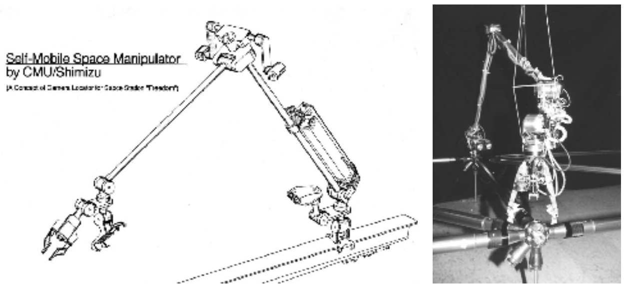

Fig.9 Self Mobile Space Manipulator

Technologies for space robots, such as control of the flexible arm, vision, mobility and lunar gravity demonstration were developed in the term of 5years. The results were opened to the US and Japanese space society to promote the future space programs. [12]

4.4 Space Robots Experiment and Demonstration on the ETS-VII (Engineering Test Satellite VII)

Fig.10 ETS-VII on Orbit

NASDA (National Space Development Agency of Japan, current JAXA(Japan Aerospace Exploration Agency)) had an orbital robot experimental project and the authors had participated the development of experimental facilities on orbit and operation facilities on the ground, proposed and sponsored by NAL (National Aerospace Laboratory, current JAXA). The orbital experimental facilities were composed form deployable truss system and truss joint mechanisms for single-armed space manipulator fixed on ETS-VII. (Fig.10)

After the successful launch in 1989, robotic experiments on the ETS-VII were executed for 3 years. Time delay of a few seconds on the communication between the control console and the orbital robot on the satellite in the 550km altitude, was a key issue for robotic work, especially work with force control. Real-time simulator and graphical operator supporting system worked well and all of the experimental programs were successfully completed. Technology developed and obtained in this project will support Japanese space exploration programs utilizing robotics. (Fig.11)

Space environment and rocket launching environment is critical for robotic system, and the author experienced technology and engineering on robotics in vacuum, temperature fluctuation, vibration and strong impact of force. Time delay seemed to be one of the critical conditions for the future space robotic system. [13] [14]

Fig.11 Orbital Camera View

4.5 Access to the Moon

The author is working on the robotic lunar exploration for the future Japanese space program now. Robots will be utilized not only exploration but also mining and sampling the resources on the Moon for the preliminary stage of colonization. Lunar base and related systems construction will be one of the major tasks for robots on the Moon. Such robots are suffered from fine soil dust, low gravity, heated by the sun in the noon and cold nights on the lunar surface. Challenging R&D will be continued by the time some people could enjoy life on the Moon developed by lunar robots. (Fig.12) [15]

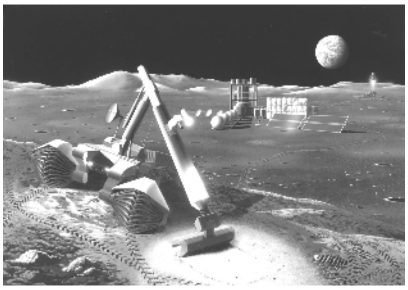

Fig.12 Robots on the Moon

5. ROBOTIC BUILDINGS

Form 2005, new R&D for robotic building and robotic district was started to realize an advanced life with robots. If buildings and houses could have enough intelligence and could communicate robots located inside of them, robots will be facilitated less intelligence and less performance making them cheaper and more reliable. This will mean robot will be compact in hardware, software and technology. And robots design will be more flexible supplementing components for users and more applicable to various tasks for human life.

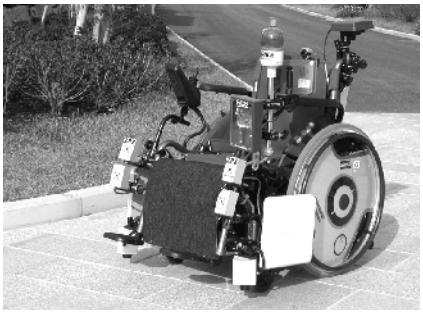

Fig.13 Robotic Wheeled Chair

The first trial in the city of Fukuoka, Kyusyu in Japan, using a robotic wheel chair indicated the evidence that structured environment for robot works well if there were no human beings as a noise and obstacles. Then the author's team got started to study on totally robotic space including robots, human and buildings. (Fig.13)

6. CONCLUSIONS

6.1 Lessons Learned

1) SSR-1

The first robot impressed peoples so deeply. The robot itself was just a prototype to examine the possibility to apply fine electronics and mechanisms. But misunderstanding has happened such as losing job and profitable new business. Pioneering works must be accompanied with sound advertisement process, or make it secret.

2) SSR-2

Basic research on construction production and site management must be continued seeking business innovation forever. Challenging spirit is really required for the bases where the engineering industry is standing on. Purchased materials price is visible but miscellaneous and fragmental work costs are sometimes invisible.

3) SSR-3

Pioneering R&D needs strong management but it is difficult to find in this world. "Try and error" approach may be only one approach for the normal industry, especially in the case that unfamiliar technical and engineering are utilized for R&D. Too much expectation or too fast decision makings may mislead new trend or shorten the life of the challenging R&D. Top management is expected to be aware of its responsible for the future business and world.

4) Decommissioning Robots

Fruits from R&D inhabit researchers or engineers who were worked for, and are possible to be revitalized at any time after. It may happen so frequently that time of R&D was too early for its market. Unsuccessful or terminated R&D works are so precious and filled with intelligence. Construction robots prototypes are good examples for technology storage for the future.

5) Space Robots

National R&D programs integrated by researchers or engineers are really powerful. International cooperation might be more. Not only researcher but so many managers, teachers and officers should be formed in a nice collaboration team and should not hesitate to contribute other's achievement.

6.2 The Next Step

The author introduced briefly his own experience on robotics and automation R&D in these 30 years. The next stages are continued from before and challenging ones. Final goal of construction robots are still not established. Spreading area for application and expecting innovative engineering, R&D efforts will be endless.

7. ACKNOWLDGEMENT

Capek's novel made the author scared for an advanced robot and concentrated in another side of humanoid. But at the same time, the author believe in robotics must be useful for industries and individuals. Construction field is really attractive for the future robotics and automation.

The author would like to support younger generations participating in construction robotics and automation, and appreciate everyone in the world who could support the author and, work together with the author.

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