Development of the Remote Decontamination Robot “MHI-MEISTeR II” for an Upper Floor of Reactor Building in Fukushima Daiichi NPP

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ABSTRACT
In Fukushima Daiichi nuclear power plant (NPP), the environment with high dose rate causes a serious problem. The dose is especially high inside of the reactor building, so it is difficult for people to access there. Therefore, many kind of work in this severe environment by the remote devices is required strongly. These works include decontamination to reduce the environmental dose rate. MHI has implemented the development of remote-operated robot, and we continue to struggle for settling the accident of Fukushima Daiichi NPP. This article describes the actual performance of “MHI-MEISTeR II ” which was developed in 2015 to decontaminate for an upper floor at Fukushima Daiichi NPP.

KEYWORDS
robot, disaster response, manipulator, teleoperation, Fukushima Daiichi NPP, decontamination

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1. Introduction
After the accident of Fukushima Daiichi NPP, inside of the reactor building of Fukushima Daiichi NPP is under high radiation area. Because of this high environmental dose, workers can’t access the area and progress of settling accident is not grad. Therefore, it is necessary to lower the environmental dose and recover the area so that workers can access there by decontamination, shielding, and removing contaminated equipment by using remote controlled robots.

In order to establish the remote decontamination technology, the decontamination project is planned and promoted by initiative of Japanese government. In the decontamination project, decontamination target areas are divided into “lower area”, “high area”, and “upper floor”. Also the using robots are different respectively, requirement tasks are same. The requirement tasks are as follows.

• To access the areas by remote control
• To lower the environmental dose by using the decontamination tools

This article describes the remote controlled robot “MHI-MEISTeR II ” developed by Mitsubishi Heavy Industries, LTD (MHI) as a decontamination device in the upper floor decontamination project. In the upper floor decontamination project, MHI, Toshiba and Hitachi GE develop the decontamination device respectively based on distinct method each other and construct an upper floor decontamination system by combing each device. MHI-MEISTeR II was developed as a part of the system. In addition, MHI developed MHI-MEISTeR II to apply not only upper floor decontamination but various tasks such as follows.

• To move between floors by using stairs
• To operate various tasks(e.g. handling valves) in addition to decontamination by changing the end effectors

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2. MHI-MEISTeR II

MHI has been developing the remote controlled robots which can operate in severe environments where are difficult for people to access [1, 2]. By using these experiences, MHI developed double arm remote controlled robot “MHI-MEISTeR II” (Fig.1) which can meet a functional requirements that are indicated in 2.1 in order to realize the work performance described above.

Fig.1. MHI-MEISTeR II

2.1. Functional requirement

The functional requirements of MHI-MEISTeR II are as follows.

i ) It is capable of decontaminating an upper floor
   - It is capable of accessing reactor building upper floor (2 or 3 floor) via an equipment hatch by using a lifting platform (e.g. It is capable of moving on slope with 15° angle and step with 50mm height)
   - It is capable of decontaminating a floor and a wall (approximately 2 m height)
   - It is capable of working in cooperation with other upper floor decontamination devices when the robot operates the above task
   - It is capable of using and changing various decontamination tools
   - It is capable of recovering the power supply and communication using buck up if they were lost
   - It is capable of being operated by remote control by using equipped cameras and sensors in dark place
   - It is capable of being operated by remote control by using communication methods (wire or wireless)

ii ) It is capable of having expansibility to operate various tasks (e.g. handling valves) in addition to decontamination
   - It is capable of changing various end effectors easily
   - The accuracy of the manipulator’s end point position is less than ±5mm to operate various tasks
   - It is capable of going up and down stairs with a 40° angle and 200mm step
2.2. Specification

Table 1 shows the specification of MHI-MEISTeR II to realize the above functional requirement.

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>L1,200mm x W740mm x H1,700mm</td>
</tr>
<tr>
<td>Weight</td>
<td>500kg [approx.]</td>
</tr>
<tr>
<td>Moving mechanism</td>
<td>4-crawler drive</td>
</tr>
<tr>
<td>Traveling speed</td>
<td>1km/h [max.]</td>
</tr>
<tr>
<td>Communication method</td>
<td>Wire (300m) / Wireless</td>
</tr>
<tr>
<td>Power source</td>
<td>Outside supply / Lithium-ion battery [max 4hours.]</td>
</tr>
<tr>
<td>Double 7-axis manipulators</td>
<td>The manipulators have the same number of joints as human and the capacity for each manipulator to carry 25kg</td>
</tr>
<tr>
<td>Narrow space mode</td>
<td>It is capable of rotating with an external diameter of 850mm This function is for passing through the Fukushima Daiichi NPP’s stairs landing</td>
</tr>
</tbody>
</table>

2.3. Characteristic function

As follows, we explain three important functions to decontaminate upper floor called “moving ability”, “operability”, and “manipulation ability”.

2.3.1. Moving ability

MHI-MEISTeR II has various drive axes to move. The axes are four crawlers, one center of gravity control axis and four titubation axes (Fig.3 left). MHI-MEISTeR II can move on irregular ground and stairs using these drive axes to adjust own center of gravity and position. For example, if force is added to crawlers, titubation axis drives to reduce the force and crawlers follow the shape of ground automatically. In addition, if robot inclines to a horizontal direction, robot detects own inclination by an internal angle sensor and keeps the own posture level automatically by standing the crawler of leaning side by driving titubation axis (Fig.3 right). On the other hand, if robot inclines sagittal direction, robot keeps the own posture level automatically by driving center of gravity control axis.

Fig.3. Drive axes of MHI-MEISTeR II
2.3.2. Operability

MHI-MEISTeR II has two main PTZ cameras, eight fixed point cameras and various sensors such as 3D-Laser Range Finder, angle sensor, load sensor, and torque sensor. The operators are able to understand the circumstances clearly through the virtual images received from the cameras of all angles. Using such functions, MHI-MEISTeR II has realized high quality remote operability. Fig.4 shows the operation screen of MHI-MEISTeR II.

![Operation screen](image)

2.3.3. Manipulation ability

MHI-MEISTeR II has two 7-axis manipulators (weight capacity is 25kg) and they can perform complex work in the narrow space and avoid the obstruction. MHI-MEISTeR II decontaminates the target by linear sweeping like the blue line with the end point position of manipulator draws in Fig.5. Our original control method has realized the reduction of complex operability due to the increase of axis. MHI-MEISTeR II can operate various tasks by changing end effectors easily using tool changer (Fig.5).

![End effectors](image)
3. Functional test

In order to confirm that MHI-MEISTeR II meets the functional requirements i), ii), the functional tests were conducted. Table 2 shows the test items and results of each functional requirement.

<table>
<thead>
<tr>
<th>Functional requirement</th>
<th>Test item</th>
<th>Criterion</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Move on irregular ground</td>
<td>It is capable of moving on slope with 15° angle and step with 50mm height</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Series of upper floor decontamination test</td>
<td>To pass through the area where is modeled after the environment of Fukushima Daiichi NPP and operate decontamination normally by remote control with other trucks and blast decontamination unit</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Cooperation ability with incidental devices</td>
<td>To complete decontamination operation by remote control working in cooperation with MHI-MEISTeR II and others</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Safe performance of the event of failure</td>
<td>It is capable of recovering the power supply and communication using buck up if they were lost</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Remote operability</td>
<td>Operators can operate the robot by remote control using equipped cameras and sensors in dark place</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Changing the communication method</td>
<td>Operators can operate the robot by remote control using communication methods (wire or wireless)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Tool changer ability</td>
<td>It is capable of changing various end effectors using tool changer</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>ii) Manipulator accuracy</td>
<td>The accuracy of the manipulator’s end point position is less than ±5mm to operate various tasks</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Move on Stair</td>
<td>It is capable of going up and down stairs with a 40° angle and 200mm step</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>

The test of functional requirement i) includes the demonstration in connection with an upper floor decontamination system. Fig. 6 shows the upper floor decontamination system and Fig. 7 shows the upper floor decontamination state.
4. Conclusion

MHI developed MHI-MEISTeR II and proved the usefulness of it by functional test of MHI-MEISTeR II and demonstrated with the upper floor decontamination system. In addition, we got the likelihood of realization of the project. We continue to struggle for settling the accident of Fukushima Daiichi NPP with this robot and others.

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References