*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 17-18, 2012*

# Wireless Power System Design for Mobile Robots used in Nuclear Power Plants

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## 1. Introduction

The robots used in nuclear power plants (NPP) have received much attention in recent years due to the Fukushima nuclear accident, which is considered as one of the worst nuclear disasters. In general, the NPP robots can play important roles in fuel exchange, repair work, radiation monitoring, rescue, and scouting out NPP [1]-[2]. Under these conditions, human access to NPP during normal and emergency operations is strictly restricted due to the risks of high level radiation and contamination. However, in practice, robots have not been widely used in NPP because of the following limitations. First, the NPP robots cannot be of multi-purpose use because of their mission complexity and uniqueness. Second, the demand of the NPP robots is low due to the limited number of NPP over the world. Third, the NPP robots developed so far have no enough confidence in spite of the improvement of robot technology. Lastly, the NPP robots cannot carry on their mission continuously due to the limited energy capacity of the battery [3]-[4]; mobile robots should stop working every two hours to recharge their batteries and spend least twenty minutes. As the solutions for this 'energy hungry' problem, high capacity batteries, quick battery chargers, power cables, and internal combustion engines were proposed; however, they still have the problems such as limited mission time and range, frequent recharging, or exhausting emission and noise.

In this paper, the wireless power transfer systems (WPTS) for NPP robots are proposed. This technology can let NPP robots free from mission time and range limits, and exhausting emission. The requirements for the NPP robots are newly proposed, and two types of WPTS, roaming and railway, are suggested in this paper.

## 2. Review of Mobile Robots in Fukushima Accident

### *2.1 PackBot*

(a) (b)

Fig.1 (a) A PackBot originally developed for military uses by iRobot, (b) T-Hawk by Honeywell, both in USA.

PackBot, as shown in Fig. 1 (a), is the first robot to enter the damaged Fukushima NPP in 2011. Its missions were finding out the plant status and detecting gamma radiation level, temperature, radioactive material, and flammable gas existence. It is equipped with a real time thermal video camera and a strong arm and gripper to handle potential hazards safely from explosive or radioactive source; also, it can be controlled within 500 m range by radio control [5].

### *2.2 T-Hawk*

T-hawk, as shown in Fig. 1 (b), is a vertical take-off and landing micro unmanned aerial vehicle (VTOL MUAV), which has 8.4 kg weight, and an endurance of around 40 min. Its areal missions were conducting surveillance and taking photographs of the damaged reactor, turbine buildings, spent fuel containment pools, and related facilities of Fukushima NPP [6].

### *2.3 Moni-Robo*

Fig.2 Moni-Robo by Nuclear Safety Technology Center in Japan.

Moni-Robo, as shown Fig. 2, is a Japanese robot used in the Fukushima accident to measure radiation levels. It is 1.5 m height and has a strong arm to remove and collect samples. It is equipped with a radiation detector, a real time 3D thermal imagery camera, temperature and humidity sensors. Also, it can be remotely operated by radio control within 1 km [7].

## 3. System Requirements for NPP robots

One of the lessons we learned from the Fukushima accident is that NPP robots are quite essential for the high radioactive and dangerous working environment. Another lesson is that NPP robots should be prepared to use in normal operation condition as usual; if not, it cannot be used for emergency case due to the lack of available robots ready to use. Reminding that the causes of the accident are power black-out and hydrogen explosion [8], the NPP robots should be designed to perform missions under these circumstances. Thus, the system requirements (SR) for the NPP robots are suggested in this paper as follows.

1) They shall be resistant to water and radiation.
2) They shall be remotely controlled in real time.
3) They shall be for multi-purpose use, if possible.
4) They shall be powered regardless of range and time.

The water resistance of SR1 is found to be important for the disastrous nuclear accident. As in SR3, NPP robots should be able to use their payloads for various missions such as radiation detecting, thermal imaging, pressure, temperature, gas, and humidity sensing. As in SR4, to provide power consistently is crucial for the success of missions, which will be explained in the following section.

## 4. Wireless Power Systems for NPP Robots

As a remedy for the conventional battery power and cable power, wireless power is adopted for the NPP robots. While the battery-power and wired power robots have time and range limits respectively, mobility is infinitely increased in the wireless power. Two wireless power systems are proposed in this paper as follows.

### *4.1 Roaming Wireless NPP Robots*

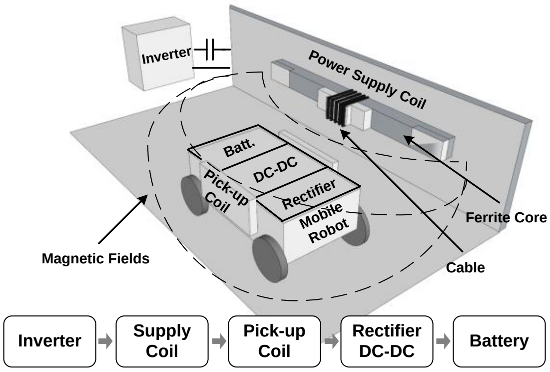


Fig.3 Configuration of proposed Roaming Wireless NPP Robots.

With a virtue of recent advancement in wireless power technologies, NPP robots can be powered from magnetic floor [9]. For wide and flexible mobility, magnetic wall is proposed in this paper, as shown in Fig. 3. This is based on the recent achievement of 5 m wireless power experiment [10]. The pick-up coils, rectifiers, DC-DC converters, and a battery pack are included in the robot while the supply coil powered by an inverter is attached to the NPP wall [9]-[10].

### *4.2 Railway Wireless NPP Robots*

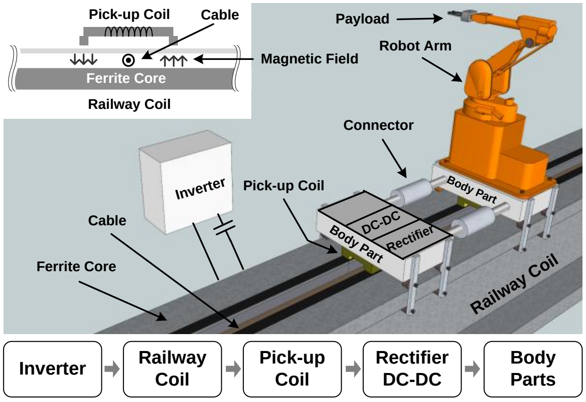


Fig.4 Configuration of proposed Railway Wireless NPP Robots.

For a reliable and robust power delivery, wireless rail ways can be used for NPP robots, as shown in Fig 4. The contactless power system that has been used in factory [11] is adopted, however, a rigid mechanical structure on a vehicle for vertical and horizontal movements and a magnetic communication link are attached in this paper. The battery pack is no longer needed due to the reliable and continuous power system.

## 5. Conclusions

The wireless power systems proposed in this paper can solve the 'energy hungry' and 'mission range' problems of NPP robots, as summarized in the Table.

*Table : Comparison among the power supply systems*

| Robot Type | Battery-powered Robots | Cable-powered Robots | Roaming Wireless Robots | Railway Wireless Robots |
|---|---|---|---|---|
| **Battery Capacity** | Big | NA | **Small** | **NA** |
| **Endurance** | 2 hours | ∞ | ∞ | ∞ |
| **Charging Time** | 20 min. > | NA | **NA** | **NA** |
| **Operating Range** | Free | Limited | **Free** | **Free (on rails)** |

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