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Mechanical analysis of flying robot for nuclear safety and security control by radiological monitoring

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ABSTRACT

The flying robot is investigated for the nuclear accident and security treatment. Several mechanics are introduced for the movement of the drone. The optimized motion of the drone should cover all areas of Nuclear Power Plants (NPPs) over the site where the circular and surmounting motions are needed with traverse of zigzag shapes. There is the Yaw motion in the circular moving and the Pitch motion in the climbing and downing against reactor facility. The fallout is calculated from the radiation concentration in the breaking part of the NPPs where the radioactive material leaks from the containment, coolant loop, plant facility and so on. The dose equivalents are obtained where the values are changeable following the random values of the y value, average wind speed, and dispersed concentration in the detection position. The simulation of new positions of x, y, and z are normalized from 0.0 to 1.0. The mechanics of flying robot produces the multidisciplinary converged technology incorporated with the aerial radiation monitoring information.

1. Introduction

Possible nuclear disaster controls are imagined related to safety and security in the industrial aspect which are treated by the flying robot, drone. Safety is considered in the event by several kinds of affects where the human errors could be involved. Otherwise, the security is to maintain the stability of the Nuclear Power Plants (NPPs) in the human's intentional attack. Although drone has been used for the military purpose, there are many applications for incredible useful tools (Anderson, 2014; Carrington and Soffel, 2013). Furthermore, the mobile radiation monitoring system has been focused on the usage of the drone where the Gamma and X-rays including airborne radioactive plume mapping for Alpha, Beta, and Gamma are detected by the several kinds of the detectors (Technical Associates, 2015). Hence, the real-time information could be transferred to the formal control room in the disaster of accident or terror incident. Especially, the Fukushima disaster site has been studied for the monitoring by the drone which is expected to use for the real operation in 2015 (Voice of Russia, 2013). At that time, the emergency response team had in the extremely confused conditions. This was happened due to the ignorance of the accident situations. So, if the drone is used by the rescue team, the effectiveness of accident control strategy could be highly enhanced. The United Kingdom's teams in the University of Bristol and University of Strathclyde are developing the drone design for the Fukushima disaster scan for the radiation which are funded from the Royal Academy of Engineering's ERA Foundation Entrepreneurs Award (Clark, 2014; Harris, 2014). IAEA also has a part of the action plan on nuclear safety using the aerial vehicles for environmental monitoring (Quevenco, 2014). In addition, the United States has the research part of the application of the drone in nuclear explosion accident case (McMahon, 2013).

In the accident of NPPs, one of most important matters is the leaking of the radioactive material to the environment. Therefore, the detection of the aerial radiation dispersion could give the information of the accident condition. The higher doses in the aerial monitoring could be guessed as the severer accident. Although the dose rate can't show the exact damage condition, it is possible to guess the accident degree by the operator. Even the coolant related accident situation for the primary loop in pressurized water reactor (PWR) or general coolant loop in boiling water reactor (BWR) usually emit the radioactive material which is contained in the coolant. So, the environment radiation in the disaster site is very important factor to find out the damaged situation. For the radiation detection system, several studies have been done for the lightweight aerial vehicles in the environmental radiation monitoring as the Fukushima Daiichi Nuclear Power Plant (FDNPP) incident's significant mass of radioactive material into the atmo-

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sphere where rapid and high spatial resolution assessment of radionuclide contamination in the environment could provide to the operator or rescue personnel in the nuclear accident (MacFarlane et al., 2014). In addition, Unmanned Aerial Vehicle for radiation surveillance equipment was mounted with a commercial CsI detector for count rate measurement and a specially designed sampling unit for airborne radioactive particles applicable for the Chernobyl nuclear accident (Pöllänen et al., 2009). Furthermore, the remote sensing airborne sampling system for Unmanned Aerial Systems (UAS) has developed for providing the capability for the detection of particle and gas concentrations in real time over remote locations (Gonzalez et al., 2012). Recently, Li et al. (2014) studied that the novel prototype Unmanned Aerial Vehicles (UAVs) have developed for aeromagnetic and aeroradiometric integrated system purposes in which the research is progressed in the aircraft modification including the extremely low altitude terrain following survey and remote control techniques.

In this work, for the purposes of the mechanical descriptions of the drone based radioactive material surveillance system, the radiation information based flying robot systems are discussed. Drone, the flying robot, could give the information to the operator from the sky which produces the wide-ranged upper view. Fig. 1 shows the simplified configurations of the NPPs where the sky view and side view are shown respectively. Fig. 2 shows the simplified configuration of the flying robot for this study. The Section 2 explains the method of the study. The Section 3 describes results of the study. There are some conclusions in Section 4.

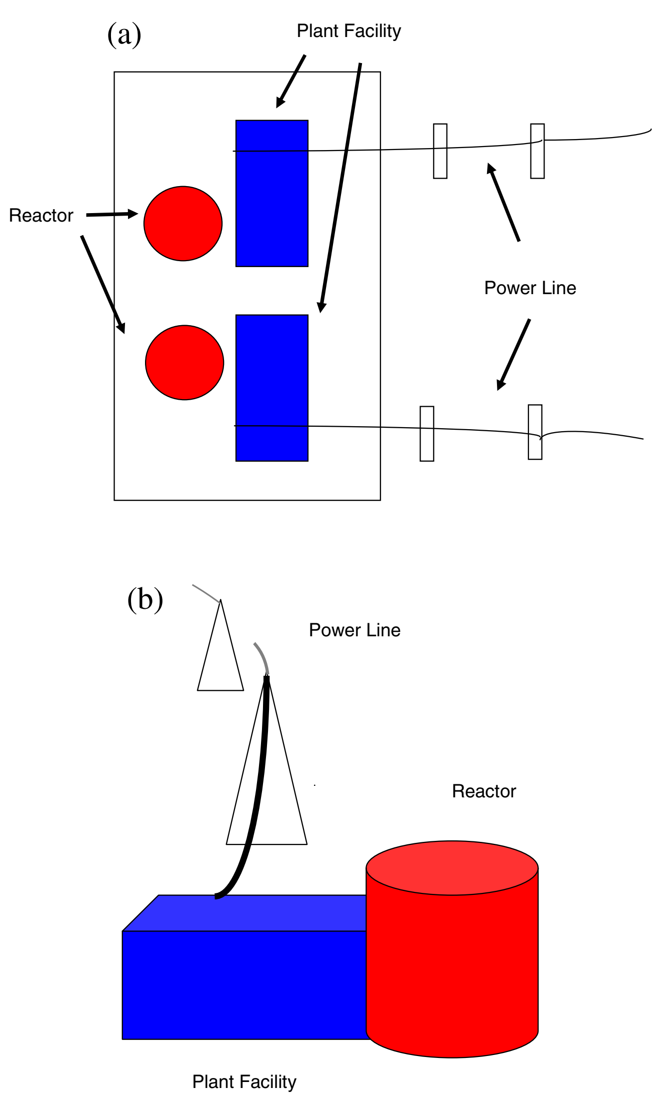

Fig. 1. Simplified configuration of Nuclear Power Plant (a) sky view and (b) side view. This shows the simplified configuration of Nuclear Power Plant as (a) sky view and (b) side view.

2. Method

The important thing of the application with the drone is to move and to detect the aerial radiation in the interested places. So, this study is done as the mechanics of the motion, radiation control, and the position mapping. These are explained as the examples for the NPPs site where the simplified descriptions are used.

2.1. The mechanics of the motion

In the modeling, there are the mathematical forms of the movement of the flying. According to the flight dynamics, there are three kinds of the parameters as roll, Pitch, and Yaw which are angles of rotation in three dimensions about the vehicle's center of mass (NASA, 2014). The easily understandable figure is also seen in Fig. 3 (The Smithsonian's National Air and Space Museum, 2014). For the angle control of the four thrust forces from four rotors, there are three angles $\emptyset, \theta, \psi$ and the altitude z to produce the six motions and then the control inputs are (Jeong and Jung, 2014),

$$
\begin{aligned}
V_{\emptyset} &= k_{p\emptyset}(\emptyset_d - \emptyset) + k_{i\emptyset}\int(\emptyset_d - \emptyset)dt + k_{d\emptyset}\left(\dot{\emptyset}_d - \dot{\emptyset}\right)\\
V_{\theta} &= k_{p\theta}(\theta_d - \theta) + k_{i\theta}\int(\theta_d - \theta)dt + k_{d\theta}\left(\dot{\theta}_d - \dot{\theta}\right)\\
V_{\psi} &= k_{p\psi}(\psi_d - \psi) + k_{i\psi}\int(\psi_d - \psi)dt + k_{d\psi}\left(\dot{\psi}_d - \dot{\psi}\right)
\end{aligned} \tag{2.1}
$$

where $k_{p\emptyset}, k_{i\emptyset}, k_{d\emptyset}$ are the proportional–integral–derivative (PID) controller gains for the roll angle control, $k_{p\theta}, k_{i\theta}, k_{d\theta}$ are PID controller gains for the Pitch angle control, and $k_{p\psi}, k_{i\psi}, k_{d\psi}$ are PID controller gains for the Yaw angle control. In addition, the altitude control of PID controller is shown as follows (Jeong and Jung, 2014),

$$V_{th} = (V_z + mg)\frac{1}{\mathrm{COS}\theta\mathrm{COS}\emptyset} \tag{2.2}$$

where m is the mass, g is the gravitational acceleration, and then V_z is,

$$V_z = k_{pz}(z_d - z) + k_{iz}\int(z_d - z)dt + k_{dz}(\dot{z}_d - \dot{z}) \tag{2.3}$$

where k_{pz}, k_{iz}, k_{dz} are PID controller gains for the altitude control and altitude data z can obtained by a sonar sensor.

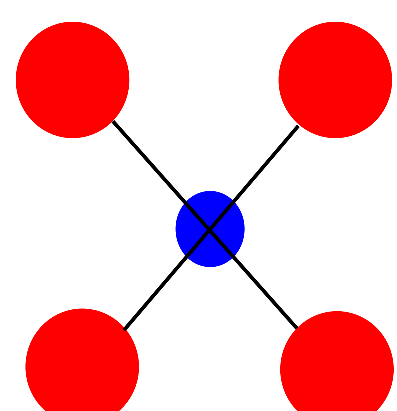

Fig. 2. Simplified configuration of flying robot. This is the simplified configuration of flying robot, drone.