Air-ground Collaborative System for Nuclear Accident Monitoring

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Abstract: Nuclear accidents involve radioactivity leakage, which can cause a catastrophic environmental disaster. Therefore, the emergency response to nuclear accidents is crucial in the early stages. Generally, nuclear power plants are huge and consists of many auxiliary buildings. In addition, the individual buildings are high, large and complicated. Therefore, it is practically difficult to acquire information of the accident with the existing robot systems in a quick manner. In this study, we propose a joint operation system of unmanned ground vehicle (UGV) and unmanned aerial vehicle (UAV) to perform rapid ground to aerial accident monitoring.

Keyword: Air, ground, drone, ATV, monitoring, nuclear, accident

1 Introduction

A nuclear power plant accident causes significant social costs. Therefore, when a nuclear accident occurs, a mobile monitoring system is required to take action immediately and prevent the spread of the accident during the early stage. Because radiation leaking from a nuclear accident can result in a loss of life, research on a remote monitoring system for nuclear facilities using a ground or aerial vehicle has been actively conducted.

In the case of the Fukushima nuclear power plant accident, many ground vehicles have been utilized for monitoring inside and outside the reactor buildings. Packbot is used to investigate and handle nuclear contamination inside the power plant, and Quince is used for measuring the radiation distribution around the reactor [1].

In addition, various types of drones were deployed in the air to relay accident situations in real time, and they are actively being used to measure environmental radiation dose around accident nuclear power plants.

In this study, we propose a joint operation system of unmanned ground vehicle (UGV) and unmanned aerial vehicle (UAV) to perform rapid ground to aerial accident monitoring.

2 Accident monitoring scenario

The robot system primarily consists of the two parts: an unmanned ground vehicle for wide area monitoring and an unmanned aerial vehicle for tall and complex area inspection. The ground vehicle has the ability to cover various types of terrain at high speed. It has a relatively small size and narrow width compared to the other existing robot vehicles, so it is an ideal mobile platform for travel inside and outside of buildings with monitoring devices and sensors. The aerial vehicle is attached to the ground vehicle and can inspect tall and complex facilities that the ground vehicle cannot reach.

As shown in Fig. 1, the ground and aerial vehicles approaches to the accident site at a fast speed. When the collaborative system arrives, the aerial vehicle takes off and starting to observe the whole accident situation. Based on the initial aerial monitoring information, the whole system moves to the area of interest. At the place, the ground vehicle collects information of inside and outside of the buildings, while the aerial robot operates to monitor the high and small area.

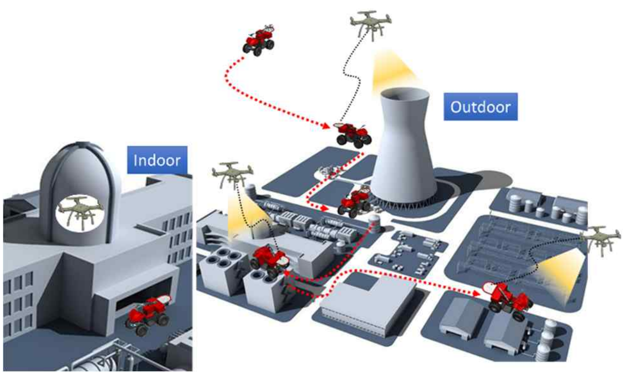

Fig.1 Monitoring scenario

3 Unmanned ground vehicle

A nuclear accident monitoring vehicle should have appropriate characteristics for the internal and external environment of a nuclear power plant. A nuclear power plant and the surrounding area consist of concrete structures, iron stairs, ramps, hills, and drains. Therefore, the ground vehicle is adaptable to these topographic features. In addition, it should be easy to control in order to gather information at a distance. A large payload and high speed are also required to travel rapidly to the site with measuring equipment.

Table 1. Decision Matrix

Criterion	Weight	Car	Forklift	Mini Excavator	ATV	Robot
Terrain adaptability	5	3	1	7	10	5
Control	5	8	5	5	7	10
Speed (~30km/h)	3	10	6	4	10	5
Payload (~30kg)	3	10	10	10	10	3
Turning radius	2	3	5	10	7	10
Narrow width	2	2	4	7	8	10
Reliability	4	10	10	10	10	3
Quantity	1	10	3	3	5	1
	Total	175	139	179	220	152

A nuclear power plant consists of various internal structures and equipment. Therefore, a narrow width and a small turning radius are required for the vehicle to move inside the reactor building. In addition, the ground vehicle as an emergency response system should be guaranteed with a high level of reliability.

To select the most appropriate vehicle, a decision matrix was built based on the requirement as a ground mobile monitoring platform. The candidates are automotive, forklift, excavator, ATV, and robotic platforms, which are commonly used for an emergency response. Each criterion has a rating of 1 to 10 points, and the weight on each criterion was set to 1-5 points, the results of which are as shown in Table 1.

As a result of the decision matrix, an ATV was selected as the most suitable mobile platform for nuclear power plant monitoring. An ATV is relatively easy to control and excellent in terms of terrain adaptability. It also has a decent payload and speed and can move in narrow terrain. ATVs are inexpensive, readily available, and highly reliable. In many previous studies, the all-terrain vehicle showed the superiority under this type of situation [2].

Table 2. Functions of Allcourt 100

No.	Functions	Engine start	Gear change	Drive	Park
1	Handlebar			O	
2	Brake lever(front)	O		O	
3	Brake lever(rear)	O		O	
4	Throttle lever			O	
5	Starter button	O			
6	Reverse lever		O		
7	Blinker button			O	
8	Main switch	O			
9	Gear change lever		O		
10	Hone switch			O	
11	Parking brake lever(front)				O
12	Parking brake lever(rear)				O
13	Emergency switch			O	
14	Head light			O	

3.1 Control degrees of freedom

An ATV is operated in four different modes (engine start, gearshift, driving, and parking). Each mode is composed of 14 functions (Table 2) and each function works independently. Therefore, 14 degrees of freedom (DOFs) are required for full control of the ATV.

When utilizing the actual 14 DOFs, the complexity of the system increases and control becomes more difficult. Hence, it is necessary to simplify the system by excluding the DOFs that do not directly affect the mobility.

Table 3 shows the DOFs required in the control according to the unmanned levels. If driving the ATV only forward, but removing other functions such as flashing, horn, emergency switch, headlamp, and rear brake, the least number of control DOFs in a two-dimensional plane is only three, i.e., the handlebar, front break lever, and throttle.

Table 3. Control DOFs required according to unmanned levels.

Required DOF	Autonomous level	Engine start	Gear change	Drive	Park
14	Fully-autonomous	O	O	O	O
10	Drive		O	O	
8	Forward drive only			O	
3	Forward drive only (without blinker, hone, emergency switch, light and rear brake)			O	

Fig.2 Unmanned ground vehicle

4 Unmanned aerial vehicle

Unmanned aerial vehicles can be classified into fixed wing and rotary wing depending on the shape of the fuselage. Fixed-wing aircraft are highly maneuverable, capable of high-speed, long-haul flights, but require a runway for takeoff and landing. In addition, it is not suitable for continuous monitoring of accident situation at one point due to difficulty in stopping flight.

Rotating wing aircrafts can vertically take off and land, therefore they are appropriate for carry and operation in a small space. Especially hovering capability is suitable for long-term accident area monitoring mission. The drones are the representative fixed wing aerial vehicle and have excellent maneuverability for wide-area monitoring tasks in the air. In this study, the octocopter type drones were selected as the airborne flying robot.

The wingspan of the octocopter is 1 meter and can take off to 11kg with a maximum output of 4kW.

The drones have sensors such as GPS, IMU, and barometer, and are equipped with a small camera for monitoring and a gimbal system. The landing gear was specially designed for landing on unmanned ground vehicles. In particular, a wired power transmission module is installed to overcome the short operating time, which is a weakness of the drone, to perform a long time mission, and it is possible to fly in the air for over an hour if necessary.

Fig.3 Unmanned aerial vehicle

5 Air-ground Collaborative System

The proposed UGV-UAV combined system, RAM (Remote control system for Accident Monitoring) was built as shown in Fig 4. The RAM runs at a maximum speed of 60 km/h with a payload of 160 kg and operation duration is over 5 hours in the distance of 1 km. The collected data will be sent to the operator to make crucial initial decision-makings

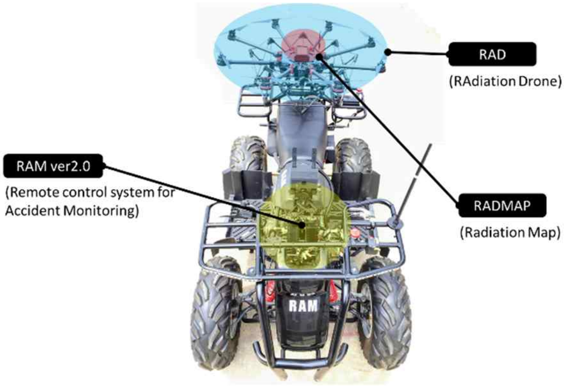

Fig.4 Air-ground Collaborative System, RAM

6 Conclusion and Future directions

In this study, we discussed about air-ground collaborative system for nuclear accident. The characteristics of the platform for the objective were defined and the ground and aerial vehicles were selected. Finally, the collaborative system, RAM was introduced.

In the future, we will verify the performance of the RAM through the mock-up environment, and improve the sensor and control systems.

Acknowledgement

This paper was supported by the Ministry of Science and ICT.

References

[1] Nagatani, Keiji, et al. Emergency response to the nuclear accident at the Fukushima Daiichi Nuclear Power Plants using mobile rescue robots, Journal of Field Robotics 30.1, 44-63.

[2] 2. Soto, Alvaro, et al. "Cyber-ATVs: Dynamic and Distributed Reconnaissance and Surveillance Using All-Terrain UGVs." (1999).

[3] Jongwon Park, Young-Soo Choi and Kyung-min Jeong, A Ground Vehicle for Monitoring Nuclear Accidents, ANS D&RS 2016