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Development of drone mounted aerial gamma monitoring system for environmental radionuclide surveillance in BATAN

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Abstract. Environmental radioactivity surveillance in a large area is undertaken commonly by using ground-based vehicle mounted gamma monitoring system or airborne gamma monitoring system. An alternative of using drone (unmanned aerial vehicle)-mounted gamma monitoring system may give advantages of saving resources and time, more rapid preparation and operation, fewer and safer operators, better access coverage area, and more flexible adjustment of flight parameters. A prototype of drone-mounted gamma monitoring system is under development in BATAN. The design of the system will consist of drone module and other modules mounted in the drone e.g. radiation detection module of a simple and lightweight CdZnTe gamma detector system that expected to be equivalent to one inch of NaI(Tl) in efficiency, position monitor module with a GPS, a telemetry-based data communication system with a radio frequency (RF) module for collecting data of radiation level, position coordinates, visual data locations and real time transfer to a receiver module located in a station where the data acquisition and analysis module will also be positioned. This paper reports the latest status of design development of the drone mounted gamma monitoring system based on the results of partial testing of the capacity characteristics of the drone module and the developed data transfer and receiver modules for the radiation levels and position coordinates.

1. Introduction

Gamma rays monitoring system has been widely used for many purposes in the field [1] including for search for radioactive material or orphan sources [2], geological and soil mapping [3], [4], [5], search for radioactive contamination in a post nuclear accident [6], [7], [8] and as part of verification regime equipment in such international treaty [9] and safeguard [10]. Indonesia has some areas of naturally high radiation background like in Bangka Island [11] and in West Sulawesi [12]. The increase trend of the use of radioactive materials for many purposes in the fields and their potential loss due to human negligence and thievery also need to be anticipated. Mapping of environmental radioactivity or radionuclide contamination or search for loss of radioactive materials in a large area commonly is undertaken by several methods, e.g. ground-based surveys by using hand held or vehicle mounted gamma monitoring system and aerial surveys by using airborne gamma monitoring system. The gamma monitoring system



mounted in a ground vehicle can be loaded with complete and relatively heavy equipment. However, the operation of the ground vehicle has limitations of the availability of road infrastructure that can be bypassed by the vehicle. Whereas, the airborne gamma monitoring system mounted in a helicopter will be more effective and efficient as it capable to access above the inaccessible area like buildings, forests, swamps, and mountains. Moreover, the use of a helicopter mounted monitoring system will give a larger coverage area of scanning in a rapid manner at 60 – 125 meters above the area. However it also has limitations on flight parameters (altitude, speed and line spacing) including operation costs, number of operators, time limit for flight, and time loss for refueling. To fill the gap between and limitations of the ground-based and manned aerial vehicles, the use of small unmanned vehicle (drone) became a potential alternative. The gamma monitoring mounted in a drone has been developed by many researchers, for example, design and testing of a radiation surveillance unit for an unmanned aerial vehicle have been undertaken by researchers in STUK, Finland [13], [14], and then IAEA declared their support on using unmanned aerial vehicle for environmental monitoring after a consultancy meeting as part of Action Plan on Nuclear Safety at 2013 [15]. Following the meeting, the trend on the development of the unmanned aerial vehicle system by member states has increased [6], [16], [17]. There are some advantages of using drone for gamma monitoring vehicle e.g. saving a lot of time and resources including more rapid in preparation and operation, fewer operators, good access coverage area that cannot be reached by conventional ground-based operation, more flexible adjustment of flight parameters like speed, altitude and line spacing compared to helicopter. The capability of drone to fly in lower altitude will give better detection efficiency due to the closer distance to the ground. The techniques for environmental radionuclide surveillance by using a remote-controlled vehicle is an improvement step to the currently popular use of a drone with camera on board to visualize such even in the ground. The drone is possible to take off and hovers in any place and flies along a pre-determined path. However, the use of drone-based vehicle for radionuclide monitoring still need some improvements and optimization, particularly the current state of lightweight detector technology, methods related to aerial surveys, and the appropriate drone capacity. A lightweight and compact instrument needs to be explored by taking advantages of the rapid development of digital instruments and information technology. In BATAN, the development of drone-based radiation monitoring system has been initiated by several researchers and engineers like Ahmad Rivai et al [18] and Joko Sunardi et al [19]. Ahmad Rivai et al have developed an environmental radiation monitoring system for nuclear power plant and Joko Sunardi et al have developed data acquisition system for searching of nuclear radiation sources using hexapod type drone. This paper presents the latest status of the design development of a drone mounted gamma monitoring system based on the results of partial testing of the capacity characteristics of a quad copter type drone and the developed data transfer and receiver system for the radiation levels and position coordinates.

2. Design of the Gamma Monitoring System

2.1. Conceptual Design

The designed gamma monitoring system for environment radionuclide surveillance shall be lightweight, simple, and easy to be operated and capable to map the environmental dose rate and preferable also to identify such radionuclide. The gamma monitoring system that will be mounted to a drone shall be capable to be used for mapping of naturally high radiation background or radionuclide contaminated areas, mapping of fallout, tracking a radioactive plume, and searching for radioactive sources. The designed system shall be capable for collecting data of radiation levels and theirs corresponding locations by using equipment for radiation detection, position monitor, and standard electronics and onboard computer for data collection. The collected data during the flight shall be transmitted in real-time to the ground station(s) using telemetry based data communication system with RF (radio frequency) or better option. Microcontrollers powered by lightweight smart phone size battery shall be the main electronic component

to be used to control the drone and to run the mounted modules. The radiation detection equipment shall be an independent module that can also be mounted to an airplane, a helicopter or a car. As a drone is capable to fly at lower altitude of around 10 - 20 m compared to commonly helicopter flight altitude of around 100 m, for the same radiation detection module the drone is expected to have detection efficiency up to 100 fold higher. In other words, a radiation detection module mounted to a drone requires detection efficiency two order lower than the one mounted to helicopter. This requirement will reduce the weight and size of the detection system and therefore allow of using smaller crystal size detectors like Cadmium Zinc Telluride (CdZnTe) semiconductor detector.

2.2. Detailed Design.

The gamma monitoring system will consist of drone module and other modules mounted in the drone e.g. lightweight radiation detection and position monitor modules with the main functions are to collect data of radiation level (count rate or dose rate) and the correspond coordinate of locations. The radiation detection module shall consist of CdZnTe semiconductor detector equivalent to one inch of NaI(Tl) scintillation detector in efficiency, a pre-amplifier and pulse shaper or digital signal processing system, and a multi-channel analyzer while the position monitor module will consist of a GPS monitored with a micro-controller. The both modules will be powered by an array of smart phone size batteries. The collected data will be transferred to receiver station located in a base-camp or field laboratory area real-timely through a telemetry-based RF (Radio-Frequency) communicator system. The RF module will consist of 433 MHz antenna, transmitter and a microcontroller. The drone will be driven by a remote control equipped with a smart phone that capable to monitor the drone position through image data by using a wireless communicator with 2.4 GHz antenna. A video camera may also be mounted in the drone for visualization of data location. To minimize equipment damage or missing, a software will be set in the micro-controller so that the drone will be able to return automatically to the takeoff location when it loss of contact with the remote control or when the charge of the battery low. The modules located in the ground shall consist of data acquisition and analysis system for processing the data received through the RF receiver. The ground modules display the digital maps taken from online mapping of google maps. The system will be completed with software for data fusion, e.g. processing and integrating data of radiation level, coordinate locations, altitude, and google maps.

2.3 Design of Cadmium Zinc Telluride (CdZnTe)-based detection module.

The choice of detector type as part of the radiation detection module is important because the drone module has weight and size limitations for onboard components and the flight efficiency shall not be reduced too much due to the payload. The radiation detector should be easily attached and detached from the drone. The detector should have low power requirements so that the integration into the drone will not affect so much to the battery power. CdZnTe semiconductor detector is preferably used for gamma ray detection due to the better energy resolution compared to NaI(Tl) detector at ambient temperature without need cooling system and therefore it significantly simplifies the system for practical uses including suitable to be mounted into a lower capacity of aerial vehicle like drone. One of the limitations of CdZnTe detector is the small crystal size that causes low detection efficiency. So the main development should be focused to increase the detection efficiency without sacrificing the energy resolution. Currently the available off-the-shelf products of single crystal CdZnTe are 0.5 cm³ up to 24 cm³ active volume [20]. To obtain the detection efficiency that comparable to NaI(Tl) crystal, an array of some CdZnTe crystals is an option solution as reported by Kwak et al [10] and many other authors. A typical aerial gamma monitoring system with NaI(Tl) detector mounted into a helicopter commonly use 3" x 3" or larger crystal sizes which is equal to 1.4 liters up to more than 60 liters of sensitive volume. However, as the flexibility of the flight parameters of a drone, e.g. speed, altitude, and line spacing, is better than helicopter, the detector efficiency can be increase by lowering the distance of drone to the ground. As the typical flight

altitude of helicopter is 100 m, the 10 m flight altitude of a drone can increase to detection efficiency of more than 100 fold or two order higher, so it will compensate to smaller sensitive volume of CdZnTe. Typical sensor of a CdZnTe detector with active volume of $2.5 \times 2.5 \times 6.1 \text{ cm}^3$ (0.0381 liters) need power consumption of about 250 milliwatts [17].

3. Equipment and Methods

For the initial testing, a quadcopter type drone module with four propellers was used. The drone consists of a AVR ATmega8 microcontroller functioned as electronic speed controller, a 11.2 V brushless motor powered by an array of three units of 4V lithium polymer (LiPo) batteries through a power distribution board, auto-pilot flight controller with Ardu Pilot 2.6 type of Ardu Pilot Mega module, frames and remote controller. The main specifications of the AVR ATmega8 microcontroller are internal memory of 8 k-bytes, internal SRAM of 1 Kbytes, 23 programmable I/O lines, one serial port, internal and external interruption sources and operation voltage 4 – 5.5 V. Prior operation, the microcontrollers have been loaded with relevance computer programs by using USB ISP Downloader and USB ISP Programmer hardware and BASCOM-AVR software. As the designed radiation detection module with ZnCTe semiconductor detector for gamma monitoring was still not available, the testing was done by using a simple radiation detection module with GM detector sensitive to alpha and beta particles. The radiation detection module completed with 400 V DC high voltage power supply, a pulse shaper circuit, and an AVR ATmega8 microcontroller functioned as counter and timer. Together with the position monitor module, the output data of the radiation detection module was used for the testing of the data communication system. The data communication system consists of RF module in the drone and data receiver module at the ground. The RF module consists of AVR ATmega8 microcontroller loaded with a computer program by using BASCOM AVR compiler, a Nice RF transmitter, and a 433 MHz antenna, while the data receiver module consists of 433 MHz receiver antenna and AVR ATmega8 microcontroller connected to radiation indicator module. The indicator module consists of an LED indicator and a buzzer.

4. Testing Results and Discussion

As a gamma detector was not used in the testing, the performance of the data acquisition and data transfer for the gamma spectra could not be reported yet. The testing started with investigation of the capacity characteristics of the drone. The quadcopter type drone has been tested for its payload and flight duration capacities. According to the specifications written by manufacturers, the maximum load capacity of the drone is 5 kg. It can be reported that the drone has been loaded with 1.1 kg load and the flight duration of 9 to 11 minutes without any trouble, while without any load the drone has been fly for more than 16 minutes. The limitation of the flight duration is the battery power capacity. The battery power system is mainly used to supply the brushless motors, while the power consumption for the micro-controller is relatively low, in the order of several hundreds milli-watts. A software has been set in the micro-controller so that the drone will return to the takeoff location automatically when it loss of contact with the remote control or when the charge of the battery getting lower with voltage indicator was below 11.1 V. This control mechanism is intended to prevent equipment damage or missing. It could be suggested that for more optimum uses, the drone carrying load capacity need to be increased up to more than 5 kilograms with the flight time of about 20 minutes by using higher battery power and higher brushes motor power.

The other testing has been done for the data transfer module. The testing started by setting net parameters, serial parameters, and RF parameters by using Network Module Communication Tools Software. The RF module is work both as data transmitter for sending data from the drone and as data receiver for receiving data in the ground stations or base-camp laboratory. The testing was focused on the farthest distance from the drone to the receiver which the data can be sent smoothly. It can be reported that the RF has been tested for several distances. The drone was positioned at the altitude of 16 m, and the distance from the drone to the receiver was varied from a short to farthest distances. As results, the data can be received well up to the distance of 500 m. However, the data cannot be received at the distance of 450 m when there was an obstacle between the drone and the receiver. It means that without obstacle the drone will be capable to cover the area with radius of 500 m or equal to about 0.785 km². As comparison, the use of helicopter for mapping of 1000 km² with line spacing of 100 m need more than 1150 line-km. As the typical helicopter speed for a small up to medium radiometric survey is around 125 km/h, this survey require 9 – 10 hours continuous operation. This operation cannot be completed in a single flight because the helicopter commonly capable to fly only for 2 to 2.5 hours, depending on the fuel capacity. It can be concluded that the covered capacity of a drone is not comparable to the covered capacity of a helicopter. The use of telemetry based data communication system limits and forms the covered area as a circle. Therefore the monitoring work using a drone need different strategy of scanning compared to helicopter. It arise a new idea that in addition to the use of multi-array detectors to the system, the use of multi-drone may provide more effective operation coverage. Furthermore, as the current AVR Atmega8 microcontroller can be functioned only for counter, timer, and serial data communications, so a different type of microcontroller is required to be functioned as a multi-channel analyzer for gamma rays spectra in the radiation detection module. The microcontroller suggested by Shahid Khan [21], J M Cardoso et al [22], or Arduino and Theremino type microcontrollers [23] may be used.

5. Summary and Conclusions

The development of drone mounted gamma monitoring system that could be used for environmental radionuclide surveillance has been initiated. The drone and the developed data transfer and receiver modules have been tested by using beta sensitive GM detector system as a temporary sensor. The designed system is still not fulfilled by the current realization. To be a complete system, the gamma sensor of lightweight array of CdZnTe semiconductor detectors with detection efficiency equivalent to one inch of NaI(Tl) need to be realized and the data acquisition, analysis, and fusion system need to be tested. A more powered drone with capacity of 5 – 10 kg is required to carry the radiation detection and other modules.

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