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드론과 센서를 이용한 저수지 수량 측정 시스템에 관한 연구☆

A Study on Measurement System for Water Volume of the Reservoir using Drone and Sensors

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요 약

현재 건설되고 있는 댐이나 농업용 저수지와 같은 하천 시설의 준설은 안정적인 저수량을 확보하기 위해 이루어져야 한다. 그러나, 저수지나 댐의 정확한 담수량을 실시간으로 알려 주는 시스템을 찾기는 어렵다. 이러한 측정을 위해서는 매우 정확한 데이터를 실시간으로 수집하고 분석하기 위한 자동화된 시스템이 필요하다. 본 연구에서는 드론을 이용한 다중분할체적 계산을 통해 저수지의 담수량을 실시간으로 측정하는 방법을 제안하고 있으며, 이 방법을 이용하면 침전물 상태를 실시간으로 감지하고 정확한 준설 시기와 규모를 파악할 수 있다.

☞ 주제어 : 드론, 담수량, 웨이포인트, 다중체적계산법, 센서

ABSTRACT

Social dredging of various river facilities, such as dams and agricultural reservoirs currently being constructed, should be done to ensure stable reservoirs. However, it is difficult to find a system that tells the exact amount of water in real-time in a reservoir or dam. These measurements require an automated system to collect and analyze highly accurate data in real time. In this study, we propose a method to measure the amount of water and soil of reservoir in real time through multi-division volume calculation using a drone, and this method can detect sediment conditions in real time and determine the exact timing and scale of dredging.

☞ keyword : Drone, Water volume, Waypoint, Multi-division volume calculation, Sensors

1. Introduction

Over the past few years, many dams have been built across South Korea with the aim of controlling floods, maintaining adequate river discharges for various water supply, hydroelectric power and water conservation. The government has spent a lot of money each year on dealing with floods, droughts and water pollution, but it cannot be said to have improved as much as it has spent. Therefore, dredging of various river facilities, such as dams and agricultural reservoirs, must be performed in order to perform their original functions such as stable water storage, and accurate measurement of water and soil mass is required to determine the exact dredging time and the size of dredging. [1]However, it is difficult to find a system that provides real-time information on exact amount of water and soil. These measurements should collect and analyze very accurate data in real time using automated systems rather than manual tasks.

In this study, a method of measuring the amount of water and soil in real time through multi-division calculation using drones is proposed. This information, such as changes in desalination and sedimentation conditions, detection of hazards, accurate dredging time and size, will be useful for management agencies such as dams and reservoirs.

The order of rest of this paper is as follows. We first describe the background and the related work in Section 2.

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The architecture design of drone, server, and terminal, waypoint design, and calculation method are proposed in Section 3. And, finally we conclude this paper in Section 4.

2. Related Study

The measurement method of water and soil volume has been steadily developed. Measurement method using water pressure sensor is often different from actual quantity as it is not possible to compensate for changes in sensor load due to deposition of soil or suspended solids. In the case of water level measurement methods using ultrasonic sensors, which are widely used in recent years, sound waves are used, and the results of measurement vary according to the density of the medium due to climate change, which requires periodic and ongoing correction and management. Due to the development of information and communication technology and the diversification of spatial information services, various measuring equipment and methods are being developed, and modeling techniques based on various sensors such as radar and optical cameras are being used.

The IoT-based small reservoir or dam water and soil deposits monitoring system measured in the real-time through modeling and provided the related information with video information. This system was developed to provide information for detecting changes in the conditions of reservoirs or dams, and identifying the exact dredging period and dredging size. [2]

In the field of civil engineering, studies are being conducted on various technologies of utilization using drones. In particular, research is being carried out to generate various spatial information using cameras or sensors that can be mounted on drones, and to quickly produce terrain monitoring data. In Korea, research is underway on the use of drones to produce three-dimensional field information on civil construction sites or monitoring reservoirs for disaster prevention. [3]

Today, most researchers and manufacturers are always interested in drone and IoT with sensors because of its potential applications in many areas, such as military, industrial and civilian areas. Sensors is a basic component of IoT, which is the core of machine-to-machine communication and the future Internet. Various methods are proposed to efficiently operate disaster safety systems that link drones with IoT sensors, and many studies are also going on regarding open disaster safety systems that link and operate disaster safety services using drone control system and IoT sensor platform based on Cloud. [4][5]

To measure the water volume of a reservoir, the water level of the reservoir was measured using a buoyant and ultrasonic water level meter.

The buoyant water level system measures the level with the height of the buoy, and since the level is measured based on a previously formed floor without taking into account the amount of soil deposited in the reservoir, the reliability of water volume was reduced by the most error rate.

Ultrasonic water meter is a method of measuring the distance of water, and since the distance of water is measured, it is difficult to measure the distance of the water level as the medium changes depending on the climate change and the measured value of the water level changes. [6]

Unlike the conventional water level measurement method, the water level is measured using a laser sensor while automatically flying to designated points on the water surface of the reservoir and keeping the surface hovering using a drone, and the water level is measured using a multi-point water level measurement method, which is an optimal method of storing information while moving to another point.

3. System Design

3.1 System Architecture Design for Drone, Server, and Terminal

Water and soil measurement system using a drone as shown in Figure 1, consists of a drone to automatically make a flight to either of the preset water level measurement locations and hover close to the water surface to measure the water level and produce a value of water level, a drone station for storing and charging a drone, a server for calculating amount of water and soil by dividing the volume of the reservoir for setting the level measurement location and calculating the volume of each level measurement location by receiving the level value from the drone, and a terminal for receiving and displaying calculated amount of water and soil.

(Figure 1) Water and Soil Volume Measurement System using a Drone

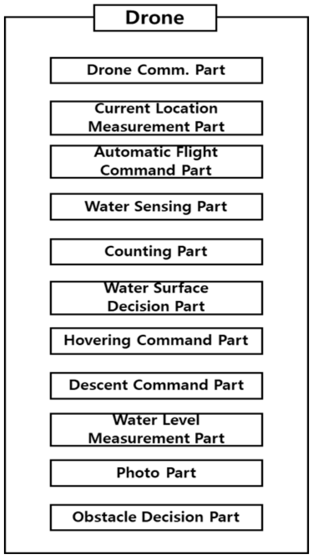
Figure 2 shows a drone architecture design in water and soil volume measurement system. The drone consists of Drone Communication Part to communicate with the server, Current Location Measurement Part to measure the current location of the drone, Automatic Flight Command Part to preset the sequence of flights and order automatic flight in order to make a flight by level measurement location received from the server via the Drone Communication Part, Water Sensing Part to generate a water sensing signal, while locating at water level measurement location via Automatic Flight Command Part, Counting Part to count the water sensing signal generated from Water Sensing Part, Water Surface Decision Part to determine if it is located on the water surface, based on the determination whether the number of counts from Counting Part and the preset normal sensing signal are same, Hovering Command Part, Descent Command Part, Water Level Measurement Part, Photo Part to photograph the surface of the water level measurement location, and Obstacle Decision Part to determine which obstacle exist on the surface of the water, which is taken a photograph via Photo Part.

In the case that Water Surface Decision Part decides it is the surface, Hovering Command Part is operated for commanding the hovering.

In the case that Water Surface Decision Part decides it is not the surface, Descent Command Part is operated for commanding the descending flight vertically.

The Water Level Measurement Part is operated to measure the level of the level measurement location by examining the laser beam when hovering through the Hovering Command Part and touching the water surface.

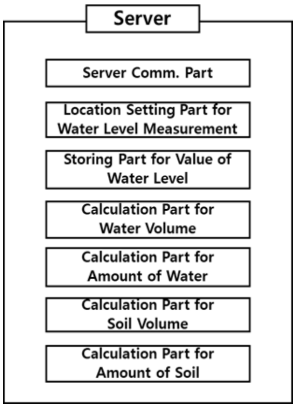
A Drone Communication Part uses wireless network to communicate with the server. The Current Location Measurement Part can measure the location of the current drone by installing GPS inside the drone and measures the location of the drone from time to time. The Automatic Flight Command Part receives multiple water level measurement locations from the server through the Drone Communication Part and sets the flight order in advance to make a flight to a number of water level measurement locations.



(Figure 2) Drone Architecture Design in Water and Soil Volume Measurement System

The Automatic Flight Command Part orders automatic flight by controlling the direction of flight in comparison to the position of the current location measured by the Current Location Measurement Part and the location of the level measured by the flight order, in order to place the drone at the level measurement location according to the set flight sequence.

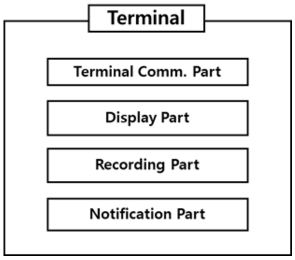
Server Architecture Design in Water and Soil Measurement System is shown in Figure 3, which consists of Server Communication Part to communicate with the drone, Location Setting Part for Water Level Measurement to set in water level measurement location, Storing Part for Value of Water Level to receive and store values of water level by location of measurement, Calculation Part for Water Volume to calculate the water volume by water level measurement location, Calculation Part for Amount of Water to calculate the total water amount by adding the water volume calculated by level measurement location, Calculation Part for Soil Volume to calculate the soil volume by level measurement location, and Calculation Part for Amount of Soil to calculate the total amount of soil by adding the soil volume calculated by level measurement location.



(Figure 3) Combinable Multi-functional Portable Status Measurement System

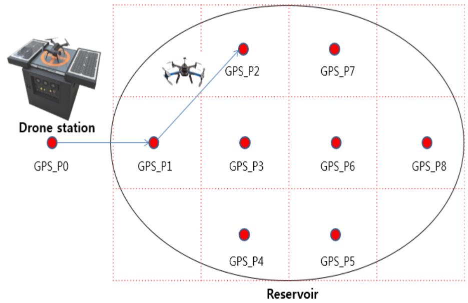
The Calculation Part for Water Volume shall be stored for each location of water level measurement, and the values of the horizontal axis and the vertical axis of the volume by each level measurement can be calculated using the values of the water level stored in the Storing Part for Water Level Value and the values of the water level and the values of the water volume.

Figure 4 shows Terminal Architecture Design in Water and Soil Volume Measurement System, which consists of Terminal Communication Part to communicate with the server, Display Part to display amount of water and soil received from the server via the Terminal Communication Part, Recording Part to record amount of water and soil received, and Notification Part in order to notify the recorded amount of water and soil if the amount exceeds the stored proper amount of water and the soil. The Recording Part shall record the amount of water and soil. Because of the Recording Part, the amount of water and soil in the reservoir can be checked, and disasters can be predicted in advance.



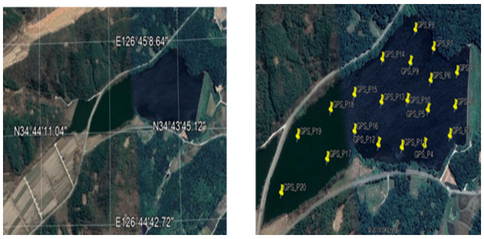
(Figure 4) Terminal Architecture Design in Water and Soil Volume Measurement System

3.2 Waypoint Design



(Figure 5) Waypoint Flight Concept Diagram based on GPS

Multiple divisions for precise measurement of the reservoir desalination are performed based on map data from the designated reservoir. GPS information at a corresponding location is measured and stored in a drone for self-driving waypoint with each surface divided on Figure 5. The waypoint setup process of drone is following. First, the target reservoir is selected and the coordinates of the target site through the Google Earth is check. Using Google Earth's icon addition function, we set the coordinates of the waypoint and by extracting the GPS coordinates which is automatically generated, and set them as the waypoint coordinates required for the drone's autonomous flight. To test the drone's GPS-based waypoint autonomous flight, the Google Earth screen was set up at Hakdong Reservoir in Gangjin-gun, Jeollanam-do in Figure 6 (a). Using the Google Earth icon addition function, the waypoint coordinates is set as shown in Figure 6 (b).



(Figure 6) Google Earth screen (a) and waypoint coordinates set up screen (b) in Hakdong Reservoir

(Table 1) Waypoint GPS Coordinate for HakDong Reservoir

	Latitude	longitude
GPS_P1	34°43'41.95"N	126°45'1.75"E
GPS_P2	34°43'42.68"N	126°44'59.25"E
GPS_P3	34°43'43.65"N	126°44'57.28"E
GPS_P4	34°43'46.29"N	126°44'57.10"E
GPS_P5	34°43'45.50"N	126°44'59.55"E
GPS_P6	34°43'44.82"N	126°45'1.68"E
GPS_P7	34°43'44.09"N	126°45'4.05"E
GPS_P8	34°43'45.78"N	126°45'5.94"E
GPS_P9	34°43'46.72"N	126°45'3.44"E
GPS_P10	34°43'47.48"N	126°45'0.63"E
GPS_P11	34°43'48.56"N	126°44'57.35"E
GPS_P12	34°43'50.84"N	126°44'57.98"
GPS_P13	34°43'50.15"N	126°45'1.03"E
GPS_P14	34°43'49.65"N	126°45'4.25"E
GPS_P15	34°43'52.87"N	126°45'2.11"E
GPS_P16	34°43'53.11"N	126°44'59.42"E
GPS_P17	34°43'55.97"N	126°44'57.99"E
GPS_P18	34°43'55.38"N	126°45'1.45"E

The GPS coordinates set automatically when the icon is added are shown in Table 1.

In this study, the target GPS coordinate information and the current GPS coordinate information of the current drone are compared to calculate the travel distance and travel angle for the drone's autonomous flight. The travel distance between GPS coordinates and the travel direction are calculated, using Equation (1), (2).

radian_distance = acos(sin(Lat1) * sin(Lat2)
+ cos(Lat1) * cos(Lat2) * cos(Lon1-Lon2))
distance(kM) = radian_distance * 3437.7387 * 1.852
--- Equ. (1)
direction = acos((sin(Lat2) – sin(Lat1)
* cos(radian_distance)) / (cos(Lat1)
* sin(radian_distance))) * (180/π) ----- Equ. (2)

Lat1 : Latitude of current location
Lat2 : Latitude of goal location
Lon1 : longitude of the current location
Lon2 : longitude of the target location

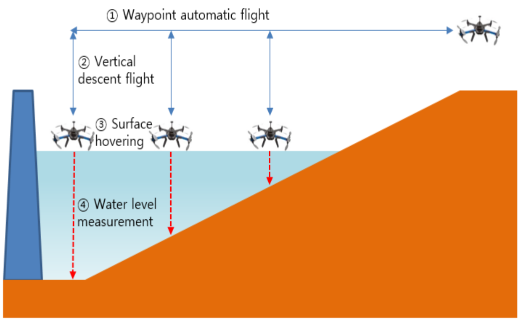
(Table 2) Measurement result of autonomous flight accuracy of drone

way point	Preset GPS Coordinates		Drone's actual GPS coordinates		Distance error (m)
	Latitude	longitude	Latitude	longitude	
GPS_P1	34.434195	126.451075	34.434172	126.451051	3.3
GPS_P2	34.434268	126.445925	34.434278	126.445932	1.3
GPS_P3	34.434365	126.445728	34.434378	126.445736	1.6
GPS_P4	34.434629	126.44571	34.434639	126.44579	7.4
GPS_P5	34.43455	126.445955	34.43462	126.445961	7.8
GPS_P6	34.434482	126.451068	34.434492	126.451078	1.4
GPS_P7	34.434409	126.454005	34.434419	126.454017	1.6
GPS_P8	34.434578	126.455094	34.434603	126.455095	2.8
GPS_P9	34.434672	126.453044	34.43469	126.453052	2.1
GPS_P10	34.434748	126.450063	34.434762	126.450051	1.
GPS_P11	34.434856	126.445735	34.434872	126.445751	2.3
GPS_P12	34.435084	126.445798	34.435068	126.445772	3.0
GPS_P13	34.435015	126.451003	34.435034	126.451022	2.7
GPS_P14	34.434965	126.454025	34.434943	126.454012	2.7
GPS_P15	34.435287	126.452011	34.435261	126.452031	3.4
GPS_P16	34.435311	126.445942	34.435334	126.445965	3.3
GPS_P17	34.435597	126.445799	34.435572	126.445763	4.3
GPS_P18	34.435538	126.451045	34.435552	126.451067	2.5
GPS_P19	34.43588	126.450013	34.435898	126.450032	2.7
GPS_P20	34.44005	126.445658	34.440077	126.445682	3.7

The distance between two GPS coordinates and their direction of travel can be obtained by substituting the longitude and latitude values for the equation. The direction of travel indicates the angle between the straight line and north direction, when a straight line between the two coordinates in made. This allows the drone decide the direction to be moved. After calculating the direction of travel and the direction travel and rotating the drone in to the fixed angular velocity (0.087rad/sec) in order to adjust the direction to be moved, move the drone forward at a constant speed by the calculated distance.

In this study, control signals from embedded boards were matched to signals transmitted through conventional controllers in order to control autonomous drone flights. Through testing, the control signals of the Elevator, Rudder, Aileron, and Throttle used to control the drones were generated through the embedded board in the same way as the signals transmitted through the controller. The accuracy of the drone's autonomous flight was assessed for the Waypoint shown in Table 1.

As shown in the results of the measurement of the accuracy of the autonomous flight of the drones in Table 2, all 18 measurements on the target points showed 100% self-flight accuracy by flying within the error range of 10 m.



(Figure 7) Waypoint Autonomous Flight Procedure

Figure 7 shows the basic configuration of the system and the drone moves first to the level measurement point via the waypoint autonomous flight. Second, vertical downward flight is performed by utilizing information for calculation of surface points through measurement of laser sensor that is mounted on drones. Third, drones that reach the surface of the water perform hovering. At this point, the laser sensor is in contact with the water surface. Fourth, water level measurement is performed by laser sensors that are in contact with the water surface.

Once the measurement for the level is complete, the drone fly up to the waypoint, and then move to the next waypoint to proceed with the iteration.

In this study, SF11 laser altimeter is used to measure level by attaching it to drones. The SF11 laser altimeter is an essential feature for unmanned aircraft that requires fast, accurate, and reliable AGL altitude measurements for ground and water.

SF11 works by measuring the time it takes for laser light to move to the ground and back again in a very short time. The accuracy of the measurement is not affected by the color or texture of the ground or by the angle of incidence of the laser beam. Operating on standard 5 V DC power, SF11 includes both analog and digital interfaces that can be easily connected to a Pixhawk flight controller or other standard processing platform. Each interface on SF11 can be accessed via a built-in micro USB port.

(Table 3) SF11 Specification Details

	SF11/C (120 m)
Range	0.1~120meters(natural targets), 2~40 meters (moving water)
Resolution	1 centimeter
Update rate	16 readings per second
Accuracy	±0.1 meter
Power Supply Voltage	5.0 V ± 0.5 V DC
Power Supply Current	200 mA (maximum)
Outputs & interfaces	Serial, I2C & analog
Dimensions	30 x 56.5 x 50 millimeters
Weight	35 grams (excluding cables)
Connections	Plug & socket, micro USB
Laser power	15mW (average)
Optical aperture	51 millimeters
Beam divergence	0.2°
Operating temp.	0~40°C
Approvals	FDA: 1410968-002 (2016/01)

Drone control is simulated using the flight control API DroneKit for ArduPilot-based drones and the SITL Simulator, software simulator. In addition, an algorithm that can measure level through water surface hovering flight is simulated by utilizing Raspberry Pi and Laser Sensor (SF11). DroneKit is an open API provided by 3D Robotics, which connects drones and Ground Control Station (GCS) to provide status information and operational commands. Based on Python programming language, DroneKit API was utilized to produce and test drone control code in this paper.

Based on the data, an algorithm was designed to autonomously modify the flight control for water surface hovering in Table 3.

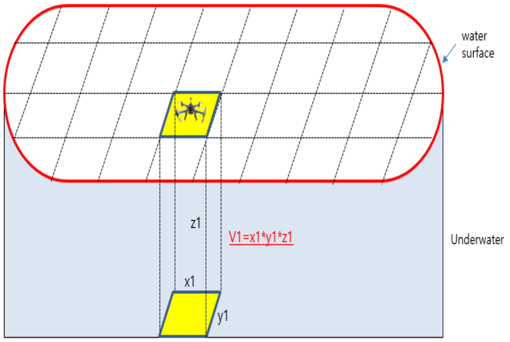
3.3 Calculations Method

The Zn value is obtained by measuring the level information using a laser sensor attached to the drone while sleeping on each segmented volume surface. From the x1, y1, z1 information obtained at point 1, the segmented volume V1 is calculated.

$$V1 = x1*y1*z1$$

When the drone obtains information of each partition through autonomous by point, it finally calculates the total volume of desalination information.

$$Volume = V1+V2+V3+ \cdots. +Vn$$



(Figure 8) Drone Waypoint Flight and Algorithm for Water Level Measurement

After a certain period of time, the difference between the sum of the unit volume (Volume) measured at the same point and unit volume measured (Volume')

after increasing level due to inflow of soil into the reservoir, is calculated at each time of the measurement. Figure 8. illustrates the process of obtaining a segmented volume V1' through the level information z1' measured at point 1 after a certain period of time. The desalination increase at point 1 measured after a specified time can be calculated as V1-V1'.

4. Conclusions

Unlike previous water level measurement methods, the proposed technology maintains surface hovering while flying at designated points of reservoir surface using a drone, and measures level using laser sensors to store optimal information and move to different points. In addition, it is allowed to measure the desalination of water in a precise reservoir by performing a multi-division volume calculation using the level information obtained by point.

This study indicates that the improvement of the existing dam/reservoir integrated management system will enable stable water storage capacity of the stream facilities and predict the accurate dredging time and dredging size.

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