Design and Concept of the Sediment Sampling Robot and Dynamic Buoy

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***Abstract*— In this paper, we present a new design and concept of the sediment sampling robot capable of collecting samples for water quality monitoring. In addition, we describe a dynamic buoy designed to transport the sediment sampler to desired sampling point. With this improved concept and approach, we will be able to realize a fully autonomous water monitoring system that can be used in various environments.**

I. INTRODUCTION

As the importance of the water monitoring system increases, various types of unmanned vehicles and robotic devices have been developed to more frequently collect large data. Unmanned Surface Vehicles (USVs) and robotic floating sensors have developed and validated their performance [1][2]. Since collecting water and sediment samples is necessary to monitor water quality, robotic samplers have been developed to reduce the cost of the sampling process and to help users sample more effectively [3]. In the previous research, we developed an underwater sediment sampling robot to sample sediment with the proposed method [4]. This was the first step to the proposed autonomous water monitoring system; however, many challenges and problems remain. Designing an improved sediment sampling robot and unmanned vehicle to send the sampling robot to the sampling location is the next step. Fig. 1 shows the concept image of the sampling system, comprised of the sediment sampling robot and unmanned vehicle.

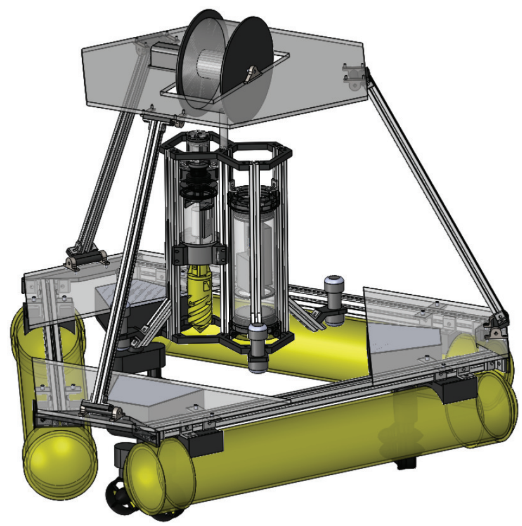

Fig. 1. A concept image of the sampling system: Sediment sampling robot, Dynamic buoy.

II. SAMPLING SYSTEM DESIGN

The main objective of this paper is to design an improved sediment sampling robot and an unmanned vehicle called a dynamic buoy. The sediment sampling robot and the dynamic buoy are the main components of the sampling system. The role of the sampling system is to collect meaningful samples for monitoring. The dynamic buoy will transport the sediment sampling robot to the desired sampling points and maintain its position during the sampling process.

A. Improved sediment sampling robot

From the development of the first version of the sediment sampling robot, we discovered areas for improvement. The main challenge of the sampling robot is stability control during the drilling process. In the previous work, the stability control system was implemented and its performance was validated. However, there were some arbitrary fluctuations in the attitude angle from the sensor reading at the beginning of the sampling process. More sensitive and accurate stability control systems should be designed based on repulsive force analysis. The repulsive force acting on the sediment sampling robot is closely related to the size and weight of the robot, the design of the drill, and the sediment type. Stability when the sediment sampling robot is not in drilling process, also should be improved. The current robot is stable as the center of gravity is below the center of buoyancy due to its bottom-heavy design. Nonetheless, the distance between the center of buoyancy and center of gravity must be increased in order for better stability.

The waterproofing of the mechanical and electrical hardware components is another challenge. In the previous work, the electrical components (e.g. microprocessor, motor controllers, and power supply) were located outside of the water, only the motors were sealed with 3D-printed enclosures. With this composition, multiple wires were exposed to the water and the tension acting on wires could cause disconnection of the wire. For the improved sediment sampling robot, the acrylic tube and cap with multiple layers of O-rings are used for the enclosure of the hardware components, which is the most common method in underwater robot development. All the electrical components including the battery will be installed in the enclosure (right acrylic cylinder), as shown in Fig. 2. Only the physical rope and network cable are connected to the dynamic buoy. Moreover, since the least

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Fig. 2. A concept image of the improved sediment sampling robot.

waterproof point is where the bearing and the connection shaft of the DC motor and drill is assembled, development of the sealing system of the bearing and rotating shaft still remains a problem.

B. Dynamic buoy

The purpose of the dynamic buoy is to transport the sediment sampling robot to the desired sampling location and maintain the position of itself during the sampling process. Key challenges include the navigation and stationary positioning system designs. The navigation system is required to deploy the sampling robot to the particular sampling point. The dynamic positioning system is necessary for the dynamic buoy to maneuver the same location while the sampling robot is sampling. The sampling robot is physically connected to the dynamic buoy by the rope to reach the bottom of the water and return to the surface. The rope withstands the tension between the sampling robot and dynamic buoy. The network cable is also connected to receive data from the sampling robot and send control commands. The dynamic buoy is composed of three parts: main platform, propulsion module, and cable reel module.

1) Main platform: The geometry of the main platform is based on the tetrahedron as shown in Fig. 1. The main platform size is subject to the size of the sediment sampling robot. Since the height of the sediment sampling robot is $526.36mm$, the height from the base to the top of the main platform should be taller than that. The length of each hull is $1,016mm$ to make a passage for the sediment sampling robot. The hull is cylindrical shape and the base plate is installed above the hull structure. The propulsion module will be installed at each corner of the main platform. On the top of the main platform, the cable reel module will be installed. The key design challenge for the main platform is stability. It must float and maintain stability with the weight of the structure, propulsion module, cable reel module, and sampling robot. In addition, optimizing the tetrahedron design is another challenging problem.

2) Propulsion module: The main purpose of the propulsion module is to generate maneuverability of the dynamic buoy. The propulsion module is inspired by the thruster unit, called an azimuthing podded drive (AZIPOD) [5]. This thruster unit increases the maneuverability of the large vessel. In the AZIPOD unit, the propulsion module is connected to the pod unit. The propulsion unit is composed of the main motor and the propeller, which is directly connected to the motor shaft. The pod unit rotates the propulsion unit. The underwater thruster of small unmanned vehicles will be used as the propulsion unit and the step motor will be used as the pod unit to rotate the thrusters. The key challenge here is calculating the required thrust force to create maneuverability of the dynamic buoy.

3) Cable reel module: A network cable reel, DC motor, rope and network cable are the main parts of the module. The main purpose of the cable reel module is to generate descending, landing, elevating, and holding processes for the sediment sampling robot. For each process, accurate position and speed control is required. In case of the descending process, the speed should be synchronized with the underwater freefall speed of the sediment sampling robot. Landing is the challenging part. The cable reel has to stop when the robot satisfies the stable landing. If the sediment sampling robot lands on the unsettled surface, the sampling robot cannot begin drilling. The challenge here is that how system can identify the stable landing and stop the cable reel. After drilling, the cable reel elevates the sampling robot outside the water on the dynamic bouy. After elevating, the cable reel must hold the sediment sampling robot securely, in particular when the dynamic buoy is moving.

III. FUTURE WORKS

An underwater sediment sampling robot was developed as the first step in realizing an autonomous water monitoring system. In this paper, We presented the design and concept of the improved sediment sampling robot and the dynamic buoy as next steps. The stability control design, drill design and water sampling system installation of the sediment sampling robot remain as challenges. The navigation and dynamic positioning system development are the main challenges for the dynamic buoy. In addition, the field test of performance validation is our future works.

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