Towards an Autonomous Water Monitoring System with an Unmanned Aerial and Surface Vehicle Team

Jun Han Bae, Eric T. Matson, and Byung-Cheol Min

***Abstract*— In this paper, we describe a grand vision of our project, which is to develop an autonomous water monitoring system by operating an unmanned aerial and surface vehicle collaboration team with the focus on large and long rivers. Key backgrounds and challenges in realizing this vision are briefly outlined, and we show a simple path planning for an unmanned surface vehicle for the effective water sampling in the Wabash River, the natural river in the US, as one of our envisioned scenarios. Lastly, some future works are described.**

I. Introduction

A river is one of the most important natural resources to conserve. A river provides not only the drinking water but also the fresh water for agriculture. A survey by the US Environmental Protection Agency (EPA) reported, however, that approximately 40 percent of rivers and lakes in US are polluted [1]. Although a number of organizations and corporations put great efforts into improving water quality, it is still challenging to monitor and understand large and open water features such as rivers, large lakes, and seas. For example, collecting samples for a long duration, in deep or distant places is one of the challenging tasks. [2].

A main objective of this research is to develop an autonomous water monitoring system with an unmanned surface and aerial vehicle team for long and large rivers. The Wabash River is a great target of our research in that the river is the main stream in Indiana [3] and it flows over 503 miles across the 92 counties (33,000 square miles). The Wabash River is Indiana's official state river and the longest free flowing river east of the Mississippi. The Wabash River and its connected streams and rivers provide drinking water to approximately 70% of Indiana counties and are home to 120 endangered, threatened, or rare plants and animals [3]. Therefore, it is vitally important and our responsibility to conserve such an important natural resource.

II. Backgound

Collecting water sample is one of the most important activities prior to monitoring the condition of the water properly and effectively. Current water sampling methods are generally based on human samplers (i.e., they dip a bottle into the water off the side of a boat) [4], floating sensor devices [5], aerial vehicles [2], and surface vehicles [6]. A human water sampling is the most common technique, and it has played a pivotal role in the activity. However, this technique entails some inherent disadvantages. For instance, in case of a large river with fast flow, it is dangerous to the samplers (see the left of the Fig. 1). In addition, it is slow and costly because human samplers should move on to sites for conducting a water sampling on their own. In fact, since fall of 2009, the Wabash River Enhancement Corporation (WREC) has conducted a snapshot assessment of water quality of the Wabash River watershed. Around 250 volunteers were involved in water sampling project and there were 169 sampling points. Volunteers monitored temperature, water cloudiness (turbidity), nutrient levels, and pathogen concentrations. This annual activity shows the importance of the river monitoring, but it requires a great deal of time and human samplers.

Fig. 1. The left image shows a human conducting water sampling [7]. The right image shows an Unmanned Surface Vehicle (USV) developed for water monitoring by CMU [6].

Recently, autonomous water monitoring systems composed of mobile sensors for real time monitoring and data collection have been introduced [5]. The research team at the University of California, Berkeley developed floating sensor devices, deployed the devices to Sacramento-San Joaquin River, and validated their performance. However, a fixed positioning required for a long monitoring remains difficult because the developed system is designed to be floating on the water and thus is not capable of recovering a position deviation. In addition, the system can only be deployed and retrieved by a human as it is not motorized.

As the development of Unmanned Aerial Vehicle (UAV) has been greatly evolved, the use of UAVs has been also introduced and applied for a water sampling task. For instance, Nebraska Intelligent Mobile Unmanned Systems Lab developed an autonomous aerial water sampling system using an UAV to obtain scientifically useful water samples [2]. With its agility, the system can be quickly sent to disconnected water sites from a single deploy point. However, this system is more suitable for small areas (e.g., streams or ponds) due to its relatively short operation time.

Unmanned Surface Vehicle (USV) (as shown in the right

Jun Han Bae, Eric T. Matson, and Byung-Cheol Min are with the Department of Computer & Information Technology, Purdue University, West Lafayette, IN 47907 USA `bae21@purdue.edu; minb@purdue.edu; ematson@purdue.edu`

of the Fig. 1) have been demonstrated for various applications such as environmental monitoring, geological mapping and defense since 1990s [6]. Using USVs for water sampling can overcome the disadvantages of a human water sampling mentioned earlier by being equipped with a fully autonomous system [6]. In other words, the samplers do not need to take risks for water sampling that they cannot access to the sampling point. In addition, USVs have much longer operation times and greater payloads compared to UAVs. Therefore, USVs are more suitable for places where a long duration operation and multiple sampling are required, like the Wabash River monitoring case. In fact, multiple water sampling from various locations as well as from different water depth are often required, and such activities generally take longer than an hour.

III. Challenges and Approaches

Knowing the exact area of the river surface is essential for determining accurate sampling points and for effective pre-planning of USV's paths along the points. However, it remains challenging, particularly in large and natural rivers, due to the fact that a level of the river surface frequently changes depending on the weather condition. In addition, even if USVs have longer operation times compared to other platforms, energy efficiency should be always considered for better performances and operations. Therefore, as a first step toward our grander goals of this project, we are developing the autonomous robotic team that combines a variety of technologies including robots, crowdsourcing, advanced ROI (region of interest) selection and path planning. A key component of our current work is our commitment to a framework for a coordination of USVs with UAVs to obtain images of the ROI before the USV deployment. More specifically, UAVs fly over the ROI and take images, providing a real time global map for effective path planning of USVs. Furthermore, UAVs can be even deployed to do water sampling themselves in places where USVs are not accessible due to environmental obstacles.

One of the scenarios that we envision is depicted in Fig. 2. The mission given to the UAV and USV team is to effectively and autonomously carry out water sampling at multiple sampling points that are equally placed with a certain interval within the ROI. To successfully achieve this mission, selecting a ROI is the first step. Then, an UAV flies over the ROI and takes images. Based on the images, the exact area of the river surface is obtained and optimized paths are planned for the USV. Figure 2 partially shows the result of this mission. For this mission, we set 45 meters as the interval of sampling points. All the sampling points were equally generated (red circles) with the specified interval and the exact area of the river surface provided by the UAV (blue dot line). The shortest paths passing all the sampling points for the USV has been generated using the Travel Salesman Problem (TSP) algorithm and they are depicted with cyan solid lines.

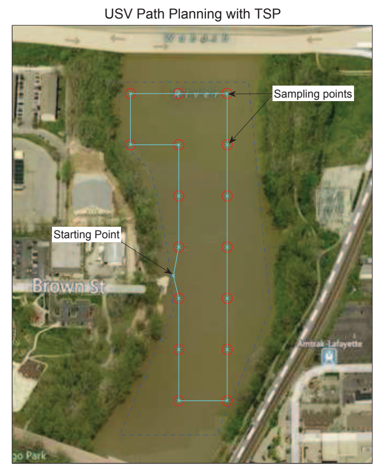

Fig. 2. USV paths planned with TSP for the Wabash River water monitoring.

IV. Future Works

Deploying USVs to the river for water monitoring is not just substituting humans effort to water monitoring. It is one step toward to the better river environment monitoring system to conserve the river around us.

We are at the beginning stage of this project. We will meet various stakeholders relevant to the river environment research in order to incorporate their comments and feedback into our research while developing our system that is composed of an unmanned aerial and surface vehicle team and an autonomous water sampling device. Based on the needs assessment, our system will be iteratively designed to be fully capable of various tasks, such as water sampling, water pollution monitoring, sediment sampling, and flood warning and mitigation. The final goal of this research is not just to contribute to conserving the Wabash River, but rather our autonomous water monitoring system will be an innovative and reliable solution to the water environment problems that exist in Earth.

References

[1] U.S. Environmental Protection Agency, "Nonpoint Source Pollution: The Nation's Largest Water Quality Problem," Internet: http://water.epa.gov/polwaste/nps/outreach/point1.cfm, Sep. 15, 2014 [Aug. 30, 2015].

[2] J. P. Ore, S. Elbaum, A. Burgin, and, C. Detweiler, "Autonomous aerial water sampling," *Journal of Field Robotics*, 2015.

[3] WabashRiver.us, "Wabash River in Indiana," Internet: http://www.wabashriver.us/index.htm, [Aug. 30, 2015].

[4] F. Fornai, F. Bartaloni, G. Ferri, A. Manzi, F. Ciuchi, and C. Laschi, "An autonomous water monitoring and sampling system for small-sized ASV operations," in *Oceans*, IEEE, pp.1-6, 14-19 Oct. 2012.

[5] A. Tinka, I. Strub, Q. Wu, and A. M. Bayen, "Quadratic programming based data assimilation with passive drifting sensors for shallow water flows," *International Journal of Control*, 83(8), 1686-1700, 2010.

[6] A. Valada, P. Velagapudi, B. Kannan, C. Tomaszewski, G. Kantor and P. Scerri, "Development of a low cost multi-robot autonomous marine surface platform," *Field and Service Robotics*, Springer Berlin Heidelberg, 2014.

[7] USGS - Wyoming-Montana Water Science Center, "CLARK FORK WATER-QUALITY MONITORING," Internet: http://wy-mt.water.usgs.gov/projects/clarkfork/project_description.html, [Aug. 30, 2015].