DESIGN OF REMOTE CONTROLLED AND UNMANNED WATER SAMPLERS FOR STPs AND SEWAGE FED LAKES

Chaitali Shah [1,2], Seema Sukhani[1]*, Chanakya HN[1]

*Corresponding Author, seemasukhani@iisc.ac.in, [1]-*CST, IISc, Bangalore,* [2]-*NITK, Surathkal,Karnataka India*

ABSTRACT – *With increasing urbanization, increased connectivity to UGDs and resultant sewage ingress into water bodies nearby there is a need for constant monitoring of water quality and sampling by boats is often not possible and needs remote controlled or unmanned water samplers across the spread of the water bodies including large sewage treatment plants. This paper presents the design for a remote operated floating boat like device capable of collecting water samples from different depths in typical Indian lake systems and similar water bodies. Most devices available in the market are generally complicated and cannot be used under Indian Water Bodies that often have floating macrophytes. The structure, propulsion and other characteristics are heavily dependent on the objective of the vessel or device [1] and its target area [2]. An outrigger design based mini boat like device was first designed and then was integrated with electronic control system for single tube sampling to evolve the prototype. This can collect water samples from GPS designated locations while being visually navigated from the safety of a shore. Real-time monitoring could also be carried out by integrating with GSM cards with data forwarding options and there is potential for being solar powered. This makes water quality monitoring of in-land water bodies and STPs less risky and personnel independent.*

Keywords – Unmanned surface vehicle, water sampling

MOTIVATION

With increased urbanization and higher levels of households getting connected to underground drainage (UGD) systems, there is usually a long time-lag between connections to sewage lines and complete sewage collection and treatment facilities being accorded. No city in India has 100% sewage treatment capability and as a result most of the sewage that flows from 900-1000mm diameteric drain pipes, flow in open drains and reach nearby water bodies firstly polluting them and second causing various levels of eutrophication. This warrants constant monitoring of water bodies. The two large water bodies of Bangalore suffering sewage ingress are the Bellandur and Byramangala systems with water spread areas of >1000acres each. There are many such water bodies in South India. Needless to say, different parts of these water bodies need to be monitored constantly to understand the threat levels and be able to predict harm to aquatic fauna or algal blooms. Chanakya and Sharatchandra (2008) calculate that this load could be as high as 77t N_r/d. Elsewhere, secondary treated sewage is being used to fill up some of the lakes/tanks such as Jakkur and Rachenahalli. Early summer temperature builds up with simultaneous increase in nutrient levels create higher algal mass and resultant near critical hypoxic situations that is noticed only when fish death occurs early April every year. However, it is obvious that such situations gradually build up and can be averted by allowing for fish harvesting or population reduction measures such that excessive fish can be harvested while also ensuring trying options to reduce nutrient loads in incoming waters. In this way mass death, and loss of food for water birds can be avoided.

The process of collecting samples from lakes until now has been very tedious and problematic. Makeshift boats and Coracles are used in the process while most of the water professionals do not have the capacity to swim long distances to the shore in the event of any untoward incidents. Besides this, as many of these water bodies have been converted to bird preserves, it is inappropriate to use large boats that disturb and scare away these water birds. Further, it is also dependent on availability of local fishermen /boatmen for taking water analysis professionals into the water body, supervision by trained personnel, appropriate sensors and favorable weather conditions. While, a few parameters can be analyzed by onboard probes [3], a lot of qualitative analysis of water from bodies requires obtaining samples from various depths as well as different locations of the water body before the sunlight intensities increase beyond some threshold levels. Since there is high spatial and temporal variability in physicochemical and microbial parameters at different depths, this needs to be resolved. Further, as indicated above, large high-speed motor boats are taboo, while Coracles are too slow and accident prone. Thus, the utilization of unmanned and /or remote controlled mini-boats can save time and manpower, along with reducing the risks to life that come with the current procedure of getting into the water body and doing manual collection. This provides a more comprehensive water quality profile [4].

A few GPS enabled, obstacle sensing remote controlled and pre-programmable water mini-boats are available on the market, most are suitable for very large and still water bodies. While these can sense mineral based obstacles – rocks, sand bars, etc., these are not programmed to function in waterweed infested choppy waters of urban lakes. They will be prone to become trapped in large and loosely matted water weeds that are not visible to near-field radar systems designed for hard and solid objects that reflect VHF-UHF radiation but are nearly transparent to various forms of biomass. There is then a need to simplify the navigating system and opt for visual maneuvering /navigation while the rest of the operations are automated. As there are high levels of winds on these water body surfaces, there is a need to stabilize the mini-boat by opting for various options of outriggers. Keeping the power low enables long duration of operation times between charging or battery replacement – while also allowing for solar based charging using a lean power plant. This enables nearly non-stop operations and thereby continuous functioning.

A second problem with such lake waters is the presence of a large component of suspended solids in the water which makes the choice of valves, pumps and control equipment very narrow and sometimes even needing innovations. The presence of duck weed in the sampled waters will obviously clog the small pumps and valves used to pump and control flow to various sampling equipment /storage bottles. Further, the presence of anaerobic pockets in these lakes ensures a high buildup of hydrogen sulphide (H_2S) and the resultant need to use corrosion resistant materials. Mild steel, copper, brass, gun-metal etc. components are highly prone to corrosion in these environments – the reaction rates of iron and H_2S is so rapid that it only takes a fraction of a second for the iron to react with it. Thus, various metals such as the above need to be avoided and market ready components are generally manufactured using the above. This necessitates that a large extent of plastics and stainless steels are used in the making of sampling sub-components.

A third issue is the need to simplify the sampling protocols and minimize the extent of sampling to two representative depths or strata in the water body. We thus minimize the water sampling depths to 10 and 75cm only although more options can be chosen. This gives a picture of the surface and deep-water strata of the waterbodies being measured and where algal population is high and light penetration is about 60cm, any deeper water would be the same quality. This reduces the need for multiple sampling pumps, pipes and probes. The mini-boat is always connected to two intake pipes that collect water from 10/75cm depth while using a solenoid valve to choose which is being pumped from. On the other hand, the pumped side could be as low as 4 bottles on the lower side to about 24 on the higher side for long sampling options. Here there is a need for a trade-off between, larger number of samples collected per trip Vs the short validity for the collected sample to be representative of the realities of the STP /ETP locations sampled, especially when DO and NO_3 are also being measured. This requires that there are many activated valves that divert the sample water bottle as per requirements and reaching critical water sampling conditions and protocols.

MATERIALS AND METHODS

Most existing designs were studied and their feasibility in the environment under consideration was analyzed. The Jakkur lake in Bangalore, Karnataka was chosen to be the target water body for the sampling operation and surveyed. Surface operation was concluded to be better than aerial and underwater options due to various reasons like maneuverability, sampling ability and expediency in use and design. Based on the weather and water conditions, the hull and propulsion systems were decided upon. The major part of the project consisted of implementing a functional water sampling module. The electronic system was designed and tested for over 4 sampling locations and 2 depths.

RESULTS AND DISCUSSION

The trend has been to automate the control systems with minimal manual interference.[4] This was reasoned to be counterproductive and defective in case of water bodies with significant levels of pollutants and dense algal and plant population, which is usual for tropical water bodies. Unreliable obstacle avoidance has been found to be a major problem [5], so a line-of-sight manual operation is concluded to be the best solution. The unmanned vehicle is designed to be remote controlled with a GPS module for geo-tagging the collected water samples. Moreover, there is often between 5-10m location error under cloudy or low satellite visibility conditions where in GPS based navigation to the same point in the lake or STP would be difficult to manage.

For the hull design, the trimaran structure was found to be the most appropriate for lake systems. The trimaran structure provides excellent stability against waves and also has a good payload capacity. Composite hydrophobic materials like fiberglass or PP are ideal for strength and endurance. This arrangement is ideal for water sampling because the weight of the vehicle increases with collection of each sample. The outriggers prevent overturning due to uneven weight distribution in the middle hull or due to inadequate laden weights. Catamaran structures are being increasingly used for such operations with the focus currently on Small Waterplane Area Twin Hull (SWATH) structures. But high speed and stability in extreme terrains are design requirements for highly turbulent sea-like situation applications and the SWATH structure design is a redundancy in case of the calmer water bodies [6].

The trimaran structure also optimizes the area for installation of a vessel-wide solar panel, by acting as stable supports across the body of the boat. With the aim of making the vehicle ecologically friendly, LiON rechargeable batteries are used for providing power for propulsion and other controls. A hybrid system with solar panels makes the arrangement sustainable for long term use. The entire size is limited by the requirement of portability. Since most of the lakes are located in poorly accessible areas, it becomes essential that the sampling vehicle is compact and easy to deploy and recover at the end of its operation. A modular design with detachable components is desired to increase convenience of use and easy troubleshooting and quick maintenance.

The propulsion and steering are achieved by standard propeller and rudder system. The propeller is run by a DC motor which is in turn controlled by an H bridge motor driver circuit. The rudder is controlled by a servo. Rudder and propeller assembly was chosen over twin motor operation by differential thrust as it has maneuverability and quicker turning. The propeller needs to be protected against filamentous algae and floating water plants in water. Additional measures must be taken to regain control of the vehicle in case of estrangement due to accidental entanglement with weeds on the propeller or propeller shaft. Then, the spin direction of the propeller is reversed periodically in case foreign particles get stuck and interfere with functioning of the boat.

The electronic components need to be isolated from the water sampling equipment to avoid problems due to water leakage. The microcontroller Arduino Mega based on ATmega2560 is used to control the functioning of the entire system. Arduino Mega is perfect for a complex project due to the numerous input and output pins available to control multiple operations. It is used to control the DC motor driver circuit, the servo movement, receive the input information and send it to the water sampling module. The signals are transmitted by the boat are in the very high frequency (VHF) range. Specially designed antenna with transmitter-receiver module makes a reliable transmission system.

An array of push buttons lets the user choose the depth and the sample bottle in which water is collected. The sampling system consists of a pump that draws water from inlets that hang from the vehicle into the water at different depths. Solenoid valves are used to control the flow of water from desired inlet into the chosen sample collection bottle. Each sample is about 500 ml. The sample bottles are sealed tightly to avoid leakage and have an inlet and an outlet each. Excess water drains out from the outlet pipe and joins a common outlet hose which leads back to the lake. The pumps and valves are controlled by relays using the microcontroller protected against typical chatter.

When any of the inlet button is pressed, the valve corresponding to the inlet and pump turn on simultaneously. The water flows into the chosen bottle as this specific button is pressed. If none of the sample bottle valves are kept open, then an additional flush valve opens which flushes the water out into the lake through the outlet hose. This hardware implementation of the water sampling system has been completed. The water sampling module can also be mounted on pre-designed commercially available vehicles and utilized for sample collection. Further improvements can be included by adding leakage sensor that inactivates the pumps and puts the vehicle on autopilot to return to deployment location.

CONCLUSIONS

The prototype components and subsystems are designed with consideration for structural and environmental aspects. However, we still need to evaluate the strength of structure, effect of drag on system, etc. When a higher degree of monitoring is needed, then it is necessary to add and integrate on-line water quality sensors such as DO, pH, redox, temp. etc., and convert it into an IoT. This system is expected to meet the functional requirements of inland water body and STP's water sampling devices.

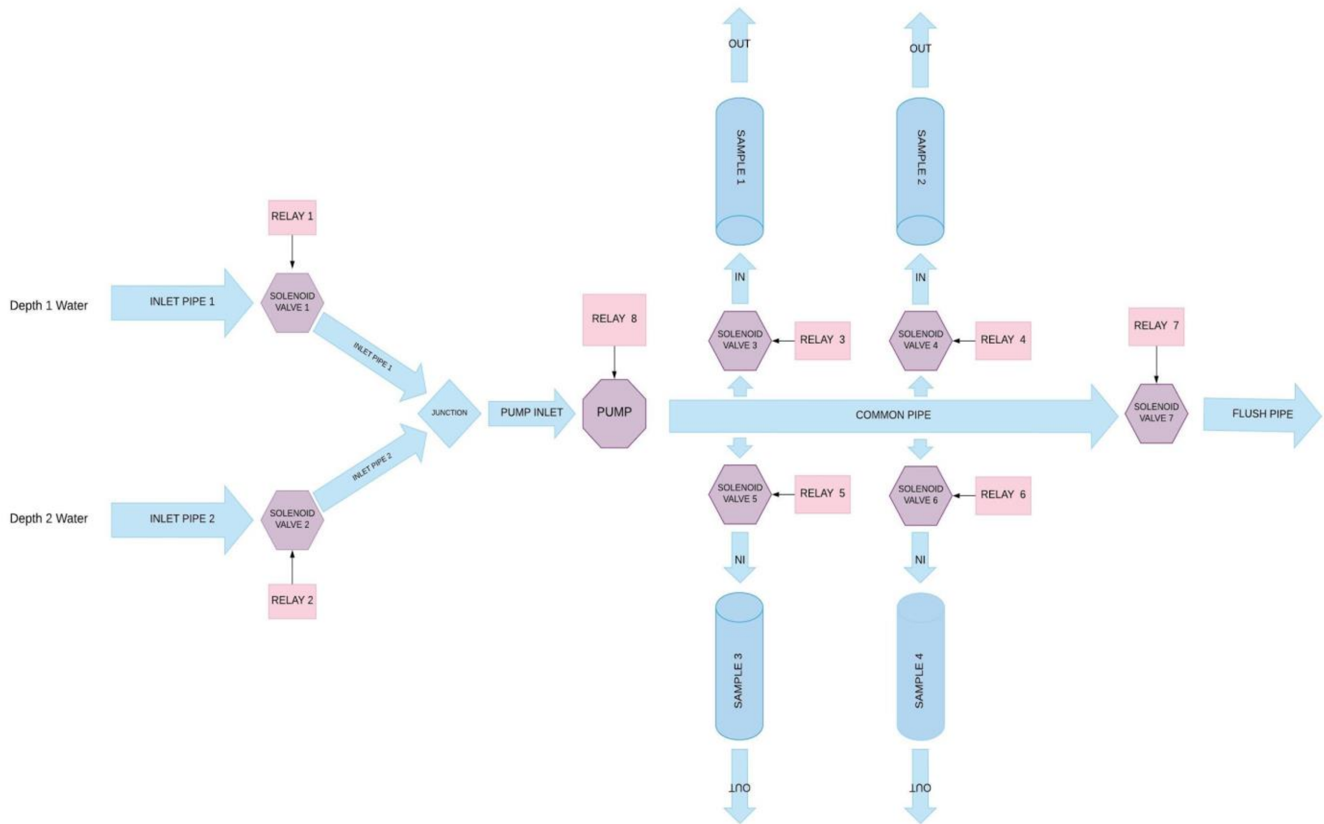

Figure 1: Control system for two inlets and four sample bottles

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