State-of-the-Art of the Swarm Ship Technology for Alga Bloom Rapid Monitoring

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***Abstract*—The swarm intelligence has become an interesting topic for employing of multi-agent robotics with specific purpose. The capability of multi-coordination, scalability and goals-oriented control in spatial and temporal environment are already concerned and proven for several applications such as in military patrol, and drones leader-follower coordination. In marine-based environment, swarm intelligence adopted by ASV or ROV has been used for water quality and environment monitoring with sufficient optimized results making it convenient for rapid assessments. In this paper, the arrangement for building a trusted cyber-physical systems for algal bloom rapid assessment using swarm ship technology were explained in state-of-the-art perspectives. The minimum requirements for sensing, vehicle controlling, and communication of this system with others were explored as well as algorithm chosen for the best known configuration to monitor algal bloom events before spreading so fast to larger area. Some models were explained to show the robustness of autonomous unmanned ship control. From this point of view, we concluded that swarm ship technology has become an important potential implementation for near real time in situ monitoring compared to other decision making method such as laboratory examination or remote sensing-based results. The results of this review open the opportunity to realization of swarm ship technology in cyber physical system for monitoring algal bloom in specific area near real time efficiently.**

***Keywords*—Swarm ship; algal bloom; cyber physical system; rapid monitoring**

I. Introduction

Dissolved oxygen in the water is produced through the process of photosynthesis by phytoplankton. However, the degree of respiration will be greater than photosynthesis when there is no sunlight. This doesn't just happen at night. In the surface layer, the oxygen level will be higher, due to the diffusion process between water and free air and the process of photosynthesis. With increasing depth there will be a decrease in the level of dissolved oxygen, since the process of photosynthesis is decreasing and the existing oxygen levels are widely used for breathing and oxidation of organic and inorganic materials. Dissolved oxygen concentration is an important parameter in determining the quality of waters. Oxygen concentration is influenced by the balance between oxygen production and consumption in the ecosystem. Oxygen is produced by the autotrophic community through the process of photosynthesis and consumed by all organisms through breathing. The solubility of oxygen in the waters is affected by temperature and salinity. The higher the temperature and salinity of the waters, the smaller is the solubility of oxygen. When phytoplankton bloom, the sunlight is blocked from entering the water column. So that dissolved oxygen is decreasing [1]. Phytoplankton is a major component of the food chain and the main production of the marine environment. However, a high abundance of phytoplankton can have a harmful effect on aquatic ecosystems. In addition, they can produce toxic substances that will accumulate in their consumers. This accumulation can be dangerous for humans or animals [2].

The phenomenon of algal bloom occurs quite often in several waters in Indonesia and the world. Research conducted by [3] in Jakarta Bay mentioned the occurrence of eutrophication since 1986 which caused the death of several types of fish and other organisms due to several types of phytoplankton such as Skeletonema which reached 534 x 106 cells / m3 in September 1984 and in April 1985 reached 2,316 x 106 cells / m3. Chaetoceros reached 5.6 x 106 cells/m3 in April 1985. Noctiluca reached 0.4 x 106 cells/m3 in September 1984. Prorocentrum was found to be very dominant in June 1988. The phenomenon of algal bloom on Ringgung beach, Lampung Bay, also resulted in the death of fish farmed in the Floating Net Cage [1]. Other events are also triggered by several types of algae such as Cyanobacteria, Dinoflagellates, Cyanobacteria, and Diatoms in the Ambon Bay and Jakarta Bay areas [4]. Research on the analysis of phytoplankton abundance causing HAB (Harmful Algal Bloom) in Lampung Bay Waters in the western season and eastern season was also carried out to identify algae that have the potential to cause HAB in Lampung Bay and see patterns of phytoplankton abundance relationships that have the potential to cause HAB with nutrients contained in the waters of Lampung Bay, Pesawaran Regency, Lampung Province. In the eastern season, the abundance of phytoplankton that causes HAB in the waters of Lampung Bay is dominated by the species Ceratium sp. with an average of 1,802 ind/L while in the western season the abundance of phytoplankton in Lampung Bay is dominated by Nitczchia sp., with an average abundance of 161,207 ind/L [5]. The incident that occurred in the Thousand Islands, Jakarta Bay on October 15, 2020 was caused by the phytoplankton type Trichodesmium. Real time sampling of phytoplankton that undergoes blooming has been carried out and the parameters analyzed are the composition of phytoplankton types and water quality. This is closely related to seasonal changes and an increase in nutrient content in waters, especially nitrates and orthophosphates, which support the rapid growth of phytoplankton [6].

Factors causing algae abundance carried out in tropical lakes, Telaga Menjer Wonosobo Indonesia mentioned that observations and sampling carried out three times with an interval of one month at seven locations in the photic zone resulted in concentrations of macronutrients and micronutrients in Telaga Menjer spatially even in all locations and temporal concentrations increased slightly the same during the measurement period. The macronutrients Cu, NO_2, Si, and Na are the determining factors for algae bloom in Lake Menjer Wonosobo. The effect of Cu, NO_2 and Si concentrations is inversely proportional to the abundance of algae, while the concentrations of Ca, Na and Mo are proportional to the abundance of algae [7]. Meanwhile [8] links the causes of algal bloom events with climate change in the process of assessing and mitigating risks in mariculture and marine fisheries.

II. Problem Statement

In monitoring the condition of the aquatic environment, some important parameters that need to be considered are the concentration of dissolved oxygen, turbidity conditions (turbidity), water temperature, chlorophyll-a concentration and the type of algae that develops. By using the necessary sensors, and installed directly in a fixed or moving condition, monitoring can be carried out in real-time or periodically.

The use of water vehicles that can move simultaneously opens up the potential for the application of swarming methods, which are inspired by swarming intelligence in animals or mammals in nature. A group robotics system is the application of a multi-agent system that has intelligence when in groups such as multi-robots that apply ant colony optimization algorithms [9]. This system was introduced by [10]. The application of other Swarm Robotic systems can be found in studies conducted by [11] [12] [13] and [14].

To provide some proof-of-concept to this swarmship technology, we need to build several surface vessel integrated with sensors, control and communication system and make some performance measurements.

III. Research Framework

In this study, an algal bloom monitoring system used several autonomous vessels that could directly sense environmental conditions and water quality. At the initial stage the autonomous ship is designed starting from its mechanical part, then equipped with a propulsion system, a control system, These ships will communicate with each other at a certain distance in order to exchange information related to the parameters of acidity, dissolved oxygen, algae concentration and weather in a certain water area. If in the region it is informed of an anomaly related to the parameters measured by one or several ships simultaneously, decision-making for monitoring together will be carried out and the handling is quickly carried out both automatically and by humans. The system to be designed and implemented is 3 – 5 autonomous vessels that have group intelligence in ensuring water conditions related to potentially harmful algae concentrations. Once it is confirmed that the anomalies in the parameters of the waters being monitored have the potential to produce algae abundance, then the next treatment will be carried out automatically or handed over to humans as decision makers. The real-time data retrieved will also be disseminated through the selected communication network so that it can be used for other purposes.

After reviewing several libraries related to Harmful Algal Bloom (HAB) and its monitoring methods, one of the in-situ measurement methods using several autonomous ships that can coordinate with each other using wireless communication by running an intelligent swarm-based optimization algorithm was chosen. In its application, these ships will send spatial and temporal data from the aquatic environment and be monitored through physical cyber systems located on land so that human in-the loop system can be made.

At this time several preliminary studies have been carried out related to the construction of prototypes of Automatic Surface Vehicle (ASV) ships that have sensors, control systems, navigation and standard communications. In the year of this research, several additional ASV ships will be built and developed as a physical cyber system that can communicate with each other in exchange for sensor information and their respective positions. In this section, an intelligent computing model is also developed by ships in order to be able to analyze water quality containing potential toxic algae, exchange of information with other vessels, actions that need to be carried out automatically and feedback systems for these information. Next, by testing several intelligence algorithms that have been analyzed and simulated before, the joint decision making interpreted by the navigation system and the movement of these autonomous ships can be optimized. It is hoped that from the results of some of these trials, several characteristics can be mapped in determining the most effective time in monitoring algal bloom in certain waters. This research also opens up opportunities for further research in terms of mitigating algal bloom conditions quickly and precisely.

IV. Literature Review

Early detection of Algal Bloom is an important topic to do, so that earlier and more accurate treatment can be carried out before it spreads more widely to the surrounding waters. Various direct (in-situ) studies in identifying algae that cause it or indirectly in the laboratory have also been carried out by several researchers in the field of environmental ecology. Several technologies have also been used, such as placing special buoys that are used to monitor their abundance, as well as the factors that cause them. But until now, this incident has not been well predicted.

In monitoring, detecting and handling the abundance of harmful algae (Harmful Algal Bloom), several studies have been carried out in several ways. Generally, the method used is to take samples directly in the water environment to be observed, and then the characteristics will be determined in the laboratory. Sampling is carried out several times in several places during a certain time and season. The sample is then examined by cyst extraction, sediment culture experiments, cyst culture experiments, DNA extraction and molecular identification. The parameters measured in general are water quality, oxygen concentration, macronutrients and micronutrients such as nitrates and orthophosphates along with concentrations [15] of phytoplankton and or chlorophyll-A in the sampling area. Another approach taken is to extract information from imagery captured by remote sensing satellites. Research conducted on the [16] [17] algal bloom phenomenon that occurred in the waters of Lampung Bay verified SPOT 4 satellite images using the Red Tide algorithm quantitatively and qualitatively. This remote sensing approach is sharpened by the use of several machine learning algorithms based on CNN with spatial and temporal analysis methods, LSTM alongside random forests, and SVM classification methods as performed by the HABNet application architecture. The results showed that their method could detect the incidence of algal bloom with a maximum accuracy of 91% and a Kappa coefficient of 0.81 for Karenia brevis (K. brevis) type algae on the Florida coast (as many as 2850 events from 2003 to 2018 [18]. The use of biosensors to monitor the incidence of algal bloom is also an opportunity to accelerate the handling of these events such as several studies reviewed where the biosensor has the potential to be installed far enough but can provide measurement information quickly and continuously on algae measurements and biotoxin levels as needed and at a low cost using [19] an environment sample processor (ESP) that can analyze DNA quickly and continuously in-situ.

During the years when research began to consider mobile robotics, the behavior of animal groups appeared in several key observations. The V formation arises from the basic local behavior of each bird. A proposed behavior-based formation control for multi-robotic teams also began as related research such as the coordination of groups of mobile robots using the rules of the nearest neighbors. Another articles focus on algorithms and theories regarding its flocking multi-agent dynamic systems. Some of the reasons to consider are instability and dynamic systems as its problems with oscillations. The chain of formation requires fine tuning of local control. Control engineers should consider 3D scenarios when dealing with a group of AUVs or UUVs [20].

Swarm intelligence is a decentralized collective behavior, a self-organized system (natural or artificial) that can maneuver quickly in a coordinated manner. In nature, this closed loop, that is, collaborative behavior is unique in each species. Nature has proven that when individual beings collaboratively work and think together as a unified system towards a common goal, they are more likely to achieve that goal faster and more accurately than if they tried it individually. In other words, they are smarter together than themselves. Ants lay pheromones that direct each other to the resource, the bees use vibrations, the fish feel vibrations in the water and the birds detect movements that spread through the swarm.

Swarm intelligence in the robotics domain has a wide range of applications and benefits. The main benefits of herd intelligence include:

1) Flexibility: The swarm system responds to internal disturbances and external challenges.

2) Resiliency: The task completes regardless of whether some agents fail.

3) Self-organization: Roles are undefined - they arise.

4) Adaptation: The herd can adapt to predetermined and new stimuli.

5) Decentralization: There is no central control, allowing for fast local collaboration.

The most suitable applications for robot swarms require smaller fleets of robots to perform tasks, such as mapping and foraging in places that are difficult for humans to reach. For example, swarms of search and rescue robots of various sizes can be sent to places that rescue workers cannot safely reach. In general, swarms of robots can be utilized for tasks as mentioned in Fig. 1 [21] [22].

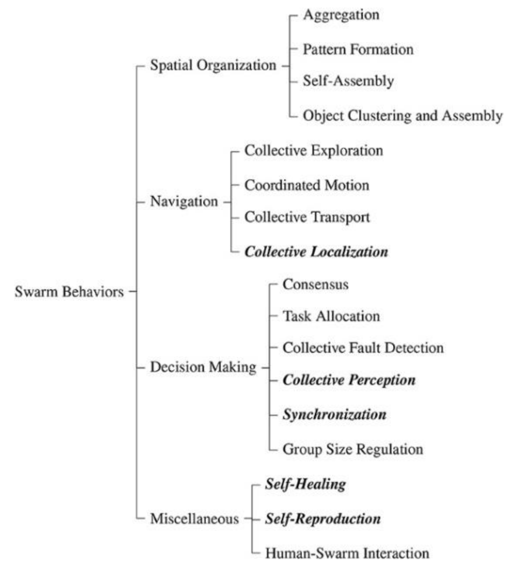

Fig. 1. Taxonomy of the application of swarm behavior to robotics.

V. Challenge and Discussion

Swarmship techology is proposed as a novel solution to the global threat posed by harmful algal blooms. This work is being done in parallel with the development of physical USVs that can strain and skim algae from the water [23]. The rate of algae collection need to be studied relative to: the diffusion of the algae in the water (due to turbulence), the composition of the swarm as either few large USVs or many small USVs, and the quantity of constant-size USV collected by the swarm formation. The results should be shown as plots of uncollected biomass vs. time, and as maps of the algae distribution after the swarmship have begun collection. Both a partitioning and non-partitioning controls approach are taken, which impose different hardware and communication requirements on the swarmship.

Meanwhile we developed several ships which has water quality monitoring device as shown on Fig. 2.

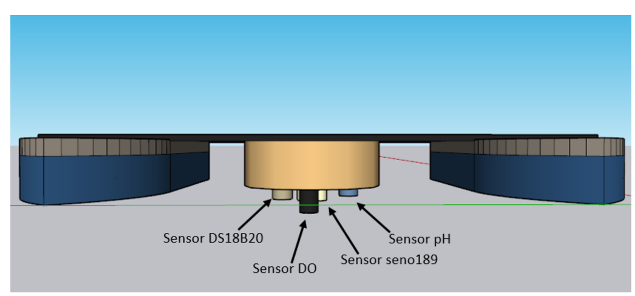

Fig. 2. Ships model for algal monitoring.

Fig. 3. Two models of swarmship implemented.

To aid in the development of this swarmship, several sets of scenarios are needed to inform the swarm designer about (i) the ability of the swarmship to collect a diffusive substance, i.e. the algae, (ii) whether how many USVs should be used, and (iii) what scaling effects are present as more and more USVs are need to be added to the swarm formation. Collecting a diffusive substance is an interesting problem, although somewhat specific to this application, but the second and third points are generally applicable to any swarm technology. Fig. 3 shows two kind of USVs used.

Several sets of simulations were needed to be performed, with a list of the most important parameters. These simulations address and are referred to as: Diffusive Collection, USV Size vs. Quantity, and USV Density. As its scenarios, swarmships move through water at a speed of one unit per second and collect 90% of the algae that they pass over.

As previously mentioned, this simulation environment is a very complex system. These simulations only included the effect of algae diffusion, due to turbulence in the water. This work also started with a homogeneous algae distribution. In reality, algae is sometimes distributed homogeneously The inclusion of collision tracking, algae advection, and the possibility of a heterogeneous initial algae distribution are three areas targeted for the swarmships system for future work as shown on Fig. 4.

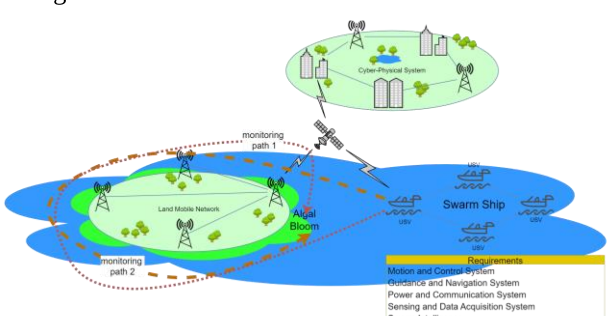

Fig. 4. Illustration of swarmship technology for harmful algae monitoring.

VI. Conclusion

From this point of view, we concluded that swarm ship technology has become an important potential implementation for near real time in situ monitoring compared to other decision making method such as laboratory examination or remote sensing-based results. The results of this review open the opportunity to realization of swarm ship technology in cyber physical system for monitoring algal bloom in specific area near real time efficiently.

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