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Coral Reefs 3D Mapping using Low Cost Autonomous Water Surface Vehicle

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Abstract

Coral reefs could act as bio-indicator reflecting current condition of the sea such as biodiversity, effect of climate change and marine law enforcement. Majority of the world's reefs were reported to continuously decline which Caribbean reefs suffering a significant decline in living corals over the past half century. Reliance on primary data and remotely-sensed data from satellite would be complicated and lengthy process in order to obtain results. Thus, this situation required a rapid monitoring and assessment method for coral reef future management. In this study, a new method of underwater photogrammetry is proposed to construct 3D mapping of the reef ecosystem which would reveal the reef geographical distribution and conditions. A specially- designed water surface platform was described in detail with characteristics of shallow waterline, innovative hull and propeller system, image acquisition platform and lastly autonomous navigation for coral reef imaging without damaging the ecosystem.

Keywords: 3D Mapping; Autonomous; Coral Reefs; Low Cost; Vehicle.

INTRODUCTION

Coral reefs are an essential part of marine ecosystems because they are very highly productive and rich in species diversity which supports many organisms. Coral reefs have been essential and crucial sources for livelihoods in terms of tourism industries, fishing and the new discovery of drugs and biochemical products [1]. Nowadays, coral reefs are under severe threat from many sources, including high seawater temperatures, solar irradiance and anthropogenic impacts.

South East Asia encompasses approximately 34% of the world's reefs, as well as the global biodiversity triangle formed by the Peninsular Malaysia, Indonesia, the Philippines, Papua New Guinea, Timor Leste, and Solomon Islands [2]. Corals were affected during the global mass bleaching event in 1998 and 2010 which had caused corals bleached and recovered. Nevertheless, there were also coral degradation happening after the events. Coral reefs are mostly affected by agriculture activities and human development causing sedimentation, sewage disposal and nutrient runoff [2].

75% of the world's coral reefs are under direct threat of human such as overfishing, coastal development, pollution, combined with thermal stress [3]. In Great Barrier Reef, hard coral cover was declined from 28 % to 13.8% over 27years, mainly because of Crown of Thorns (COTS) outbreaks, mass coral bleaching and declined coral growth rates [4]. Across the entire Caribbean corals, the hard coral cover on reefs was reduced by 80% in three decades, caused by combined of natural factors (disease, storms, temperatures) and anthropogenically (overfishing, sedimentation, eutrophication) [5].

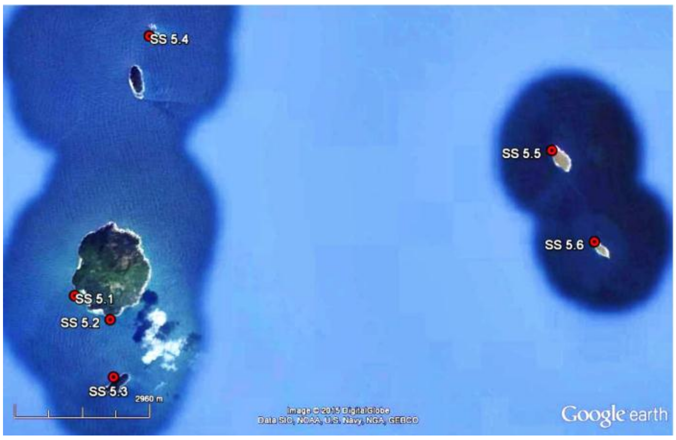

Figure 1: Surveyed sites in Bidong and Yu archipelago [6]

About 50% of the Pacific reefs were recorded the largest increase in threat for the past 10 years [3]. Coral's degradation and its big loss in the ecosystem are a great significant towards social and economic impacts for 850 million people around the world who depends on coral reefs and related resources [3]. These need an urgency from countries, marine park management, stakeholders to control the local threats to corals reefs, in order to lower the resilience and survival of corals in the increased of climate change impacts [3].

CORAL REEFS DOCUMENTATION

Coral reefs information all around the world is documented in Reef Check initiatives (www.reefcheck.org). Reef Check relies on crowdsourcing in order to gather and compile the information collected by the community. The data collection has been devised to be simple and easy to use for anybody in the community after a little training. The scientific methods are peer reviewed, with an aim to monitor how the coral reefs change from time to time. These changes can be used as a flag signalling whether the coral reefs are under threat or disappearing [7]. Fig. 1 shows an example of coral reefs survey sites in Bidong and Yu archipelago [6].

There are four types of survey being used in Reef Check: Substrate survey; fish, invertebrate, and impact survey; photo survey; and video survey. Substrate survey is the study of percentage of hard corals, which is the important aspect to build reefs. The percentage of hard corals is used to indicate the health of coral reef. Fish, invertebrate, and impact survey represents the invertebrates and fish that are important for the ecology and economically of the coral reefs. Fisheries industry looks into the economically important tspecies, while the ecologically important species can be considered as the coral reefs health indicator [7].

In Reef Check, photo survey and video survey are considered as auxiliary survey methods. They are usually done by volunteers, reporting any findings regarding coral bleaching or diseases. These surveys are later examined and reviewed by coral researchers to ensure the data are accurate. These surveys provide a permanent record of the coral reefs that might be important in the future [7]. All data collected using these four type of surveys are integrated into Reef Check global database, so that it can be used by scientists and coral reef managers [7].

Information gathered by mapping coral reefs can be used as an indicator whether the reef is under threat or otherwise. Nevertheless, the photo survey is two dimensional, and only acts as an auxiliary method to report irregularities of the coral reefs that might affect their health. Researchers has been exploring 3D capturing and photogrammetry of coral reefs [8][9]. The structure-from-motion photogrammetry method is relatively accurate and less destructive than the surface area and volume surveys [9]. Nonetheless, the process is done using specially designed underwater camera and requires divers to operate it. The generated image also lacks longitudinal and latitudinal information because the GPS signal could not travel underwater.

Based on the Reef Check studies, ease of use is one of the important criteria for a crowdsourcing method to be successful [7]. The underwater photogrammetry is reported to be a less intrusive survey method; however, the location information is not recorded in the images, and it requires divers to operate the camera in order to capture the coral reefs [8][9]. In order to complement all the coral reefs survey methods, photogrammetry using autonomous boats can be implemented. The vehicle should be unobtrusive towards the coral reefs, and capable of mapping large area of coral reefs. The design principles and the navigation techniques are discussed in following sections.

VEHICLE DESIGN

Corals are sensitive and fragile. Their growth can be affected by pollution, and physical contact can destroy corals that have been years in the making. For that reason, there are several features need to be focused on when designing an autonomous boat that will be used in the coral reefs area. The vehicle should be unobtrusive towards the coral reefs, and at the same time powerful enough to sail against the waves.

Hull Design

Boats hull can be divided into two parts: the part above the waterline is called freeboard; and the part below the waterline is called draft. There are several types of boat hulls: deep V-bottom hull; flat bottom hull; and catamaran. Each of the type has their own advantages and disadvantages. The deep V-bottom hull has good capability in rough water, however the hull rocks badly at low speed or at rest. The flat bottom hull has low draft; however, it does not perform well during turns. The catamaran is the most stable of the hull designs. Nevertheless, the turning characteristics is the worst between the three designs [10].

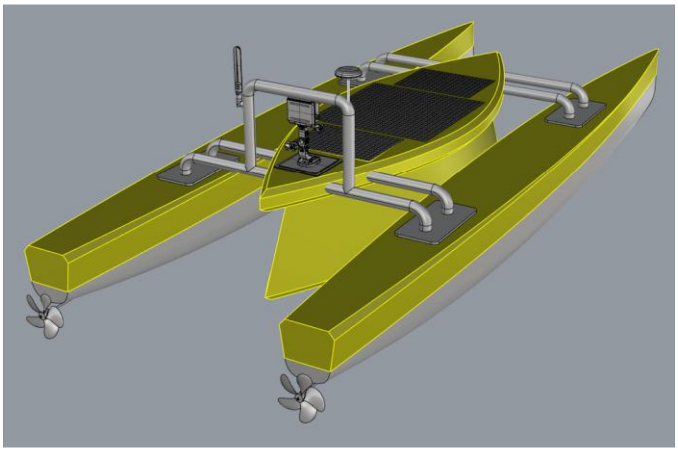

Figure 2: Autonomous vehicle ¾ rear top view.

Coral can grow up to several inches from the low tide waterline. Hence the boat should be designed to have a shallow draft so that the vehicle would not cause damage to the corals that grew close to the water surface. The flat bottom hull draft is shallower than the catamaran. Nonetheless, the former when compared to the latter is subject to heavy pounding by the waves [10]. The pounding might cause the hull to be less stable, and less suitable for data collection.

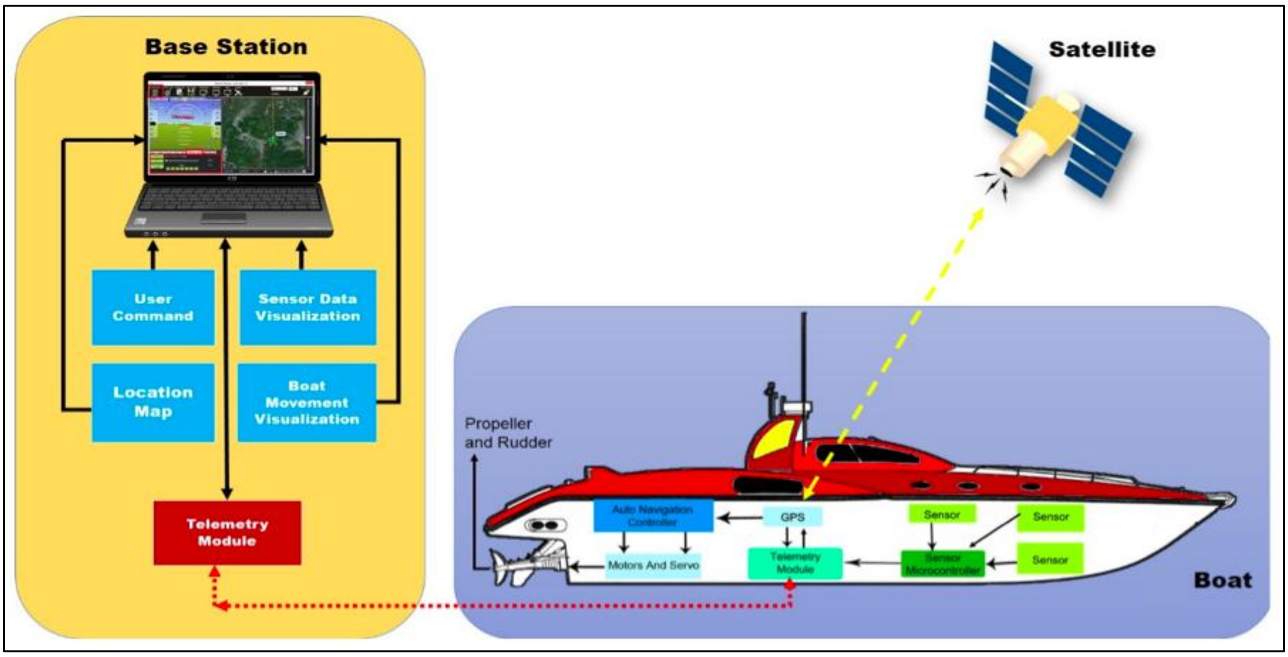

Figure 4: Framework of the autonomous control

The catamaran hull design has been chosen for this autonomous boat. Catamaran hulls usually have deeper draft than the flat bottom hulls, however, considering the vehicle is autonomous, the draft will be shallow, suitable for usage in the coral reefs area. This is due to the fact that this vehicle does not need to carry people on board, consequently making it lightweight and has a lower waterline. Furthermore, the design is more stable than the other hulls, making it well suited to be used for collecting image from the vehicle. Fig. 2 shows the autonomous vehicle design.

Propulsion

Using propulsion forces, ships are able to manoeuvre themselves in the water. Initially while there were limited number of ship propulsion systems, in the present era there are several innovative ones with which a vessel can be fitted with. Current ship propulsion is not just about successful movement of the ship in the water. It also includes using the best mode of propulsion to ensure a better safety standard for the marine ecosystem along with cost efficiency.

Propulsion systems for ships with limited draft, primarily intended used in shallow water regions (coastal and interior navigation) demand, also due to the limited distance to the bottom, the use of small propellers. To achieve the necessary thrust, the propellers are linked to a relatively high rpm. This combination of a small propeller diameter and high rpm gives these propulsion systems a low degree of efficiency [11]. A propeller's efficiency can be improved by increasing its size and decreasing its rotational speed.

This leads to the challenge of developing a technical solution that increases propeller size and thus decreases rotational speed while taking into account the ship's limited draft and the need to provide the required thrust. By using two contra-rotating, half-submerged controllable pitch propellers, propeller size can be enlarged by about a factor of 2.5. Rotational speed can be reduced accordingly. The goal is to accommodate the draft with the radius and utilise the entire width of the ship with the two diameters. When controlling direction with a rudder blade, the propeller's thrust is deflected along the longitudinal axis of the ship.

In addition to the longitudinal thrust component, a half-submerged propeller also generates a high lateral thrust component which can be manipulated by changing rotational speed/direction and, above all, pitch. Speed control can be achieved with a simple control function. The propeller parameters are customised to generate optimum thrust for each ship. Propellers have an efficiency curve every rotational speed has a corresponding optimum efficiency pitch. These values can either be determined in tank tests, or they can be calculated, if suitable data are available. Control should ideally be exerted with rotational speed and pitch along an efficiency curve that is stored in the control system as a combinatory curve.

The proposed propulsion and control system for this autonomous water surface vehicle will be using surface-cutting double propellers, designed for shallow-draft ships, can improve efficiency by as much as 40% compared to conventional propulsion systems. The ship will use no directional device, but is steered by varying the rpm, pitch and rotational direction of both propellers and therefore needs a special control system. Fig. 3 shows the autonomous vehicle propulsion design.

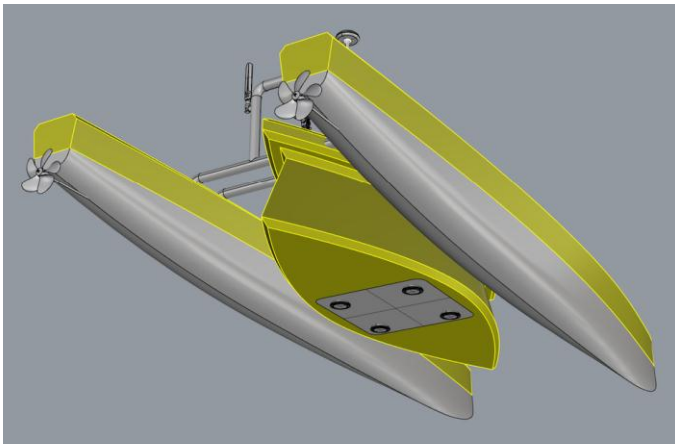

Figure 5: Autonomous vehicle ¾ rear bottom view.

Opening for Cameras and Lighting

The bottom surface of the autonomous water surface vehicle will be partially constructed with sealed laminated tempered glass to provide transparent surface for image acquisition. Tempered glass was chosen for its long-lasting properties as compared to polycarbonate which would degrade and cloud over time. Additional pairs of high-lumen submersible Cree LED will be assembled at the bottom external surface of the autonomous water surface vehicle to provide illuminance during image acquisition in order to compensate the shadow created by the boat's hull (Fig. 3).

AUTONOMOUS FEATURES

Navigation and Control Unit

The auto-navigation capability of the autonomous boat will be conducted using ArduPilot module. ArduPilot is an Arduino based autopilot module designed for remote controlled aircraft hobbyists. It is designed to control fixed wing aircraft, and various rotary wing platforms, including single, tri, quad, hexa, and octocopters. The software is written in C++, and is completely open source with an active development community.

The system enables the user to fly a series of predefined waypoints using a simple cross track error trajectory following algorithm. Users can fly the aircraft on a Fly by Wire (FBW) mode, where pitch and roll angles are commanded over the transmitter using ArduPilots inner loop instead of directly commanding servos.

In addition, ArduPilot can also communicate with a ground control station, where data can be gathered, waypoints, commands or even control gains can be updated. It communicates over a wireless serial connection, using a communication protocol called MAVLink, which was designed specifically for Micro Aerial Vehicles (MAVs). This research proposes the use of ArduPilot in the autonomous water surface vehicle, which can be managed using the ground control station.

Based on Fig. 4, the autonomous framework is divided into two (2) main sections which is Base Station and Boat. The Base Station will use a receiver called 3DR Telemetry radio that will interact and receive data from the Boat. The base station will be operated using APM Planner 2.0 as the mission planner to control and monitor the boat navigation. APM Planner enables user to predefine the waypoints of the boat navigation, based on GPS coordinates. It also provides Sensor Data visualization to help user understand the status of the boat.

Camera and GPS

In this study, the automated shutter-trigger of Canon Cameras will be explored by utilizing the Canon Hacker Development Kit (CHDK). This method connects the APM trigger output to the Canon S110 using a modified cable, triggering a script running on the camera to take pictures when the relay output voltage is high. CHDK is an experimental and free development tool, which temporarily patches supported Canon cameras so it could be controlled using scripts. The custom scripts could be programmed with the function to take pictures, control the camera zoom, set the focus and access many other camera features.

In addition, the script could also be utilized to read the camera USB port voltage and execute different instructions/functions based on the signal pulse-length. A custom cable is required to connect the APM board to the camera USB port. Via the use of relay, the script can be very simple which is to check the voltage (in a loop) and take a picture when it detects the relay voltage increase. This function would be focused more during the development of this autonomous water surface vehicle.

A good 3D rendering of the coral reef could be accomplished with the minimum of 60 - 100 still pictures. Camera shutter needs to be triggered throughout the mission at every 2 - 5 seconds or at regular distance intervals based on GPS. With its geotagging capability, Canon S110 is one of the most utilized CHDK-enabled cameras. In addition of its low cost, the camera also characterized with bright lens, good image quality and compact body which is very suitable for the application in autonomous water surface vehicle. Each image taken by the camera will be geotagged based on its location which will be utilized later for the surface reconstruction in following photogrammetry procedure.

DISCUSSION

Fast technological advancements provide new tools that can help advance research in ecological and biological of coral reefs. Autonomous vehicles are becoming valuable tools for inspecting underwater structures as it could provide a higher-accuracy results compared to manually maneuvered vehicle.

Using automated underwater photogrammetry method can help researchers to document and quantify the changes in coral reef health more effectively. This will in turns be used to monitor the biodiversity of the reef environment. The proposed solution could improve the understanding of coral reef ecosystems.

Among the challenges in underwater photogrammetry method are vehicle drifting caused by the water. The drifting problem can be solved using simultaneous localization and mapping (SLAM) algorithm with alignment technique. SLAM algorithm is becoming an increasingly popular solution in computer vision problems. The SLAM alignment can be done using sonar as a mapping sensor. The sonar can provide rough data on the underwater structure to enhance the photogrammetry efficiency and solve the drifting problem.

The photogrammetry system proposed will process sequences of images from the automated shutter-trigger of Canon Cameras. The images may be acquired while the vehicle is moving above the seabed along the pre-defined navigation plan. The 3D mapping software computes the camera motion from the images and combine them using estimated motion to create continuous representations of the scene. The resulting 3D models can be viewed in 3D from any viewpoint and can be used for interactive or automated measurements of the object's sizes and distances, in virtual environments.

CONCLUSION

This paper describe a solution for coral reef monitoring using underwater photogrammetry system. The photogrammetry result will be used to construct 3D mapping of the reef ecosystem which would reveal the reef geographical distribution and conditions. A specially-designed water surface platform was described in detail with characteristics of shallow waterline, innovative hull and propeller system, image acquisition platform and lastly autonomous navigation for coral reef imaging.

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