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DEVELOPMENT AND INITIAL TESTING OF AN AUTONOMOUS SURFACE VEHICLE FOR SHALLOW WATER MAPPING

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ABSTRACT

Current technology offers variety of methods for underwater mapping a.k.a. bathymetry where Autonomous Surface Vehicle (ASV) is used to complement the weakness of other bathymetry approach. In initializing the design of AquaDrone ASV, it started from deciding the specification of the ASV to draw a guideline of the prototype limit. The hull of the ASV was the first to be taken into consideration due to the measure of the vessel's payload and stability. It was built with dual control modes which are the autonomous and the tele-operated mode with Global Positioning System (GPS) receiver and compass module to assist its localization and navigation. The ASV was then tested at swimming pool, ponds and lakes to analyze its performance on maneuvering, sensors fusion, data logging, and communication range. It was proved to be operational.

Keywords: autonomous surface vessel, shallow water, bathymetry, asv, water quality, temperature measurement, environment sensors.

INTRODUCTION

The underwater topology mapping known as bathymetry provides significant insight of the geological features, erosion process, local currents and marine habitats. The need of bathymetry data at shallow water such as inland water and coastal line is crucial to render the social and industrial needs.

Airborne Light Detection and Ranging (LIDAR) systems, satellite imagery and maritime vessel based multi-beam echo sounders (MBES) are the most common bathymetry technology used today. Airborne LIDAR is capable of plotting high spatial resolution bathymetry map of very shallow water but limited to a certain depth due to the water absorption of light which limit to two to three Secchi depth range 10-15m [1]. It is very expensive and only justified for wide area surveys. Satellite imagery is lacking in spatial resolution and accuracy. However, it is a good solution for wide area survey with a tight budget and time constraint. It is limited to 25-30m depth penetration because of light penetration issues. [2]. Hydrographic vessel is the most widely use bathymetry technique. It offers high accuracy data and is capable for wide range of water depth. However, it is limited for a very shallow water area as the draft of the vessel may damage the instrument as well as harming the environment.

As most of the riverine or estuary channels are shallow, minimum depths allowed for beaming usually being reduced to less than 1 meter. It affects the bathymetry reliability as most data derived mostly from data interpolation than the collected field data. Therefore, small autonomous surface vehicle (ASV) with echo sounder and water probes installation provide the solution for bathymetry data collection especially in the shallow and tight area with low operation cost. The ASV allows data collections in shallow channels, able to transverse between riverbanks with erosion or sedimentation properties and penetrates mangrove areas. It removes the danger to the operator in inhospitable and harsh maritime condition. ASVs diminish human error due to long duration and mind fatigue operation.

The objectives of the current work are three. The first is to present system design with some details about electronics and mechanical including its specification, system setup, hardware architecture, block diagram and system integration. The second objective is to observe maneuverability and third is to test data acquisition and logging system.

The paper is organized as follows. Section 2 presents background about ASV and related work done by other researchers. Section 3 discuss the system design by elaborating system requirement and specification of mechanical consideration, controller, communication, power supply, navigation, sensor integration, data logging and payload. Section 4 discusses result of buoyancy test, maneuvering test, sensors reading and logging test and some field test. The last section consists of conclusion and future work.

UNMANNED SURFACE VESSEL

Autonomous surface vessel (ASV) is also known as Unmanned Surface Vessel (USV) or Autonomous Surface Craft (ASC). It has been developed to conduct wide range of marine operations such as bathymetry survey, water quality monitoring, researcher tools, and multiple military operations such as mine sweeping, patrolling, and target pursuit. Thus it can be classified into two either military or scientific ASV. The size of the ASV pays another consideration since it can be as large as a speed boat to as small as a remote control (RC) boat. As for application at shallow water, within 1m depth, small size vessel under 4m length is ideal to ensure the ASV is maneuverable. Most of the contemporary ASVs have a set of automation and navigation system such as GPS, automated waypoint navigation, path following algorithm, wireless communication, supervisory control, and etc.[3]. Bathymetry ASV is mounted with the sonar depth sounder as the transducer for depth measurement. Numerous ASVs have been developed which for some are made for the same purpose of our AquaDrone. Among the similar ASV projects that had been done are, Springer [4], ROAZ[5], DELFIM[6], MESSIN[7] and SESAMO[8]. All of the mentioned ASV used catamaran hull design.

SYSTEM DESIGN

As a preliminary stage of the system design the ASV is more focused on the stability of the ASV and the maximum payload rather than how fast can it travels. The initial decision was made to meet the requirement for the ASV to be able to maneuver a tight area and capable of carrying necessary payload sensors. Minimum operation time is currently set to 3 hours for the ASV to be check-up for the next trial mission for safety reason. Table-1 shows the targeted criteria of the system.

Table-1. ASV initial specification.

Item	Specification
Hull Configuration	Catamaran
Dimension	1170mm x 360mm x 150mm
Turning diameter	2m
Max Payload	10kg
Average speed	4.5kt
Operation time	3hours

Consideration

The first step in the development of the ASV was to design or select an appropriate hull form. The design is expected to be robust enough for field deployment, reliable payload capacity and provide enough roll and pitch stability for automated bathymetry measurement. In order to be able to withstand the roll effect as well as enable to withstand large payload, catamaran hull was selected as the most suitable design [9]. The large water plane and wide beam of catamarans reduces rolling motions and increases displacement without the significant drag penalty a similarly sized mono hull would experience [5, 10, 11]. It also provides easy water access for different systems to be mounted on-board such as sonar transducer and other deployable sensors that need to be fully submerged into water.

On-board Computer and Communication

The boat's on-board navigation and control computer made up of low power embedded microcontroller Arduino Mega [12]. A serial port is used in AquaDrone to read serial data from GPS and compass and to gather oceanographic sensor data from echo sounder. The control of rudder and propeller are done by PWM outputs.

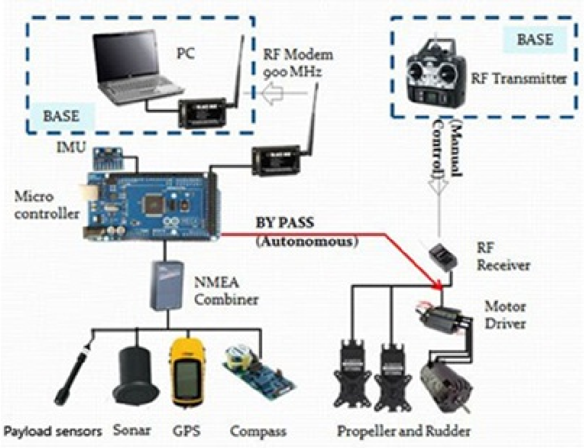


Figure-1. Electronics system setup.

The boat has two control modes, a tele-operated mode and way point mode. A tele-operated mode is achieved through a 2.4GHz Futaba RC radio transmitter which range about 1.6 km. For way point mode, a pair of Black Box RF Modem 900 Mhz transceiver with Omni-directional antenna is used to provide point to point communication with base station from shore. The transceiver supports links at distances up to 32.1 miles outdoors with clear line-of-sight on the ground surface. However, water is a powerful RF absorber thus reduced the communication link strength down to 1 km approximately.

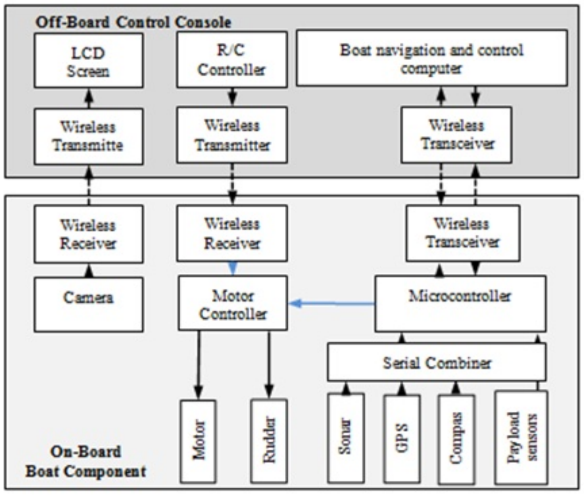


Figure-2. Block diagram of the boat components.

Power Supply

AquaDrone power supply system consists of two 12V/4000mAH batteries connected in series, providing 24V nominal voltage for the brushless motor. Other sensitive devices like sensors and computer system use independent energy supply with Li-ion 12V 9800mAH battery pack. Additional DC/DC converter is used to provide power sharing between the devices.

Navigation

Vehicle navigation and positioning uses Garmin eTrex® H, a high-sensitivity GPS receiver that can to lock onto satellite signals quickly and maintain accuracy up to ±3m during clear view sky. It is coupled with KVH C100 Fluxgate Industrial-grade compass module that has accuracy up to 0.1°, ±0.5° resolution, ±45° tilt angle compensation and 1 second response time. Both sensors are RS-232 and NMEA 0183 compatible for easy integration. Sensor fusion algorithms estimate the vehicle state required by navigation controller.

The control algorithm is used to navigate the vehicle utilized location information from GPS to calculate distance, velocity and bearing to the next way point. Preset velocity used as the set point for a PID controller of propeller speed. The calculated bearing is used as the set point for rudder control while the compass gives heading feedback. The details of the algorithm will not be discussed here as it is outside the scope of this paper.

Navigation component support both piloted and automated navigation. For automated navigation, the low level control (propeller and rudder control) is being implemented on the on-board microcontroller. Position data are acquired from the on-board microcontroller and wirelessly route to the off-board computer where mission plan is updated. Upon reaching the way-point, a news way point is updated and relayed back to the boat and routed by the on-board controller to the motor driver board for execution.

Sensors Integration

Shallow water survey requires varieties of sensors for data collection. Several of the commercial of the shelf (COTS) transducers are using different format of data transmission apart from NMEA. Therefore there is a need for built-in communication protocols for seamless integration to your monitoring platform and data logging. NMEA 0183 protocol is being selected as the common protocol since it is used by many marine equipment and vehicles. The technique lies on extracting the non-formatted asynchronous serial data and generates a custom made NMEA sentence that complies with the format.

In developing AquaDrone hydrography survey ASV, four Atlas Scientific water probes (e.g. pH, conductivity, dissolve oxygen, and oxidation reduction potential) non-formatted asynchronous serial data were fused into NMEA 0183 protocol as shown in figure 3. This was made possible by linking the non-formatted asynchronous serial data through Arduino Uno as to parse data and generate a custom NMEA 0183 sentences.

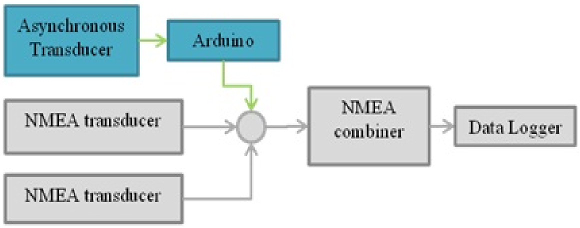


Figure-3. Architecture of transducer data logging.

Data Logging

The survey data were collected in two different ways; 1) Internal logging in the ASV system using SD card reader 2) telemetry transmission using Black Box RF Modem 900MHz transceiver. The SD card reader is considered as the primary data storage. Making parallel data collection can benefit in both ways; whenever either system malfunction (e.g. SD storage breaks down or beyond RF coverage) the other may serves as back up. The data recorded are GPS location, UTC time, compass heading, orientation, depth, temperature, and the water quality parameter.

Payload

The ASV is equipped wireless camera for live transmission to base station for on-board monitoring and localization purposes. To accomplish bathymetry measurement, CruzPro® ATU120BT active depth/temperature transducers with NMEA 0183 output having a depth rating up to 300 m and sensing water temperature from 0 to 90 °C is used. These active transducers operate at 120 kHz to prevent interference with other nearby depth sounders.

GPS, Compass and depth sensor reading will then be fed into the NC20- NMEA Combiner. It can handle any mix of NMEA and any RS232 input signals at 4800/9600 baud rate (user selection). Multiple units can be daisy-chained up to four channels. After that, the Combiner output is connected to the Arduino Mega µ-Controller for data processing as the system architecture shown in Figure-1 and Figure-2. The payload depends on the vehicle size and operational requirement. The ASV is designed to be modular for easy integration with new sensors if required.

RESULT

During the development course of this project, the ASV was deployed in numerous locations including swimming pool, lakes and ponds. Challenges aroused during each testing were overcome and the ASV durability and functionality were improved.

Buoyancy Test

Figure-4 Buoyancy test at swimming pool, IIUM.

Buoyancy test of AquaDrone was conducted to determine the draft displacement at various weights (Figure-4). The boat is designed to support up to 10 kg of payload including existing components. Given that draft is the vertical distance between the waterline and the bottom of the hull. Thus, the draft is designed to be 80-100 mm range. Draft determines the minimum depth of water a ship or boat can safely navigate which is must be taken care of especially during shallow water operation.

Maneuvering Test

Straight Line Test

First subsystem to be tested is the propulsion system. Motor operation is verified using remote control operation. The tests include straight line test (forward and reverse) and circle maneuver as well as variety of duty cycle test. Since asymmetry is found in the weight distribution of the payload component, the rudder angle needs to be calibrated to make sure it can follow a straight path.

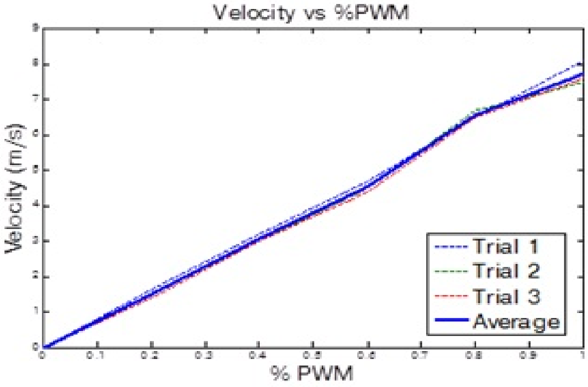


Figure-5. Relationship between velocity and %PWM.

The boat offers great thrust for forward direction but significant low thrust during reverse direction. It is due to the design of the propeller with only allows a greater forward thrust than reverse. Greater reverse thrust offers better control and safety during maneuvering a tight confined area. Following this test, the vehicle is allowed to run across the pool at various duty cycles. Figure 5 show the data steady state translational velocity vs. the %PWM level. Using this data, the following relationship, is formulated using linear fitting method and we get equation (**Error! Reference source not found.**).

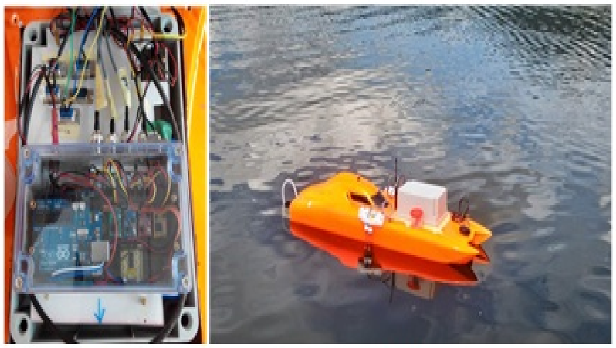
Circle Maneuver

From a steady speed, zero yaw rate condition, the rudder is moved to a maximum angle right/left. The vessel responds by turning in a circle. After steady state is reached again, parameter of interest is the turning diameter. It is found that the boat turned at an average diameter of 4 m which is enough for the boat to maneuver in lawn mower pattern with line spacing of minimum 4 meter.

Sensors Reading and Logging

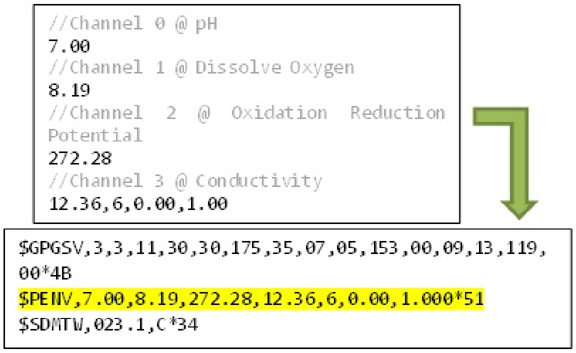
AquaDrone had been tested together with the sensor fusion box (Figure-6(a)) and deploy at Taman Layang-layang lake as shown in Figure-6(b). This box contains Arduino Uno, and Atlas Scientific data acquisition system (DAQ) which link to a NMEA 0183 combiner. The data collected is GPS stamped. The total speed response of the data logging is 1Hz according to the frequency of the GPS and the rest of the NMEA 0183 devices even though the AltasScientic probe was operating at 4800 baud rate. Figure-7 exhibits a sample reading of the serial data controller and the reading after fusing with the other NMEA 0183 data.

All sensors and navigation reading are according to the NMEA 0183 protocol. In addition to the non-formatted asynchronous serial data from Atlas Scientific, a new propriety sentence is applied. According to the rule of NMEA 0183, this sentence is categorized as non-standard NMEA 0183 message. A non-standard NMEA 0183 message has to begin with the letter P and followed by 3 letters that identifies the manufacturer. Therefore the code “PENV” is used as to refer to “propriety: environment”.



(a) (b)

Figure-6. Data fusion box (b) AquaDrone in operation at Taman Layang-layang lake.



```
//Channel 0 @ pH
7.00
//Channel 1 @ Dissolve Oxygen
8.19
//Channel  2  @  Oxidation  Reduction
Potential
272.28
//Channel 3 @ Conductivity
12.36,6,0.00,1.00
```

```
$GPGSV,3,3,11,30,30,175,35,07,05,153,00,09,13,119,
00*4B
$PENV,7.00,8.19,272.28,12.36,6,0.00,1.000*51
$SDMTW,023.1,C*34
```

Figure-7. Result of conversion of 4 AtlasScientific asynchronous serial data transducers into a NMEA 0183 sentence.

Field Test

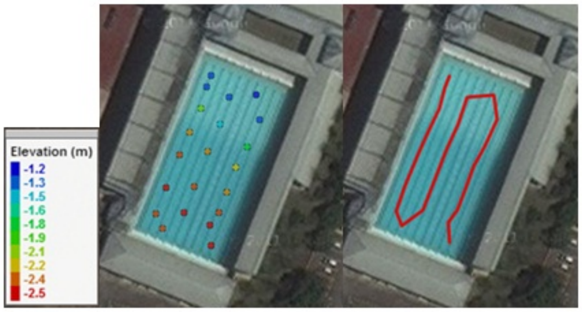


Figure-8. (a)Bathymetry plot of IIUM swimming pool. (b) Survey path during the bathymetry operation.

The final phase was testing the integrated system for data acquisition capability and communication. The ASV is design to operate at minimum water depth of 1 m and will be used to map underwater depth. It has an operating range of approximately 800 m for line of sight. During the test, vehicle's position (longitude and latitude) and depth data were transmitted wirelessly to an onshore based station where the data were logged for analysis. The test was carried out at IIUM Sport Complex pool, Figure-8(a) & (b) and a small pond at NAHRIM, Selangor, Malaysia Figure-9. The field test layout is as in Figure-10.

During the small pond test, AquaDrone was pre-planned to capture a cross section depth data at a distance of 85 meter. With the average speed of 0.87ms-1, 86 data points were collected and plotted on Google Maps by using GPS Visualizer. The test was run during a clear day without any strong wind interference and calm water. The communication range between the off-board computer and the boat is within 10-60 meter at line of sight. The location of the off-board communication is marked as star on the satellite image Figure-9.

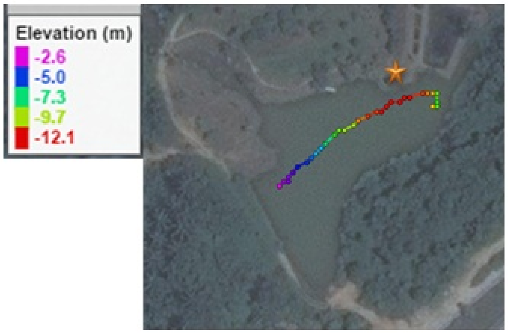


Figure-9. Bathymetry plot of NAHRIM pond, Bangi, Nahrim created on March 2014.

The gap distance of every data points vary from 0 to 5 meter. From the collected data, the depth plot respect to the distance travelled was plotted as shown in Figure-11. It shows that the pond has a deep surface close to the off-board computer station that reached 12.1 meter. The cross sectional bathymetry test was not done all the way to the edge of the pond due to keep a clear distance for the ASV to make its turnaround before colliding to bottom ground of the pond and to keep a distance from the water weed surrounding the lake.

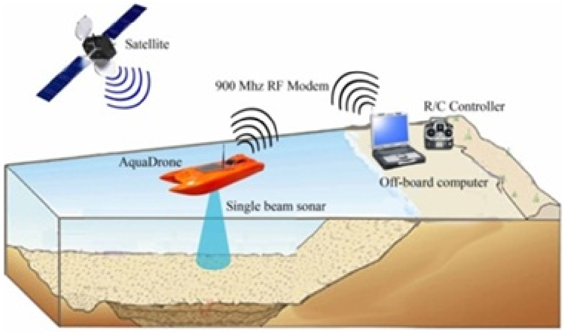


Figure-10. Field test devices setup.

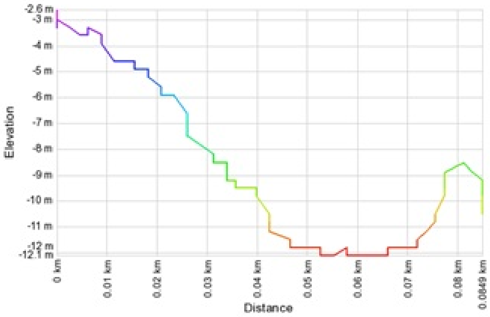


Figure-11. Elevation plot of NAHRIM pond.

CONCLUSION AND FUTURE WORK

This work describes the design and operational field operation capabilities of the AquaDrone autonomous surface vessel. Autonomous surface vessels had proven to be important tool to fill the gap of other system like AUVs, airborne LIDAR, satellite bathymetry or hydrographic vessels are not capable to operate at very shallow, high turbidity and tight area.

The use of catamaran hull design allows very shallow water operation and provides platform roll stability to enhance the performance of scientific instrument. The mission test and real scenario trial proved the operability of the ASV for a shallow water mapping operation.

In its current form, the boat meet its design objectives by its capability of safely maneuver at a very shallow and tight area while collecting bathymetry data.

Future development of AquaDrone includes (a) development of additional payload modules (b) upgrade of navigation sensors (c) incorporation of robust navigational controller to enhance performance in strong current and wind and (d) the used of vision-based navigation system in negotiation above and below water obstacles.

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