Development of sea glider autonomous underwater vehicle platform for marine exploration and monitoring

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Present study discusses preliminary design of sea glider autonomous underwater vehicle platform referred to as ITB-SGAUV. AUV is designed to be compact in size, with the purpose of exploring and monitoring marine living resources. Its hardware is designed to be reconfigurable enabling the researchers to change the placement of the sensors for testing different navigation scenarios. Hardware and software components are designed to be re-usable, which reduces the development and testing time. A low-cost sea glider has 1 degree-of-freedom utilizing buoyancy driver (glider) with fiberglass hull material that can operate up to a depth of 200 meters. Experimental result demonstrates that the sea glider works well in ascent and descent motion with maximum slope 30 degree. Maximum yaw angle is set to +3/-3 degree relative with respect to North. Thus it is expected that the sea glider can be used effectively in real environment. Future works include modeling the dynamic of the AUV and its advanced control design, along with its sea-trial.

Keywords: Sea glider, low-cost system, autonomous underwater vehicle, mission.

Introduction

Importance of underwater exploration lies on the fact that the underwater environment is rich with hard mineral and renewable resources, and oil/gas reserves. Operations using human divers, research vessel, manned submersibles, towed systems and by remotely operated vehicles introduce high risk, high cost and require dedicated surface support such as support/research vessel. Autonomous underwater vehicle (AUV) is inevitable in the above scenario. Most of the AUVs are employed in known environments and commonly depend on some support from a surface vessel or on ground fixed transponder networks for localization. A cost effective AUV technology should be developed to make it a viable alternative.

These challenges lead to research and development activities in the areas of buoyancy driven (glider), along with its navigation, path planning, sensing, power supplies, information processing, computer system design, and in controls. A test-bed facility for sea glider AUV needs to be developed to facilitate design, development, testing and evaluation of the AUV technologies, methods, and algorithms under real-word conditions. While development of various types of AUV has attracted a lot of attention in recent years, only a few works on sea glider type AUV appeared in the literature. This type of AUV is ideal for exploring marine resources and covering long distance travel. In this paper, a low cost and low power sea glider AUV platform is developed. The AUV is designed to have hardware modularity and software reusability.

Materials and Methods

Vehicle Design

The Pressure hull

A low-cost Institut Teknologi Bandung Sea Glider-Autonomous Underwater Vehicle, referred to as ITB-SGAUV, is currently being designed and implemented. Fig. 1 and Fig 2 show the AUV has 1 degree-of-freedom utilizing buoyancy driver (glider). The fiberglass hull and the connectors are designed for a depth of 200 m. Trimming weights are added to make the system neutrally buoyant. One motor pump is used for oil displacement between ballast tanks, which enable heading orientation and allowing the vehicle to ascent or descend with specific angle. However, the AUV is not actuated for rolling. The vehicle is trimmed in such a way that the rolling and pitching effects are kept to a minimum. The dry-
weight of the vehicle is 10 kg and is neutrally buoyant. The AUV carries on-board sensors, which measure and receive the information diving depth, range, and marine physical and chemical data.

Unlike underwater drones, ITB-SGAUV is able to travel without the aid of a propeller. Instead, they move up and down through the top 0 to 10 meters of sea water (pre-mission) by adjusting their buoyancy while gliding forward. With this strategy, the AUV can travel a remarkably long way on a small amount of energy. When submerged and thus out of GPS connection, the AUV steers itself with the aid of sensors that measure depth, heading, and angle from the horizontal plane. Fig. 3 and Fig. 4 show the AUV operation for pre-mission is shown in for complete mission. In complete mission, ITB-SGAUV can be pre-programmed to submerge to depth of 200 meters.

**Hydrostatics of ITB-SGAUV**

On every submerged object a buoyancy force is acting upward. The buoyant force acts through the centroid of the displaced volume of fluid, and is equal to the weight of the fluid displaced by the object. Facing into the opposite direction, the gravity force is pushing the object downwards. The working point of the gravity force is the centre of mass of the body, and the gravity force is proportional to the mass of the object. If the gravity force is bigger than the buoyancy force the object sinks, and conversely if the gravity force is smaller than the buoyancy force, it floats.

The mass distribution of the vehicle is arranged in such a way that it is statically in equilibrium at zero velocity. The ITB-SGAUV is designed to satisfy the following requirements for static stability. The resultant of weight and buoyancy forces is zero can be described in equation (1)

\[
FG + Fb = 0 \quad \ldots (1)
\]

The location of center of gravity and center of buoyancy is aligned in the vertical direction, and thus total hydrostatic moment is zero can be written in equation (2)

\[
Mg + Mb = 0 \quad \ldots (2)
\]

The basic behaviour of vehicle can be simulated by adding weight proportionally to both tanks at constant flow rate and by using zero plane angle. It is needed to add weight proportionally to eliminate the moment effect since these ballast tanks are not located in the

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**Fig. 1**—The ITB-SGAUV construction and location of ballast tanks in the ITB-SGAUV (Adapted from Spray Glider and Slocum Glider)

**Fig. 2**—Longitudinal Section of ITBSGAUV

**Fig. 3**—Sea glider mission design (pre-mission)
same distance from center of gravity. Fig. 1 shows the location of $L_1$ and $L_2$ from center of gravity is 49.3 cm, 48.6 cm respectively where $L_1 > L_2$.

A submerged AUV is exposed to a pressure, increasing linearly with the depth. The equation for the pressure in no compressible fluid is given as equation (3).

\[ p = p_a + \rho gh \quad \cdots (3) \]

Where $p_a$ is the atmospheric pressure, $\rho$ is the density of the fluid, $g$ is the acceleration of gravity and $h$ is the height of the water column.

As an AUV is moved through the water, it has to overcome drag forces opposing the movement. The drag force can be modeled by using equation (4).\(^{11-15}\)

\[ D = \frac{1}{2} \rho V^2 A C_d \quad \cdots (4) \]

Where $D$ is the drag force, $\rho$ the density of the fluid, $V$ the velocity of the object, $A$ the reference area and $C_d$ the drag coefficient. Using equation (4), one can calculate $C_d$ from experimental data.

**Water-resistant system**

Fig. 5 shows the ITB-SGAUV has 3 sections cover located in the upper hull. To avoid the seeping of water between the gap closing silicon rubber o-rings for nuts is used. Water-resistant characteristics are tested in stages. First, fill water into the hull and observe whether there exists water seeping through cracks or holes nuts; if not then proceed on the other cover. The next stage is to close all cover hull and then soak in water for about 6 hours and if whether there exists water coming into the hull. Our experimental results indicate that the platform’s water-resistant characteristics turn out to function properly.

**Embedded Computer System**

The ITB-SGAUV computer system must meet a rigorous set of requirements. It must be compact in size and meet stringent power specifications. Moreover, navigation, trajectory generation, and control functions have to be simple to implement. From a software perspective, an efficient real-time, multitasking infrastructure is required. Both hardware and software should be expandable to accommodate more complex sensors and future missions.

**Hardware Structures**

Capturing data from depth sensor and processing it to extract useful information is a very important issue in autonomous mobile systems. The ITB-SGAUV has three processing units: pressure sensor (depth), 3-axis accelerometer (pitch angle), and compass sensor (yaw angle) connected into a combined sensor unit to determine state of oil pump motor (counter clock rotation, clock wise rotation, or stop), depth operation, ascent/descent angle, and rudder angle. Fig. 6. shows the main block diagram of the interconnection.

A microcontroller ATMEGA64 is used as main controller of ITB-SGAUV. It is single chip microcomputer with 64 kilobyte flash memory programmable, RS232 ports, shared 8-Ch ADC, I²C/SPI communication, and programmable 53-Digital I/O lines. All desired signals such as position and heading are measured by several sensors located all over the glider. To enable controlled AUV system, sensory data are collected from the internal and external sensors.\(^{18}\)

**Internal Sensors**

The internal sensors provide motion parameters of the vehicle with respect to vehicle’s coordinate system. We used cheap components to implement several sensor units. The chip ADXL-330 is used as 3-axis accelerometers which measure roll, pitch, and yaw angles.\(^{19}\) The ADXL330 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs, all on a single monolithic
IC. It can also be used to measure acceleration with a minimum full-scale range of ±3 g. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. Fig. 7 shows the raw data captured from the sensor of the ADXL-330 is further processed using an ATMEGA64 which is expandable to ATMEGA128 computing unit. Interface to the ADXL-330 is through 3 analogue channels 10 bit resolution.

Fig 8. shows a low-cost digital magnetic compass module CMPS-03 was chosen to provide yaw or heading control. The small module delivers high accuracy and low power, interfacing with microcontroller via a digital input port. However, since the mechanical design of the vehicle sought to create a statically and dynamically stable vehicle with a passive roll and pitch control system, roll and pitch would be kept to a minimum and consequently only yaw would need to be actively controlled.

External Sensors

A HP-03S pressure sensor measures the external pressure experienced by the vehicle and is used to measure the depth. Fig 9. shows the sensor provides a pressure level in the form of ASCII data that can be retrieved using an I_2_C interface.

Power Supply

Rechargeable Panasonic NiCad of 12Volt DC is used to supply the power. It is a compact battery with nominal capacity of 10 Ah. The batteries provide the power distribution circuit which distributes power to
each device through a regulator and fuse for the safe operation of the devices. The power supply is designed to provide a 24-hour endurance time to the ITB-SGAUV. We plan long endurance time operation by using solar cell embedded on top surface of body form. With this model, ITB-SGAUV can be operated in monthly or yearly mission. Fig 10. shows the internal component arrangement.

Software Algorithms

To control the maneuver the glider, a microprocessor is installed and programmed using C language. After system initialization, the program will detect the current status of the 3-Axis sensor, compass, and pressure. When the position of the glider at an angle of zero and be on the surface, the program will provide control logic to the port to operate the oil pump motor, enabling the liquid in the tank located at the tail flows toward the tank contained in the head. This process continues by detecting the angle generated by the indirectly glider in position 30 degrees then the program will stop motor. Detection of the depth range is measured by reading a pressure sensor value, when the pressure is greater than 500 millibar, the program will return to provide the oil pump activation in the opposite rotation, enabling the fluid flows from tank head to its tail. The program detect the ascent angle; when it reaches 30 degrees then it will stop the activation of the oil pump and continue to detect in real time the depth of the glider until it reaches 200 millibar pressures before reaching the surface. This program continues over time until the power is turned off. For the laboratory testing, glider will stop after 5 times iteration ascent and descent moving. Once this condition is reached, the glider will float on the surface. High level description of gliding control system is shown in the following:

```
/*Port initialization */
OilPumpMotor off
RudderMotor zero position
Read SensorPressure
Read Compass
If(SensorPressure < 200 millibar AND Iteration== 5)
{RudderMotor zero position
  3-AxisSensor at X coordinate zero degree
  OilPumpMotor off at balance condition
  Iteration = 0}else{Iteration=Iteration + 1}
//Descent position
If(SensorPressure < 500 millibar AND 3-AxisSensor > -30 degree AND)
{keep OilPumpMotor ON // displacement oil from tail to head
  Clockwise rotation motor direction}
else{OilPumpMotor OFF }
//Ascent position
If(SensorPressure > 500 millibar AND 3-AxisSensor <30 degree)keep OilPumpMotor ON // displacement oil from head to tail Counter Clockwise motor direction}
else{ OilPumpMotor OFF }
//Keep heading zero – Keep North direction
//Check Compass status and 3-AxisSensor (Yaw Angle – Z)
```
If(Compass > 3 degree){RuddermotorControl ON //set rudder wing to 10 degree inclination}
If(Compass > 257 degree){RuddermotorControl ON //set rudder wing to +10 degree inclination}
Else{RuddermotorControl OFF //set rudder wing to-10 degree inclination}

Results and Discussion
Currently, a set of experiments is conducted at ITB swimming pool facility to determine trimming characteristics (in pitch/glide) and identifying the buoyancy model of the ITB-SGAUV. Iron bars are placed in the hull space, which is below the pressure hull, to enable the ITB-SGAUV neutrally buoyant. Fig. 2 shows a simplified longitudinal section of the ITB-SGAUV. The total hull length L is the sum of nose, mid-body, and tail cone length, and equal to 1.12m. The maximum hull diameter D = 0.12m, result in a fineness ratio (L/D) of 9.33. Table 1 shows the current specification (Pre-Mission) of the glider. Complete mission in this table refers to the capability of the AUV to perform exploration, monitoring, and marine living resources.

Particularly, Fig. 11 and Fig. 12 show the minimum system schematic and PCB layout to support ITB-SGAUV testing. The minimum system is used to design an ITB-SGAUV controller in controlled gliding. The microcontroller serves as the brain of the system. The device has an average power consumption of about 5 Watts. The entire software structure is based on C-Language Code Vision that runs on a Windows Operating System. Port A collects data from specific sensors and receiving data is stored in 1 Gigabyte of the SD Card from where control programs access.

In our control system structure, heading, ascent/descent are controlled in two separate single-input single output (SISO) systems that is assumed to be independent of each other. During testing this assumption has proved reasonable.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Pre-Mission</th>
<th>Complete Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform</td>
<td>Sea glider</td>
<td>Sea glider</td>
</tr>
<tr>
<td>Body Type</td>
<td>torpedo</td>
<td>Torpedo</td>
</tr>
<tr>
<td>Size (L×W×H)</td>
<td>1.1 m × 1 m × 0.4 m</td>
<td>1.1 m × 1 m × 0.4 m</td>
</tr>
<tr>
<td>Hull Material</td>
<td>Fiberglass</td>
<td>Fiberglass</td>
</tr>
<tr>
<td>Weight</td>
<td>15 kg</td>
<td>15 kg</td>
</tr>
<tr>
<td>Maximum Depth</td>
<td>10 m</td>
<td>200 m</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Obstacle</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Endurance (nominal load)</td>
<td>24.0 hours</td>
<td>1 month</td>
</tr>
<tr>
<td>DOF (Buoyancy driven)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hovering</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Nominal Speed</td>
<td>1.5–1.7 km/h</td>
<td>1.5 – 1.7 km/h</td>
</tr>
<tr>
<td>Navigation System</td>
<td>Compass</td>
<td>Compass, GPS, sonar</td>
</tr>
<tr>
<td>Sensor</td>
<td>depth, temperature, 3-axis accelerometer</td>
<td>depth, temperature, 3-axis accelerometer, turbidity, salinity, fish finder, x-chlorophyll</td>
</tr>
<tr>
<td>Battery</td>
<td>Nickel Cadmium</td>
<td>Lithium Polymer</td>
</tr>
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</table>
Actuators and Driver

The ITB-SGAUV has 1 DOF and two motors. The first motor is a DC Servo type that is used to control rudder angle. The second motor is used to control displacement of liquid between two ballast tanks. The capacity of each ballast is 300 ml. Fig. 13 shows the oil pump has flow rates at average 200 mL/minute depending on motor speed. The ITB-SGAUV is actuated in the ascent and descent using weight change between the ballast tanks. Fig. 13 also illustrates the mechanism of ITB-SGAUV in ascending and descending maneuver with respect to horizontal axis and this value is detected by the sensor 3-axis accelerometer. Fig. 14 shows the schematic of DC motor driver with L293D H-bridge integrated circuit.

In diving operation, the motor will pump fluid at the ballast tail enabling it to flow towards the ballast head. Motor stop the operation when the oil fluid displacement in the ballast tank produces pitch angle of +30 degree. Microcontroller read the depth cruise information every 100 ms through the HP-03S depth sensors. When ITB-SGAUV reaches a depth of 5 meters, the computer system instructs the motor to reverse its direction and the liquid in the head flows to the tail. The motor pumping is stopped when the angle formed reaches -30 degrees until the vehicle reaches about 2 meters of the surface. If vehicle reaches the surface, the vehicle repeats its action in diving operation.

Our the experimental results show that measurement of flow pump to 100% of the fluid between the tank capacity of 300 ml takes 1 minute on average. Accuracy of the length of time the pump motor operates is not required; the most important characteristic is the change in angle that occurs due to inter-tank fluid transfer. If a change in angle occurs, the motor stop and the computer system detect the target depth to change the maneuver.

In case of heading, the controlled value is 3-axis orientation aided with gyro compass. Since SG-AUV’s glide and rudder motor already come with a built in positioning controller, this sub system is sufficiently controlled by providing a reference value to the motor controller. The reference value is derived from a predefined optimal condition. The maximum yaw angle is set to +3/-3 degree relative with respect to North. When the vehicle reaches the maximum yaw angle value, the control program activates the motor to move rudder wing in the right or left rotation and move back to the zero angle of rudder wing when yaw angle value is less than +3/-3 degree.
A twin-rudder system was selected to make sure that it has sufficient steering effect in every gliding situation. Angular mounted twin-rudders provide better control at high healing angles compared with single rudders. Assembled outside the hull, the rudder actuator (motor servo) is well sealed and protected against water and humidity.

Conclusion

Sea glider AUV platform was designed with various low cost and low power electronics components including sensors, signal conditioning, data acquisition, data communication, power system are selected and designed such among cost effective designed and produced without degrading significantly AUV performance. Future works include modeling the dynamic of the AUV and its advanced control design, along with its sea-trial.

A sea glider AUV was designed for future use in conducting research in the area of marine biology exploration, marine physical and chemical data acquisition, school fish identification, and ocean pollutant monitoring. The ITB-SGAUV has a modular hardware and software architecture which enable researchers to implement or use specific sensor depending on their requirements.

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