# Design of an Underwater Glider for Education and Research

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***Abstract*—The last decade has established the underwater glider as an important platform for oceanographic research. To further the capabilities of glider research three Florida Institute of Technology students have been actively designing a glider that is considerable cheaper than commercial gliders. This vehicle introduces external wing control surfaces for steering and a mechanical buoyancy engine. The aim of the work in progress is to develop a fully functional underwater glider as a platform for oceanographic research and design of underwater navigation and control algorithms. This goal is to be reached through a complete redesign and unification of the previous control components of both systems and the implementation of device driver libraries. Mechanical components such as the buoyancy engine have been reviewed and field tested off the Atlantic coast of Florida during the summer of 2012. Designed for a maximum depth of 100m the glider's payload bays will enable the usage of various instruments in the coastal shelf region. The low weight (less than 25 kg) and small size (2m in length) allows deployments from small boats. GPS navigation, radio frequency and satellite communication (when surfaced) will make the glider an excellent vehicle for student research. Completion is expected for December 2012.**

## I. Introduction

In the late 1970's Douglas C. Webb envisioned fleets of autonomous vehicles using the thermocline of the ocean to power a buoyancy engine and wings to convert the vertical sinking and rising into horizontal movement [1]. He named these vehicles *Slocums* after Joshua Slocum, who was the first solo circum-navigator of the world. Henry Stommel was the first to make Webb's idea public, in a fictional article looking "back" on the phenomenal achievements of the Slocum program from the future [2]. Almost 20 years later in 2004, the first four members of this new family of underwater vehicles so called underwater gliders, were deployable: *Slocum Battery* and *Thermal* by Webb Research Inc., Falmouth, MA, USA, *Spray* from the Scripps Institution of Oceanography, and *Seaglider* constructed by the University of Washington.

Although not all gliders use the thermocline of the ocean as an energy supply, they adapted the idea to convert vertical into horizontal movement resulting in a saw-tooth dive pattern, which is characteristic for gliders. The sinking to a defined depth and rising to another depth in the water column is referred to as a *cycle*. Typically gliders perform multiple cycles before ascending to the surface to transfer data via satellite link. In general the speed of glider movement is just fast enough to overcome slow currents, and in some cases allows them to be used as virtual moorings in currents that match their speed.

### A. The Big Four

The four gliders mentioned above are described by David et al. in [3]. They are small and lightweight enough to be deployed by a small crew of two or three persons without use of the heavy equipment found only on large vessels. Their price is comparable to the cost of a few days ship time, making them an economic choice compared to using ship based measurements.

All gliders, except for Slocum Thermal, use hydraulic buoyancy engines with battery powered pumps or pistons. Slocum Thermal uses the thermocline of the ocean to change the aggregate state of a medium from solid to liquid and vise versa to change its displacement. Because of this feature its operation is restricted to areas with a well developed thermocline. Slocum Battery is designed for use in shallow water, which makes great demands on its ability to change direction and buoyancy. Features of Spray and Seaglider, both designed for long range operations in the deep sea, include a sophisticated hydrodynamic design. Spray's payload section is variable in size. A neutral compressibility pressure hull reduces Seaglider's energy consumption by keeping neutral buoyancy in great depths [4].

### B. Glider Research at Florida Institute of Technology

Despite the commercial availability of Glider Systems, no such vehicle has been available for student research at Florida Institute of Technology. The underwater glider described here is based on two works performed during 2011. The first one was a thesis on graduate level by Cheryl Skibski . The second an undergraduate thesis by Alexandra Gottschall.

Cheryl Skibski's work aimed to be a proof of concept for the use of external wing control surfaces or wing flaps on underwater gliders. It's goal was to produce a fully functional underwater glider, featuring wing flaps, a buoyancy engine, a gumstix computer, an emergency system, a navigation system, satellite and Radio Frequency (RF) communication and a broad sensor package. No in-water tests were performed due to technical difficulties and the implementation excluded a buoyancy engine [5]. During the same time, the author developed a piston type buoyancy engine. The project included

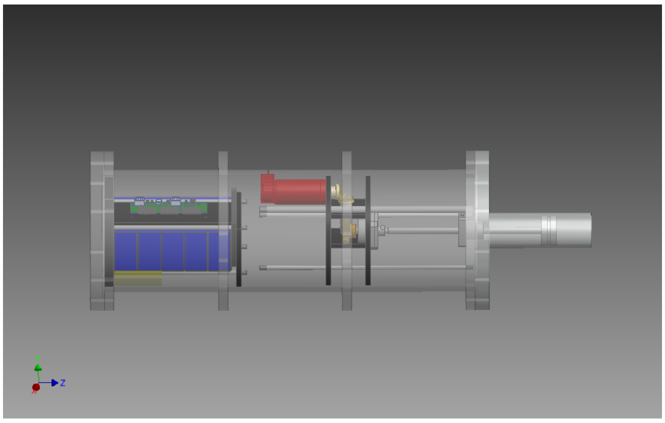

Fig. 1. Computer model of the pressure housing, buoyancy engine and electronics.

the hardware design as well as a simple control system. Basic functionality was tested in Fall 2011 and many components are reused with slight alterations.

## II. System Overview

The produced vehicle, called Bumblebee, is roughly 1.96m long and weights about 20kg (without payload). The tear drop shaped fiber glass fairing has a maximum diameter of 0.33m. The wings, fastened just behind the widest point of the fairing span 25 cm each. A piston type buoyancy engine enables dives to 100m water depth.

### A. Mechanical

Bumblebee's hydrodynamic properties are primarily influenced by the outer fairing. Two fiberglass hull halves provide an attachment points for wings, tail wing and instruments, a low drag surface and impact resistance. Electrical components are protected from pressure and water intrusion within a cylindrical 6061-T6 aluminum alloy pressure housing (shown in Figure 1). Integrated is a piston type buoyancy engine. A cylinder, open to the water on one end, connected to the pressure housing on the other end, acts as displacement chamber. A plumber, moved by a traveling lead screw, controls the displacement volume. Positive buoyancy, and therefor rising, is induced by displacement of the plunger from its center position towards the open end of the cylinder, sinking by the reverse motion. Trim weights and syntactic foam can be fastened to the inside of the fairing to adjust buoyancy for varying water density.

Wings were originally designed as a modified NACA 65-010 airfoil, but the manufacturing process (hand layout fiberglassing) resulted in a thicker profile. While updated flow simulations will be necessary, no obvious performance loss manifested itself during field tests. Wing control surface flaps are used for horizontal steering through roll. Wings and wing flaps are built as one structure, a flexible fiber glass cloth forms the hinge. Oil filled servo motors, cast in apoxy and fitted inside the wings, are used to incline the flap.

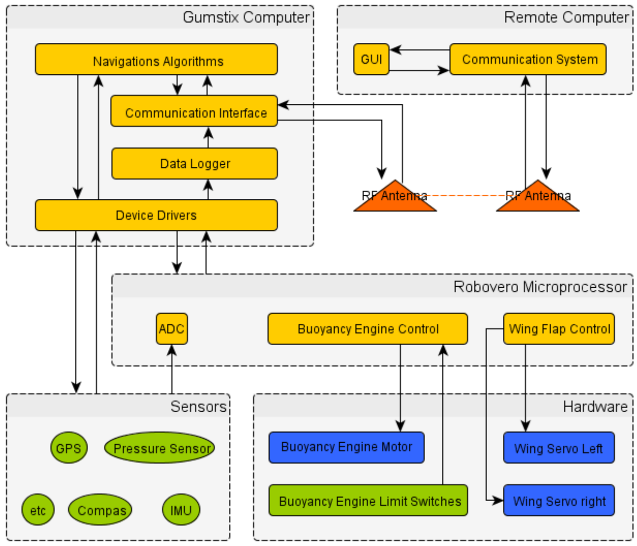


Fig. 2. Schematic of the control structure. The Environmental Board is excluded for clarity.

### B. Instrumentation

The glider's main control system is the gumstick sized Overo Fire computer-on-module (COM) by Gumstix. Attached to a Robovero extension board by the same manufacturer it provides all necessary hardware interfaces, a Linux operating system and integrates a inertial measurement unit (IMU) and a magnetometer. As can be seen in Figure 2, the Overo module controls the buoyancy engine and the wing flap servos. It also communicates to remote computers via RF and to the environmental board via a serial connection. Lastly, the Overo COM polls and logs all on board sensors. In addition to handling the integrated pressure sensor, IMU, compass, Global Positioning System (GPS) and environmental board, the Overo COM will offer ports to log data from payload sensory.

The system is powered by five 6V lead acid batteries. 30V are supplied to the H-Bridge that controls the buoyancy engine motor and regulated down to 12V for further use in the Robovero extension board as well as the environmental board. The Robovero performs the power management for all components connected to the main control system. Excluded are the drop weight, RF-antenna, and GPS which are part of the isolated Environmental and Emergency System powered by 6 Nickel Metal Hydrate Cells. In its current state the vehicle will be able to perform missions of up to approximately two and a half days duration. Lithium Ion Batteries will yield deployments of up to a week duration when necessary.

The environmental board and emergency system (shown in Figure 3) is located next to the main battery, within the pressure housing, but completely isolated from all other components. Cast into epoxy and equipped with an independent power supply it will remain functional even in the case of pressure housing failure. An internal pressure sensor, a thermistor and a leak switch are used to monitor the health

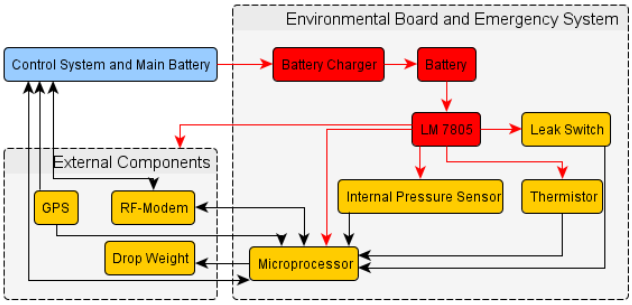


Fig. 3. Schematic of the Environmental Board and Emergency System

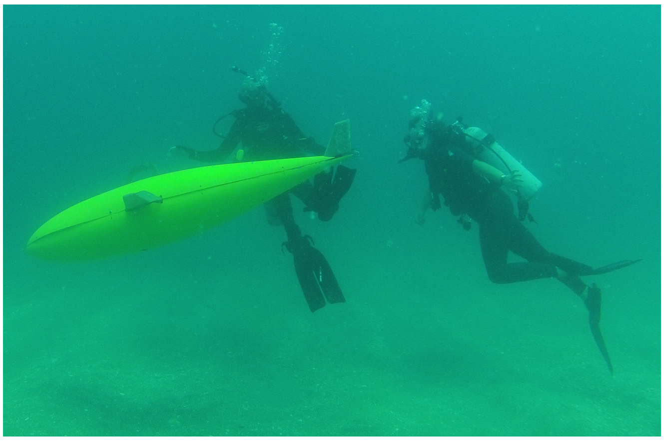

Fig. 4. Bumblebee during the first open water tests in June 2012.

of the pressure housing. In case of failure or an abort signal from the Overo COM, a drop weight is electro-magnetically released and positive buoyancy induced. Upon surfacing a GPS (located at the tail wing and normally used for position fixes) is polled and an emergency signal broadcasted via RF. During normal operation the emergency battery is permanently recharged from the main batteries by an internal circuit.

### C. Software

Software based tasks are shared between programs running on the Overo COM as an top layer and the Robovero micro-controller as a close to hardware layer. The emergency and environmental system is, except for communication, isolated from the main control to ensure function in case of a system failure. Outside the vehicle, remote computer software will facilitate the communication with Bumblebee.

*1) Overo:* A Armstrom Linux for ARM operating system makes the Overo COM a powerful platform for all navigation, communication and control purposes. While a basic control and navigation system will be implemented for test purposes, the strenght of the system is the ability to be upgraded and expanded without in depth knowledge of the hardware layers or system specific programming techniques. Libraries for all on board sensors will further facilitate the aim to make Bumblebee the ideal test platform for navigation and AI algorithm research at Florida Institute of Technology. The standard Linux operating system also allows the usage of available implementations of well-proven algorithms. These could facilitate Bumblebees use in oceanographic research or be used as benchmarks for new developments.

*2) Roborovero:* The Robovero expansion board is equipped with a NXP LPC1769 microcontroller. This, ARM Cortex-M3 based chip works as an interface between low level hardware functions and high level software. Drivers are written in C and based on the LPC17xx CMSIS-Compliant Standard Peripheral Firmware Driver Library. Python wrappers allow functions like analog digital converter (ADC) and pulse-width modulation (PWM) generation to be called via a serial connection from the Overo COM. Thereby making the Robovero a relay station between analog sensor inputs and motor control outputs on one and the Overo COM on the other side, allowing future software designers to concentrate on high level navigation and control algorithms for the Overo COM.

Beside its relaying function the Robovero also handles the control loop for the buoyancy engine. Control signals for the motor are generated based on limit switch information from the buoyancy engine and target positions from the Overo COM.

*3) Environmental Board:* All functions of the Environmental Board and Emergency System are performed by an Atmel Atmga 8 microprocessor. The software, written in AVR C, is composed of three parts. Two for the main functions: Environmental monitoring and emergency behavior and one providing additional hardware capabilities (e.g., a second UART implemented in software). During Environmental monitoring, sensors are polled roughly every 5 minutes. Values are compared to extreme values and communicated to the Overo COM. The microcontroller goes to sleep in between measurements to preserve battery life. A signal from the Overo COM as well as a positive signal from the leak switch will result in immediate wake up.

In case of an abort signal from the Overo COM, a leak or any excess of the maximum sensor values, the environmental board will change into emergency behavior. The drop weight is released by a solenoid and an abort signal sent to the Overo COM. Upon surfacing the emergency system will poll the GPS and send an emergency signature via RF. The microcontroller sleeps between broadcasts to preserve battery life.

*4) Remote Computer:* A remote computer Graphical User Interface (GUI) program will be provided to facilitate communication, data exchange and mission planning with and for the vehicle. The main feature will be a map to allow, in a first step, interactive mission planning, and finally vehicle tracking and mission adjustment during deployments. Mission planning will encompass GPS way points and dive profile adjustment as well as safety settings. The user will be able to download and display dive and payload data after vehicle retrieval or on the fly in case of satellite usage.

## III. Field Tests

Field tests were performed in the Atlantic off the coast of Florida, near Sebastian Inlet, from the 3rd to 6th June 2012, off of the M/V Thunderforce. On the 3rd of June, the vehicle was trimmed for neutral buoyancy in the water. Foam and additional drain holes were added after this experiment. On the following day two divers accompained the vehicle to 16 m water depth and performed several fall tests to observe flight properties. The test also served as first verification of calculated pressure housing rating and hyperbaric chamber tests. The following day, three more dives to 8m water depth were performed. During the first two dives, alterations of trim and minor repairs were tested. During the third dive the influence of different positions of the wing control flaps on roll behavior and steering were evaluated by tying them into position. Figure 4 shows Bumblebee during one of these glides. Finally, weight was removed to simulate the rising behavior of the glider and observe the upward glide path. Further in water test of the buoyancy engine had to be postponed because of illness of one of the scientific divers.

Tests were successful in terms of the generation of forward lift through the wings, the pitch of the vehicle, and water proofness up to a depth of 16m. However, they also showed limitations of the system when a bottom current impaired the turning capabilities of the vehicle during tests on the second day. Valuable experience was gathered concerning on board maintenance and deployment of the glider and will be reflected in the further design process. Additional tests will have to be performed to determine maximum current speeds the vehicle can safely maneuver, as soon as the on board sensor package is operational. A acoustic Doppler current profiler will be used to verify current data.

## IV. Conclusion

The autonomous underwater glider Bumblebee presented in this paper is on its way to become a fully functional platform for glider research and education at Florida Institute of Technology. The custom piston type buoyancy engine and its aluminum pressure housing allow dives to 100m water depth. And the new approach of using wing control surface flaps for steering will result in superior maneuverability during missions. In the current set up, batteries will allow deployments of up to 2.5 days or a week by upgrade to lithium-ionen technology. With its dimensions of only 2m length and 0.80m width and a weight of less than 30kg with payload, Bumblebee can be handled by small crews and without heavy equipment. A completely independent emergency system and a communication package complete the vehicles instrumentation and make it a well rounded tool.

A layered software approach composed of top level software running on a on board Linux system, sensor and hardware drivers as well as an independent emergency system and a GUI for remote computers allows easy adjustment and upgrade of the system. It also permits the use of Bumblebee as a platform for AI experiments and navigation algorithm research without the need for intimate hardware knowledge.

Field tests in June 2012 proofed the function of the new wing flap concept and basic flight capabilities. Further tests, planned for August 2012 will aim to verify the work of the buoyancy engine and instrumentation under real conditions. Tests performed in June revealed that the influence of currents will also have to be investigated further. A comparison of flight behaviors of Bumblebee and a Slocum Battery Glider (manufactured by Webb Research Inc.) is in discussion for late 2012.

Bumblebees completition is planned for December 2012. The vehicle will be made available for a broader community of students and scientist at Florida Institute of Technology to take on its purpose as platform for oceanographic and underwater robotics research.

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