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SEA SLUGG - Student Experiment Again: Submarine Launched into µGravity from Gdansk

Szymon Krawczuk[a]*, Adam Dąbrowski[b], Kacper Loret[c], Norbert Szulc[c], Dominika Tomaszewska[c], Marcin Jasiukiewicz[c], Konrad Jeznach[c], Wiktor Lachowski[c], Wojciech Wysocki[c], Adrian Pluto-Prondziński[c]

[a] *Faculty of Mechanical and Ocean Engineering, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland, szymon.r.krawczuk@gmail.com*
[b] *Faculty of Mechanical and Ocean Engineering, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland, ad.dabrowski@gmail.com*
[c] *Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland,*
* Corresponding Author

Abstract

Search for extraterrestrial life has been a drive wheel for space technology research for half a century. Recent research in astrobiology suggests that underwater oceans on Jovian moon Europa, Saturnian moon Titan and possibly asteroids may be a potential habitat for such microbial life. The unique combination of an actively recycled ice shell and rocky, possibly magmatic interior may give rise to a geochemical system suitable to life and not so terribly different from the terrestrial cryosphere, where the ice may act as a suitable interface along which melt and freeze provide chemical gradients of which life can take advantage. To investigate such environments, utilization of unmanned underwater vehicles (UUV) is proposed. This research proposes validation of a technology demonstrator of a UUV in microgravity conditions. Few typical control algorithms, both linear and nonlinear will be tested during a parabolic flight campaign. Along with visualization of streamlines with dye, this research may be a first insight into technical challenges of operating a UUV in a space underwater mission in search for extraterrestrial life. A student team project to verify the system in a parabolic flight campaign is presented including a prototype of the UUV, first test results and management of the student project.
Keywords: (maximum 6 keywords)

Acronyms/Abbreviations

This section is not numbered. Define acronyms and abbreviations that are not standard in this section. Such acronyms and abbreviations that are unavoidable in the abstract must be defined at their first mention there. Ensure consistency of abbreviations throughout the article. Always use the full title followed by the acronym (abbreviation) to be used, e.g., reusable suborbital launch vehicle (RSLV), International Space Station (ISS).

1. Introduction

The Fly Your Thesis! (FYT) programme provides university students at bachelor's, master's, or PhD level, the opportunity to perform scientific or technological research in microgravity conditions. Student teams selected to participate in the DYT campaign are provided the opportunity to perform 31 parabolas onboard the Novaespace plane.

Participating student teams integrate their experiment and later can operate them onboard the plane. The total number of 31 parabolas provides the possibility to perform relatively high number of repetitions, total 10 minutes of microgravity. It is also possible, to perform tests in reduced gravity, like martian or lunar.

2. Scientific background

The main scientific objective is to study existing control algorithms for unmanned underwater vehicles (UUV) in microgravity conditions.

The secondary scientific objective is to visualise streamlines around an operating UUV in microgravity conditions.

One of the most promising candidates for hosting extraterrestrial life is Jupiter's icy moon, Europa [2]. The unique combination of an actively recycled ice shell and rocky, possibly magmatic interior may give rise to a geochemical system suitable to life and not so terribly different from the terrestrial cryosphere, where the ice may act as a suitable interface along which melt and freeze provide chemical gradients of which life can take advantage.

A series of studies suggest architectures for exploration missions [3-6], including search and return to Earth missions [7]. Many of these involve drilling a hole through ice on Europa's surface (or using a geyser) and injecting a small UUV into the under ice ocean. It is a well-known fact that surface gravity is 1.314 m/s2 (0.134 g) [8]. Some research suggests that a number of asteroids might have water under the surface [9] and be potential habitats for life [10]. Some authors suggest that terrestrial life could have originated from somewhere else (so called panspermia theory [11]). Gravity conditions in such environments are typically very close to microgravity, but also tend to be highly irregular [12].

This is very different to what typical underwater vehicles, not to name UUV. Existing buoyancy control and navigation algorithms have been designed and developed with Earth 1 g in consideration. Existing navigation and control algorithms rely heavily on buoyancy force. According to Archimedes' principle:

Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

In mentioned environments, little to no gravity is present, therefore fluid does not weigh. Apart from concepts [3-7], only two technical research has been performed on operating an UUV in microgravity: NASA Titan submarine report [13], and [14] however no actual tests have ever been performed. Figure 1. presents an artist's impression of a hypothetical ocean cryobot (a robot capable of penetrating water ice) in Europa.

Fig. 1. An artist's impression of a hypothetical ocean cryobot (a robot capable of penetrating water ice) on Europa [14].

2. Proposed project

3.1 Experiment idea

In proposed research, an investigation into UUV behaviour and control algorithms in microgravity is planned. Throughout the years various models of control techniques have been proposed. This includes linear controllers. [15-18], which have performed satisfactorily; SMC controllers [19], adaptive control [20], FLC (Fuzzy Logic Control) [21], predictive control [22], static feedback control [23], and neural-network-based control [24] have also shown good robustness and tuning ability. Since almost all control methods have some pros and cons, a proper controller can be achieved by the combination of classical and modern intelligent methods.

One of the most important disadvantages of linear controllers like LQR and LQG is that they are unable to account for the nonlinearities of the system, thus they can result in suitable performance and even instability in high maneuver treatments. In brief, the adaptive control is a type of nonlinear control using a system with uncertainty or time-varying parameters. It is implemented on plants with a definite structure with unspecified fixed or slowly varying parameters. Adaptive method is useful for AUVs because of variation of real model parameters.

The controller can adapt itself according to the level or characteristics of waves and currents or to the changing weight of AUV. Also, a neural network has some weak points that bind its improvement. It converges to a precise model with long training time and slow rate, which is not acceptable by many systems. Also, classical neural networks do not qualify the main requirements such as fast response, less overshoot–undershoot. SMC is an earlier method that is a good solution for nonlinear systems but it can cause chattering on actuators, waste energy, and make faults on fins. However, there are some methods like combination with fuzzy or changing the sign function by saturation function to reduce chattering. The FLC is easy to use in industrial processes because of its simple control structure, easy and cost-effective design. However, FLC with fixed scaling factors and fuzzy rules may not give complete performance if the controlled plant has uncertainty and high nonlinearity.

The main scientific goal is to compare control of a UUV on a simple linear trajectory in microgravity using above-mentioned methods:

- LQR controller,
- adaptive controller;
- fuzzy logic control.

A sample UUV will be used with two propellers at the rear for forward/aft/heading control and one vertical propeller for submerging will be used. Such a device has already been tested by the SEA SLuGG team at a towing tank of Gdańsk University of Technology [25], see Figure 2 and Figure 3.

3.2 Experimental procedure

To fulfil the objectives of the experiment, the SEA SLuGG team proposes to perform a parabolic flight experiment with a double sealed tank of water. The team has already experimented with a remote controlled UUV (however no research has been published yet).

The UUV will be (and already is) remotely controlled via a pilot connected to a PC with Matlab software. The system will also contain a set of video cameras that will record and identify the pose of the UUV using IR. The signal from cameras will be fed as input to Matlab. Output control signal will be fed from Matlab through the remote controller to the UUV.

The various control methods would be tested on consecutive flights. Additionally, some flights (last flights of each day) will be used for fulfilling the secondary objective: visualization of streamlines in microgravity. For that purpose, the tank of water will have small containers of dye, also double contained, that will allow it to release its content on demand (during microgravity phase).


Fig. 2. Sea SluGG AUV.


Fig. 3. Tests of an UUV by the SEA SLuGG team..

Variables in the experiment:

- varied: method of control of the UUV;
- varied: gravity: 1.8g, 0g, 1g;
- constant: planned trajectory of the UUV (straight line);
- constant: geometry of the UUV;
- constant: parameters of the fluid: volume, density, temperature, etc.

4. Experimental setup

The most important part of the experiment safety is providing proper sealing. This is why there is a reduced mechanical/electrical interface between the inner and outer space of the experiment. To make this more robust, parts involving interfaces needed for cameras and pigment injector will be placed in an additional outer vessel. The inner tank will not be fully filled with the liquid as shown in Figure 4. in order to create a possibility of fluid discontinuities (i.e. water bubble). The connection between the mission control unit and sub will be established via remote control (49 MHz, upon consent of Novespace).

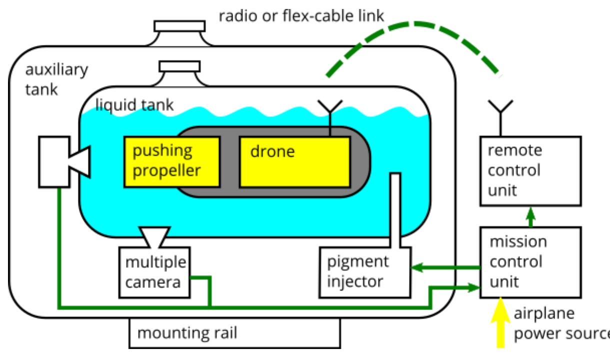

Fig. 4. Experiment electronics diagram

The electronic design of the experiment is based on a PC computer connected to a custom made Microcontroller board. The Microcontroller is tasked with managing the mechanical components of the experiment (pigment injector & mini-sub) and collecting information from IMU & sensors. The PC will take data from the microcontroller and cameras and use them in a realtime Matlab simulation.Results should be clear and concise.

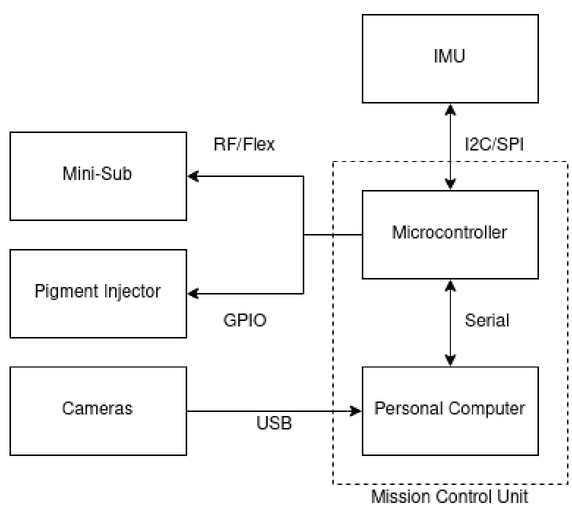

Fig. 5. Experiment electronics diagram

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