An Interactive Virtual Simulator for Motion Analysis of Underwater Gliders

Alan López-Segovia, Luis García-Valdovinos, Tomás Salgado-Jiménez, Isabel Andrade-Bustos, Luciano Nava-Balanzar, José Luis Sánchez-Gaytán and Juan Pablo Orozco-Muñiz
Energy, CIDESI, Av. Playa Pie de la Cuesta 702, 76125, Queretaro, Queretaro, Mexico

Keywords: Virtual Reality, Underwater Gliders, Modelling and Control, Haptic Interfaces.

Abstract: Autonomous Underwater Gliders (AUG) have become a very useful and cheap tool to sample the ocean's environment compared with oceanographic ships to perform the same task. AUGs can glide along the ocean up to a specific depth thanks to their aerodynamic shape, wings and rudders, and a buoyancy-driven system composed of a bladder and an eccentric movable mass that modifies the net buoyancy and the pitch/roll angles of the vehicle, respectively. One of the main concerns of glider's pilots is to understand and/or predict the behaviour of the glider when it is affected by ocean currents under the water. In this paper, an interactive virtual simulator for motion analysis of underwater gliders is given. The simulator considers the online solution of the full nonlinear hydrodynamics of a well-known glider. The virtual simulator is a tool that will help technicians and pilots to increase their training process, to carry out performance analysis of new control schemes and validation of new glider's models before the physical construction.

1 INTRODUCTION

An Autonomous Underwater Glider (AUG) bases its operation on its buoyancy change to move through the ocean in saw tooth patterns, reaching a specific depth target. The AUG missions can explore thousands of kilometres in long time missions (several months) because of its low power consumption. It can have different kinds of sensors to analyse several water columns in ocean's environment following a zigzag trajectory until a specific depth is reached; this vehicle has become more and more popular for oceanographic studies due to its low cost in comparison to traditional methods. However, the cost of a commercial AUG is not negligible so a real glider mission is considered a critical task, therefore, a glider's pilot must have a full knowledge of the physical glider behaviour under different environmental conditions (e.g. marine currents) and inherent mission conditions (e.g. velocity changes due to glider attitude). This paper addresses the design and development of an interactive virtual simulator for the study of the behaviour of an AUG. The aim of this interactive virtual simulator is to make the learning process faster and easier for pilots before a real mission deployment, performance analysis of new control schemes and validation of new glider's models before the physical construction.

An interactive virtual simulator is a system where can be reproduced the behaviour of a physical phenomenon in a computer created environment under conditions nearly to reality, the user can handle the phenomenon parameters while simulation is running. Through a virtual simulator can be either predicted or analysed the phenomenon behaviour without a physical implementation, virtual simulator results are nearly approximated to real phenomenon behaviour results. An AUG's virtual simulator development implies three main tasks: i) validation and analysis of a mathematical model able to reproduce real glider behaviour, ii) validation and analysis of a mathematical model able to reproduce environmental conditions wherein the AUG will interact with, and iii) design of a virtual environment (scenario and AUG graphical design and animations) to give a real visual sensation for users.

Graver and Leonard (Graver & Leonard, 2001), using a Newtonian approach, proposed a mathematical model which sat the foundations to obtain and do a formal analysis of AUG dynamics, until that moment, a lot of AUGs had been used in several successful oceanographic missions but

López-Segovia, A., García-Valdovinos, L., Salgado-Jiménez, T., Andrade-Bustos, I., Nava-Balanzar, L., Sánchez-Gaytán, J. and Orozco-Muñiz, J.
An Interactive Virtual Simulator for Motion Analysis of Underwater Gliders.
DOI: 10.5220/0006476804810488
In *Proceedings of the 14th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2017) - Volume 2*, pages 481-488
ISBN: Not Available

neither a precise physical behaviour nor mathematical properties had been comprehended yet. Later, several research groups around the world were dedicated to discover and understand physical properties of that mathematical model (Bender, Steinberg, Friedman, & Williams, 2008) (Ali Hussain, Arshad, & Mohd-Mokhtar, 2011) (Upadhyay, Singh, & Idichandy, 2015), programming and computing the differential equations system using a specific numerical method; by their own, in (Wang, Singh, & Yi, 2013) a Lagrangian approach has been used in order to compute a mathematical model of the Slocum Glider, a commercial AUG model. On the other hand, the mathematical model presented in (Zhang, Yu, & Zhang, 2013) captures general behaviour of an AUG whose pitch and roll angles are generated by an eccentric movable mass. Hydrodynamic parameters are an important part of AUG mathematical model that describe interaction between vehicle and surrounding fluid and they depend of fluid characteristics as well as vehicle geometry. The hydrodynamic study of an AUG for obtaining hydrodynamics parameters is a complex task; currently there are a lot of commercial computer software which can compute high precision hydrodynamic parameters for complex structures, under numerous simulated scenarios. Using this techniques, there are several papers, like (Zhang, Yu, & Zhang, 2013) (Seo, Jo, & Choi, 2008) (Seo & Williams, 2010) (Singh, Bhattacharyya, & Idichandy, 2014), that employ a CFD (Computational Fluid Dynamics) software to estimate the coefficients and hydrodynamic forces of an AUG.

In the literature are reported a number of AUG simulators, most of them use the 2D mathematical model presented in (Graver & Leonard, 2001), very few use 3D mathematical model and none of them a mathematical model implemented on a virtual environment. A simulator presented in (Phoemsapthawee, Le Boulluec, Laurens, & Deniset, 2013) represents an AUG with six degrees of freedom. The objective of this work was the hydrodynamic study of a vehicle to improve glider designs and evaluate the control strategy performance. The mathematical model used in this work is based in Newton-Euler equations and considers that mass centre is moved with respect to a coordinate system fixed to the vehicle. Other work about virtual simulator is presented in (Woithe & Kremer, 2010), in this work a virtual simulator for Slocum glider is presented. It's not clear if the 3D hydrodynamic model is used. In (Asakawa, Watari, Nakamura, Hyakudome, & Kojima, 2013), Tsukuyomi glider movements are observed numerically, the depth effect produced in AUG's (water density change, AUG buoyancy, etc.) is incorporated in the numerical simulation. This work does not include interactive animations.

The discussion in this paper will procced as follows: In section II the mathematical model used for AUG behaviour and ocean environmental reproduction is presented. Then, in section III simulation testing and validation of mathematical model is discussed. The AUG interactive virtual simulator implementation is described in section IV. Finally, conclusions are exposed in Section V.

2 MATHEMATICAL MODEL OF AN UNDERWATER GLIDER

The mathematical model of an AUG used in the interactive virtual simulator is proposed in (Zhang, Yu, & Zhang, 2013); a well-known commercial AUG model is incorporated in the interactive virtual simulator. The model takes into account a moveable eccentric mass for inducing a θ (pitch) angle and ϕ (roll) angle.

2.1 Kinematics Model

Figure 1 shows the coordinates frame used for the AUG mathematical model calculation: Inertial frame, body frame and flow frame, established to describe the motion of the AUG. The body frame origin $\boldsymbol{e_0} : (\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$ is established at the Buoyancy Center (CB) of the AUG. The x axis matches with longitudinal axis of the AUG. The z axis points downward, forming 90° with $\boldsymbol{x}$ axis. The y axis lie on the wings plane and is the result of the right hand rule. The inertial frame is described by $\boldsymbol{E_0} : (\boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k})$, where i, j, k represents the frame axis and they are unitary vectors. At the body frame, translational velocity and angular velocity of the AUG are defined as $\boldsymbol{V} = [V_1, V_2, V_3]^T$ and $\boldsymbol{\Omega} = [p, q, r]^T$, respectively. At inertial frame, AUG position and orientation are described by $\boldsymbol{b} = [x, y, z]^T$ and $\boldsymbol{\theta} = [\phi, \theta, \psi]^T$, respectively. Rotation matrix $\mathbf{R}_{\mathrm{EB}}$ maps $\boldsymbol{V}$ of the body frame to the rate of change of b at inertial frame as follows:

$$\dot{\mathbf{b}} = \mathbf{R}_{\mathrm{EB}}\mathbf{V} \tag{1}$$

Rotation matrix $\mathbf{R}_{\mathrm{EB}}$ is defined as:

$$\mathbf{R}_{\mathrm{EB}} = \begin{bmatrix} c\theta c\psi & s\phi s\theta c\psi - c\phi s\psi & c\phi s\theta c\psi - s\phi s\psi \\ c\theta s\psi & c\phi c\psi + s\phi s\theta s\psi & -s\phi c\psi + c\phi s\theta s\psi \\ -s\theta & s\phi c\theta & c\phi c\theta \end{bmatrix} \quad (2)$$

where $s \cdot := \sin(\cdot)$ y $c \cdot := \cos(\cdot)$.

The relationship between $\boldsymbol{\Omega}$ y $\dot{\boldsymbol{\theta}}$ is given by:

$$\dot{\boldsymbol{\theta}} = \begin{bmatrix} 1 & s\phi \tan\theta & c\phi \tan\theta \\ 0 & c\phi & -s\phi \\ 0 & s\phi \sec\theta & c\phi \sec\theta \end{bmatrix} \boldsymbol{\Omega} \quad (3)$$

Often is more useful and convenient to compute and analyse at flow frame denoted by $\boldsymbol{\pi_0} : (\pi_1, \pi_2, \pi_3)$ in Figure 1. For flow frame definition, first is necessary to define attack angle α and sideslip angle β as follows:

$$\tan\alpha = \frac{V_3}{V_1} \quad (4)$$

$$\sin\beta = \frac{V_2}{\sqrt{V_1^2 + V_2^2 + V_3^2}} \quad (5)$$

The flow frame is defined with respect to body frame as: First, the body frame is rotated by $-\alpha$ angle around y axis, this yield that z axis is rotated to a new position now called π_3 axis. Later, the new frame is rotated around π_3 axis by β angle. So, both, x axis is converted at π_1 axis, and y axis is converted at π_2 axis of flow frame.

2.2 Hydrodynamic Model

As mentioned above, the hydrodynamic model used in the AUG's interactive virtual simulator is proposed in (Zhang, Yu, & Zhang, 2013), which can reproduce the behaviour of any AUG's.

Figure 2 shows mass distribution of an AUG: static mass m_s, eccentric movable mass m_r, and net buoyancy m_b which represents the difference between total buoyancy (m) and AUG total mass $m_v (= m_s + m_r)$. The movable mass is modeled like a half cylinder with eccentric offset R_r. Its mass center is located at r_{rx} along $\mathbf{x}$ axis and it is rotated by γ angle around $\mathbf{x}$ axis. The vectors $\mathbf{q}_{rE}, \mathbf{q}_{bE}$ and $\mathbf{q}_{sE}$ denote mass center position of eccentric mass, net buoyancy and static mass, respectively respect to inertial frame. In turn, the vectors, $\mathbf{r}_r$, $\mathbf{r}_s$, and $\mathbf{r}_b$ express mass center position of eccentric mass, static mass and net buoyancy respect to body frame, respectively.

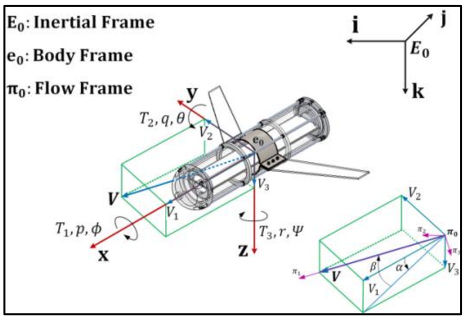

Figure 1: Coordinate frames.

The hydrodynamic equations that describe the AUG behaviour are given by:

$$\mathbf{M}\dot{\mathbf{v}} + \dot{\mathbf{M}}\mathbf{v} - \begin{bmatrix} \mathbf{P} \times \boldsymbol{\Omega} \\ \boldsymbol{\Pi} \times \boldsymbol{\Omega} + \mathbf{P} \times \mathbf{V} \end{bmatrix} - \begin{bmatrix} m_b g(\mathbf{R}_{EB}^T \mathbf{k}) \\ (m_r \mathbf{r}_r + m_s \mathbf{r}_s + m_b \mathbf{r}_b) g \times (\mathbf{R}_{EB}^T \mathbf{k}) \end{bmatrix} - \begin{bmatrix} \mathbf{F} \\ \mathbf{T} \end{bmatrix} = \mathbf{0} \quad (6)$$

$$\dot{m}_b = u_b$$

For more details refer to (Zhang, Yu, & Zhang, 2013).

2.3 Hydrodynamic Forces

In the flow frame, the hydrodynamic force $\mathbf{F}_h = [-D \quad SF \quad -L]^T$ and hydrodynamic moment $\mathbf{T}_h = [T_{DL1} \quad T_{DL2} \quad T_{DL3}]^T$ are expressed as:

$$\begin{aligned} D &= (K_{D0} + K_D \alpha^2) V^2 \\ SF &= K_\beta \beta V^2 \\ L &= (K_{L0} + K_\alpha \alpha) V^2 \\ T_{DL1} &= (K_{MR}\beta + K_p p) V^2 \\ T_{DL2} &= (K_{M0}\beta + K_M \alpha + K_q q) V^2 \\ T_{DL3} &= (K_{MY}\beta + K_r r) V^2 \end{aligned} \quad (7)$$

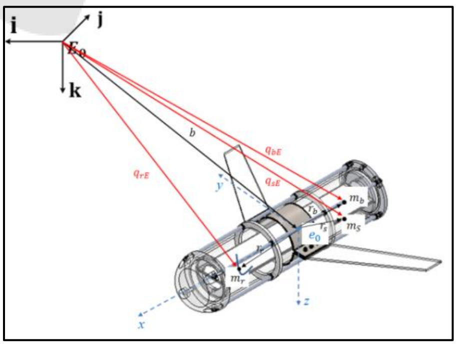

Figure 2: Mass distribution.

A rotation matrix $\mathbf{R}_{BC}$ is defined as follows:

$$\mathbf{R}_{BC} = \begin{bmatrix} \cos\alpha\cos\beta & -\cos\alpha\sin\beta & -\sin\alpha \\ \sin\beta & \cos\beta & 0 \\ \sin\alpha\cos\beta & -\sin\alpha\sin\beta & \cos\alpha \end{bmatrix} \quad (8)$$

$\mathbf{R}_{\mathrm{BC}}$ maps the hydrodynamic force and hydrodynamic moment from flow frame to body frame as shown next:

$$\begin{aligned}\mathbf{F} &= \mathbf{R}_{\mathrm{BC}}\mathbf{F}_{\mathrm{h}} \\ \mathbf{T} &= \mathbf{R}_{\mathrm{BC}}\mathbf{T}_{\mathrm{h}}\end{aligned} \tag{9}$$

2.4 Ocean Currents Model

In (Fossen, 2002) is described an ocean current model widely accepted in underwater robotics. Although the current model considers a laminar and constant flow it is useful to analyse the hydrodynamic behaviour of an AUG when this is disrupted by a current with diverse directions and intensities.

The ocean current model establishes that the hydrodynamics can be expressed in terms of a relative velocity as follows:

$$\mathbf{V}_{\mathrm{r}} = \mathbf{V} - \boldsymbol{\nu}_c \tag{10}$$

where $\boldsymbol{V}_r$ is the relative velocity between the AUG velocity $\boldsymbol{V}$ and the ocean current velocity $\boldsymbol{\nu}_c = [u_c \;\; v_c \;\; w_c \;\; 0 \;\; 0 \;\; 0]^{\mathrm{T}}$ expressed in the body frame.

The ocean current components with respect to inertial frame $\boldsymbol{\nu}_c^E = [u_c^E \quad v_c^E \quad w_c^E]$ can be related to current intensity V_c defining two angles: attack angle α_c and sideslip angle β_c, which describe the V_c orientation respect to y axis and z axis, respectively, as is shown in Figure 3.

The average ocean current velocity in terms of attack angle and sideslip angle, expressed with respect to the inertial frame is:

$$\begin{aligned} u_c^E &= V_c \cos\alpha_c \cos\beta_c \\ v_c^E &= V_c \sin\beta_c \\ w_c^E &= V_c \sin\alpha_c \cos\beta_c \end{aligned} \tag{11}$$

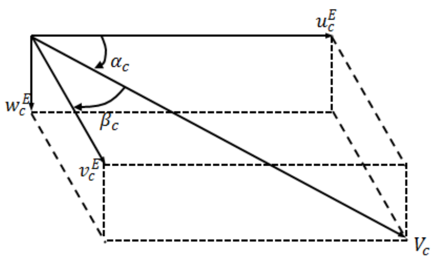

Figure 3: Flow frame.

To express the ocean current components from inertial frame to body frame is necessary to use the matrix $\mathbf{R}_{\mathrm{EB}}$ as follows:

$$\begin{bmatrix} u_c \\ v_c \\ w_c \end{bmatrix} = \mathbf{R}_{\mathrm{EB}}^T \begin{bmatrix} u_c^E \\ v_c^E \\ w_c^E \end{bmatrix} \tag{12}$$

The hydrodynamic model equations including the ocean current effects now are described as:

$$\mathbf{M}\dot{\mathbf{v}} + \dot{\mathbf{M}}\mathbf{v}_r - \begin{bmatrix} \mathbf{P} \times \boldsymbol{\Omega} \\ \boldsymbol{\Pi} \times \boldsymbol{\Omega} + \mathbf{P} \times \mathbf{V}_r \end{bmatrix} - \begin{bmatrix} m_{\mathrm{b}} g(\mathbf{R}_{\mathrm{EB}}^T \mathbf{k}) \\ (m_{\mathrm{r}}\mathbf{r}_{\mathrm{r}} + m_{\mathrm{s}}\mathbf{r}_{\mathrm{s}} + m_{\mathrm{b}}\mathbf{r}_{\mathrm{b}}) g \times (\mathbf{R}_{\mathrm{EB}}^T \mathbf{k}) \end{bmatrix} - \begin{bmatrix} \mathbf{F} \\ \mathbf{T} \end{bmatrix} = \mathbf{0} \tag{13}$$

where $\mathbf{V}_{\mathrm{r}} = \mathbf{V} - \mathbf{R}_{\mathrm{EB}}^T \boldsymbol{\nu}_c^E$. Now the mass, Coriolis-centripetal and hydrodynamic force and moment terms are only functions of acceleration and relative velocity. For the hydrodynamic force and moment described in (Graver J. , Thesis: Underwater Gliders: Dynamics, control and design., 2005), the resultant velocity V in equation (6) is substituted by the next resultant relative velocity:

$$V_{res} = \sqrt{(V_1 - u_c)^2 + (V_2 - v_c)^2 + (V_3 - w_c)^2} \tag{14}$$

3 MODEL VALIDATION

Once we have raised and analysed the AUG hydrodynamic model, a validation of this becomes necessary for its implementation in the AUG interactive virtual simulator. The model validation is made through a numerical simulation using the mathematical software MATLAB/Simulink.

In a numerical simulation the results are shown numerically through graphs for easy interpretation and analysis. The variable values used for validation model simulation are presented in Table I and Table II.

Normally, an AUG does hundreds of cycles during its mission, in one cycle the AUG sinks from the ocean surface until a specific depth, then the AUG rises from specific depth to ocean surface again, that is one cycle end. For the model validation the parameters for one cycle is summarized in Table III and Table IV.

The eccentric mass is held at γ=0 (ϕ=0) at all time to avoid inducing a turn in the AUG. Notice that the Slocum glider induces a turn in the yaw angle ψ by means of an actuated rudder. Depending on the AUG position the movable mass is moved to produce the desired pitch angle θ.

Table 1: Physical parameters of Slocum glider (Bardolet, 2012) (Teledyne Webb Research, 2012).

Variable	Value
m_s	$48\ \text{kg}$
r_s	$[-0.0753 \quad 0 \quad 0.0032]\ \text{m}$
I_s	$\text{diag}[3.6 \quad 11.5 \quad 10.3]\ \text{kg m}^2$
m_r	$9\ \text{kg}$
r_r	$0.3516\ \text{m} \le r_{rx} \le 0.4516\ \text{m}$
I_r^0	$\text{diag}[0.02 \quad 10.16 \quad 0.17]\ \text{kg m}^2$
m_b	$-0.27\ \text{kg} \le m_b \le 0.27\ \text{kg} @ \rho = 1000\ \text{kg/m}^3$
r_b	$[0 \quad 0 \quad 0]\ \text{m}$
m	57 kg (water mass displaced by the vehicle @ $\rho = 1000\ \text{kg/m}^3$)
A_r	$0.015\ \text{m}^2$ (rudder area)

Table 2: Hydrodinamic parameters of slocum glider (BARDOLET, 2012).

Variable	Value
M_A	$\text{diag}[5 \quad 60 \quad 70]\ \text{kg}$
I_A	$\text{diag}[0.4 \quad 0.5 \quad 0.7]\ \text{kg m}^2$
C_A	$N_{\dot{v}} = 2.57\ \text{kg m}$, $Z_{\dot{q}} = 3.61\ \text{kg m}$
D	$K_{D0} = 2\ \text{kg/m}$ $K_D = 45\ \text{kg/m/rad}^2$
SF	$K_\beta = 20\ \text{kg/m/rad}$
L	$K_{L0} = 0\ \text{kg/m}$ $K_\alpha = 135\ \text{kg/m/rad}$
T_{DL1}	$K_{MR} = -60\ \text{kg/rad}$ $K_p = -20\ \text{kg s/rad}$
T_{DL2}	$K_{M0} = 0.28\ \text{kg}$ $K_M = 0\ \text{kg/rad}$ $K_q = -60\ \text{kg s/rad}^2$
T_{DL3}	$K_{MY} = 100\ \text{kg/rad}$ $K_r = -20\ \text{kg s/rad}^2$
λ_r	$-\frac{\pi}{2} \le \lambda_r \le \frac{\pi}{2}$ (rudder angle of rotation)

Table 3: Sinking trajectory conditions.

0 – 50 s	**50 – 150 s**	**150 – 250 s**
$\theta = 0°$ $m_b = 0$ Kg	$\theta = 0° \rightarrow -35°$ $m_b = 0 \rightarrow 0.27$ Kg	$\theta = -35°$ $m_b = 0.27$ Kg

Table 4: Rising trajectory conditions.

250 – 350 s	**350 – 450 s**	**450 – 550 s**	**550 – 600 s**
$\theta = -35° \rightarrow 35°$ $m_b = 0.27 \rightarrow -027$ Kg	$\theta = 35°$ $m_b = -0.27$	$\theta = 35° \rightarrow 0°$ $m_b = -0.27 \rightarrow 0$ Kg	$\theta = 0°$ $m_b = 0$

Table 5: Ocean current parameters.

V_c	$0.12\ \text{m/s}$
α_c	$180°$
β_c	$0°$

Figures 4 and 5 depict the behaviour of the Slocum glider with and without ocean currents. Evidently, when ocean current is present the glider is restricted to move freely.

The hydrodynamic model raised shows a coherent behaviour with reality and reported data in literature. Numerically, as is shown in Figure 4 to 5, it presents good stability which is reflected with moderate transition and low frequency signals. Thus, the hydrodynamic model with and without current effects is validated and available for its incorporation in the AUG interactive virtual simulator.

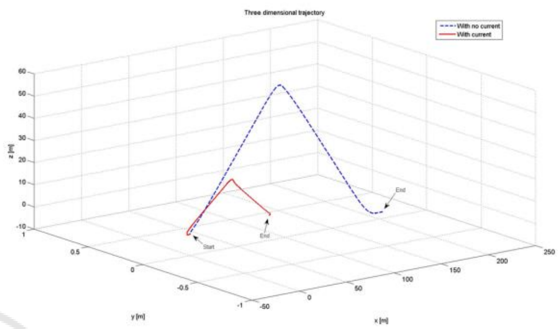

Figure 4: Glider behavior during a cycle, wih and without ocean current.

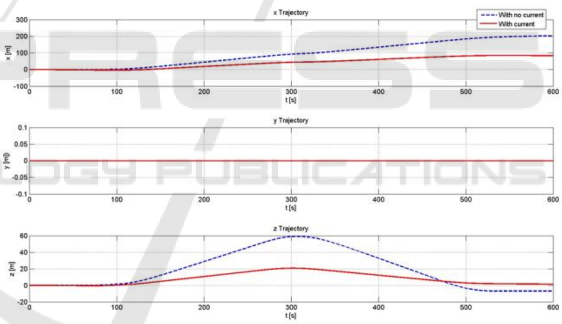

Figure 5: Trajectories followed by the glider with and without ocean current.

Next, the main contribution of the paper is given.

4 GLIDER SIMULATOR IMPLEMENTATION

The AUG interactive virtual simulator was created by using a set of software tools such as Unity 3D, Blender, Visual C++ and Matlab/Simulink. Figure 6 shows the combination of this Software tools.

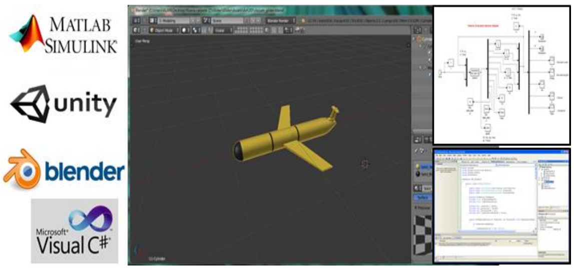

Figure 6: Software tools used for the development of the interactive virtual simulator.

Unity 3D is one of the most popular and powerful game engines used for the development of virtual environments. Unity works as a platform that offers a variety of tools to develop realistic scenarios along with the capability to interface with scripts performed in Visual C# and to import CAD models from Blender.

The mathematical model along with the parameters of each glider was added to the virtual simulator using script files under C# language, inside this script files was programmed the Heun numerical integrator for the model resolution.

In Figure 7 a block diagram of the interactive virtual simulator is displayed. The virtual simulator is formed by a high performance PC and a haptic interface (Falcon) which can be operated by the user for controlling the AUG control. As shown above, in the high performance computer the hydrodynamic model is programmed which is solved online by the Heun integrator. The model solution is processed by the render module to recreate visually the AUG motion in the virtual environment.

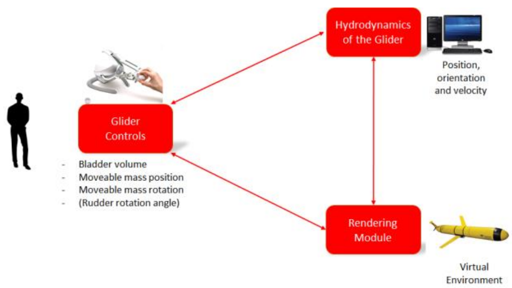

Figure 7: Block diagram of the interactive virtual simulator.

The interactive virtual simulator allows the users (pilots) to analyse the AUG motion in the 3D virtual environment by manipulating the control variables (bladder volume, moveable mass position and moveable mass rotation), as shown in Figure 8.

Figure 8: The pilot can modify online the main variables of the selected glider by means of a haptic interface, a mouse or the keyboard.

The main screen displays three different types of information and two types of controllable variables. The types of information are: 3D visualization, graphic visualization of variable values and numerical visualization of AUG state variables. The types of controllable variables are: AUG control variables and ocean current velocity. Figure 9 and Figure 10 depicts, respectively, the 4 different views and the control variables and ocean current panels.

Figure 9: (a) Isometric view, (b) Superior view (Gulf of Mexico map), (c) xzplane view, (d) xyplane view.

Figure 10: Control variables and ocean current control panels.

Finally, it includes a button which allows choosing between the AUG 3D models: Seaglider, Slocum, Seawing and soon the CIDESI's glider. Any other commercial or academic glider can be added to the simulator provided the whole parameters are available. When the AUG 3D model is chosen the corresponding hydrodynamic model and parameters are chosen too. Once a simulation is running is not possible to change the AUG model until the button "Restart" is pushed.

Each control panel is fitted with a button to expand or collapse the information. While the simulation is running the AUG creates navigation marks, which stores historical data about AUG trajectory, as can be seen in Figure 11.

Figure 11: Equidistant navigation marks (red balls) draw the glider trajectory. A green ball is a particular point selected by the pilot to know the glider's state in the inertial frame.

5 CONCLUSIONS

In this paper, preliminary results of an interactive virtual simulator are presented. The simulator solves online the full nonlinear hydrodynamics of underwater gliders and the solution is fed to the rendering module (virtual environment) to display the motion in a realistic 3D scenario in order to analyze the behavior. The simulator is provided with different tools to analyze the motion and the generated information. At this moment, the virtual simulator is interactive; it means that the pilot can modify online the three main control variables of an underwater glider: volume of the bladder, position of the moveable mass and the rotation angle of the eccentric mass. In the case of the Slocum glider, an actuated rudder has been considered into the hydrodynamics instead of the eccentric mass. Additionally, the simulator has a panel to arbitrarily set the intensity and direction of the ocean current. The simulator represents a useful tool for the Oceanographic Monitoring Group with Gliders (GMOG) pilots.

Future work is to implement the functionality of "automatic mode" and add the map of the Gulf of Mexico wherein the pilot will be able to indicate on it the starting point and the subsequent way points that the glider has to reach, with or without currents. Not only the virtual environment and the graphic user interface have to be modified but also it is necessary to choose the correct control law.

ACKNOWLEDGMENT

This study is part of the project number 201441 "Implementation of oceanographic observation networks (physical, geochemical, ecological) for generating scenarios of possible contingencies related to the exploration and production of hydrocarbons in the deepwater Gulf of Mexico", granted by SENER-CONACyT Hydrocarbons Sectorial Fund.

REFERENCES

Ali Hussain, N. A., Arshad, M. R., & Mohd-Mokhtar, R. (2011). Underwater glider modelling and analysis for net buoyancy, depth and pitch angle control. *Ocean Engineering*, *38*(16), 1782 - 1791.

Asakawa, K., Watari, K., Nakamura, M., Hyakudome, T., & Kojima, J. (2013). Motion Simulator for an Underwater Glider for Long-term Virtual Mooring Including Real Devices in Loop. *IEE/MTS Oceans.*

Bardolet, A. (2012). Contributions to Guidance and Control of Underwater Gliders. Master Thesis, University of Southern Denmark.

Bender, A., Steinberg, D., Friedman, A., & Williams, S. (2008). Analysis of an autonomous underwater glider. *Australasian Conferencie on Robotics and Automation.* Canberra, Australia.

Fossen, T. (2002). *Marine Control Systems Guidance, Navigation, and Control of Ships, rigs and Underwater Vehicles.* Marine Cybernetics.

Graver, J. (2005). Thesis: Underwater Gliders: Dynamics, control and design. Mechanical and Aerospace Engineering.

Graver, J. G., & Leonard, N. E. (2001). Underwater Glider Dynamics and Control. *12th International Symposium on Unmanned Untethered Submersible Technology.* Durham.

Graver, J., Bachmayer, R., & Leonard, N. (2003). Underwater Glider Model Parameter Identi_cation. *Proceedings 13th International Symposium on Unmanned Untethered Submersible Technology (UUST).*

Graver, J., Liu, J., Woolsey, C., & Leonard, N. (1998). Design and Analysis of an Underwater Vehicle for Controlled Gliding. *Princeton University. Conference on Information Sciences and Systems (CISS).*

Phoemsapthawee, S., Le Boulluec, M., Laurens, J., & Deniset, F. (2013). A Potential Flow Based Flight Simulator for an Underwater Glider. *Journal of Marine Science and Application*, *12*, 112-121.

Seo, D., & Williams, C. (2010). *CFD Predictions of Drag Force for a Slocum Ocean Glider.* National Research Council Canada.

Seo, D., Jo, G., & Choi, H. (2008). Pitching Control Simulations of an Underwater Glider Using CFD Analysis. *OCEANS.* Kobe.

Singh, Y., Bhattacharyya, S., & Idichandy, V. (2014). CFD Approach to Steady State Analysis of an Underwater Glider. *IEEE/MTS Oceans.* St. Johns, Canada.

Teledyne Webb Research. (2012). *Slocum G2 Glider Maintenance Manual.* East Falmouth, MA: Teledyne Webb Research.

Upadhyay, V. K., Singh, Y., & Idichandy, V. (2015). Modelling and Control of an Underwater Laboratory Glider. *Underwater Technology (UT), 2015 IEEE.*

Wang, P., Singh, P. K., & Yi, J. (2013). Dynamic Model-Aided Localization of Underwater Autonomous Gliders. *IEEE International Conference on Robotics and Automation (ICRA).* Karlsruhe, Germany.

Woithe, H. C., & Kremer, U. (2010). An Interactive Slocum Glider Flight Simulator. *IEE/MTS Oceans.*

Zhang, S., Yu, J., & Zhang, F. (2013). Spiraling motion of underwater gliders: Modeling, analysis, and experimental results. *Ocean Engineering*, *60*, 1-13.