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BIOMIMETIC APPROACH TO UNDERWATER CURRENT CORRECTIONSFOR AUTONOMOUS UNDERWATER VEHICLES' INERTIAL NAVIGATION SYSTEMS

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Abstract: *Autonomous Underwater Vehicles' (AUV) guidance on a desired course is done by two main navigation systems, acoustic and inertial. Acoustic navigation systems depend on fixed reference points - acoustic transponders laid on the sea floor in the case of long baseline (LBL) grids - while the inertial navigation systems (INS) are based on integration of own accelerations and velocities in order to compute a dead reckoning path of the AUV. Both methods pose, respectively, either technological/operational constraints or a low accuracy of navigation on the preset trajectory, due to a hydrological factor having a great impact on the AUVs motion: underwater currents. In the INS navigation case, which relies only on internal signals as input of computing the estimated course, underwater currents add a still undetectable error for the present navigation sensors.*
The authors propose a method of underwater current correction for INS navigation based on a biomimetic approach. Fish and aquatic mammals are using hydrodynamic reception, i.e. detection of subtle changes of water pressure around them that signal the presence of a moving body (friend or foe) within their sensorial envelope. Fish use their lateral line as a pressure sensing system, allowing them to react in changing their course for attacking pray or social schooling. By considering that the lateral line system can also explain navigation of fish during migrations, the authors present a study of how the pressure distribution differences on the AUV's body can measure the speed and incidence of an underwater current hence satisfactorily triggercurrent corrections of INS-based AUV navigation.

Introduction
Accurate guidance of AUV on a desired course over long distances is a major problem standing in front of the control subsystem's designers. The main cause of the errors in keeping the AUV's straight course while on an underwater trajectory is the sea currents. This constant input force on the hydrodynamic array of forces and moments acting on the AUV cannot be predicted before the run. The current influence on the AUV's motion is variable over the operational range of the AUV, in both horizontal but also in the vertical planes. The error applied by the sea current on the trajectory's control system has ultimately two components: speed and incidence relative to the vehicle's hull.
Even though the current pushes and rotates the AUV like any other hydrodynamic force that can be taken into consideration by the automatic control system, the lack of information about the incidence and intensity of this force on a certain moment poses a big problem in measuring it, hence taking corrective measures.
Therefore, to date, the correction measures against the current-inflicted sway (the lateral drift of AUV) just ignore this unpredictable variable. That is, AUV guidance on a desired course is done by two main navigation systems, acoustic and inertial. Acoustic navigation systems depend on fixed reference points - acoustic transponders laid on the sea floor in the case of long baseline (LBL) grids - while the inertial navigation systems (INS) are based on integration of own accelerations and velocities in order to compute a dead reckoning path of the AUV. Both methods pose, respectively, either technological/operational constraints and high operation costs or a low accuracy of navigation on the preset trajectory. In the case of INS, the course sensor (gyroscopic or magnetic compass) does keep the preset bearing to the reference direction. However, the transport movement from the current determines this lateral translation of the AUV which finally moves not on the intended direction, but on a “inclined” path, as a resultant of its relative and transport motions. The correction of the trajectory, i.e. mitigation of current sway is usually performed by surfacing the AUV after a certain period. Subsequently, this produces the decrease of the underwater time and the need of electronic positioning equipment while surfaced (GPS, radar, radio communication systems).
The authors asked themselves: How can we improve accuracy of control by taking into consideration the very cause of the problem, the influence of the current, rather than avoiding it? As technology doesn't use it, is there any other example from the nature that shows us any method of current correction?
Indeed, we found out some answers to these questions, that we present hereby.
This is how this paper proposes a method the underwater current correction for INS navigation based on a biomimetic approach. Fish and aquatic mammals are using hydrodynamic reception, i.e. detection of subtle changes of water pressure around them that signal the presence of a moving body (friend or foe) within their sensorial envelope. Fish use their lateral line as a pressure sensing system, allowing them to react in changing their course for attacking pray or social schooling. By considering that the lateral line system can also explain navigation of fish during long range migrations, the authors present a study of how the differences between pressure distributions on the AUV's body can measure the speed and incidence of an underwater current hence satisfactorily trigger current corrections of INS-based AUV's automatic navigation systems.

Measuring the current influence on the AUV.
In order to extract the input given by the sea current on the AUV's motion, we have to measure the disturbance that the current produces on its body, taking also into consideration the actual operational requirements.
Obviously, if the vehicle has no self-propulsion, the current is eventually aligning the AUV in the current. The relative motion is the same as the transport motion, therefore there are no dynamic pressures acting on the hull. Yet, the AUV's compass, preset on a certain course, gives the control system the reference direction. Consequently, any error in following the reference direction is corrected by the controller which commands the propellers in order to re-establish the set course.
That means that the AUV, having a constant speed through the water, also keeps unchanged the absolute bearing in a fixed reference system. In these conditions, a given sea current will always have the same incidence relative to the AUV's body, which supposedly will produce different hydrodynamic pressures on the AUV's sides. In this work we will change the adverb “supposedly” to “definitely”, as the following argumentation depicts.
Measurements of the pressure distributions have been performed by the means of ANSYS software. As the dynamic pressures on the hull are a result of both speed of current and its incidence to the vehicle, the simulations were done for two situations: constant speed and variable incidence, respectively constant incidence and variable speed. This allows us to eventually draw the pressure on a given spot as a function of two variables, speed and incidence.

The simulations considered a series of incidence angles of 0°, 45°, 90° and 135°. The values of speed are 1.5 and 2.8 m/s. Other initial conditions are water temperature 25° C and a turbulent flow. The pressures are measured in the port and starboard sides, in the horizontal plane (AUV's equator).
The results of the simulations are presented in the figures below.

a) Speed 2.8 m/s.

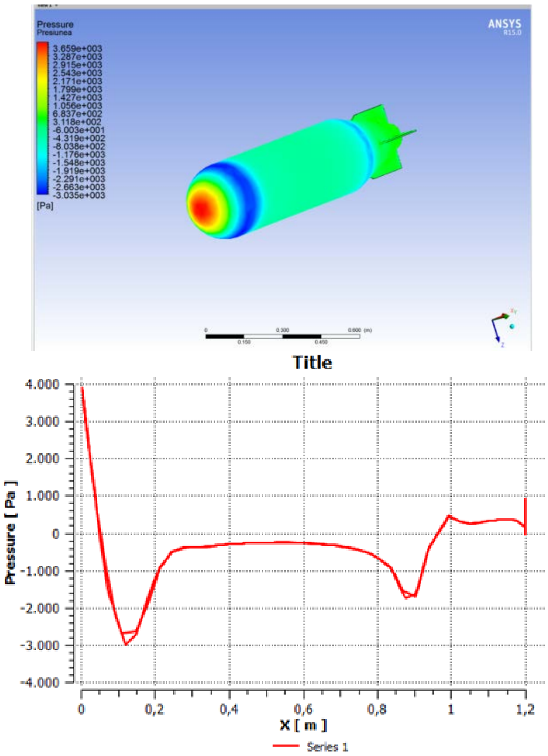


Fig. 1. Pressure distributions at incidence 0°

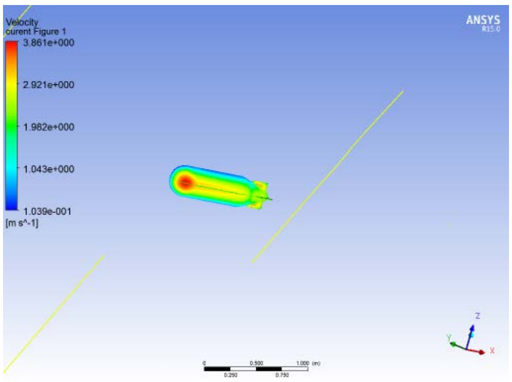


Fig. 2. Pressure distributions at incidence 45°

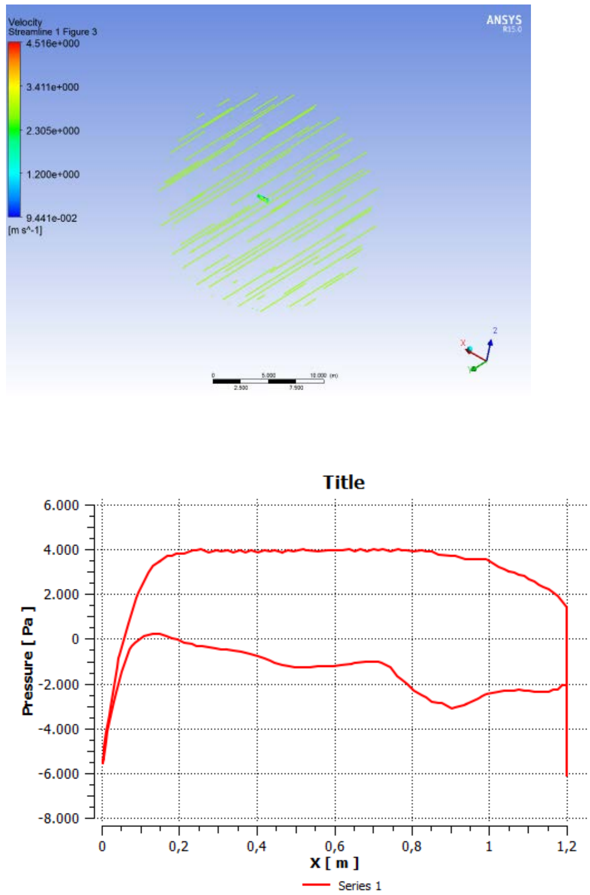
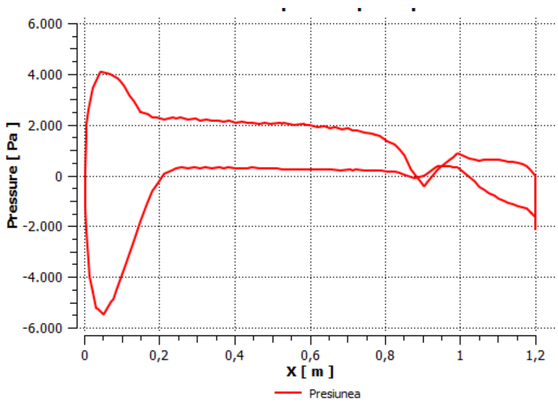


Fig. 3. Pressure distributions at incidence 90°



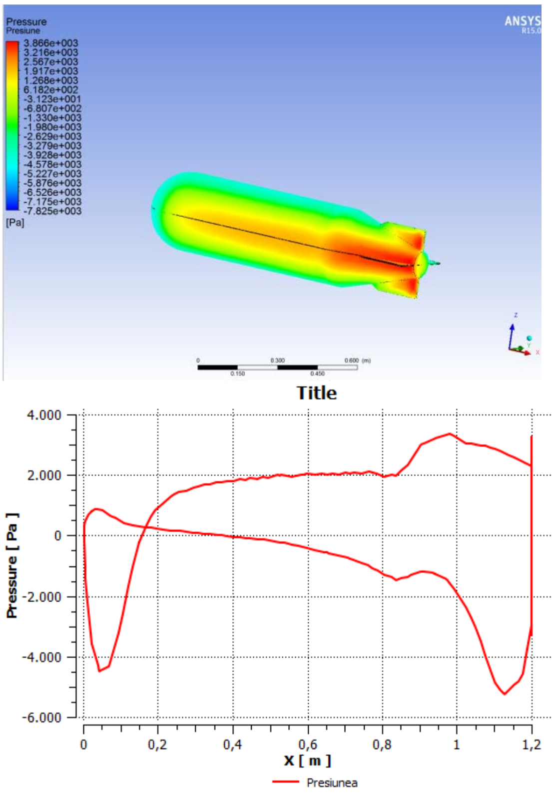


Fig. 4. Pressure distributions at incidence 135°

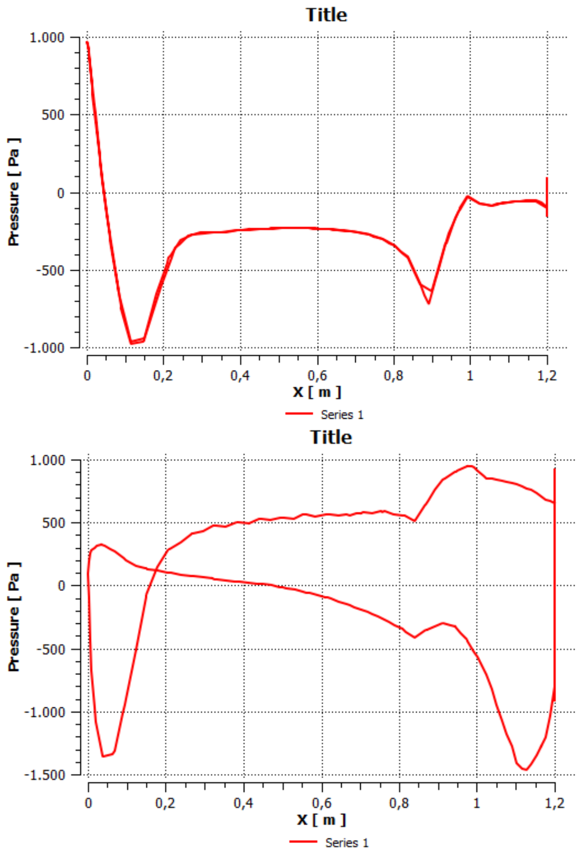


Fig. 5. Pressure distributions at incidences 0° and 135°.

b) Speed 1.5 m/s.

In order to save space, for the speed of 1.5 m/s we only present the pressure distributions for two angles of incidence: 0° and 135°.

Conclusions

From the study of the simulation results one can observe that, indeed, the action of current on the AUV that keeps its longitudinal axis parallel to itself determines different distribution curves on port and starboard side. The differences are not very big – in the order of Pascals – but still measurable with appropriate sensors.

On the other hand, the profile of pressures is identical in shape for constant incidences, or for constant speeds. This will allow to step forward onto the problem of recognition of these diagrams and the differences between pressure on two symmetrical points located on the same meridian. As the sensors are able to differentiate between two side pressures on the same meridian of the hull, a programme for the AUV’s controller can be further developed. In the end, information from the pressure sensors along the AUV can be processed in order to command the gyrocompass not to keep the absolute course, but a corrected one, which will add the necessary yaw to it.

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