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Design and Modelling of Innovative Propulsion Layouts with Pivoted Thrusters For Underwater Vehicles

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Abstract: Autonomy, performances and manoeuvrability of underwater vehicles are deeply influenced by the features of their propulsion layouts. In particular, the manoeuvrability and the reliability are very important requirements for ROV (Remotely Operated Vehicle) and AUV (Autonomous Underwater Vehicle), for this reason it is necessary to improve these features for underwater vehicles especially if they are emploied in shallow water or potentially dangerous environments. In this work are introduced an application of reconfigurable and redundant propulsion system.

Keywords: Autonomous underwater vehicle, fast prototyping, optimised motor design, oil-pressure compensated actuators, propulsion magnetic transmission systems.

1. INTRODUCTION

In this work, it will be investigated the feasibility of a configurable propulsion layout for underwater vehicles based on an array of low cost pivoted thrusters, that can be easily customised and optimised with respect to operating and mission profiles, as visible in the scheme of Figure 1. In particular, in order to optimize cost, encumbrances and maintenance, it's supposed that the orientation of each thruster can be controlled with respect to a single and fixed pivoting axis.

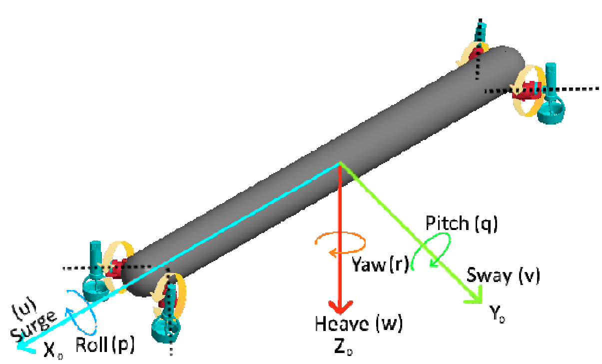

Figure 1 Example of application with four orientable thrusters with SNAME notation.

In existing solutions available in literature such as the Smart E AUV, e.g. Meyer et al. (2013), e.g. Ehlers et al. (2014), three pivoted thrusters are used to perform a holonomic control of the six degrees of freedom of the AUV.

In the proposed study, authors want use four pivoting actuators to control the vehicle motion to improve manoeuvrability, efficiency and failure robustness respect of a traditional AUV.

In details, the work is organised as follows:

- Current state of the art and definition of a benchmark vehicle and operating scenario.
- Preliminary design of an actuator unit according to the chosen benchmark, including preliminary tests and simplified models adopted to identify main features of the prototype in terms of performances and efficiency.
- Development of a virtual model of the whole system aiming to investigate the potential features of the proposed approach.

2. CURRENT STATE OF ART

This work is based on the experience acquired by authors in the prototyping of hybrid multi-role AUVs TIFONE, e.g. Allotta et al. (2001, 2012, 2015b), and MARTA, e.g. Allotta et al. (2015a), whose propulsion layout is visible Figure 2. Two rear propellers are used for forward navigation and a certain number of tunnel thrusters are devoted to control orientation or to keep the vehicle hovering over an assigned target. Considering the high number of controlled independent actuators (six), fixed pitch propellers are usually adopted in order to reasonably reduce costs and increase modularity and reliability of the whole system, thanks to a reduced number of simple, standard components, which are almost identical for all actuated axis.

The resulting propulsion layout makes possible the control of five degrees of freedom, which are described according to the classical SNAME (Society of Naval Architects and Marine

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Engineers) notation, widely adopted in literature e.g. Fossen (1994):

- Surge motion: longitudinal load X is the sum of the thrust delivered by the two rear propellers.
- Sway and Heave motions: lateral load Y and Z are respectively the sum of the trust of the two lateral and vertical tunnel thruster.
- Pitch and Yaw rotations: vertical and lateral thrusters respectively control these rotations. A remarkable point is the Yaw actuation. Indeed, this rotation have a redundant actuation, since a rotating torque N can be also produced using the two rear propellers.
- Roll rotation: usually (ad example on MARTA) is the only degree of freedom leave uncontrolled. The stability of this D.O.F is ensured by appropriate choice of barycentre position (it is possible to use appropriate fins).

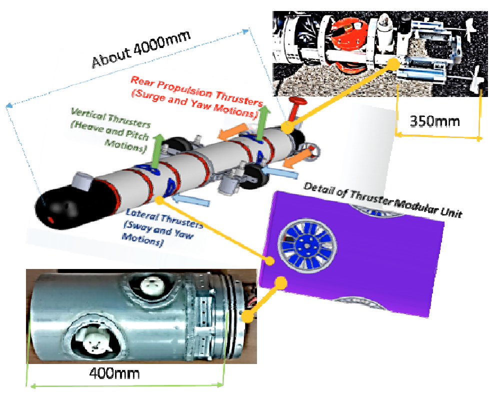

Figure 2 MARTA propulsion system layout and corresponding encumbrances.

Many existing AUVs adopt similar combinations of fixed pitch rear propellers and lateral tunnel thrusters to increase vehicle manoeuvring. It is possible to cite many examples such as C-Scout, e.g. Curtis et al. (2000), Remus, e.g. Stokey et al. (2005), Proteus, e.g. Whitney et al. (1998), Delphin2, e.g. Phillips et al. (2009), and Folaga, e.g. Alvarez et al. (2009).

In this kind of layouts, the actuation of different degrees of freedom is highly decoupled, making quite easy the control of the vehicle. In addition, a wise choice of the propeller rotation sense can reduce the motion disturbances arising from propellers reaction torques.

Obviously, an easy controllability is a very important requisite for the design of commercial ROVs, where the vehicle has to be manoeuvred by a human operator, with a limited level of additional automation. Some examples of propulsion layouts often adopted on ROVs are visible in Figure 3 and in Table 1.

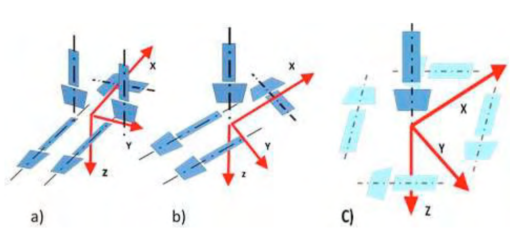

Figure 3 Examples of AUV propulsion system layout.

Unfortunately, one of the drawbacks of the propulsion layout adopted on MARTA is the encumbrances of the propulsion system with respect to the payload. As visible in Figure 2, the length of the MARTA is about 4000mm (about 18 times bigger with respect to hull diameter). However, the total length of the three propulsion modules is more than 1.2 meters. In addition, it should be noticed that over-cited propulsion layouts couldn't be dynamically reconfigured during the mission, so their usage should be critical in scenarios with uncertain operating parameters such as water density, currents, expected mission profile, availability or reliability of one or more actuators.

Table 1. Controlled and Uncontrolled Degrees of Freedom for some typical Propulsion Layouts Adopted by commercial ROVS.

	Surge	Sway	Heave	Roll	Pitch	Yaw
a)***	C*	C*	C*	C*	NC**	C*
b)***	C*	C*	C*	NC**	NC**	C*
c)***	C*	C*	C*	NC**	NC**	C*

C*=controlled D.O.F.; NC**uncontrolled D.O.F.
***corresponding layout of Figure 4

For this kind of applications, the usage of pivoted thrusters should be a cheap and reliable solution, as shown in some innovative commercial products such as the Italian Sea-Stick, e.g. Faccioli et al. (2013), which is visible in Figure 4.

In addition, pivoted thrusters have been recently used for research oriented vehicles such as the Smart E, developed by University of Lubeck, where three pivoted thrusters are used to control the six degrees of freedom of spherical/saucer AUV, e.g. Meyer et al. (2013), e.g. Ehlers et al. (2014).

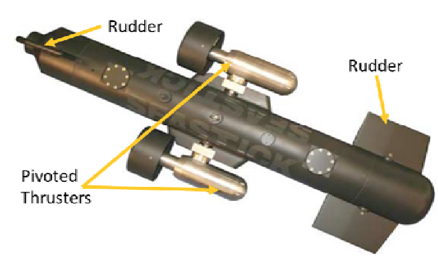

Figure 4 Examples AUV-ROV with pivoted Thrusters (Seastick, e.g. Faccioli et al. (2013)).

3. DESIGN OF PIVOTED THRUSTER

Table 2. Specification of servomotor.

Name: HS-5646WP	
Alimentation	6.0V/7.4V
Torque [Nm] (6.0V/7.4V)	1.11/1.26
Dimension [mm x mm x mm]	41.8x21.0x40.0
International Protection Code	IP67
Weight [g]	61

Each pivoted thruster, visible in Figure 5, is designed as a modular and independent unit composed by an oil