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A brief taxonomy of autonomous underwater vehicle design literature

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Approximately three-quarters of the Earth's surface is covered by water in the form of lakes, rivers, seas or oceans. The surface area covered by water on the Earth is ten times larger than the surface area of the Moon (Ross, 2006). While mankind is actively pursuing explorations of the Moon and outer space, in its backyard around 95% of the world's oceans and 99% of the ocean floor still remain unexplored (Mohseni, 2006). The quest for understanding what lies below the water bodies has motivated the development of autonomous underwater vehicles (AUVs).

AUVs are robotic mobile instrument carriers that have self-contained propulsion, sensors and intelligence, allowing them to successfully complete sampling and survey tasks with little or no human intervention (Chryssostomidis and Schmidt, 2006). One of the early attempts was the development of ‘Special Purpose Underwater Research Vehicle’, or SPURV to study diffusion, acoustic transmission, and submarine wakes. With significant developments in artificial intelligence, control theory, and computer hardware, totally autonomous underwater vehicles have become a reality (Chryssostomidis and Schmidt, 2006). Being untethered and independent, AUVs provide a platform for ocean exploration and fill in the gap left by existing manned submersibles and remotely operated vehicles (ROVs) (Shah, 2007).

Over the last few decades, ocean research and exploration have gained a lot of momentum driven by the advances in research, development and successful commercial implementation of AUV technologies. As part of the current research, a survey was done based on a search made on *Scopus* that covers nearly 18,000 titles from more than 5000 international publishers, including coverage of 16,500 peer-reviewed journals in the scientific, technical, medical and social sciences field, with the keywords *AUV* or *Autonomous Underwater Vehicle*. From the survey, 5393 most relevant articles that were published before June 2013 have been used to conduct a research trend analysis. As illustrated in Fig. 1, the AUV research trend shows a steep climb in the number of published articles indicating increased research emphasis in recent years.

AUVs provide a new marine platform that has proven to be an asset in many areas of oceanographic research and exploration. Consequently, there has been a growing interest in AUV research among several communities. These include the use of deep water AUVs to map bathymetry around oil wells, surveillance or mine information gathering by the navies, and a host of scientific and engineering communities for data collection (Desa et al., 2006), oceanographic measurements in adverse weather (Shome et al., 2008).

The wide range of applications has resulted in development of AUVs with a variety of shapes, sizes, working depth limits, sources of energy and means of propulsion. The specifics of the mission determine these features (Chyba, 2009). Fig. 2 shows a classification of AUVs that are currently being used.

A global search on a number of AUV research and development projects indicates around 155 unique configurations in different stages of use and development (AUVAC, 2012). An extensive classification of these AUVs is presented in Fig. 3.

Based on the above survey, the following observations can be made:

- AUV technology has evolved from concept demonstrators to commercial products (Vestgard et al., 2001) and they are routinely being used for military and civilian applications (Woolsey and Techy, 2009). Despite significant progress, AUV design still poses significant challenges due to its varied nature of applications (Jun et al., 2009).
- AUVs appear in a wide variety of shapes and sizes. The shape and the size of an AUV dictate its performance such as

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minimum drag, minimum flow separation, improved vehicle stability and adequate space for accommodating necessary hardware (Shome et al., 2008). These considerations tend to prefer a torpedo-shape body based on the classical Myring (1976) hull profile equations. Therefore, a majority of the researchers have chosen medium size torpedo shaped AUVs. In addition, torpedo shaped AUVs have advantages in areas such as modularity, ease in launch and recovery, flexibility in the arrangement of wet end transducers, and attainability of higher speed with less propulsive power as compared to non-torpedo or torpedo-with-wings shaped AUVs.

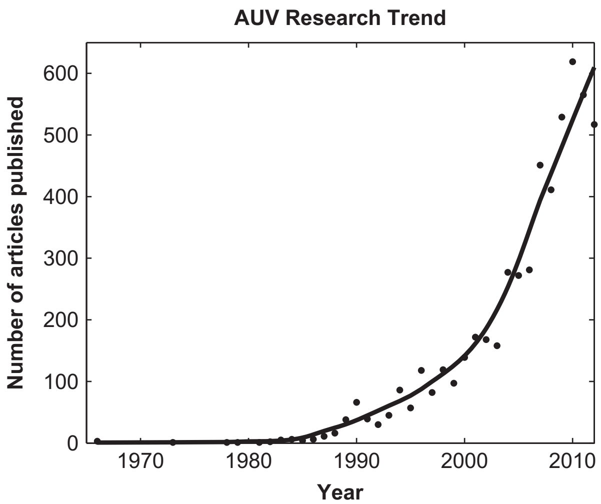

Fig. 1. AUV research trend.

- Most of the designs focus on AUVs with a working depth of more than 300 m, while surface layer AUVs have had little attention.
- The sources of power for AUVs are dictated by several factors such as mission endurance, speed requirements, vehicle size and weight constraints, and energy reserve requirements. Most AUVs in use today are powered by low cost rechargeable batteries. A few of the larger vehicles are powered by solid Polymer Electrolyte Fuel Cell (PEFC) (Hyakudome et al., 2002), aluminium/oxygen fuel cell (Vestgard et al., 2001) and by solar energy (Jalbert et al., 2003) where endurance is a critical issue. However, they require substantial maintenance and expensive refills for continuous deployment. Therefore, battery powered inexpensive AUVs tend to be more widely preferred.
- Although a majority of AUVs are equipped with propeller and rudder mounted at the tail on the centre line for propulsion and steering (Alvarez et al., 2009b), using jet-pumps for propulsion and steering is also an option. Pump and jet systems

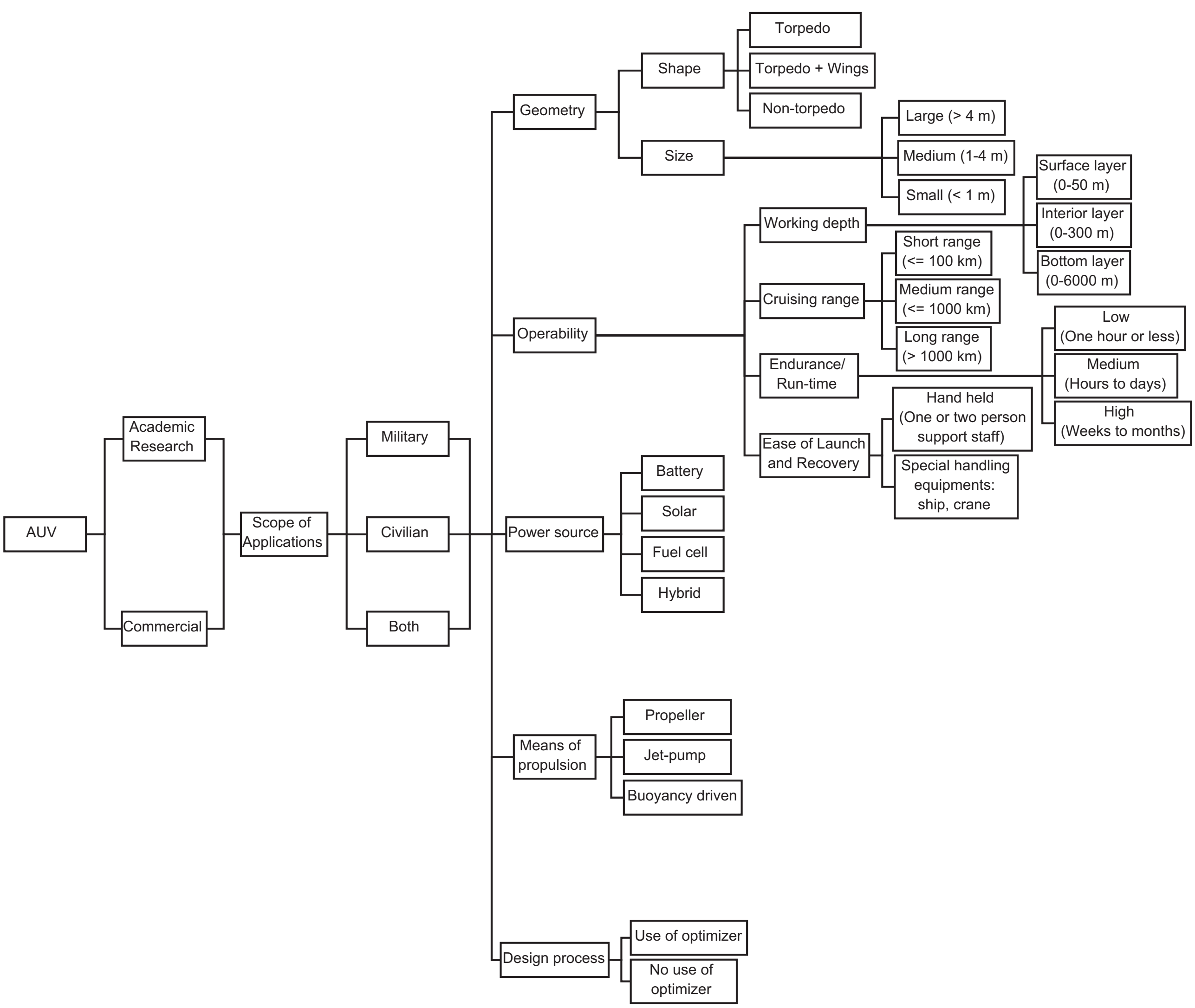

Fig. 2. Classification tree of AUVs.