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UNMANNED SYSTEMS AS ENHANCERS OF THE ARMED FORCES' TOPO-HYDROGRAPHIC CAPACITY[1]

SISTEMAS NÃO TRIPULADOS COMO POTENCIADORES DA CAPACIDADE TOPO-HIDROGRÁFICA DAS FORÇAS ARMADAS

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Abstract

This study used an inductive approach, a qualitative research methodology and a case study research strategy with documentary analysis and semi-structured interviews. The general objective was broken down into three specific objectives. The study begins by describing unmanned systems for topo-hydrographic data collection according to capabilities and techniques. Next, the study examined the relationship between the Armed Forces' topo-hydrographic capacity and the planning and execution of the Armed Forces missions from a political and strategic perspective. Finally, the study explained how unmanned systems can enhance the efficiency and effectiveness of topo-hydrographic surveying. It was found that: different types of unmanned systems have specific strengths and weaknesses; topo-hydrographic capacity should play a prominent role in the National Defence strategy; the use of unmanned systems enhances the efficiency and effectiveness of the Armed Forces' topo-hydrographic capacity.

Keywords: Unmanned systems, hydrography, topography, Armed Forces.

Resumo

A investigação baseou-se no raciocínio indutivo e numa estratégia qualitativa, adotando-se como desenho de pesquisa o caso de estudo, recorrendo à análise documental e a entrevistas semiestruturadas. O objetivo geral foi decomposto em três objetivos específicos. Inicialmente,

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efetuou-se a caraterização dos sistemas não tripulados de aquisição de dados topo-hidrográficos, descrevendo como se classificam e distinguindo as respetivas capacidades e técnicas. Posteriormente, detalhou-se a relação existente entre a capacidade topo-hidrográfica das Forças Armadas e o planeamento e execução das suas missões, nas vertentes política e estratégica. Finalmente, evidenciaram-se as melhorias na eficiência e eficácia dos levantamentos topo-hidrográficos que podem advir da utilização de sistemas não tripulados. A investigação permitiu concluir que: os diferentes tipos de sistemas não tripulados possuem potencialidades e vulnerabilidades específicas; a capacidade topo-hidrográfica deve ter um papel destacado na edificação da estratégia de Defesa Nacional; e a utilização de sistemas não tripulados melhora a eficiência e a eficácia da atual capacidade topo-hidrográfica das Forças Armadas.

Palavras-chave: *Sistemas não tripulados, hidrografia, topografia, Forças Armadas.*

Introduction

The use of unmanned systems (US) to acquire hydrographic data has increased exponentially all over the world (Potgieter, 2016). Furthermore, increasing technological advances have increased the efficiency of topo-hydrographic surveying (THS) and provided access to areas that were previously unsurveyable due to technical limitations or risks to people and equipment (Russon, 2015). Several hydrography agencies such as the National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2016b), the United States Navy (USN), and the Naval Oceanographic Office (NAVOCEANO) (Sebastian, et al., 2016) have tested and implemented such systems. The Portuguese Armed Forces (AAFF) have conducted studies with a view to implementation, although those studies do not specifically address topo-hydrographic data collection (Oliveira, 2015) or focus only on aerial platforms (Morgado, 2016).

By employing US, which operate autonomously through automated processes, the AAFF will be able to tackle some of its current challenges, including: rationalizing and optimising the relationship between operational product and resources (Smart Defence); using existing resources more efficiently; promoting scientific research and innovation (CM, 2013a); reducing personnel costs (CM, 2013b); solving staff recruitment and retention problems (Lusa, 2018b).

The AAFF's topo-hydrographic capacity is managed by the Navy and is part of the operational component of the System of Forces (SF). This capacity is involved in six of the seven AAFF capacity areas (and is instrumental to two of them) (CCEM, 2014c) and in fifteen of the twenty AAFF missions (CCEM, 2014b). Enhancing this capacity will help achieve one of the short-term objectives outlined in the National Defence Strategic Concept (CEDN), strengthening and boosting the country's scientific and technological capabilities (CM, 2013a).

In light of the above, this article addresses a particularly relevant and timely topic by analysing how USs can enhance the AAFF's topo-hydrographic capacity.

1. Methodological framework

1.1. Object of study

The article analyses the "topo-hydrographic capacity of the Armed Forces". The name of this capacity derives from hydrography, the science that measures and describes the physical features of bodies of water such as oceans, seas, lakes, rivers (OHI, 2015), and adjacent land areas (NOAA, 2017b). In this context, "topo-hydrographic capacity" includes both hydrographic surveying (HS), which measures the depth and morphology of the seabed, and topographic surveying (TS), which measures coastal attitude and morphology.

The independent variable in this study was "USs for topo-hydrographic data collection", and the dependent variable was the "Armed Forces' topo-hydrographic capacity". The variables are discussed in the second and third chapters, and the fourth chapter analyses the effects of manipulating the independent variable on the dependent variable (Vieira, 2009).

Based on the findings of earlier studies (Oliveira, 2015), the use of USs is expected to enhance not only the Armed Forces' topo-hydrographic capacity, but also all other capacities. This effect will be analysed from two perspectives: the efficiency gains obtained by optimising the relationship between operational product and resources; and the effectiveness gains achieved by expanding the range of uses and the quality of the final products.

1.2. Research objectives and research questions

The study's general objective (GO) was to analyse how the topo-hydrographic capacity of the AAFF can be enhanced by USs for topo-hydrographic data collection. The GO was broken down into the following specific objectives (SO):

– SO1: Providing a classification of USs for topo-hydrographic data collection;

– SO2: Explaining how the Armed Forces' topo-hydrographic capacity contributes to the planning and execution of missions;

– SO3: Describing how US for topo-hydrographic data collection can enhance efficiency and effectiveness in THS.

1.3. Methodology

This study was conducted according to the layers of scientific research (Saunders & Tosey, 2013), shown in Figure 1.

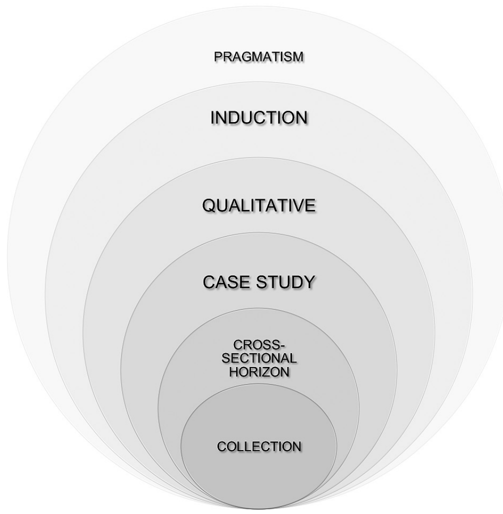

Figure 1 – Layers of scientific research
Source: Saunders & Tosey (2013).

The adopted research philosophy was pragmatism, which allows for the use of different methods as appropriate and examines their practical consequences. To that end, the study followed an inductive approach (Santos & Lima, 2016) to draw general conclusions by examining and analysing specific cases. The study used a qualitative strategy that emphasised the personal and interpretive role of the researcher from a construction of knowledge perspective (Stake, 1999).

The choice of a case study research strategy was based on the following factors: the investigator has little control over events and the object of study is a contemporary phenomenon within a real-life context (Yin, 2001). This strategy involved the use of explanatory reasoning to interpret and explain the nature of the relationships between variables (Yin, 2012). Because the study focused on a specific moment in time, a cross-sectional time horizon was chosen.

Two main instruments were used to carry out the research: a literature review and semi-structured interviews (Flick, 2004) to collect information from experts and representatives of authorities in the field, such as: the Hydrographic Institute (IH), the Naval Research Centre (CINAV), the Naval Command (NC), the No. 3 Sappers Divers Detachment (DSM3), the Navy General Staff (EMA), the Army Geospatial Information Centre (CIGeoE), the Portuguese Air Force (PoAF), RIEGL[2], ASV[3] and Kongsberg[4]. The GO was achieved by analysing and comparing data from multiple sources.

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[2] RIEGL – Laser Measurement Systems (privately owned company) (http://www.riegl.com).

[3] ASV – Unmanned Marine Systems (privately owned company) (https://www.asvglobal.com).

[4] Kongsberg Maritime (privately owned company) (https://www.km.kongsberg.com).

2. Unmanned systems for topo-hydrographic data collection

2.1. Types of unmanned systems

The main feature of USs is that they do not require a human operator on board. These systems can be divided into three types of platforms:

– Aerial platforms, or Unmanned Aerial Vehicles (UAVs);

– Surface platforms, or Unmanned Surface Vehicles (USVs);

– Underwater platforms, or Unmanned Underwater Vehicles (UUVs).

Depending on how the operator interacts with the platform, they can also be classified as:

– Autonomous, when they operate independently after being programmed to perform a scheduled task (for example, autonomous UUVs are called Autonomous Underwater Vehicles or AUVs);

– Remotely operated, when the system is controlled remotely, usually through an umbilical cable (UUVs of this type are called Remotely Operated Vehicles or ROVs).

Recent advances in dynamic positioning systems and on-board sensors (Hydro, 2018) have led to the proliferation of autonomous systems, which are able to overcome the manoeuvrability and range limitations inherent to remotely operated systems (Giodini et al., 2015).

The above is not meant to be a definitive classification, as the terminology is far from consensual and there are several variants in use (AltiGator, 2018). The above classification is adopted in this article for the sake of consistency.

2.2. Unmanned Aerial Vehicles

Currently, UAVs employ two techniques to acquire topo-hydrographic data: aerial photography and Light Detection and Ranging (LiDAR) (Higgins, 2016). Some photography studies suggest that it is possible to take bathymetric measurements using UAV imagery, although not yet with the necessary accuracy (Aarnink, 2017). As this technique has only been consolidated for TS, it will not be addressed in this study. Instead, the study will focus on LiDAR, specifically bathymetric LiDAR, which can be used to carry out both TS and HS.

Bathymetric LiDAR systems emit two laser beams at different wavelengths: a pulse at 1064 nm (infra-red) that reflects from the surface of the water; and a green pulse at 532 nm that passes through the water column and reflects from the sea bottom. Depth is determined by calculating the time elapsed between the emission of the green pulse and the reception of the echo, which corresponds to the distance travelled by the light.

A LiDAR instrument usually consists of a laser scanner that emits and receives light pulses and a navigation system with an integrated inertial sensor (IMU[5]) that determines the attitude of the platform (roll, pitch, and yaw) and a Global Navigation Satellite System (GNSS) receiver (Quadros, 2016). Among the system's several advantages, the following are unique to it: it is installed on an aerial platform, which reduces the time required to

[5] Inertial Measurement Unit.

survey a given area (greater efficiency) and the risks involved in surveying dangerous areas; it produces a higher measurement density per unit area and, unlike acoustic systems, the swath width does not depend on depth but on the aircraft's altitude. However, there are still some limitations to the use of bathymetric LiDAR in HS. The penetration of the laser beam depends on water clarity (usually to a Secchi depth[6]) and agitation, as well as on the presence of seagrass and algae. All these factors affect the system's performance and limit the survey scope (depth range). The range can be extended but this implies a compromise: although increasing the power and pulse duration of the laser beam increases the depth range, this produces lower density measurements (Quadros, 2016).

The main challenge in installing this type of system in a UAV relates to its weight. To address this issue, some companies have developed custom solutions: YellowScan[7] has developed lightweight UAV systems, although currently only for topographic use (YellowScan, 2018), and RIEGL produces a system (BathyCopter) (RIEGL, 2018) with topo-hydrographic capacity (Mandlburger et al., 2016), shown in Figure 2. However, the proliferation of UAVs and the constant advances in LiDAR technology, the most recent of which is the LiDAR Focal Plane Array (FPA), suggest that this challenge may be overcome in the short term (Higgins, 2014).

Figure 2 – UAV for topo-hydrographic data collection (RIEGL's BathyCopter)

Source: RIEGL (2018).

2.3. Unmanned Surface Vehicles

The platforms that evolved the most over recent years are USVs for topo-hydrographic data collection, and several types of vehicles are available (Geo-matching, 2018). The main reason for the rapid development of these systems is that they use consolidated technology adapted from larger survey vessels. Unlike UAVs, which use sounding techniques that do

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[6] A Secchi depth is the depth at which a Secchi disk is no longer visible by an observer positioned above the surface. It measures the transparency or turbidity of the water column. A Secchi disc is a circular disc with alternating white and black quadrants, 20 to 30 cm in diameter.

[7] YellowScan (privately owned company) (https://www.yellowscan.fr).

not yet provide sufficiently accurate results, USVs employ acoustic systems that have been in development for over 55 years, such as multibeam echosounders (MBE) (Theberge, 2013).

Several studies have confirmed that USVs enhance the efficiency of HS, and these vehicles have been successfully employed in different environments to survey: offshore areas (Orthmann, 2016), coastal areas (Williams, 2016), and harbours (Hydro, 2017c). The results of these surveys have also attracted attention from hydrography agencies, among them the NOAA (NOAA, 2016a).

USVs for hydrographic surveying are usually fitted with an acoustic sounder, preferably an MBE, and an integrated navigation system that can be complemented with a sound velocity profiler (SVP) to measure the sound velocity through the water column (Williams, 2016) and a side-scan to acquire data between lines in projects where the survey lines do not overlap (Orthmann, 2016). The platform can also be fitted with a topographic laser scanner (Renishaw, 2018) for topo-hydrographic surveys (Renishaw, 2015), as shown in Figure 3.

Figure 3 – USV for topo-hydrographic data collection (C-Target 3 ASV)

Source: Renishaw (2018).

Water conditions are the main limitation when using USVs in THS. Water agitation can affect both the deployment of the USV from the base vessel and the quality of acquired data when attitude values are higher than the limits for which the system is able to compensate. Sea currents can also reduce the manoeuvrability of the USV if it does not possess sufficient thrust. However, this limitation can be overcome by building more stable and robust platforms and deploying them in sheltered areas.

2.4. Unmanned Underwater Vehicles

UUVs are the USs that have been in use for the longest time, and are also the most advanced. They were first used in large numbers by the oil and gas industries to map the seabed and inspect pipelines. However, over recent years, scientific (NOAA, 2013) and military organizations such as NAVOCEANO (Kongsberg, 2017) and the North Atlantic Treaty Organization (NATO) have also recognised the benefits of this technology (Hydro, 2017a).

UUVs have unique advantages when compared to other USs: they are appropriate to military applications because they are difficult to detect and can operate in hostile environments; they are multipurpose systems that can operate at various depths and in different environments such as harbours, coastal areas, or offshore; they have technical benefits because they can maintain a constant altitude from the bottom, ensuring that the scanned swath has a fixed width (Sebastian et al., 2016), and can inspect underwater objects in greater detail, providing more accurate seafloor maps. Figure 4 shows an example of a UUV.

Figure 4 – UUV for hydrographic data collection (Kongsberg's REMUS)
Source: Kongsberg (2017).

A UUV for hydrographic surveying generally consists of an acoustic sounder, preferably an MBE or a synthetic aperture sonar (SAS), a side-scan, an acoustic positioning system, and an inertial navigation system (INS) fitted with an IMU and a Doppler Velocity Log (DVL). Because GNSS signals are not available in underwater environments, alternative methods are used to accurately position the UUV. The acoustic system determines the vehicle's position through a network of transponders installed on the base vessel and on the surveyed area (Underwater Transponder Positioning or UTP), and the inertial navigation system estimates the position from IMU and DVL data. Using both methods in a synchronised, integrated manner significantly improves positioning accuracy (Sebastian et al., 2016).

There are two crucial limitations to the use of UUVs for HS. The first, as mentioned above, refers to positional accuracy, which requires integration of several systems instead of a single GNSS receiver. The second refers to underwater communications. In early models, there was no way to communicate with the UUV once it was launched (Crimmins & Manley, 2008). This reduced the vehicle's autonomy due to the need for a physical link through which data could be sent and received. As a result, ROVs became more widespread than AUVs because data can be transferred through the umbilical cable. However, the fact that AUVs are more manoeuvrable and efficient led to the development of underwater communications that use acoustic waves to encode data, as they propagate more effectively in water than electromagnetic waves (Giodini et al., 2015).

The challenges involved in this type of communication are the nature of the signal and the environment: the bandwidth is limited by transmission losses that increase with frequency, limiting the amount of information that can be transmitted; environmental noise and the multipath effect, which occurs when the signal is reflected multiple times, create interference and degrade the transmission (Giodini et al., 2015); the variations in sound speed propagation along the water column can create shadow zones that cause connectivity dropouts. Recent studies have focused on video transmission, which is feasible up to 200 m depth (Kortnieiev et al., 2016), and on underwater communication protocols and interoperability between existing systems (Hydro, 2017b).

3. The Armed Forces' topo-hydrographic capacity

3.1. Politico-strategic analysis

The Military Defence Planning Cycle (MDPC) is part of the Military Defence Planning (MDP) process and aims to build military capacities in line with the NATO planning cycle and the European Union's (EU) capacity development process. A military capacity is a set of functional, structuring, and complementary elements used to accomplish tasks or create operational effects, and covers aspects related to doctrine, organization, training, material, leadership, personnel, facilities, and interoperability (DOTMLPFI) (MDN, 2014).

The SF is a structuring document that consists of a detailed list of Military Strategic Options, which is issued after the Military Strategic Concept (CEM) and the Armed Forces Missions (MIFA) and defines the capabilities that the AAFF must hold in order to fulfil its missions (AR, 2009). The SF organizes the AAFF's capabilities into joint capacity areas based on operational scenarios, military strategic objectives, level of ambition, and priority of employment, relating them to the MIFA (CCEM, 2014a).

The AAFF's topo-hydrographic capacity is listed in the SF as an oceanographic and hydrographic capacity and is one of the Navy's eleven capacities. It is involved in six of the seven capacity areas and is instrumental for two of them, and contributes to fifteen of the twenty AAFF missions across all six operating scenarios (CCEM, 2014c). Figure 5 shows the total investment in this capacity in the period from 2015 to 2026, as provided for in the Military Programming Law (MPL) – the fifth highest value in comparison to the other Navy capacities (AR, 2015).

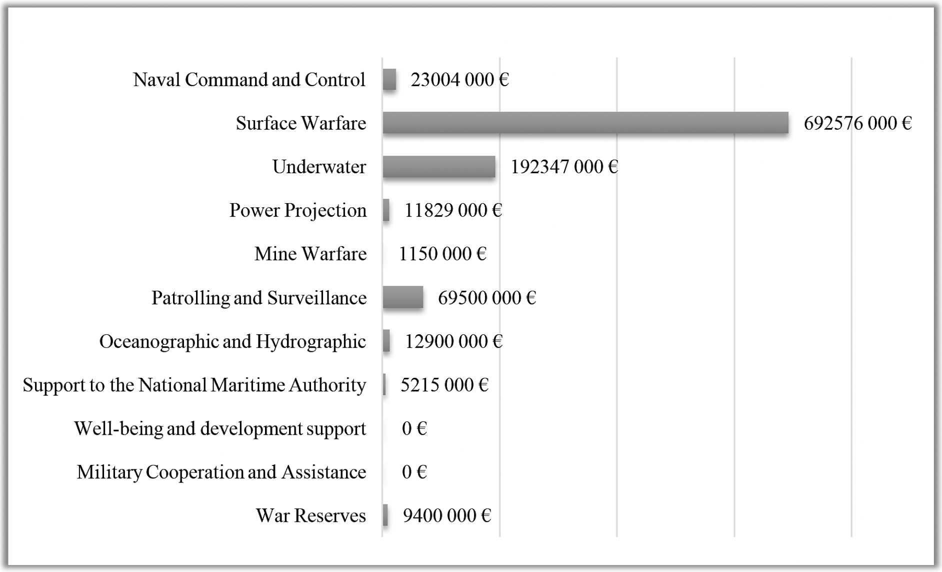

Figure 5 – Planned investment in the Navy capabilities (2015 to 2026)

Source: AR (2015).

Capacity building planning implies defining requirements and identifying gaps in a timely manner, as well as prioritising the capacities to be developed (MDN, 2011). In terms of policy, priority capacities are those involved in: cooperative, collective, and autonomous security missions; surveillance and protection of the maritime areas under national jurisdiction; and resistance to cyber-attacks (MDN, 2014).

3.1.1. Resistence to cyber-attacks

The CEDN identifies cybercrime as a major global threat (CM, 2013a). There have been increasing concerns over the security of underwater cables in recent years (Sechrist, 2010). These cables carry 95% of the world's voice and data traffic (Matis, 2012) and account for 99% of total internet traffic (Gray, 2016). Therefore, their interception could have catastrophic consequences for global economy and security.

A recent example occurred in 2006, when an earthquake south of Taiwan cut nine cables that took 49 days to restore, affecting seven countries. From an economic perspective, the International Cable Protection Committee (ICPC) estimates that interruptions of underwater communications have a financial impact of approximately $1.5 million per hour (Matis, 2012). From a security perspective, there are concerns regarding the possibility of communications being intercepted or tapped, much like what the US did in 1971 during operation Ivy Bells. Therefore, news about Russian submarine movements along undersea cable routes (Sanger & Schmitt, 2015) and about the Yantar hydro-oceanographic vessel's surveillance capabilities (Peter, 2018) have been seen as aggressive and as a sign of a possible attack (Dorminey, 2015). Figure 6 shows the undersea cable routes that cross the national maritime areas.

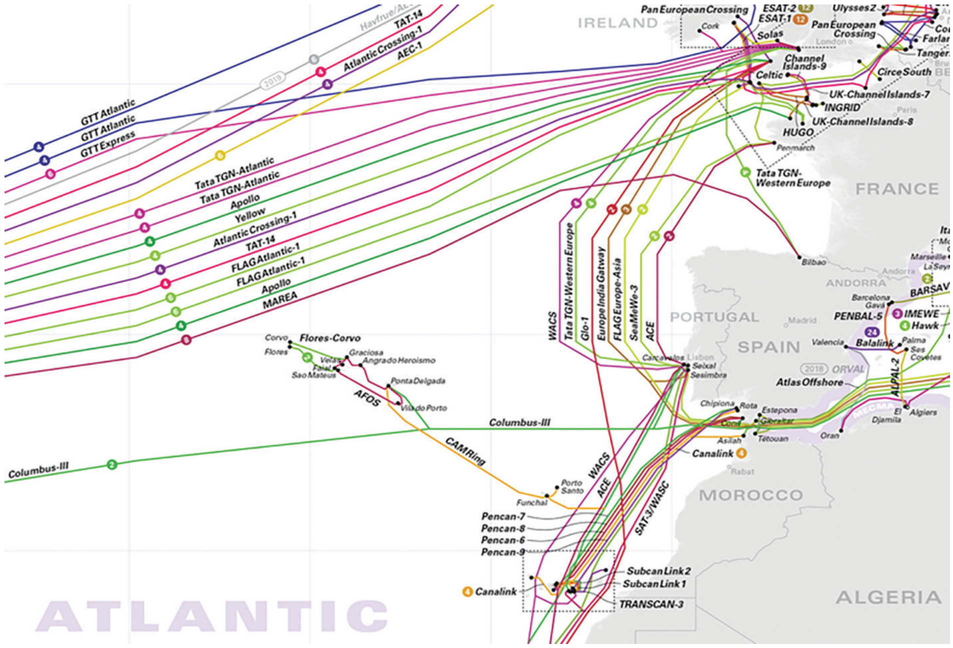

Figure 6 – Undersea cables that cross the national maritime areas

Source: TeleGeography (2018).

From the perspective of both cybersecurity and physical security of undersea communication routes, topo-hydrographic capabilities are an essential tool for planning, positioning, inspecting, and repairing undersea cables, as well as for identification and tracking (NOAA, 2017a).

3.1.2. Surveillance and protection of maritime areas under national jurisdiction

The size of the maritime areas under national jurisdiction, especially if the proposal for extension of the continental shelf (CS) submitted to the United Nations (UN) is accepted (Figure 7), requires a sustainable and effective surveillance model. Optimising the process will entail collecting detailed data on the seabed and identifying sites with scientific and economic interest since one cannot manage what has not been measured (Liquid Robotics, 2017). In order for the economics of the sea to continue to grow, the entire maritime ecosystem must be preserved. To do so efficiently will require detailed maps of the maritime areas under national sovereignty or jurisdiction, which will be obtained using the topo-hydrographic capacity.

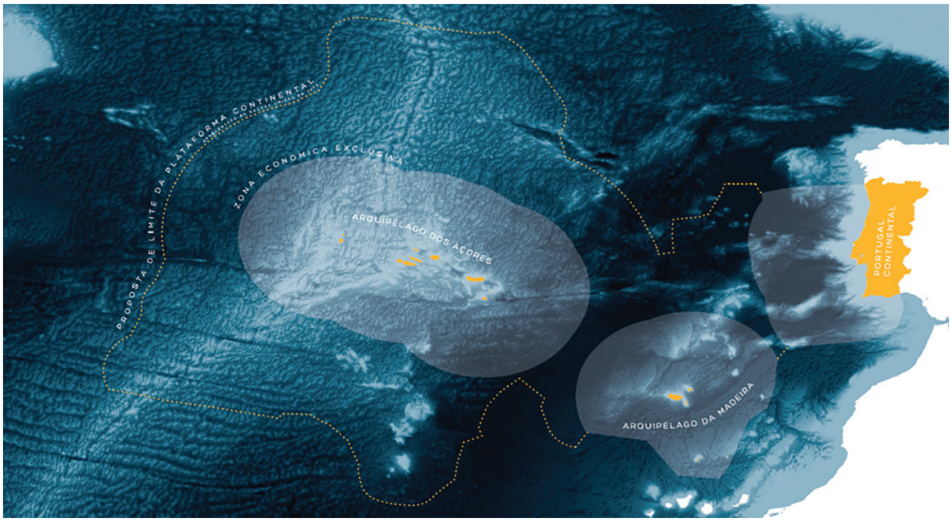

Figure 7 – Proposed national CP extension

Source: EMEPC (2014).

Having detailed knowledge of the seabed is also essential for the country's international affirmation. The national maritime spaces are often the target of foreign scientific cruises scouring the sea for resources with economic potential (Silva, 2012). International law grants the Portuguese State jurisdiction over all scientific research carried out in its exclusive economic zone (EEZ) (AR, 1997). All research activities must be authorised by the Ministry of Foreign Affairs (MFA) and the final results and findings must be made available along with access to any data and samples resulting from the project (Silva, 2015). Portugal has sovereignty over the natural resources of its CP, and if it chooses not to explore and exploit them, no other country can undertake these activities without its express consent (AR, 1997). In light of this, topo-hydrographic capabilities offer two strategic advantages: the knowledge they generate strengthens the negotiating position of the Portuguese State and raises its credibility as a potential partner for research, development, and innovation (RD&I) activities.

3.1.3. Cooperative, collective and autonomous security missions

Participating in international theatres in the context of cooperative security, collective defence, or in an autonomous capacity (to safeguard Portuguese citizens in areas of crisis or conflict, for example) (MDN, 2014), requires specific planning, which includes conducting reconnaissance on the topo-hydrographic features of the scenario, among other tasks (NATO, 2013). At the politico-strategic level, the topo-hydrographic capacity is critical to the "situational awareness" and "mobility and projection" capacity areas (CCEM, 2014c), which are vital to accomplish the above tasks.

Because the topo-hydrographic capacity is essentially of a technical and scientific nature, it will also develop the AAFF and the country. Early developments in this area can lead to significant technological advances, such as the Global Positioning System (GPS), Radio Detection and Ranging (Shu, 2014), and the Internet (Strickland, 2010), which began as defence and military research projects. Therefore, developing this capacity could represent an opportunity for national specialisation, which would put Portugal in a leading position when coordinating with its NATO (Smart Defence) and EU (Pooling and Sharing) partners (MDN, 2014). Today, topo-hydrographic capabilities are emphasised by several countries with seafaring tradition and ambitions, such as the USA (Delgado, 2009), Canada (Eelhart, 2013), England (Evans, 2013), France (Malik, 2016), Russia (Davis, 2015), China (Hydro, 2008), Australia (AHS, 2012), and New Zealand (Defense IQ, 2016).

4. Enhancing the Armed Forces' topo-hydrographic capacity

4.1. Proliferation of unmanned systems

With the increased use of USs, applications have emerged in the industry, agriculture, security, and defence sectors, among others (Handwerk, 2013). The demand for this type of technology has led to huge investments in the companies that produce them, creating a market that increases every year (Wilkers, 2018).

When considering the human-machine dichotomy, USs have obvious advantages: they allow for greater yields in systematic or repetitive tasks and reduce exposure to risks in dangerous or conflict zones. However, its mass use will tend to intensify some challenges, mainly due to ethical, security (Shifter, 2018), and privacy (Lusa, 2018a) regulations.

In light of the above, and given that technological leadership is a crucial factor to gain a "first-mover advantage" (Lieberman & Montgomery, 1988), the AAFF must keep up with the advances in USs if it wishes to benefit from the opportunities they afford and maximise their potential.

4.2. Unmanned systems in the Armed Forces

4.2.1. Navy

The Navy first identified the strategic importance of USs in its 2004 Genetic Directive, where they were referred to as unmanned vehicles or VENT [*Veículos Não Tripulados*] (CEMA, 2017). That same year, it was determined that the Navy required UAVs to support two of its capabilities: "surface warfare" and "patrol and surveillance" (CCEM, 2014c). As a result, in 2015 a Working Group for the Development of Unmanned Vehicles (GT-VENT) was established under the EMA (CEMA, 2017).

The operational tests of these UAVs are conducted by an Unmanned Aerial Vehicles Operational Testing Group (CEOV) established under the NC as part of the GT-VENT Operational Planning Group (CEMA, 2017). The CEOV aims to develop, test, and approve USs for operational use in national and foreign projects (Lança, 2018), such as the collaboration partnerships initiated in 2016 with Tekever (Navy, 2016a) and UAVision (Navy, 2016b). Although the Navy has plans to use UAVs to acquire topo-hydrographic data, the project is still in early stages, and will involve defining concepts of use, missions, and operation scenarios (Lança, 2018).

The operational tests of UUVs have been carried out by the DMS3 (Lamego, 2018) in collaboration with the Underwater Systems and Technology Laboratory (LSTS) of the Faculty of Engineering of the University of Porto (FEUP), under the cooperation partnership established with the University of Porto (UP) in 2006 (Marinha, 2006). These USs have been deployed in Mine Warfare (MW) operations to detect objects in the seafloor using a side-scan, a camera, and an MBE (Lamego, 2018). During the annual Recognized Environmental Picture (REP) exercise, the technology is used to test underwater communication protocols (such as NATO's new JANUS[8] standard) (CEMR, 2017) between UUVs, submarines, ships, and surface buoys (LSTS, 2017). Thanks to this sustainable, multidisciplinary process developed by the military, UUVs are currently the most advanced topo-hydrographic data acquisition system.

In contrast, project SeaFalcon II, which aims to develop USV prototypes for operational use, is still in preparation (CINAV, 2018).

4.2.2. Army

The mission of the CIGeoE is to provide geospatial information to the Army and to other entities and to carry out scientific and technological research (CIGeoE, 2013). The centre plays a crucial role in the Army by keeping up-to-date with technological advances in the field and providing photogrammetric processing of UAV-acquired data. Although the CIGeoE can also process LiDAR data, this technique of analysis has not yet been tested on UAVs (Franco, 2018).

The Army has planned for the use of UAVs in its operations. While these vehicles are not used exclusively to collect topographic data, they can do so if needed (Franco, 2018). Unlike the Navy, the Army does not have a topographic capacity listed in the SF, but a Geospatial Support Unit is listed under its "intelligence, surveillance, target acquisition, and reconnaissance" capacity (CCEM, 2014c).

The CIGeoE does not currently have UAVs. However, thanks to its partnerships with universities and industries, it has had the opportunity to test acquisition platforms and processing software, creating products with practical applications. The CIGeoE recognises that, in the future, USs will cover a variety of uses and is endeavouring to operationalize and adapt this technology to achieve the Army's objectives, as well as those of the AAFF (Franco, 2018).

4.2.3. Air Force

The PoAF began its research on UAVs in 2006, with the development of a MicroPilot Automatic Pilot System for radio-controlled airplane models. The research had a significant boost in 2009 with the opening of the PoAF's research and technology project on unmanned

[8] JANUS is an underwater communications protocol developed by NATO's Centre for Maritime Research & Experimentation (CMRE). The protocol is named after the Roman god of doors and portals.

aerial vehicles (PITVANT) (Caetano, 2018). These RD&I activities were carried out in four phases, and have been conducted by the PoAF's Research, Development, and Innovation Centre (CIDIFA) since 2015 (Morgado, 2016).

Currently, the PoaF has three types of fixed wing UAVs and one rotary wing insect-like drone for stealth missions. The PoAF currently participates in several projects with other partners such as the Institute for Systems and Computer Engineering, Technology, and Science (INESC-TEC), the Centre for Innovation and Excellence in the Automobile Industry (CEIIA), the Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI) (all of which are production and innovation centres), and UAVision (Caetano, 2018). Thanks to its leading role in UAV development, the PoAF has been awarded international funding to use these assets to monitor migration routes over the Mediterranean Sea (APANT, 2017).

As for topo-hydrographic sensors, photogrammetric tests were carried out in 2015, although tests with LiDAR systems (Caetano, 2018) have not yet been conducted. The PoAF's strategy has been to consolidate the platforms so that they can be equipped with the appropriate sensors for a given flight.

4.3. Topo-hydrographic surveying efficiency

The topo-hydrographic capacity is operationalized through THS. The efficiency of these surveys can be enhanced by USs, and this in turn will optimise the relationship between the operational product and the time, human resources, material resources, and financial resources invested.

4.3.1. Time

The time factor can be subdivided into three components that usually comprise a THS, which are distributed according to the following percentages: platform movements (10%), data collection (30%), and data processing (60%).

USs are smaller than traditional survey vessels and require less time to deploy and recover. In cumulative terms, the planning required to deploy them is not as complex and does not involve as much preparation, which also makes the process faster. The equipment usually remains installed on the platform when not in use, at a high level of readiness, avoiding the time-consuming task of measuring offsets between sensors and patch tests (NOAA, 2015). The use of USs significantly enhances the capabilities of the Rapid Intervention Hydrographic Team (EHIR), among others (IH, 2014).

Several publishes studies have shown that USs are able to acquire data faster than traditional methods (Williams, 2016). In the case of UAVs, this is due to the use of much higher polling rates and data acquisition rates (Quadros, 2016). In the case of USVs, the difference stems from their ability to obtain more accurate line readings (less side deviations) through a pre-programmed course maintained through dynamic positioning. In the cases analysed, it was also found that the time elapsed between lines, which usually corresponds to a significant percentage of the collection time, is lower in THS with USs (Williams, 2016).

USs are able to collect data without practically any intervention from the hydrographer, who can focus on monitoring the survey quality and on processing the data in real time. Through traditional methods, this step usually only takes place after collection is completed. The percentages above show that any technology that allows for processing and collecting the data simultaneously translates into significant time savings, as shown in Figure 8. This aspect of USs has been developed in systems such as CARIS Onboard, which sends selected data from the platform to the hydrographer, enabling real-time processing and facilitating monitoring. In an operation scenario with several USs and only one hydrographic team, this technology becomes an important force multiplier (CARIS, 2015).

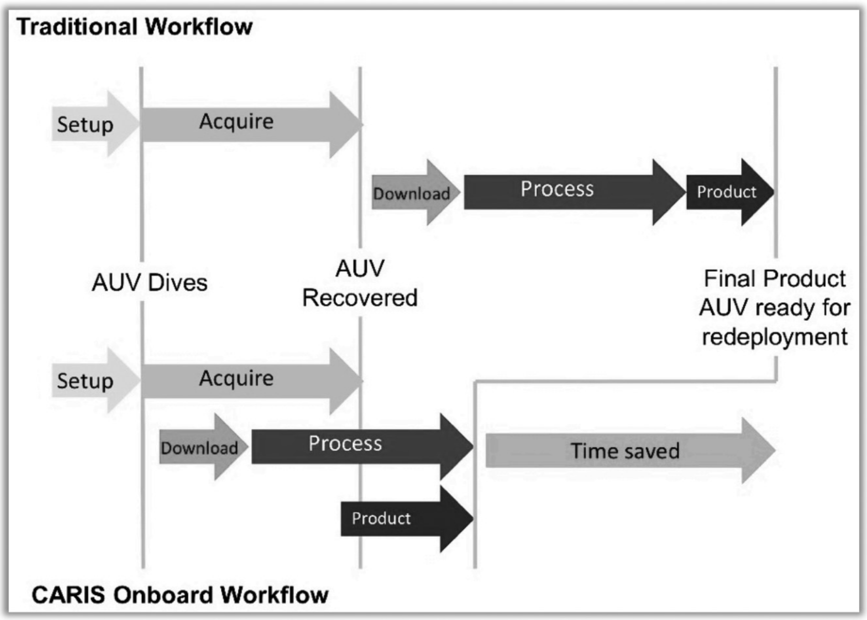

Figure 8 – Time savings in THS with real time data processing

Source: CARIS (2015).

4.3.2. Human resources

Rationalisation of human resources is an inherent feature of USs. In terms of direct savings, this means that an operator is not required to manoeuvre and operate the survey vessel.

Indirectly, USs can reduce the need for human resources in large THS or with in surveys with short delivery times. Usually, these projects require at least two hydrographers in the field, with different functions: an operational technician responsible for conducting the survey (usually referred to as THS Hydrographer); a tactical technician responsible for performing the scans (usually referred to as Scanning Director). As mentioned in the section on time resources, USs can reduce the need for duplication, freeing hydrographers from tactical-level tasks and allowing them to focus on higher-level functions.

USs automatically generate higher data volumes, bringing the term "Big Data" into the context of hydrography. Thus, it is especially important that the data acquired are subject to effective quality control, are processed quickly, and that their final products are made available (Rumson, 2018). Human resources must be given advanced specialized training in novel fields such as data science to develop tools that can fulfil these priorities (Cooper, 2018).

4.3.3. Material resources

USs are smaller than traditional survey vessels, are generally easier to maintain, and involve significantly lower costs with consumables (such as fuel) (Cruz & Varela, 2017). Comparatively, the logistics involved in transporting them are also simpler, making them a more flexible alternative that allows for rapid deployment (Mallace, 2018).

This makes them particularly suited to THS in which the distance from the base vessel to the survey area requires these assets to be deployed, as in the recent surveys carried out in Azores, Madeira, Cape Verde, and São Tomé and Príncipe. Currently, there are only two options to conduct this type of survey: transporting the traditional survey vessel aboard a larger ship, usually a Ship of the Portuguese Republic such as NRP *Dom Carlos I* or NRP *Almirante Gago Coutinho*; or shipping the equipment by carrier and installing it on site in an adapted vessel, as shown in Figure 9. Both options have disadvantages that can be mitigated by USs: the first is the high cost of ship logistics; the second refers to the technical risks of using an adapted vessel.

Figure 9 – Adapted survey vessel with an MBE mounted in the bow

Source: IH (2014).

4.3.4. Financial resources

The financial savings obtained with the use of USs relate to the three resources mentioned above. A THS is less costly the shorter its duration is, the less human resources it requires, and the simpler its logistics are.

USs are cheaper to deploy. However, they may involve higher operating costs in THS that cover vast survey areas due to autonomy and safety limitations, which stem from navigation and legal restrictions (Applanix, 2018). In this scenario, it is best to deploy several USs and more than one type of platform (USVs and UUVs, for example), as this significantly extends their endurance (Rumson, 2018). Recent advances in machine learning improved the safety of autonomous navigation by avoiding collisions. This is especially useful in the case of USVs, which operate in the most congested environments (Hydro, 2018).

The acquisition costs of USs, especially UUVs, are still higher than those of traditional means (Hart, 2018; Jiménez, 2018; Pita, 2018). These costs are expected to decrease as the technology becomes more widespread.

4.4. Topo-hydrographic surveying effectiveness

THS effectiveness can be enhanced by USs, broadening their operating scenarios and improving the quality of the final products. Next, the expected effectiveness benefits are described for each type of US.

4.4.1. Unmanned Aerial Vehicles

UAVs operate in the aerial environment, therefore, operating them involves less risk and avoids the limitations and dangers inherent to the marine environment, such as water agitation and currents. Similarly, in coastal areas with cliffs and escarpments, UAVs are cost-effective from a perspective of operator safety. UAVs are more effective than traditional platforms under adverse weather and sea conditions, in the case of hydrography, or when the terrain is extremely rugged, in the case of topography. However, although they can conduct hydrographic surveys even in adverse conditions, their performance is limited because this will affect the laser beam's ability to penetrate the water column.

The effectiveness gains of UAVs stem from the use of the LiDAR system, which exponentially increases the measurement density per unit area when compared to traditional methods, greatly improving the resolution and detail of the final products. For example, a TS using traditional methods can generate: one measurement every 10 seconds using total station; one measurement per second using GNSS. Comparatively, a laser scanner can produce about one million measurements per second (Cruz et al., 2015): if the scanner is land-based, multiple dockings have to be performed (point-to-point movements), which reduces efficiency; if the laser is installed aboard a UAV, the survey is continuous and therefore optimised.

4.4.2. Unmanned Surface Vehicle

USVs use technology similar to traditional vessels and operate under similar conditions. Therefore, from a simplistic perspective, they are not more effective. However, their advantages lie in the range of scenarios in which they can operate.

USVs can be used effectively in shallow areas, which are hazardous to personnel and equipment (Hydro, 2017c). Although these areas run along coastlines, many remain unsurveyed, or the surveys that have been conducted are old and do not fulfill the current standards (NOAA, 2015). For safety reasons, these surveys are traditionally carried out with portable equipment, usually single beam sounding systems (SBE), installed in semirigid boats with low endurance. Comparatively, a USV fitted with an MBE is not only more efficient but also more effective, as it can generate a greater number of measurements (due to the technical differences between MBE and SBE) and a more detailed operational product.

In addition to their hydrographic capabilities, USVs can be fitted with a laser scanner to take topographic measurements (Renishaw, 2018). Currently, USVs are the only USs with consolidated topo-hydrographic capabilities. As mentioned above, the hydrographic capabilities of UAVs are still significantly limited by existing techniques (LiDAR), and UUVs do not have topographic capability, at least for the time being.

4.4.3. Unmanned Underwater Vehicles

UUVs are different from other USs in that they can operate stealthily. This capability translates into tactical superiority and increases the effectiveness of covert missions, which include mine detection and determining safe routes to access ports.

Unlike traditional platforms, UUVs are able to operate regardless of sea surface conditions. This makes them more effective under adverse weather conditions even when compared to other types of USs.

UUVs can operate at different depths, which makes them more efficient than any other platform when it comes to detecting objects and providing high resolution maps of the seabed. UUVs were able to identify more targets than traditional surface vessels in mine detection exercises (Lamego, 2018) because the resolution of the beams in acoustic sounding systems is physically measured in degrees. Therefore, the closer the sounder is to the object, the smaller the acoustic footprint and the better the resolution. The better the resolution, the smaller the size of the objects that can be identified (detection threshold), which leads to better performances. UUVs can move through the water column, which allows them to overcome limitations inherent to the propagation of sound in the underwater environment (e.g. attenuation and shadow zones), which makes them more effective than USVs (Rumson, 2018).

Conclusions

This article aimed to analyse how the AAFF's topo-hydrographic capacity can be enhanced by using USs. The analysis focused on two variables: an independent variable, "USs for topo-hydrographic data collection"; and a dependent variable, "the AAFF's topo-hydrographic capacity". The three SOs were explored in the second, third, and fourth chapters.

The second chapter provided a description of USs for topo-hydrographic data collection (SO1). As mentioned above, USs are generally divided into UAVs, USVs, and UUVs, depending on the type of platform on which they operate (aerial, surface, and underwater, respectively). By comparing them, the article highlighted their advantages and limitations. It was found that: despite their multiuse nature, UAV sounding techniques are still not sufficiently effective for HS; USVs have lower acquisition costs and, because they use similar methods to manned systems, their operation is expected to require a smaller learning curve; UUVs have the most potential, despite some weaknesses regarding positioning and underwater communications.

The third chapter addressed the relationship between the AAFF's topo-hydrographic capacity and the planning and execution of the AAFF missions (SO2). It was found that the topo-hydrographic capacity is one of the eleven capacities of the Navy; that it is involved in six of the seven capacity areas and is instrumental to two of them, "situational awareness" and "mobility and projection"; that it is involved in fifteen of the twenty AAFF missions including all six operating scenarios.

From a politico-strategic perspective, the topo-hydrographic capacity is involved in the three priority areas: cooperative, collective, and autonomous security missions; surveillance and protection of the maritime areas under national jurisdiction; resistance to cyber-attacks.

The fourth chapter discussed how using USs to acquire topo-hydrographic data can enhance the efficiency and effectiveness of THS (SO3). The efficiency gains obtained with the use of USs resulted from savings in resources: shorter survey times, less human resources, and less logistical and maintenance costs, which translate into overall financial savings. By comparing the effectiveness gains in each platform, it was found that: UAVs involve less risks and have greater flexibility; USVs are currently the most robust and best suited alternative for shallow water surveys; UUVs can operate in stealthily and have enormous potential.

The above findings were used to:

– Organize the different types of USs according to their performance for topo-hydrographic data collection and list their strengths and weaknesses;

– Demonstrate the relevance of the topo-hydrographic capacity to the AAFF missions by framing it within the National Defence strategy;

– Explain how USs for topo-hydrographic data collection enhance the efficiency and effectiveness of the AAFF's current topo-hydrographic capacity.

The research carried out also made it possible to elaborate recommendations, which were organized according to the following areas:

– From a genetic perspective, the AAFF should have USs at its disposal. Other similar AAFFs have already recognised the potential of USs, and the AAFF should follow this trend to avoid the pitfalls of adopting a new technology too late;

– From a structural perspective, the proliferation of USs means that they should play a more important role within the AAFF's structure and planning. Each branch has its own projects under development, which must be coordinated so that they contribute to a common interest. Similarly to what occurred with "cyber-defence", it is recommended that the next review of the SF includes an USs capacity operating under the Armed Forces General Staff (EMGFA);

– From an operational perspective, the use of USs in AAFF missions should be encouraged, and follow-up and feedback should be provided to enable knowledge transfers and reduce the learning curve.

It was not possible to conduct experimental research during the elaboration of this study. The answer to the research problem was obtained by analysing similar studies conducted by third parties, which were adapted and contextualised. Therefore, as a suggestion for future research, the Navy could conduct a THS using USs and compare the efficiency and effectiveness gains to obtain a cost-benefit analysis in comparison with traditional survey methods.

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