"Optimal Management of Marine Inspection with Autonomous Underwater Vehicles"

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Contents

Chapter 1
Optimal Management of Marine Inspection with Autonomous Underwater Vehicles

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Abstract New technologies and system communications are being applied in the industry, improving the efficiency and effectiveness. This paper is focused on novel technologies, software and materials that allow to explore deep ocean floor. Autonomous underwater vehicles require planning navigation models and algorithms. Sensors equipped in underwater vehicles allow to inspect and analyse inaccessible areas. Monitor and control measurement process is required to ensure suitable underwater operations. This paper presents a model using the main inspection process variables. The model calculates the field of view of the autonomous underwater vehicle to be determined according to the type of sensor, the orientation and the distance from the floor. This study aims at stabilising the fundaments to develop an autonomous route for the autonomous underwater vehicles and optimize its operation performance.

Keywords Autonomous underwater vehicle · Optimization · Route · Navigation · Management · Sensors · Condition monitoring system

1.1 Introduction

The oceans cover most of the surface of the globe and contain areas that are difficult to access, e.g. the deepest floors. Fig. 1.1 shows bathymetric data (depth of ocean floor), collected in 2009 in oceans by different underwater or superficial systems. The study of the marine environment can contribute to discover new materials, geological formations, and solutions for climate change or diseases.

Management of marine resources involves controlling and monitoring marine flora and fauna, geology inspection for off-shore wind turbines, disaster preven-

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tion, plastic control, etc. All these fields are essential to human development and guarantee the correct maintenance of the marine environment. Traditionally, ocean exploitation has been directed towards oil and gas production [22], while other sectors have remained in the background. Nevertheless, the growth of new applications and current needs, require more efficient marine inspections. However, the optimization of the underwater operations is a critical challenge due to many technical difficulties, e.g. high water pressure, electromagnetic waves, communication interferences and hard environmental conditions, causing an uncomplete mapping of the seafloor [27]. Current underwater monitoring systems, e.g. wireless sensor network with buoys system and surface vessels , are not viable in terms of costs, technical challenges and time-consuming [16, 41]. These limitations trigger the need for new underwater condition monitoring systems.

Different marine monitoring systems are being developed to increase the capacity for acquiring data from the floors as a response to the challenge of ocean mapping. The European program Horizon 2020 reinforce the role of robots in different industry fields to transform the current way to perform activities by different projects [5].

Underwater vehicles are divided into two categories: manned or unmanned vehicles. Typically, remotely operated vehicles have been driven by human operators aided by supporting ships [8]. Autonomous underwater vehicles (AUV) belong to the last category. They are robots with six degrees of freedom, capable of developing safe trajectories and controlling their propulsion with an onboard computer.

AUV are employed for marine inspections, and present the following advantages:

- Autonomous trajectory control system to avoid obstacles
- Elimination of supporting ships
- Reduction of costs

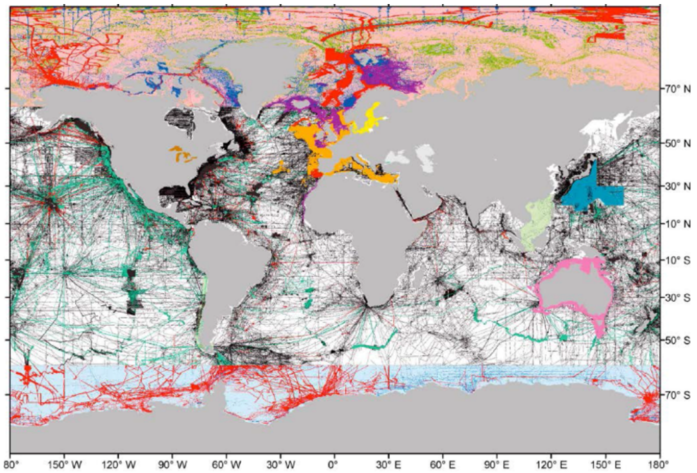

Fig. 1.1 Bathymetric data coverage 2009 [39]

- Increasing of efficiency and effectiveness of inspections
- Capacity of carrying different payload, including different sensors, communication and navigation systems.

The future of UAVs depends on several factors, but this industry increases the number of vehicles every year, as shown in Fig. 1.2 [3].

AUVs can operate in depth areas regarding on their specifications, collecting data with great accuracy and resolution [28]. Specifications are essential to determine the behaviour of the vehicle under certain conditions, e.g. depth, vehicle speed, requested autonomy, maximum weight of the payload and dimensions [12]. All these capacities depend on several factors, such as the structural design, the shape and materials of the main frame, the propulsion system, etc. Improving AUV requires the reduction of manufacturing and operation costs, reach a deeper and longer endurance, possibility of multiple operations and higher autonomy [4, 17].

Energy consumption is a critical variable in AUV design, being the sensor payloads an important part of this consumption. Several researches have been developed in this field, e.g. the increase of AUV autonomy by using hydrogen batteries [14, 15]. These improvements can convert these vehicles into attractive items to operators, researchers and investors. obtaining novel techniques to ensure ocean mapping with reliability [25].

However, the features of the AUV are not the only essential factor for marine inspections. In addition, determining the optimal route of the AUV is a complex problem that must be addressed to develop a successful inspection. In order to guarantee a proper AUV trajectory, they present navigation systems that control the telemetry, identify associated parameters in underwater inspections (depth, pressure, velocity), GPS positioning, anti-collision systems, orientation, inertial navigation, obstacle detection, etc. [7, 23, 38]. Several authors have studied this problem, developing models and path planners to avoiding obstacles. Kruget et al made parameteriza-

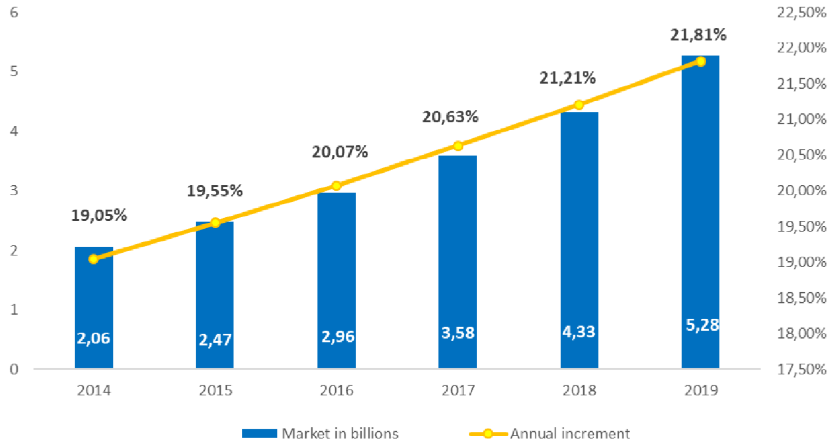

Fig. 1.2 Unmanned underwater vehicles market in $ billions and annual increment

tions and estimated cost function to generate optimal paths [24]. Alvarez et al used genetic algorithms for creating path planning and reducing the energy consumed [2]. Petres et al presented a fast marching algorithm to develop continuous paths and introduced new multiresolution methods [32]. All these authors are focused on marine path planning without considering influence of sensor payload and its characteristics.

Improve sensor capabilities of AUV is the cornerstone to improve the reliability of the inspections. The development of sensors and the new data acquisition techniques large volumes of data to be collected, obtaining better databases [40]. In addition, AUV operation requires adequate sensor payload according to the type of task. Underwater sensors are mainly divided into acoustic arrays, e.g. sonar, altimeter or multibeam echo-sounder, optical inspection with imaging devices; and enough lighting, e.g. thermal and digital cameras, radiometers or chemical analysis [31]. Galceran and Carreras analyzed the influence of selected sensors in the underwater operation, recognizing the necessity of covering all the target surfaces [10]. They presented a method to inspect an interesting area using a Coverage Path Planning. In this case, two situations were analyzed with the sensor payload: if the depth remains constant, the distance between the sensor and the seafloor will create a wider Field of View (FOV) depending on the high; on the other hand, if altitude from the seafloor is constant, FOV does not vary. The distance needs to be set correctly, because of it will determine the resolution and the goodness of the collected data.

Seabed monitoring presents diverse difficulties: real-time monitoring is a complex task because of oceans are not a homogeneous environments and speed or density variations cause signal propagation in deferent paths; The collected data can be obtained once the mission is accomplished after several weeks or months, therefore, the data acquisition capacity onboard is limited to storage devices and total weigh of the underwater vehicle [1, 13]. Wireless sensor networks are being developed to resolve these problems, using acoustic communications and a network of nodes, but this technology is expensive [21].

The main contribution of this paper is the optimization of measurement process considering the main parameters that are involved in marine inspection with AUVs. Due to marine inspection challenges, it is necessary to design and develop novel models that ensure the reliability and efficiency of data acquisition process in order to avoid wrong measurements. This situation is fundamental in autonomous operations due to configuration of the inspection process that cannot be change once AUV start its work. The model presented can be applied to any type of AUV. This model proposes a method for stablishing an optimal combination of operational variables, ensuring the maximum use of the capacities of different sensors equipped in the AUV.

1.2 Methodology Proposed

The model considers the main variables of the AUV performance in underwater operations. Operators can set the main parameters according to the type of operation and the sensor payload. The algorithm selects the optimal combination of variables to increase the accuracy of the measurements.

Fig. 1.3 shows the measurement process for any type of sensor: operation requirements, initial conditions and sensor characteristics are selected and grouped as input parameters; the required quality of the inspection is determined and the subsequent operational constraints are determined.

The FOV must be calculated when all the initial conditions are considered. The determination of the FOV allows the collected data to be distinguished between correct and incorrect data. If the data results incorrect, it is necessary to redefine the inputs. Otherwise, if the collected data is correct, the variations of measurement process, e.g. changes in orientation, must be analysed in order to decide whether the process must finish or the AUV trajectory and orientation should be corrected.

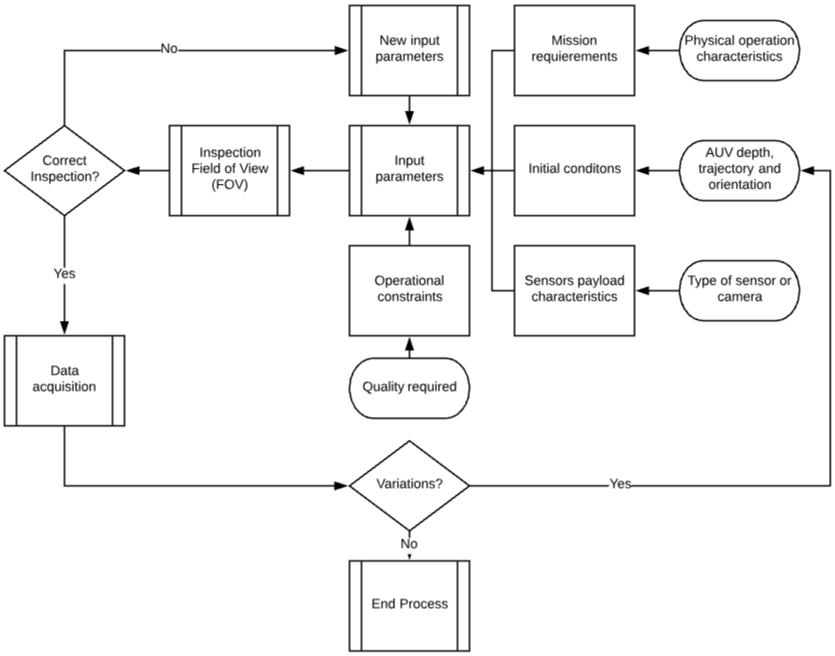

Fig. 1.3 Model diagram

1.3 Specifications of Underwater Measurements

The analysis of the seafloor reveals that several variables are implied in the inspection process. The correct adjustment of these variables will increase the reliability of seafloor mapping. Main problems in the image data acquisition are, for example, poor visibility, organic and inorganic particles in suspension or scattering, absence of natural light due to light absorption by water and the necessity of artificial light. Filtering systems and illumination-reflected model are used to solve it [11, 33]. The visibility is also considered for the object identification. It depends on contrast, scale factors and resolution [37]. In this paper, an acceptable visibility is assumed, and only parameters required for data acquisition process are taken into account.

1.3.1 AUV Measurement Parameters

The AUV is assumed to be autonomous during the operation in this paper. Sensors can have different natures and characteristics, being the identification of the measured area a critical activity to control the efficiency of the process. For this reason, sensors (imaging sensor, radiometer, acoustic…) can be disposed in two different orientations selected by operators according to the operation requirements. This orientation is set by the combination of zenithal and azimuthal angles. Azimuth angle ψ_{ZD} measures the variation regarding to the AUV trajectory. Zenithal angle θ_{ZD} quantifies the variation of sensor inclination related to the plane delimited by underwater vehicle and the horizontal. Fig. 1.4 shows the possible orientations of the sensor payload and the influence of depth in FOV formation.

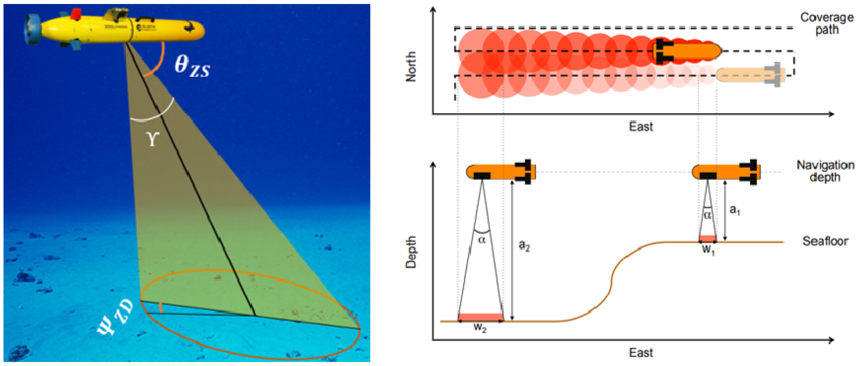

Fig. 1.4 (left) Azimuthal and zenithal orientation of sensors; (Right) Influence of depth

1.3.2 Sensor Payload Characteristics

The importance of the mission profile is defined in order to identify accuracy sensor payload dedicated to the underwater operation. Thermal or digital cameras, or any type or measurement sensor, have associated a certain FOV [26], therefore, the area inspected will be directly proportional to it [19, 29, 30]. FOV depends on the lens, the model and the type of sensor. Parameters of sensor payload are:

- Resolution: this parameter is typical of imagining sensors and it depends on the optical detector resolution and the lens, displaying the quality of captured images.

- Focal length: is the distance between lens and the image sensor. The field of view of the camera γ, focal angle F and the size of the detector D depend on the camera model. The area inspected is directly proportional to the value of γ.

$$\gamma = 2 \cdot \arctan\left(\frac{D}{2 \cdot F}\right)$$

1.4 Calculation of the Field of View

The measured area is a critical information that must be monitored to ensure the efficiency of the inspection, whatever the field of application [35]. Seafloor mapping is a challenging task to ensure data acquisition with precision, avoiding inaccessible areas due to irregularities in the seafloor. It is required a low degree of image overlap (about 35%) to maximize the measured area and reduce data storage [9]. By joining several images is possible to create a global picture thanks to geometrical calculations [33]. Calculating camera or sensor FOV with altitude and orientation values requires trigonometric knowledge of the system [20]. Fig. 1.5(right) shows the overlapped images and Fig. 1.5 (left) display the combination of several pictures.

Depth is one of the most important factors because determines the FOV size and the area covered by one single image. The influence of depth in the FOV width can be variable, considering that distance between seafloor and AUV may change. The depth of the AUV will determine the quality of the inspection if the objective of the task is the seafloor mapping with a certain resolution. It is necessary to balance the distance to the seafloor to increase measured area (more distance) or to maximize quality in the measurements (less distance). For this reason, it is necessary to introduce the Instantaneous FOV (IFOV) concept, which determines the smallest detectable object in the image [6].

$$IFOV = 2 \cdot \arctan\left(\frac{d}{2 \cdot f}\right)$$

Other method for IFOV calculation consists in using spatial image resolution for one single pixel.

$$IFOV = \left(\frac{\gamma}{Image\ \ Resolution} \right)$$

IFOV value is given in mrad, therefore, it is not useful to check the reliability of the inspection. However, Ground IFOV (GIFOV) is the projection of the IFOV at the ground level, that determines the size of one pixel in length. GIFOV is defined by using trigonometry calculations [36]. Fig. 1.6 shows a diagram with the concepts introduced previously, comparing FOV, IFOV and GIFOV.

$$GIFOV = depth \cdot \left| \tan\left(\theta_{ZD} - \frac{IFOV}{2} \right) - \tan\left(90 - \theta_{ZD} - \frac{IFOV}{2} \right) \right|$$

However, GIVOF does not provide valuable information about quality of the process. For this purpose, measured GIFOV (GIFOVmeas) defines the smallest detectable object measured at operational distance from the seafloor. To avoid wrong measurements and ensure enough resolution, a safety coefficient C is applied:

$$GIFOVmeas = GIFOV \cdot C$$

GIFOVmeas will be a critical value in operational process as a function of the required resolution or needed smallest average size.

$$GIFOVmeas < Average\ \ defect\ \ size$$

Trigonometry expressions have been employed to calculate FOV over the seafloor. Fig. 1.6 is used as reference for coordinates calculation:

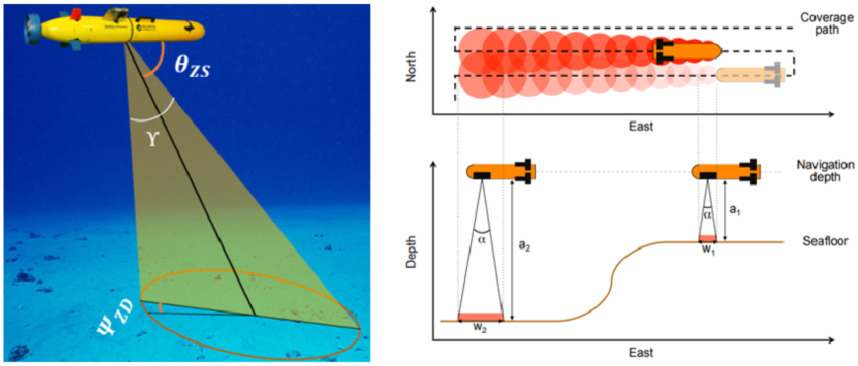

Fig. 1.5 (Left) Coverage overlapping and FOV variation in function of seafloor [10]; (Right) Image overlap [9].

$$x_{f1} = h \cdot \tan\left(90 - \theta_{ZD} - \frac{\gamma}{2}\right)$$

$$x_{f2} = h \cdot \tan\left(\theta_{ZD} - \frac{\gamma}{2}\right)$$

$$y_{f1} = x_{f1} \cdot \tan\left(\psi_{ZD} - \frac{\gamma}{2}\right)$$

$$y_{f2} = x_{f2} \cdot \tan\left(\psi_{ZD} - 90 - \frac{\gamma}{2}\right)$$

Points y_{f1}, y_{f2}, x_{f1} and x_{f2} delimitate FOV using values of orientation and sensor characteristics. Thanks to the flexibility of the model, it is possible to control the inspected area at each moment, being suitable for underwater inspections with variable or constant depth.

An example is presented to test the reliability of the system. In this case, it is analyzed the work developed by Iscar et al , an underwater acquisition system formed by the MEDUSA Deep Sea AUV and the payload transported, camera BlackFly U3-23S6C-C, with 2 meters operational depth [18]. Using the model, it is possible to obtain the following preliminary results:

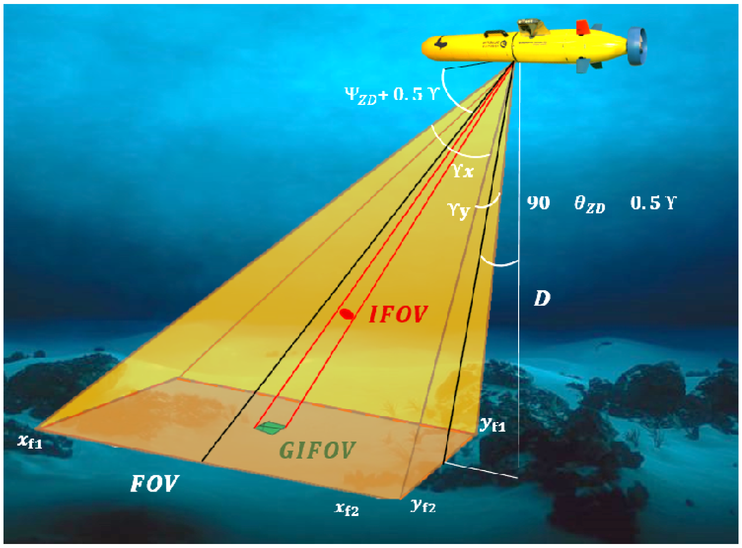

Fig. 1.6 Comparison between FOV, IFOV y GIFOV

Table 1.1 Model results

Camera FOV	40^o	IFOV vertical	0,02 mrad
Resolution Horizontal	1920	GIFOV	41,67 mm
Resolution Vertical	1200	C	2
FOV	1,5 m	GIFOVmeas	83,34 mm

The model provides that the detectable average defect size is greater than 83,34 mm for depth, UAV and camera selected.

1.5 Conclusions

Autonomous underwater vehicles have modified the capacity of inspecting depth seafloor due to their autonomy, efficiency, endurance and the capability of transporting of all types of sensors. The control of this vehicles presents a challenge in path planning and control sensor payload, where sophisticated advanced control systems are requiredEscriba aquí la ecuación. This paper has presented a model for determining the optimal use of any type of sensor regarding to the operations and the objectives. The algorithm determines the field of view of sensor payload at any moment by the analysis of measurement process variables.

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Author Index

J. Xu et al. (eds.), *International Conference on Management Science and Engineering Management 2019*,
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