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Design of the obstacle detection system with the SONAR MK3 on Guanay II AUV

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***Abstract* – Autonomous underwater vehicles (AUV) perform inspection missions and intervention in known and unknown environments, where it is necessary to ensure their safety. The AUV must have the ability to detect and avoid obstacles in the path of navigation. This article, an obstacle detection system for experimental Guanay II AUV is proposed, using a mechanical scanning SONAR Tritech Micron MK3. Since Guanay II operates autonomously, we have designed software that allows adjustment and control of the parameters of SONAR, and the acquisition and processing of the signals obtained. Experimental tests at sea have allowed to verify the correct operation of software designed, as well as, experimental tests in a controlled environment have allowed to determine the optimal values of the basic parameters of SONAR.**

***Keywords* –AUV Guanay II, SONAR MK3, obstacle detection, acquisition and signal processing, automatic operation.**

I. INTRODUCTION

SONAR (Sound Navigation and Ranging) sensors are the most used for detecting obstacles in the navigation paths of marine vehicles.

In our case, we have the autonomous underwater vehicle Guanay II [1]. AUV developed by SARTI research group of Universitat Politècnica de Catalunya, with the objective of providing a platform for measuring several variables as oceanographic temperature and salinity of a water column. Navigation control system of the Guanay II allows the vehicle to follow a predetermined path of navigation. To guarantee the safety of this AUVs in navigation is desired to develop an obstacle detection and avoidance system [2] [3] [4] [5]. With this requirements:

- Low computational load
- Low reaction time
- function autonomously and in real time
- Compatibility with the power system, the control unit and the physical structure of the AUV.

The control unit of the Guanay II is composed of a PC-104 working on Linux and LabVIEW. This unit is responsible of managing all the systems that compound the vehicle (Fig.1.).

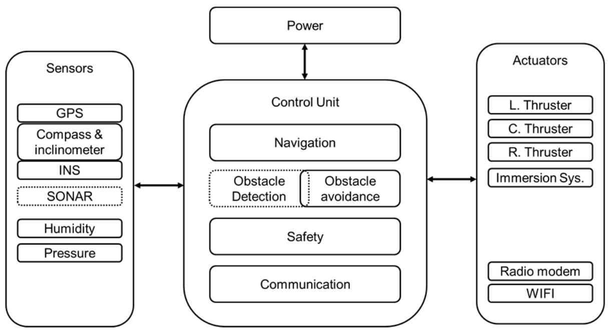


Fig. 1. General block diagram of AUV Guanay II hardware

To guarantee the autonomous navigation of the AUV, the detection and avoidance system must interact with the security system and navigation system.

This paper presents the design obstacle detection system, using mechanical scanning SONAR "Micron MK3" Tritech.

The SONAR MK3 provides a software, Seanet Tritech (only available for Windows), which allows to configure, control, display the information on the screen and store the measurement data in V4LOG format, which is a standard of Tritech. However, due to, it is proprietary software is not possible to communicate directly between the control unit of the vehicle and the sensor. To achieve this purpose, we have developed an algorithm in LabVIEW programming environment. This is designed to make the adjustment, control, acquisition and processing of SONAR signals. This system results in the location of the obstacles present in the environment navigation.

II. RELATED RESULTS IN THE LITERATURE

Obstacle detection is a fundamental issue to ensure the safety in navigation of an AUV. In literature, it is possible to find different case studies. A. Ghatk [3] shows that the software provided by the manufacturer Tritech, allows operation of the SONAR, creating the image of the environment. However, an autonomous system (in real-time) cannot use the information acquired to locate obstacles. Because we do not have direct access to information, the information is displayed on screen, but cannot be stored automatically and cannot be processed in real time. For this reason, it is necessary to design and development specific algorithms [7] [8], which allow us to visualize the environment in real time with respect to the location of the vehicle, provided by the positioning system. Furthermore, it is important to determine the distance between the SONAR and the obstacle [3].

Obstacle detection is performed by various methods [4] [7] [8]. All these methods are based on the analysis of the pixels that form the image of the environment navigation. It is important to highlight, that each one of the methods [4] [7] [8] used for the obstacle detection, are specific to each case of study and vary depending on the type of SONAR, the programming platform and operational characteristics of the AUV.

On the other hand, the literature consulted, does not specify the operation of measurement systems, and the influence of its configuration in operation obstacle detection system, and nor its relationship to the operation of the AUV or ASV. These issues are worked out in this article.

III. DESCRIPTION OF THE METHOD AND RESULTS

The objective of this work is to design and develop a system for detecting obstacles, that allows to determine the location of obstacles, with respect to the vehicle position and determine the appropriate configuration of operating parameters for the system can be installed subsequently in the vehicle Guanay II.

The obstacle detection system design can be divided into five sections: SONAR, measurement system, signal analysis, obstacle detection and finally the configuration of the operating parameters of the system.

In this section, we make the description of obstacle detection system, starting with an analysis of the performance characteristics of SONAR, followed by a description of the design and implementation of the algorithm.

Subsequently, we present the results of tests performed in a controlled environment, the results of these tests are analyzed in section III.D. In this same section, we analyze the different correlations existing between the operating parameters and we determine an appropriate configuration of the operating parameters, allowing us to meet the requirements mentioned above in the introduction.

Finally, in section III.E. We show some of the results obtained in field trials.

A. SONAR (Sound Navigation And Ranging)

This obstacle detection system is based on mechanical scanning SONAR Micron MK3 de Tritech [6]. This SONAR, generates a beam (see Fig.2) with a vertical opening of 35° and a horizontal opening of 3°. The operating parameters are shown in Table 1.

Table 1. SONAR MK3 operating parameters

Parameters	Value / range
Scan sectors (Ss)	0º a 360º
Step angle size (mechanical resolution) (Sa)	0.45º or 0.9º or 1.8º
Data samples (Ds)	0 to 800
Range Scale (Rs)	0.3 to 75 m

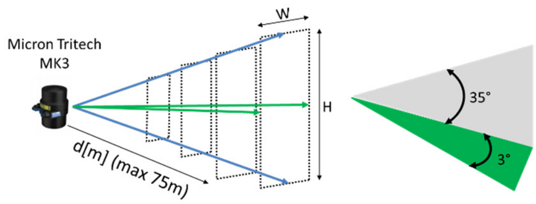


Fig. 2. SONAR MK3 Beamwidth and detection area

When analyzing the operation of the SONAR and operating parameters, we find different correlations, the analysis of these correlations allows us to determine the most appropriate settings for the operating parameters.

- *Detection Area vs. operating distance*

The beam sent by the SONAR at a specific position, generates a rectangular area of detection (X Height Width) on the vertical plane (see Fig.2), the size of this area varies with respect to Range Scale. As seen in Table 2, the higher the distance between the SONAR and the measuring point (d[m]), the higher the detection area. In theory any object located within this area could be detected.

Table 2. Dimensions of detection area

d [m]	Dimensions of detection area (Height X Width)	d [m]	Dimensions of detection area (Height X Width)
70	44 X 3.6 [m]	20	12 X 1 [m]
60	37 X 3 [m]	15	9 X 0.7 [m]
50	31 X 2.6 [m]	10	6 X 0.5 [m]
40	25 X 2 [m]	5	3 X 0.2 [m]
30	18 X 1.5 [m]	1	0.63 X 0.05 [m]

- *Distance between the centers of beam vs. Step angle, Range Scale and detection area*

Between the centers of two beams consecutively sent by the SONAR, there is a distance "L" (see Fig.3) which depends Step angle size and changes with respect to distance "d", as shown in Table 3.

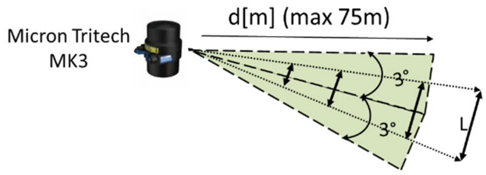


Fig. 3. SONAR MK3 Distance between beam centers

Table 3. Distance between beam centers

d [m]	L[m] (Sa=0.45º)	L[m] (Sa=0.9º)	L[m] (Sa=1.8º)
70	0.549	1.09	2.2
60	0.47	0.94	1.88
50	0.392	0.78	1.6
40	0.3	0.62	1.25
30	0.23	0.47	0.94

Correlating the results of Tables 2 and 3, we find that by sending two consecutive beams, each beam generates its own rectangular detection area (Table 2), but due to the dimensions of the rectangle and the distance between the beam centers "L" (Table 3), we have a portion of space that will be sampled by both beams, i.e. we oversampling (see Fig.4) of a portion of the detection area.

No matter the distance "d", we will always have the same relation between the distance "L" and the detection area (Table 2), for this reason the percentage of oversample area, depends on "Sa", this percentage is constant and corresponds to the values set out in Table 4. This oversampling can increase the probability of detection of smaller obstacles.

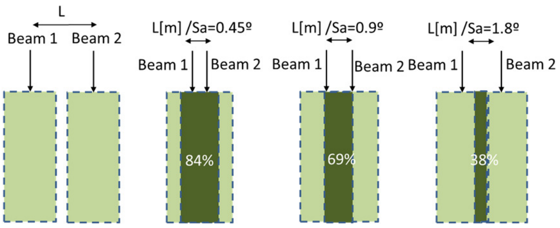


Fig. 4. SONAR MK3 Percentage oversampling

Table 4. Percentage of oversample area (POS)

POS [%] (Sa=0.45º)	POS [%] (Sa=0.9º)	POS [%] (Sa=1.8º)
84%	69%	38%

The results shown in the various tables in this section and their correlations will be used in the following sections to determine the configuration of the operating parameters obstacle detection system.

B. Measurement system, signal analysis and detection of obstacles

The SONAR MK3 can be configured by using RS485 protocol. Since the Guanay II operates autonomously, we have designed a software that is compatible with the vehicle control unit for configuration, control, acquisition and processing of the signals of SONAR.

The algorithm that we have designed is divided into three blocks, the first block is communication between SONAR and computer, in the second block, we have the data acquisition stage and, finally, we have the block in charge of processing information obtained through SONAR and perform automatic detection of objects.

This algorithm (See Fig.5) includes in its design a protocol that allows reboot the device and adjust the operating parameters of the system. Generally, the algorithm "start" running the configuration of the communication parameters and establishes communication with the SONAR. Subsequently, the state of the "Alive" device is evaluated; if necessary, adjusting the operating parameters it is performed. Finally, the subroutine "Getdata" is executed to acquire the data.

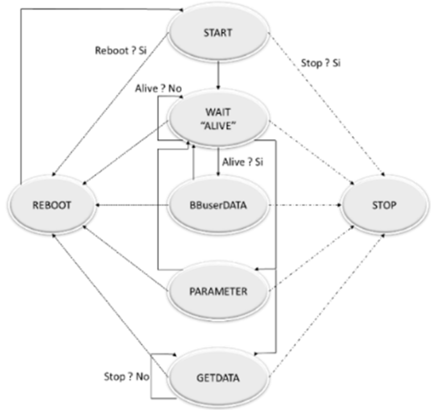


Fig. 5. General block diagram of the algorithm for the operation of SONAR.

In summary, this design allows the integration of communication blocks and data acquisition in a flexible way, ie enables the reconfiguration of the operating parameters and attention alerts without the need to stop the application.

Once the communication between SONAR and the computer is set correctly, the operating parameters of the SONAR are configured.

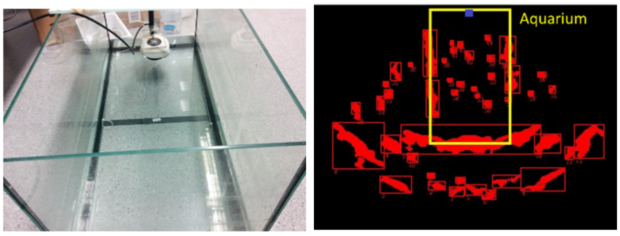
Each of the measurements performed is stored in a data matrix forming an image of the measurement area. This image is processed, filtered to remove the clutter and then the automatic identification of obstacles is performed, based on size, shape, location and tonality of the object.

As a result of this process, we obtain an image (see Fig.6.b), in which each of the obstacles detected are framed rectangles. Also, a data table is obtained with the location coordinates of these obstacles and their dimensions.

C. Laboratory tests and results

The first experimental tests of the measuring system have been developed in an aquarium (see Fig.6.a). These tests have allowed to evaluate the performance of measurement system a controlled and limited environment.

Fig.6b, show the response of the measurement system in red color, the yellow rectangle superimposed corresponds to the actual location of the aquarium walls. Due to the size of the aquarium, the SONAR beams generated wave reflections in the corners, this increases the clutter and causes the occurrence of false detections.



a b

Fig. 6. a) Aquarium used for testing in the laboratory, b) Result obtained in laboratory tests

We performed a series of tests in this controlled environment. In which the configuration parameters (Table 1) have been assigned different values.

These tests have allowed us to characterize the system, determine the correlations between the different parameters and calculate the execution time (Rt) of the algorithm. Table 5 shows the correlations between the variables Rs, Rt and Dt.

Table 5. Results obtained in laboratory of the correlations between the variables Rs, Rt, and Dt.

Rs[m]	Rt[s]	Dt[m]	Rs-Dt[m]
0,3	12	12	-11.7
5	12,02	12,02	-7.02
15	12,035	12,035	2.965
25	12,036	12,036	12.964
35	13,037	13,037	21.962
45	15,62	15,62	29.38
55	18,23	18,23	36.77
65	21,03	21,03	43.97
75	23,41	23,41	51.59

The first column corresponds to different values of the variable Range scale (Rs). In the second column the algorithm Run time (Rt), for a configuration of Scan sectors 90º, Step angle size 0.45º and Data samples 400. The third column is the maximum distance that traverse the vehicle during a cycle of execution of the algorithm "Dt". This distance is calculated from equation (1), being the maximum vehicle speed 1m/s.

$$D_t = v_{max} \cdot R_t \quad (1)$$

Finally, in the fourth column, the difference between Range scale and the distance traveled by the vehicle is presented for the different case studies “Rs-Dt”.

Table 6 shows the correlation between the Data samples (Ds), the distance between the points (Dpp), resolution image (RI) and the Run time (Rt). For these tests, we used a general configuration of Ss 90º, Sa 0.9 °, Rs 70m. The Dpp value is calculated from equation (2)

$$D_{PP} = \frac{\text{Range scale}}{Data\ samples} \quad (2)$$

Table 6. Correlation between SONAR operating parameters.

Ds	Dpp[m]	RI[pixel]	Rt[s]
800	0.087	1600x800	12
400	0.175	800x400	11.5
200	0.35	400x200	11

Table 7 presents the correlation between the Run time and different values Step angle (Sa) and Data samples (Ds). With a base configuration of Range Scale 70m and Scan sectors 90º.

The first column of Table 7 corresponds to Data samples (Ds), and the other at the Run time of the algorithm(Rt) for different values of Step angle (Sa).

Table 7. Correlation between SONAR operating parameters.

Ds	Rt[S] (Sa=0.45º)	Rt[S] (Sa=0.9º)	Rt[S] (Sa=1.8º)
800	23	12	5.75
400	22.75	11.5	5.75
200	22	11	5.5

D. Analysis of results and determination of optimal values of the parameters obstacle detection system.

The objective in this section is to analyze the correlations between operating parameters of the system, given in the Tables 5, 6, y 7, for choosing a set of values that allow us to get a lower Run time of the algorithm, a good image resolution (RI) and the ability to detect small obstacles such as buoys.

Analyzing the Table 5, we found a correlation between Rs and Rt, that indicates that if we have higher values of Rs, the Rt measured will be higher too, and consequently we have a higher distance traveled by the vehicle in one cycle of execution. It is worth noting, that for values of Rs lower at 15m, the difference between Rs and Dt is negative, therefore the value of Rs is invalidated.

Table 6 shows a correlation between Ds and parameters: Dpp, RI and Rt. For a base value of Rs 70m. If the value of Ds is modified, we note that for large values of Ds, the Dpp will be small and for small values of Ds, the Dpp will be large.

On the other hand, we note that for a large value of Ds, the image resolution will be "high", although the Run time will be high.

Finally, Table 7 shows the correlation between Ds, Sa and Rt. For the same value of Ds, we note that Sa has a high influence on the value of Rt, for small values of Sa, we obtain higher values of Rt.

The configuration of the operating parameters of the system, more appropriate, it's determined from the strategy proposed in the flowchart associated in fig.7.

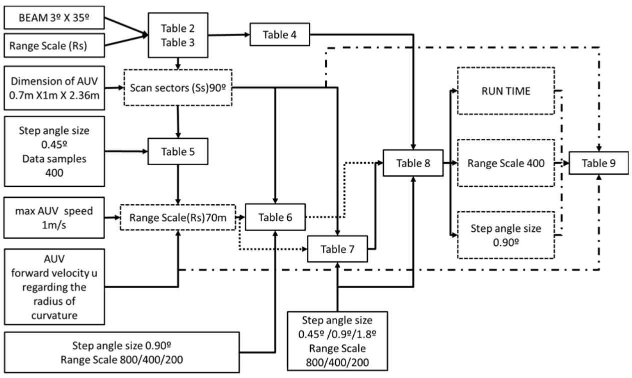


Fig. 7. Flowchart of the strategy used to find the values of the operating parameters

According with the Fig.7, The value of Scan sectors (Ss) is defined by analyzing the Tables 2 and 3, where it is observed that rectangular area of detection, generated by a single beam at a distance "d" of 1m, it's from 0.63X0.05m.

Due to the physical dimensions of our vehicle (0.7 m high, 1 m wide and 2.36 m long) and taking into account the location of SONAR inside the vehicle, we need to have a detection area of 0.7x1m at a distance of 50 cm of the SONAR, which is obtained with a Scan sectors of 90° according to equation (3).

$$\propto = \tan^{-1}\left(\frac{1m}{2*0.5m}\right) = 90º \qquad (3)$$

The Range Scale operation, as shown in Fig.7, It is principally defined from the correlation between the data of the Table 5, with the relationship existing in this AUV between the forward speed and the turning radius of the vehicle.

Analyzing this correlation, we note that the distance traveled by the vehicle, when the Scan sectors is 90°, varies between: 12m and 23m, depending on the value of Range Scale.

According with Fig.8, if the vehicle moves a speed of 1m / s, we need a turning radius of 50m. Based on this, it is calculated that the value of the Range Scale should be between 62m (12 + 50) and 73m (23 + 50), for this reason we define a Range Scale of 70m.

From the correlation between Tables 4, 6, 7, we define three types of image resolution: High, Medium and Low. We show their characteristics in the Table 8.

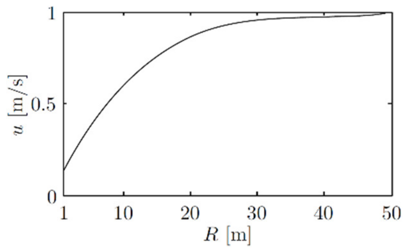


Fig. 8. Maximum forward velocity u regarding the radius of curvature [1]

Table 8. Types of image resolution and their characteristics

Types	Characteristics				
	Ds	Dpp [m]	Sa	Tr [s]	POS [%]
High	800	0.087	0.45º	23	84
Medium	400	0.175	0.9º	11.5	69
Low	<200	0.35	1.8º	5.5	38

As shown in Fig.7, the values of Step angle size (Sa) and Data samples (Ds), They are determined from Table 8 and they are selected to obtain a low run time of the algorithm. Finally, we have defined the operating parameters, which are shown in Table 9

Table 9. Optimum configuration parameters for the measurement and obstacle detection system

Parameters	Value
Scan sectors (Ss)	90°
Step angle size (Sa)	0.9°
Data samples (Ds)	400
Range Scale (Rs)	70 m

E. Field Testing and Results

Field tests have been carried out in the port of Vilanova I la Geltrú (Barcelona, Spain), with the main objective to evaluate and characterize the functioning of SONAR, to discriminate the walls; that make up the jetties and distinguish static and moving boats of different sizes.

Fig.9 shows the data obtained during tests. Fig.9.a show the location of the tests. Fig.9.b We show the original image obtained by using the configuration of Table 9.

Fig.9.c filtered by contrast, which allows to remove the clutter. Fig.9.d and 9.e. show zoom the area indicated in Fig.9.c. On the Fig.9.d a Gaussian filter is applied and the result is shown in Fig.9.e. This filter allows to unite the scattered points and improving resolution of objects. Finally, in Fig.9.f show the resulting image, where it can clearly distinguish the objects (boats, walls), and in Fig.9.g we show the result of automatic detection of obstacles.

Around each of the detected obstacles, it is automatically generating a rectangle and a numeric identified

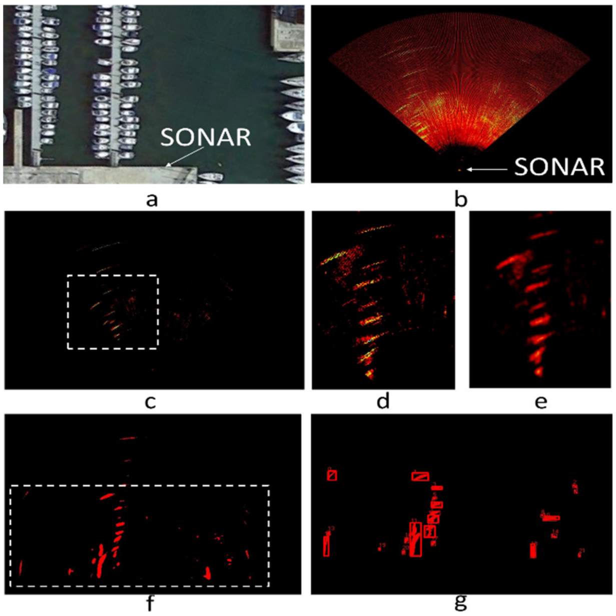


Fig. 9. Result in field trials

IV. NOVELTIES IN THE PAPER

The study developed and shown throughout of this paper allows to evaluate in detail the operation of the measurement system.

In our case this system includes: communication interface with SONAR MK3, data acquisition and subsequent analysis until is reached the automated detection of obstacles.

We have also shown, the methodology used for the analysis of correlations between the different system configuration parameters and their influence at the time of selecting appropriate for the operation of the measuring system and obstacle detection values.

V. CONCLUSIONS

According to the studies carried out as well as the results obtained in the present work, we conclude that the obstacle detection system developed for the experimental vehicle Guanay II using mechanical scanning SONAR Micron Tritech MK3, conforms to the physical characteristics and technical requirements of the vehicle.

The tests that we have done have validated the software designed by which the adjustment is achieved, control, acquisition, processing signals from SONAR and obstacle detection. The results that we have obtained are highly satisfactory, in the sense which ensure the ability to detect and discriminate objects and structures in the vehicle's path.

we have determined the optimum configuration for SONAR operating parameters respect to the theoretical specifications SONAR, vehicle operating specifications and practical results obtained in laboratory tests. This configuration allows us to meet the objective of having a good image resolution and low computational cost.

Will be needed more field tests in new operating environments to corroborate and correct if necessary, the values proposed, before, that the detection system is installed in the vehicle and later to the installation, we should perform test runs on navigation, which allows us to determine the real performance of the subsystem.

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