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JELLYFISH MONITORING ON COASTLINES USING REMOTE PILOTED AIRCRAFT

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Abstract. In the last 10 years the number of jellyfish shoals that reach the swimming area of the Mediterranean Sea are increasing constantly. The term "Jellyfish" refers to animals from different taxonomic groups but the Scyphomedusae are within the most significant one. Four species of Scyphomedusae are the most conspicuous ones inhabiting the studied area, the Barcelona metropolitan area. Jellyfish are usually found at the surface waters, forming big swarms. This feature makes possible to detect them remotely, using a visual camera and image processing algorithms. In this paper we present the characteristics of a remote piloted aircraft capable to perform monitoring flights during the whole summer season. The requirements of the aircraft are to be easy to operate, to be able to flight at low altitude (100 m) following the buoy line (200 m from the beach line) and to be save for other users of the seaside. The remote piloted aircraft will carry a vision system and a processing board able to obtain useful information on real-time.

1. Introduction

In the last 10 years the number of jellyfish shoals that reach the swimming area seem to be increasing constantly due to the effect of several factors associated with global climate change [1]. The overfishing of their natural predators such as tunas and turtles is also one of factors influencing such jellyfish proliferation [2]. Nevertheless there are few studies about the inter-annual and spatial distribution of most important jellyfish blooming species.

Despite of the importance of the phenomenon there are not appropriate methodologies available to record the presence of jellyfish in large coastal areas and that this information can be forwarded promptly to the authorities to implement remedial measures. The impossibility of being in many places at once led us to propose a new methodology based on the study of aerial images.

The term "jellyfish" refers to animals from different taxonomic groups but the Scyphomedusae are within the most important group, very often related with the problems associated with jellyfish proliferations at coastal places. Four species of Scyphomedusae are the most conspicuous ones inhabiting the studied area. Although none of them is mortal, they can stinging with a different degree of severity and produce a social alarm when they reach the bathing areas. Jellyfish are usually found at the surface waters, forming big swarms. This features makes possible to detect them remotely and helps to creating system to inform swimmers about their presence. Until last year, within the Catalan Water Agency monitoring programme, a Cessna 172 was flying over the buoy line at an altitude of 250-300 m from Barcelona to the North (Port Bou) or to the South (Les Cases d'Alcanar) on alternating days. Currently we are able to detect, remotely from a manned aircraft, two of the four studied jellyfish species using a visual camera and an image post-processing filter: the Rhizostoma

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pulmo and the Cotylorhiza tuberculata. The primarily objective of those flights is to be able to daily inform the coast guards and the citizens about the proximity of jellyfish swarms. Secondly, we are able to obtain relevant statistics about the jellyfish proliferation and their movements. The plan to move the system to a remote piloted aircraft should allow taking better images. Previous experiences exits on using remote piloted aircraft for monitoring nature over the sea, such as mammals [3], polar ice [4] or hurricanes [5].

The paper is organized as follows: Section 2 presents the technical aspects of the image processing needed to detect the jellyfish. Section 3 presents some details of the current and forthcoming regulations which may support this remote sensing mission. Section 4 presents the proposed UAS rotor-craft and its payload, together with some preliminary results. Finally the conclusions section will present the future steps of the jellyfish mission.

2. Technical Aspects

Pixel resolution is probably the most critical requirement of any remote sense service or mission. For the aerial service of monitoring jellyfish, pixel resolution becomes one of the most stringent, since some jellyfish are very small in size, and only a very high resolution image will be able to obtain the details of individual jellyfish. The species of jellyfish we plan to monitor are from 5 cm to 15-30 cm length. At least a ratio of 20 to 100 pixels per individual are required to be able to detect them and to classify the specie using some texture matching techniques. Any increase above these limits means that the detection and classification are possible, but also that the filtering algorithms are faster and the results are more accurate. On contrast, bellow 20 pixels per individual it is not possible to distinguish them.

Having the camera in nadir orientation, the pixel resolution is given as the result of the flight altitude1. The following figures show the variations of pixels size as a flight altitude increases, and for different camera resolution and field of view. Figure 1.a shows the influence of the camera resolution and Figure1.b the influence of the camera field of view (FoV). Camera resolutions are selected for 1 Mpx, 3 Mpx, 5 Mpx, 9 Mpx and 12 Mpx. Field of views of 8°, 20° and 35° are selected for typical focal distance of the lens: teleobjective 8FoV (e.g. 45-50mm focal distance), 35FoV for a wide angular (e.g. 10mm focal distance) and an intermediate 20FoV (e.g. 18-20mm focal distance). Pixel sizes are given in centimeters (cm).

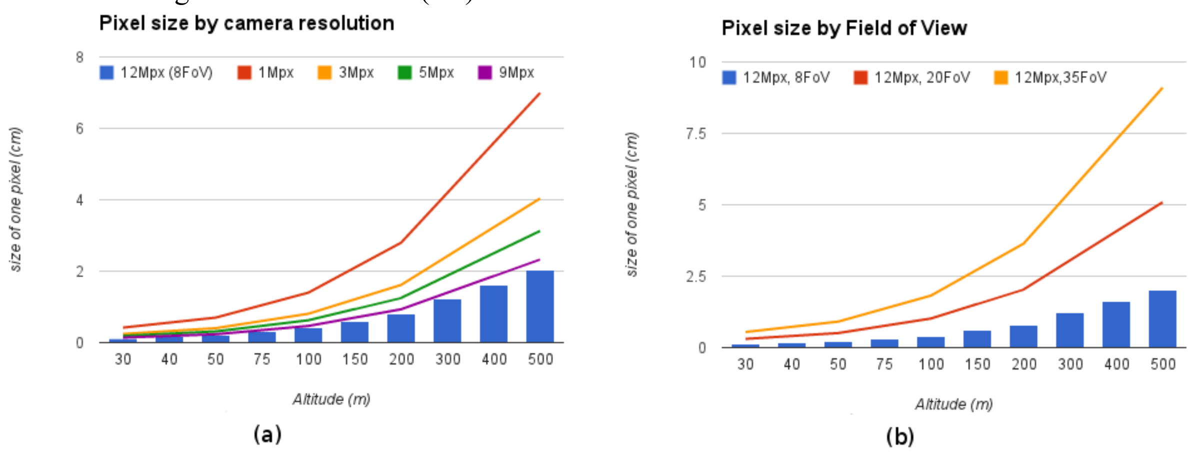

Figure 1. Influence of flight altitude, camera resolution and field of view on pixel siz

Both charts show as bars a base configuration defined as a 12 Mpx camera and 8 degrees FoV. This is the best resolution camera configuration between the ones given and is the one used previously for remote sensing from a manned aircraft. As expected the size of one pixel increases as the altitude of the flight increases, having less details on the image. In the base configuration we are able to have a pixel size of 1cm when the flight altitude is 250m or bellow. Higher altitudes will not meet the requirement to be able to distinguish a jellyfish, even with this best configuration.

Figure 1.a) shows the impact of the camera resolution on the image resolution. An increment of the camera resolution from 1 Mpx to 3 Mpx divides almost by two the size of the pixel, but further increments on mega-pixels do not have such significant impact. On the contrary, the increase of the camera resolution gives larger size images, and thus, longer processing time. Figure 1.b shows the impact of the camera field of view on the image resolution. While the best resolutions are obtained for the teleobjective configuration, the increments of the field of view angle doubles the size of the pixel, having similar effects than flight altitude. The main drawback of the narrow angles of field of view is that less area is obtained for study. If flying at 300 m an image taken with the wide field of view captures a strip of 190 meters wide. The same image taken with the teleobjective will capture only a strip of 40 meters wide. Even more, the successive set of pictures taken from the airframe in movement may need a very high frequency of frames per second if we need some overlapping of the images. For a more detailed information Table 1 shows the values of the pixel sizes for all the camera configurations at the UAS target flight altitude of 100m. Values equal or less to 1cm show the good options for the camera needed in the jellyfish mission.

Table 1. Pixel size for 100m flight (cm)

	1Mpx	3Mpx	5Mpx	9Mpx	12Mpx
8 FoV	1.40	0.81	0.63	0.47	0.40
20 FoV	3.53	2.04	1.58	1.18	1.02
35 FoV	6.31	3.64	2.82	2.10	1.82

The image processing of each picture was up to now done using a post-processing iteration. For each picture a initial phase is used to intensify the pixel differences. Then a search in done to find candidates image areas to be account as jellyfish. A the final third phase merges separate neighbor candidates.

Step 1) Initial filtering and color segmentation. In order to simplify the segmentation process, we need to run two previous filter processes to our RGB image as for example the image of Figure 2.a. First of all, we run a decorrelation stretch for adjusting pixel intensity values, in all color bands. Second, we compute a contrast stretching transformation. Both results can be observe in Figures 2.b and 3.c, and in this last one can observe that it is easier to distinguish the jellyfish.

Then color segmentation is applied in order to find the regions of interest of the captured image. The RGB space is used because it obtains a better separation between the color channels than gray images or other spaces previously tried. Three threshold values are defined, one for each channel; only pixels with a minimum amount of blue, red and green are selected. It has been difficult to establish precise threshold values for each one of the colors of the jellyfish without overlapping with other colors. Currently the thresholds are set to 80 for red and blue and 70 for green.

Step 2) Candidates selection. The objective of this step is to find regions, instead of classifying pixel by pixel, where we could find a Jellyfish. Starting from the result obtained in the previous step, two procedures are applied to distinguish jellyfish from non jellyfish images. Thus, we define the regions which could contain a jellyfish because of it size. These regions can be easily computed by grouping the pixels of the images. This grouping is done by applying first an opening morphological process and afterward by using connected component labeling. The morphological process consists in ignoring and deleting the small noise that appears in our segmentation. The opening morphological process, applied to the image, uses different structural elements for the erosion and for the dilatation. This allows the processing program not only to ignore and delete the small noise, but also to fill the spaces between parts.

Several different structural elements were tried, but the structural elements which obtained the best performance are the following ones: A 2x2 pixel square structure, which allowed us to erase small noise with the erosion; And a 3x3 pixel square structure, which allows us to join pixels with the dilatation. An example showing the result of this step can be seen in Figure 2.d and 2.e. Note that in this process we are still working with pixels and the window candidates haven't been created yet.

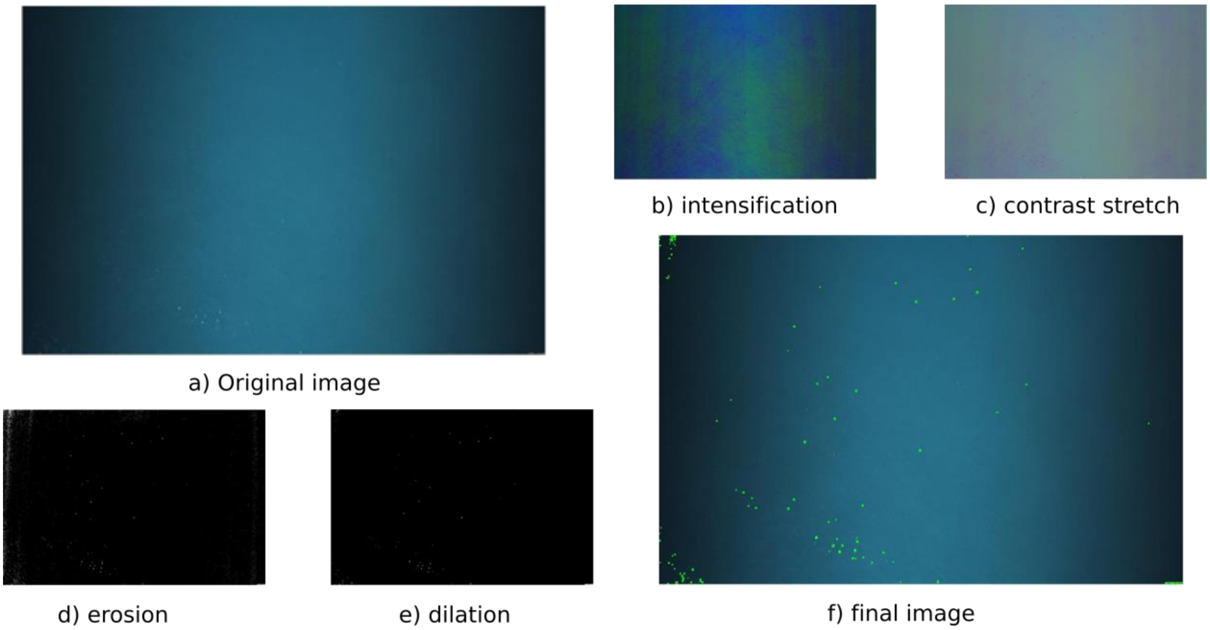

Figure 2. Image processing steps

Step 3) Connected component labeling. We used connected component labeling (CCL) to group all the different areas considered as candidates. All the pixels in contact one to each other are classified with the same label. This allows the program to compute the different properties of the groups, such as the area, number of pixels and the bounding box. The bounding box is defined as the position of the upper-left corner, and the width and height of the window candidate. With the bounding box data we can establish new selectors to better distinguish jellyfish from noise: We can omit areas below and above certain threshold values, because we will not consider tiny signals and neither enormous ones. The final result of the image processing can be observed in Figure 2.f.

Because of the required minimum safety altitude, the current aerial manned system has not always the sufficient pixel resolution to quantify the type and number of specimens within the shoal. This limitation reduces the quality of the studies of the behavior of jellyfish and of the shoal movements.

3. Legal Aspects

The Chicago Convention celebrated on 1944 by International Civil Aviation Organization (ICAO) and joining representatives of national civil aviation worldwide, created the regulation mark that still is used as the base of civil aviation regulations [6]. Its article number 8 states that “no aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting state without special authorization (...)”. This restriction in the international regulations has been a drawback for the remote piloted aircraft deployment in the civil arena for the last 10 years. Special permissions for segregated airspace has been the only means to fly. In contrast, the military expansion of the use of UAS, reflect the capabilities of this tool and pushes the necessity to revise the old regulations. Article 22 also obliges the contracting States to “adopt all practical measures, through the insurance of special regulations or otherwise, to facilitate and expedite navigation by aircraft”.

In 2011 The International Civil Aviation Organization published the Circular 328 [7] about Unmanned Aircraft Systems (UAS) with the objective to establish the rules that allow UAS to operate in the civil airspace with sufficient level of safety, such as the procedures needed to obviate danger to other civil aircraft and to population. The ICAO Circular 328 recognizes that the States should apprise the emergent use of UAS and the need to integrate them into the non-segregated airspace. To advance in this objective the document differentiates between different types of UAS: the fully piloted, the fully autonomous and the combination of both. Obviously, the pilot of a fully piloted UAS are located on ground and uses a wireless communication link to continuously monitor and command the UAS. These type of UAS are named remote piloted aircraft (RPA), and are the subset of the UAS that will be integrated into the civil airspace in a foreseeable future.

As any other aircraft, RPA have three areas to consider: operations, personnel and equipment. An evolutionary approach is expected to design and adapt pertinent standards and recommended practices (SARPs) for the RPA operations. Remote pilots must, at least, have the same knowledge (on air laws, flight performance, navigation, radio-telephony, etc.) and the same ultimate responsibilities than pilots of manned aircraft. Thus, remote pilots and other possible members of the crew must be properly trained, qualified and hold the required license that guaranties the integrity and safety of the civil aviation system. Considerations about handover of pilots (from en-route to terminal or routine shift work) include situations where pilots can be located in different States.

The required aircraft on-board equipment (both for airworthiness and for operation) has to be available to remote pilot. Equipment will be distributed over the RPA and the remote pilot's commanding station on ground. This includes the communication link and the problematics on interferences, discontinuities, spoofing, or other potential vulnerabilities of the link. Frequency bands assignment for command and control links are ITU Radio Regulations. New frequency bands need to be reserved for UAS with the same special measures (for aeronautical safety and regularity of flight) of existing aeronautical bands, to ensure their freedom from harmful interference. The documents that shall be carried in the aircraft (certificates, log books, licenses, etc.) can be in electronic formats rather than in other non-appropriate formats such as paper.

A fundamental basis for the air space rules is that pilot can see other aircraft to avoid hazards and can observe visual signals such as aerodrome lights or traffic signals. The lack of the on-board pilot must be substituted by new equipments for detect and avoid with same level of confidence than the on-board human. The final responsibility of collision avoidance is for the remote pilot, but the technology to provide sufficient knowledge of the airspace environment should be available. A key concept on the current state of regulation studies is the concept of visual line of sight (VLOS). For RPA flying within VLOS the Circular 328 mentions the non-necessity of equipment for flying instrumental procedures. The RPA flying VLOS should be conducted under visual meteorological conditions (VMC), although the raising paradox on potential conflicts with other airspace users. At the same time the circular mentions “In case where small RPA have a requirement to fly beyond VLOS, they will need a means to meet navigation capabilities for the airspace within they are operating.”

Legislation initiatives at the State level and at supra-State level (EASA at EU) include a number of CAA adopting policies to allow UAS to flight in the basis that they meet the equivalent level of safety than a manned aircraft. In the USA the process for acquiring an experimental certification is already specified in the FAA Order 8130.34 ans the RTCA SC 203 is the expert group assisting FAA for technical inputs in additional airworthiness [8]. In Europe, EASA and JARUS, with the technical support of the EUROCAE WG-73, are developing regulations basis for RPA under 150 kg, starting with light unmanned rotor-crafts. In United Kingdom, the CAP 722 [9] presented a guidance document about special provisions of the Air Traffic System to handle RPA. Also Russia and Australia have activities on regulations for RPA aeronautical activities. In general, State regulations aims at a transparent integration of RPA in the non-segregated airspace, which will be achieved with a minimum aviation system performance standards (MASPS) of the operations of RPA. The Single European Sky ATM Research (SESAR) joint undertaking is exploring the feasibility of RPA integration by 2016 [10]. In such a three years period, we expect that a regulation for small, preferably rotor-craft and over the sea might be available.

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4. Proposed Remote Piloted Aircraft

Our aerial remote sensor is basically composed by a visual camera, a processing board and a storage system. The weight of such payload is of few kilograms, which drives the decision about selecting a small size aircraft. Small aircraft (20-150 kg) have low cost, are easy to transport and minimize the impact of any possible incidence, on safety and on environment. The aircraft take-off and landing operations are crucial features to take into account when planning an aerial service, specially if costs and opportunity must be taken into consideration. In the Mediterranean cost there is a large number of maritime ports, with wide enough docks to permit a small helicopter to easily take-off and land (see Figure 3.a).

We propose the use of a Snipper RPA[11]. The technical specifications of the proposed RPA are: a MTOW of 14 kg (two of which are for payload), 1.8 m diameter of rotor and an engine power of 4 HP. The maximum autonomy is 2 hours for a cruise speed of 50 km/h (1h20m when hovering) and link range up to 100 km. It is provisioned with a high performance automatic pilot and a differential GPS.

(a) (b)

Figure 3. Remote piloted rotor-craft and the pilot in VLOS command

The use of a remotely piloted rotor-craft operation was demonstrated last October to obtain a qualitative information of selected shoals. As a particular point of interest, we have detected the proliferation of a jellyfish invading specie, the Phyllorhiza punctata, on the delta of the Ebro river (see Figure 4). This is a highly economic area in mussel farms and the jellyfish competes with the farm fauna in the resource nourishment.

The proposed system was proven to be an adequate solution. This was a second Sniper helicopter, with same structural characteristics than the proposed RPA, but commanded in VLOS by a radio control pilot (see figure 3.b) and used for testing the payload and the processing algorithms with no legal impediment. The helicopter has also an autopilot on-board, used as payload to position the images taken by the camera. The final vehicle configuration and the improvements on algorithms are being develop for the next season.

Figure 4. Ebro River delta demonstration

For the image processing we plan to translate the current MatLab code into C++ in order to execute it in parallel using a 64-core TILEPro64 processor's board. Together with its video streaming and processing capabilities, it provides a pair of 10 GE ports with an impressive 20Gbps of network I/O. First image processing tests over the images taken from the remote piloted aircraft (Figure 4.c) show that the step 1 filtering and color segmentation process can be reduced. Thus, the final jellyfish automatic detection will execute faster, and hopefully on-board.

5. Conclusions

Given the current legal situation of the RPA operation, our proposal is focused into a practical and feasible approach: the daily coastal surveillance will be still done using a manned aircraft. This system has proven to be sufficient to detect large jellyfish shoals with the post-processing method presented. Low flight altitude is a decisive condition to obtain high resolution images. Also camera resolution and focal distance influence on the image resolution. The combination of the three factors determines the capability of the image processing of detecting the jellyfish. But for a fast automatic processing it is better to reduce altitude than to increase image resolution. Remote piloted aircraft are very appropriate to flight at low altitude. The RPA we are proposing will be initially used only in VLOS, piloted remotely from a boat. At the same time we plan to develop the real time image processing capability on board the RPA and to test the automatic flight performances to be able to extend its use as soon as the legislation covers this possibility. Other limitations of the RPA other than regulation is its range. Several RPA should be used in case we need daily information of the whole coastline.

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