Underwater Vision Method for Low-Visibility Turbulent Conditions

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***Abstract*- A terrible disaster has recently happened in Portugal. A Bus with 60 people felled into a turbulent and very dirty river. In the bodies rescue operations that followed, a device has been invented and tested which can visualize underwater objects whose rough location is obtained by standard acoustic sonar methods. This was the only alternative to the impossibility of human diving or the use of any Unmanned Vehicle, hardly suitable for such extreme conditions. A canvas flexible diving bubble having a transparent window was filled with clean water. An underwater camera and light within the bubble transmit video to the surface through an electric cable. The whole set is maneuvered with the help of ropes and a rudder.**

A weight is used to overcome impulsion forces causing the device to dive. In the case of strong currents, like in the mentioned river situation, a rudder is useful for orientation of the search procedures. Given the near-zero visibility, an iteration line is followed during searches and as soon as the diving bubble touches an object, the camera transmits the contact image profile. This information, despite incomplete and 2-dimensional, can be good enough to identify medium-size objects like sunk cars, buses or boats. Also, holes can be remotely located and used to fix hooks for further hoisting.

The device working principle can also be applied to explore objects in very polluted sea waters, as in case of severe oil leaks. Any non-transparent fluid in a tank can now be inspected for possible leaks with the use of this method, provided that the viscosity is not high enough to prevent an optical path between the clean water medium and the immersed object when approached by the bubble.

I. INTRODUCTION

“Necessity breeds Ingenium” is often said. The idea reported in this paper is illustrative of that well known aphorism. In March 4th, early this year, the Hintze Ribeiro bridge over the Douro river, a 336m long bridge with 50m sections finished in 1886, collapsed its P4 pillar. In the disaster, a bus and probably three cars felled into the waters, causing the death of nearly 60 people.

After the drama of the accident direct victims, followed the drama of recovering the bodies in very difficult conditions, with all the families watching the procedures from the margins. It would take nearly four months until the last vehicle was recovered. The first could have been avoided with more effective political action regarding old bridges monitoring, sand extraction activities control and hydroelectric barrage water discharges limitation, the three most probable causes of the bridge collapse according to the official report [1]. The second might have been abbreviated if the apparatus here reported was taken more seriously by the Hydrographic authorities responsible for the search operations. In fact, the intensive media coverture also contributed to extreme prudence in terms of taking no chances, making no false steps.

A remark must also be made on the scientific background of the author which is on Telecommunications, more precisely on optical fiber communications. Thus, language and technical inaccuracies may be present, as reviewing by a oceanographic specialist was not possible.

II. THE RIVER CONDITIONS

The bridge is located 500m downstream the junction of rivers Douro and Tamega. Both rivers have dams not too far away from the bridge section. River Tamega has its last dam (Torrao) 3,3km upstream the bridge. River Douro, larger than Tamega, has dam Carrapatelo 18km upstream the fallen bridge.

According to the most sound estimates, the stream at the bridge section by the time of the accident was about 8000 m^3/s. Given the section profile this was estimated to provide an average water speed of 2m/s [1].

Another important issue is that the soil of the high Douro river is mostly composed by sediments which are dragged by the stream in the rain season. According to records, the hydrological year 2000/2001 has been the worst in many years, having the Douro torrent exceeded the limit of 3000 m^3/s for 35 days. For comparison, previous marks were 3 days in 1997/98, 19 days in 1995/96, 8 days in 1989/90 and 6 days in 1984/85 [1]. For this reason the water in the days following the 4^{Th} of March was dark brown and visibility, according to testimonies of tentative divers, was worse than 20 cm.

The river geometry in the area is such that the Tamega (1452 m^3/s at the hour of the accident) meets the Douro (6222 m^3/s by the same time) right in the middle of a 500m radius curve as shown in Fig. 1.

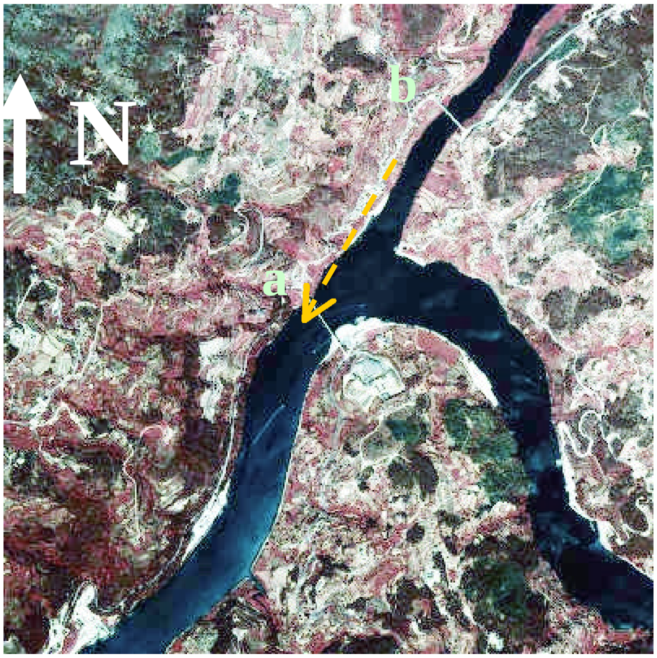

Fig. 1 - Air photo of the junction of rivers Douro an Tamega. Douro flows from East to West, whereas Tamega comes from Northeast with an alignment closely incident on the fallen P4 pillar. Also seen bridges a) Hintze Ribeiro – Douro - and b) Duarte Pacheco - Tamega. Photo width is approximately 3,5km.

The presence of two intense currents joining and the proximity of unusual water discharges from Torrao dam, whose proximity can be seen in fig. 2, leads to significant turbulence in the nearby section of Hintze Ribeiro bridge.

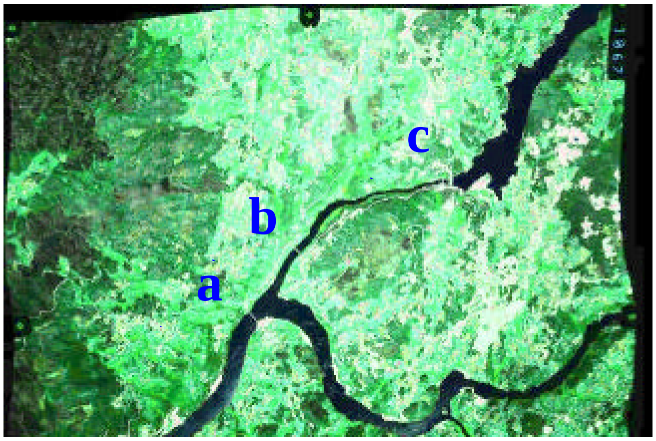

Fig. 2 - Air photo of the junction of rivers Douro and Tamega with the Torrao dam. The relative position of bridges a) Hintze Ribeiro – Douro -, b) Duarte Pacheco – Tamega – and c) the Torrao dam, 3,3 km upstream, can be assessed. Photo width is approximately 7km.

Those were, in summary, the causes of the very adverse conditions of that time. Divers of the Portuguese navy tried even though the diving with high risk for their own safety without success in the first days. Other European countries sent their best specialists, also without success. ROVs could not be used in such severe conditions and the available units were not prepared for the actual conditions.

Acoustic sonars of different frequencies and types, lateral, multi-beam, were used to try to spot the position of the vehicles. A few echoes were obtained but could not be checked or validated in the first week due to diving difficulties. It was later concluded that the first significant echo was actually an old sunk drag-boat. It was in this war-like scenario, with constant appeals of the families and the local mayor for any help to retrieve the bodies, that we came out with this diving-bubble proposal. By that time only a couple of bodies had been found floating in Douro and in Galicia, 200 km north in the Spanish coast, just four days after. No hope to find any survivor existed after the first hours and there was a real risk for divers lives.

III. BUBBLE COMPOSITION AND MANOUVER

The basic idea behind the invention is about getting a video image to the surface without too risky human diving, overcoming the low-visibility, turbulence and even taking advantage of the fast water-flow to stabilize the device towards the river mouth.

Where not stated otherwise, the following description refers to **Fig. 4**. The apparatus is essentially a flexible canvas diving bubble **-** (1) in fig. 4 **-** filled with clean water or another suitable transparent fluid (9). All the bubble can be transparent or it can have only a transparent flexible window (2) adapted to the actual field of view of the camera, as seen in Fig. 3. In this case the inner canvas should have a dark color for maximum contrast when recording with an automatic exposure control camera.

Fig. 3 – Canvas bubble with transparent flexible window.

The presence and rough dimensions of sunk objects can be first detected using different types of acoustic sonar. The

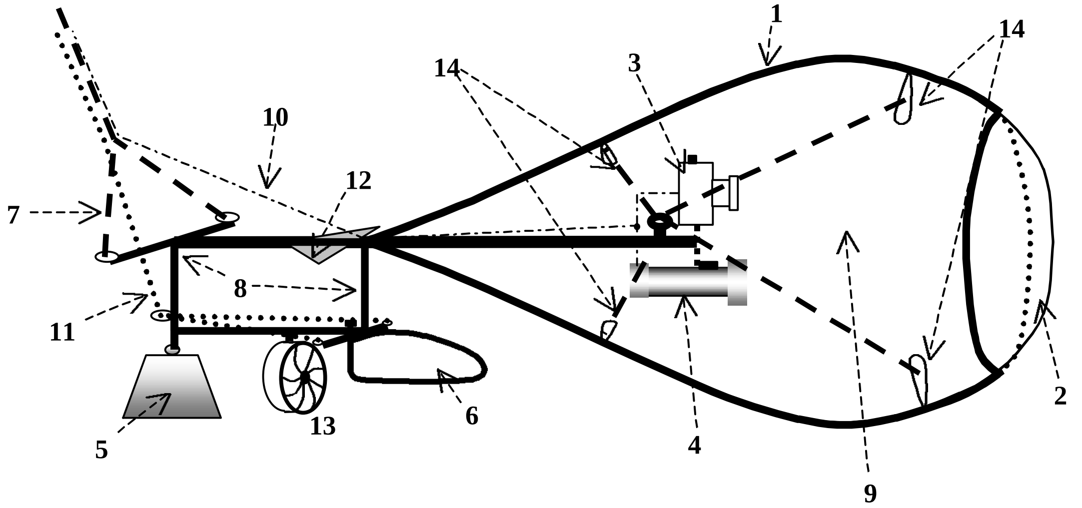

Fig. 4 - Schematic diagram of the diving bubble (1) filled with a transparent medium (9) with an optical viewing window (2), a video micro-camera (3) a light source (4) powered by an electric cable (10) also carrying the video signal back to surface; flexible ties (14) to the chassis (8); suspended by ropes (7), stabilized by a weight (5) and wings (12) and guided by a rudder (6) controlled by wires (11). Propulsion (13) can be added for low flow situations or can the set be an add-on to existent ROVs

bubble can then be launched to visualize and possibly identify the objects with much higher video resolution. How can this be accomplished? Moving around the dirty medium, even reaching its bottom, as soon as the transparent window of the bubble touches an object, the camera transmits the contact image profile. Due to the torrent forces, the transparent canvas surface can adhere to the object with a significant contact area. This 2-dimensional image can be good enough to identify medium-size objects like sunk cars, buses or boats. Furthermore, holes suitable for the fixing of hooks can be located for further hoisting. Given the near-zero visibility, an iteration line can be followed during search attempts.

Immersion of the bubble and filling can be performed simultaneously to avoid excessive tension on the canvas. Finally, mechanical pressure equilibrium on both sides of the bubble should be attained with the membrane moderately extended, thus forming the constraints of a sort of artificial bubble. Fortunately, airtight is not absolutely required, though contamination of the clean interior with the outer dirt will ultimately limit the maximum mission time.

A chassis (8) fixes the relative position of the different parts. Flexible elements (14) should be used to tie the bubble to the chassis in such dynamic media. The chassis will also hold a video B/W or color micro-camera (3) and the light source (4) used to illuminate the scenario. The camera and the light can be kept in the same or in separate airtight housings suitable for the operation depths. A common iron enclosure for the camera and light has been welded out of a standard L-shaped bar, closed by a double-plate very resistant polymer window as seen in Fig. 5.

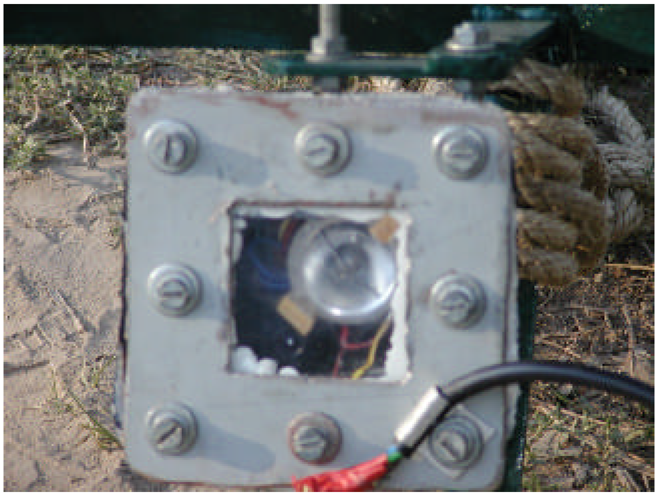

Fig. 5 - Iron housing with pressure resistant transparent window containing both the micro-camera and light source.

A three conductor electric cable (10) with appropriate mechanical and electric shielding H05VV-F is sufficient to supply energy to the electric parts and bring the video signal up to the surface. Water depths of 20m-30m are not exceeded in most rivers. Deeper waters may determine more demanding specification for the cable resistance.

The whole set can be held from a boat at the surface or a bridge with a strong cable (7) around which is wound the electric supply cable (10). It may be stabilized by a weight (5) and wings (12) and guided by a rudder (6) controlled by wires (11).

Propulsion (13) can also be added for low-flow situations. Of course the bubble can itself become an add-on to existent commercial versatile ROVs. The inspection of a pipeline, a reservoir or the bed of a river pose very different technical difficulties that must be dealt with in different ways, though maintaining the operation principle.

In Fig. 6 we may see the camera housing attached to the chassis. In Fig. 7 may be seen the complete chassis with rudder and ropes suspension of the apparatus and immersion control

Fig. 6 - The camera housing attached to the chassis.

Fig. 7 - The chassis with rudder and ropes for immersion control.

The dynamics of the bubble in the water are governed by a set of forces shown in the following diagram

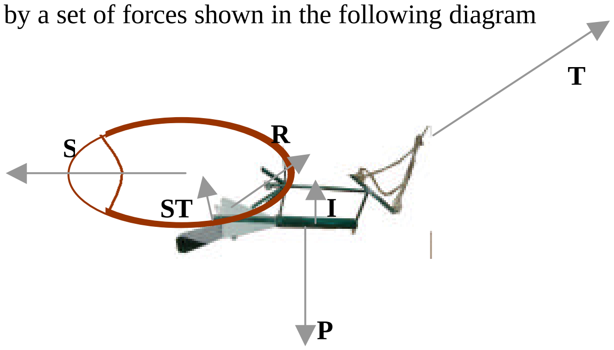

Fig. 8 - Diagram with the main dynamic and static forces acting on the bubble; *T* is the tension of the main supporting cable, *P* is the weight applied on the mass center, *I* is the impulsion from immersion in water, *R* is a rudder direction, *ST* is wing stabilization and S the stokes force due to water flow.

There is also a chaotic component due to turbulence and random variations of the average river flow due to perturbations, flow intensity variations, dragged objects, obstacles, boats and even variations on the river bed, if it has alluvium nature. Clearly, the weight and impulsion forces of the filled out bubble will cancel if the inner/outer liquid (clean or dirty water) have similar density. That is the reason why they were not referred in Fig. 8.

The analytical solution of such a system of time-dependent forces will not be possible, but simulations can be performed in order to assess the bubble dynamic behavior and optimize some design aspects like its size, and the eventual need for flexible canvas opening guides.

IV. FIELD TESTS RESULTS

The first bubble made had a rectangular visible window of about 2m X 1m and the bubble had an average length of 2,5m. The objective was to maximize the field of view. The first tests at the *Douro* river proved the ability of the device to resist the current flow. However, we also concluded for the need to reduce the bubble size in order to limit the holding force to more human limits. Also a TV set and a video-tape recorder were used. The difficulty in making all the connections, the need to use an inverter to produce the AC power voltages, made the whole operation very slow. Also the very rainy conditions made the protection of these large objects a problem. To eliminate all these drawbacks, a compact video camera recorder with video input capability was used instead. The small size and weight, enable its use while moving around a deck. Also rain and wind protection become less of a problem.

A handy CCD-TR880E-Pal Sony video camera acting as a video-tape recorder has been used just after the preliminary field trials. The underwater micro-camera signal is directly fed to its video output terminal, configured to video input when PLAYER mode is selected and REC is initiated [2].

Tests have shown that the camera housing design is sufficiently water resistant to the moderate river depths where tests were performed. The B/W video signal quality is acceptable and can be improved if a color micro-camera is used. As already mentioned, the inner canvas should be dark for maximum contrast. In the case of insufficient filling, the bubble will undulate and can sometimes obstruct the viewing window. To prevent this problem, three or four guides could make a flexible frame to maximize canvas opening still maintaining it flexible for object identification. These guides can be of similar, however more resistant type, of those used for ultra-light tents.

V. STATE OF THE ART

After the building of the apparatus, as part of the patenting process, a survey of existing diving solutions was performed. Originality of the new diving bubble doesn't seem questionable, so far.

There is a huge variety of equipment to support human diving with scientific, sports or artistic purposes. The same applies to non-manned remotely operated vehicles. These solutions are used in a number of activities spanning from the pearl collecting, sea-bottom cartography, oil extraction and probing, study of sea life, locating and rescue operations.

A variety of diving suits, diving bells, manned and non-manned vehicles is used for these purposes. The present day technology of underwater photography and filming enables high-quality images to be taken and optimum air tightness to be achieved for a large range of depths.

Materials engineers have also come out with new synthesized materials able to stand very high pressures and hard operational conditions in terms of static and dynamic stress. In particular, polymer industry is able to produce canvas of very high resistance and low porosity for osmosis contamination minimization.

We firmly believe that all the conditions exist for an easy optimization of the prototype towards a more operational and useful device. Also it is easy to develop flexible bubble add-ons to existing ROVs, thus extending a little their field of application.

VI. CONCLUSIONS

The main advantage of the diving bubble is to avoid the need for extremely dangerous human diving missions. It can also extend the visibility range of conventional present generation ROVs. The simplicity of construction along with the use of commercially available micro-cameras makes the total costs very low. This is interesting in the case of loosing the bubble by cable breakdown or hooking on some underwater branches or trees. Also in the case of permanent damage due to violent collision, a low cost is obviously welcome when replacements can be needed on a regular basis.

A design trade-off must be carefully resolved for optimum system operation. In one hand one wants a huge bubble with a very large window to "embrace" big sunk objects and show as much as possible right at the first sight. Also big bubble can become more stable than a small one, thus making it more robust towards water vortices, turbulence and fast water-flow perturbations. On the other hand a big bubble will take more time to fill up and, more importantly, it will be subject to stronger stokes forces, leading to more critical cable choice decisions and more people being needed to operate, hold and maneuver the bubble. Compromise solution recommendations must be produced, taking advantage of all the experiences realized so far.

There can be objects, in fluid media, whose status knowledge is vital in a given moment. In special situations when human diving is just not recommended or simply not allowed, this bubble can do the job without putting in risk human lives.

Other fields of application can be envisaged for this device such as the inspection of wall's status from the inside. Water supplying, oil, wine, beer are just a few but encouraging examples. This inspection can be justified by the need of early locating fluid escape points even before they become visible.

There is also a need to verify the actual status of bridge pillars, like the one that collapsed, during or shortly after significant changes of river flow. This can be an important procedure for eventual closing of bridges near-ruin. The device can help in all these situations, due to its flexibility and capacity of adapting to the actual form of the obstacle being identified.

We regret the limited contribute we were allowed to give to the operational authority. This might have contributed to a total search time of about 4 months. No military corps looses honor for using non-military technologies or ideas. We believe their mission is to use as efficiently as possible all the available technologies for the fulfillment of their missions.

We end with a word of solidarity towards the families of the victims as we dedicate this work to all the fifty nine innocent people who died as a consequence of the collapse of the Hintze Ribeiro bridge.

Acknowledgments

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