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Wetlands monitoring: hints for innovative autonomous surface vehicles design

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Abstract. Wetlands are geographic areas where water meets the earth. They cover between 5% and 8% percent of the Earth's surface including coastal areas, swamps rivers and lakes. They are essential ecosystems for human life. Various international conventions, directives and projects work on their protection that can help fighting the disasters resulting also from climate change. However, the acquisition and monitoring of environmental parameters in these areas is often difficult and ineffective. Classical vehicles (boats or wheeled vehicles) are not adequate in these areas and sometimes they are inaccessible or dangerous to human beings (critical or extreme environments). The development and the exploitation of innovative unmanned technologies can make surveys faster, more efficient and precise. Autonomous Surface Vehicles (ASVs) can work over extended periods of time and less staffing is required thanks to the high level of autonomy. In this paper, several technological solutions are explored and a modular and portable ASV with an innovative propulsion system suitable for working in shallow water is described.

Keywords. Autonomous Surface Vehicle, ASV, Marine Robotics, Wetlands, Environmental Monitoring, UMV design, Automatic Sampling

1. Introduction

The research is inspired by the practical needs of monitoring wetlands for a better acquisition of environmental parameters. In particular it is reported an analysis of the existing solutions and an innovative technological solution based on Autonomous surface Vehicle (ASV) is proposed. The purpose is to solve the difficult problem of accessing, monitoring and sampling in the wetlands.

Wetlands are those geographical areas where water meets the earth. These include coastal areas, mangroves, marshes and swamps, rivers (also mouths and deltas), lakes, floodplains and flooded forests, rice paddies, shallow coasts and even coral reefs.

Wetlands are of global interest. Present in every country and in every climatic zone, from the polar regions to the tropics, from high altitudes to arid regions they cover between 5% and 8% of the land area [1], and are essential ecosystems for human life. In fact these areas are rich of life, are a very important sources of water, but also act as natural purification systems.

Restoring and safeguarding the wetlands is important for the preservation of carbon reserves and biodiversity [2] but is especially essential to preserve sharing and distribu-

Figure 1. Various examples of Wetlands

tion of water. For this reason FAO itself is directly involved in the preservation: a better widely distributed supply of water can also enhance the agriculture and the protection of coastal and internal waters may increase fishing reserves and push the aquaculture resource for the future.

Furthermore, proper monitoring of wetlands is a key element to plan and protect from disasters caused by the anthropized climate changes especially related to environmental degradation. In addition recent authoritative analysis on climate changes are forecasting an important reduction of Sea Ice [3] with unpredictable consequences on the climate. Besides to the effects caused on wetland by the release of huge amounts of freshwater from the ice calving, the polar regions themselves represent a substantial part of the world's wetlands that need to be monitored and preserved.

In this scenario the importance of wetlands becomes clear: these are closely related to human activities.

Several national (Italian) and international projects, conventions and directives aimed at monitoring, prevention and protection of the wetlands.

The intergovernmental Convention on Wetlands, called *Ramsar Convention* [4], provides the framework for international cooperation aimed at the conservation and rational use of wetlands and their resources.

The European Environment Agency is in the forefront in the protection of *Wetlands and Waterbodies* and the EU Water Framework Directive (WFD) (2000/60/EC) [5] establishes the necessity of protecting and improving the conditions of aquatic ecosystems. This directive is implemented in Italy with *Testo Unico Ambientale* that has, for the first time, introduced the obligation for the regions to systematically monitor the coastal ecosystem and to implement monitoring programs to assess if a good environmental status has been achieved.

But the effective actions related to the directives, laws and trends are often ineffective as shown in various recent reviews [6] and [7] that suggest for more efficient assessment.

In this context it is clear that there are still many problems of a different nature to be solved. Especially from an operative and strictly technical point of view some problems arise from the the lack of adequate resources. As an example [8] show how no holistic solution exists to cover all steps of water quality monitoring programs and it is necessary to enhance approaches and solutions.

Innovative solutions are necessary and while the overall assessment of the status can be achieved by the adoption of various remote sensing techniques [9] the local monitoring of physical, geological and biochemical parameters cannot be performed in many of the most inaccessible or dangerous areas. Some works can be performed with aerial solution as shown by [10] but existing technical solutions cannot cover widespread and long-time analysis and surveys that can be performed by ASV. In particular on shallow or mixed water (where water and soil occupy the same area) the monitoring consists in the execution of surveys of different nature. Morpho-bathymetric and stratigraphic surveys are used to study the evolution of watercourses and water reservoirs and monitor their progress even during catastrophic events like flooding. These are made using sensors of different nature: bathymetry made with echo-sounders, geomorphological analysis using Side Scan Sonar, seismic-stratigraphic analysis using Sub Bottom Profiler and magnetometer analysis. The assessment of physical, ecological and chemical status of water is achieved through the collection and analysis of samples in different areas such as rivers, lakes, reservoirs and transitional waters. The parameters that are measured are the conditions of nutrients, oxygenation, salinity, temperature, turbidity, bacteria concentration, ammonium concentration, the presence of Posidonia etc. And sometimes it is important to monitor these parameters at different depths down to a maximum of 50 m.

All these actions are often carried out in areas that are difficult to access, with unsuitable tools and without a planned ”strategy”. At the moment there is a certain difficulty in finding a single technological solution that allows to monitor the different wet areas, which is efficient, effective and low-cost. The solution could be to create a series of vehicles that are compatible as much as possible with the different specific activities to allow an effective protection of these sensitive areas that may integrate the surveys carried on with remote sensing systems and autonomous fixed and distributed sensors.

2. Shallow water problem

We understand that Wetlands embrace a wide variety of mixed terrain areas. There are several peculiarities that are common to most of these areas that represent design constraints to study an autonomous *survey* system.

In the wetlands surveys are carried on in narrow and shallow waters that are often difficult to access with classic means such as boats or wheeled vehicles and sometimes are inaccessible or dangerous for human beings (*critical or extreme environments*). This makes the analyses described above difficult to implement. The commonly used exploratory methodologies (see Figure 2) are often of a obsolete technological level. In some cases, bathymetric analyses and sampling are carried out by walking operators, this means that the use of boats of any shape is already a good advantage. Almost all the analyses use classic boats: boats equipped with an outboard motor or in of very shallow waters boats are propelled by oars or even pushed by the operators. In some cases semi-automatic wire-propelled systems are used [11]. Some companies use innovative Air Cushion Vehicles like but the presence of the man is still a constant and in many situations the risk that the operator gets is not easily acceptable.

Figure 2. Some examples of the commonly used systems

The missions usually need to be carried out in protected zones where restrictions on noise and pollution necessitate the monitoring to be as non-invasive as possible. But these are critical and dangerous environments where often the presence of: stream currents up to

2.5 m/s, steep terrain, swampy areas, landslides, danger of falling elements (for example ice sheets) may affect the operators safety. These are characterised by heterogeneous terrain that changes from water to mixed and where the depth can be in the order of a few centimetres. In these areas the transport of equipment must be as simple as possible because the access constrains are high.

Monitoring in these areas requires tasks typical of robotics: safety, actuation of repetitive tasks, good ability to scan efficiently, good ability to perform sampling in specific areas, good ability to follow preprogrammed trajectories, flexibility and modularity of operativeness. All operations are difficult to be achieved without adequate control of the instrumentation.

From these considerations it is clear how the use of *unmanned* vehicles can be a solution for almost all the problems. The use of ASV allows to secure the human operator and to acquire more efficient data (less perturbed by the system to be measured). Furthermore, autonomous technologies are less expensive, faster and more precise than traditional ones. It is possible to act continuously for extended periods of time and requires less staffing thanks to the high degree of autonomy of the robots.

3. Vehicle Design Parameters

The project requirements derive both from the experience of CNR-ISSIA and MACP [12] operators and the analysis made with DITEN department of *University of Genoa*.

CNR-ISSIA has a long experience with UMV design and exploitation. *ALANIS* boat has been developed for coastal monitoring [13], Charlie is a catamaran used for bathymetric surveys [14] and sampling even in Antarctica [15], while the semi-submersible vehicles *Shark* and *Proteus* have been used for sampling in dangerous areas in front of Arctic Tidewater Glaciers [16] and [17]. Recently *e-URoPe* ROV [18] has been used in shallow waters for environmental monitoring purposes related to the mapping of Posidonia meadows [19].

Technical specifications

Technical specifications for a water drone for monitoring surface water bodies are the following:

- General arrangement: The vehicle should be modular and flexible from a reconfigurability point of view. It should be a multi-purpose craft allowing different payloads. Ideally it should be a floating platform with enhanced manoeuvring ability and a high capacity of adapting to the various type of missions such as repetitive tasks, efficient scan, sampling in specific spots, pre-programmed trajectories (as described in section 2). The hull geometry choice will be shown in Section 3.2.
- Overall dimensions: as the access to some of Wetlands and Critical zones can be done only with small cars, boats or helicopters the vehicle has to be easily transportable in standard trunk. Standard dimensions of the cargo space are 1350 mm x 1400 mm and so for a good logistics the optimal dimensions for the ASV are considered as:
length = 1400 mm, width = 1000 mm, height: 700 mm
- Operative speed, weather conditions and autonomy: standard surveys require a battery life of at least 4 hours for full operations including sampling.

Since standard operations do not require very high speeds, the maximum speed is only considered during transition paths or to counteract strong streams.

Maximum adverse current is considered to be 2 m/s, and wind up to 20 $knots$. For this reason the maximum speed is 3 m/s. This value is a compromise between autonomy, battery weight and cost and takes into consideration the maximum speed normally used during underwater surveys which do not exceed 1 m/s.

• Draft and propulsion: since we are dealing with shallow waters the maximum draft is a fundamental parameter to be considered and it is identified in 200 mm. The propulsion unit choice, better shown in 3.1 should be adequate to access in very shallow waters without the risk of damages.

• Impact ability: since the vehicle will be deployed in harsh environment, it is required that the hull structure, the system of propulsion and the sensors supports are designed and built taking into account the possible impact of the vehicle on outcropping stones, roots or similar that can damage a fragile structure.

• Power supply: electric systems and batteries are the chosen power supply.

The use of materials and power sources that do not have an impact on the monitored areas is a design constraint because the monitoring should be minimally invasive. Missions have to be carried-out in zones with environmental restrictions in which acoustic noise and pollution have to be kept at a minimum.

• Protection: the totality of vehicle components must have a degree of resistance to atmospheric agents at least *ip68* (protection from continuous immersion at least 1 m).

• Weight: transportability is one of the main parameters in harsh environments. Usually two or more operators have to carry the vehicle to the zone where it will be deployed. Therefore the maximum weight has to be contained within a maximum transportability parameter taking into account the *UNI-EN 1005-2 Safety of machinery-Human physical performance* standards.

Total lightweight including batteries should not exceed a maximum of 50 kg.

A reasonable payload can be mounted in-situ and should be around a maximum of 20 kg.

• Navigation mode: the vehicle should be remotely controlled within a range up to 2000 m. Autonomous use with pre-set route and remote control should be implemented. Wi-Fi and/or radiomodem communication systems have to be provided. Telemetry has to be recorded in a data logger.

• Payload: a basic payload will be composed of two cameras (one infrared (IR), allowing night view) and live viewing during operations from the control station on the shore, either an Inertial Motion Unit (IMU) or an Attitude and Heading Reference System (AHRS) and an RTK-GPS system for precise data acquisition, altimeter, communication system and data logging of basic parameters such as air temperature, surface water temperature and sensor of wind direction and intensity. The vehicle will have an open both hardware and software architecture and it will thus have the ability to easily mount different payloads and in manifold working configurations.

- Multi-parameter monitoring platform: it is composed of a deployable underwater multi-parameter probe (with sensors for conductivity, temperature, fluorescence, depth, turbidity, pH and dissolved oxygen etc.) and air parameters probe.
- Sampling platform: it is a water sampling system to be deployed underwater and significantly contributing to the final total weight of the vehicle. This may be

implemented by a sampling system for liquid/film present on the surface (algal blooms, hydrocarbons, foams).
- Morpho-bathymetric and stratigraphic surveys platform: it is a platform with different kind of sensors to be mounted in the hull under free water surface or in direct contact with water which are used for bed mapping and monitoring: multibeam sonar, single-beam sonar, side-scan sonar, magnetometer, ground penetrating radar. Also this one is significantly contributing to the final total weight of the vehicle.
- Aerial drone landing and take-off platform: it requires the presence of enough space for the take off and landing of an aerial multi-copter drone whose dimensions are contained in a diameter of 550mm. Video cameras and other sensors will be installed on board for monitoring the mutual interactions of the two autonomous vehicles.

Furthermore, most of the above mentioned requirements suggest the presence of a wide main deck on the top of the vehicle.

3.1. Propulsion systems notes

In shallow waters propulsion units with free propeller or ducted propeller are efficient but subject to damages caused by obstacles at low depths or to breakages due to the suction of extraneous objects and therefore not recommended. Hull-contained propellers (e.g. Charlie [15]) have very low efficiencies and should be avoided. On the other hand the use of a Waterjet could be a good choice, especially because of the lack of protruding appendices solves the problems of drafting and navigation in shallow waters (e.g. Sonobot [20]). However, this system is penalized by low efficiency at low speeds [21] and by suction issues.

The adoption of paddle wheels could be a good solution for shallow water problems (also in mixed terrain) and its adoption has recently been investigated by [22] and [23]. A paddle wheel system that includes a wheel for both sides of the vehicle has already been used in manned applications and proved to be exceptionally manoeuvrable and with good directional control [24]. One of its variations could be the systems that are already widely used in amphibious vehicles that use wheels, tracks or screw-propelled [25]. Another solution is the aerial propulsion used by AerRobotix [26]. This is a good solution but has the disadvantage of noisiness and low thrust efficiency resulting in higher power consumption in case of adverse current.

3.2. Hull design notes

The number of vehicles used today for unmanned surveys is high [27] but the geometric typologies are essentially the monohull ([28] [29]) and the catamaran (or multi-hull).

The monohull vehicles (also kayak type [30]), of which we have several examples in[27], are suitable to travel wide sections at high speed and therefore not suitable for the restricted and difficult-to-access areas of wetlands. Moreover, the reduced stability does not allow the precise use of sensors for monitoring and scanning of the seabed.

The catamaran type (used for example bye the aforementioned Charlie and Sonobot and others [31]) on the contrary is most suited for this type of survey: it is stable enough to support analysis with sensors of any kind, has a good load capacity and allows the use of double propulsion systems that can be used in a differential configuration, reducing the number of elements necessary for the manoeuvring. Catamarans also allow the possibility of innovative constructive solutions which are always possible thanks to the multi-hull flexibility, as demonstrated by the Wam-V [32] with its articulated catamarans.

The Small-Waterplane-Area Twin Hull (SWATH) solution (as [33]) has the peculiarity of being very stable and less subject to interface effects but due to its submerged nature is not so suitable for operating in shallow waters and for this reason also the other submerged geometries are not suitable too.

A very interesting solution could be the air cushion design that would certainly be a novelty but the unmanned technology is at very preliminary stages in this field.

4. Proposed Solution

The proposed solution will be a vehicle based on the adoption of a completely modular catamaran. It will be composed of two mono-hulls that can host the adequate electronics for control but can also be transformed in a catamaran platform. The modular hull may host both classic and alternative propulsion solutions by adopting an innovative solution where two holes in the hull (one fore and one aft) are studied to host a classical thruster module of propulsion system or an innovative module based on pump-jet (industrial references [34],[35] and [36]). The vehicle will be so suitable for working in very shallow waters thanks to its endo-containment in the hulls and the low-suction pressure created beneath the craft.

The adoption of four thrusters coupled with fore-aft symmetrical hulls enhances the manoeuvring capabilities of the ASV.

Finally, the vehicle will be based on the adoption of innovative materials with a concept similar to Softhull [37] where the hull cannot be destroyed and cannot sink after an impact.

A resume of the main geometrical characteristic of this solution is reported in Table 1.

Table 1. Characteristics

Type:	Catamaran Type				
Main Requirements:	Modularity & Flexibility				
Maximum Length	$[mm]$	≤ 1400	Autonomy	$[h]$	4
Maximum Width	$[mm]$	≤ 1000	Operating speed	$[m/s]$	3
Height	$[mm]$	600	Water Current	$[m/s]$	2
Maximum Draft	$[mm]$	≤ 200	Wind Speed	$[kn]$	20
Maximum Lightweight	$[kg]$	45	Maximum wave height	[mm]	˜300
Expected Payload	$[kg]$	20	Expected Consumption	$[W]$	$300 \div 800$
Total Weight	$[kg]$	65	Battery voltage	$[V]$	$36\ or\ 48$
Payload Area	[mm x mm]	$\leq$ 950 x 950			

5. Conclusions

The importance of Wetlands monitoring is huge and for enhancing the survey ability in these areas there is the necessity of developing innovative solutions based on the exploitation of autonomous robotic systems. But there is still a need to devise new technologies.

The first aim of this analysis is to provide the guidelines for the design of ASV for Wetlands monitoring, in particular the idea is to stimulate the development of innovative solutions. This may have positive effects also in the industrial field since often engineering solutions come from the market that is not aware of the needs of the operators, then the development of ad-hoc solutions is a researchers' duty.

The second goal is to propose a solution that is now at a preliminary design stage: a modular ASV capable of carrying out missions for a wide range of applications. This vehicle can be useful in critical environments and wetlands where landslide, contaminations, spills of hydrocarbons, radioactivity, etc. may occur and in extreme zones such as volcanic or polar areas. All operators who usually meet these situations could benefit from the use of unmanned technologies and also the environment will benefit as well as human beings.

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