On the design of a robotic system composed of an unmanned surface vehicle and a piggybacked VTOL

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Abstract. This paper presents the core ideas of the RIVERWATCH experiment and describes its hardware architecture. The RIVERWATCH experiment considers the use of autonomous surface vehicles piggybacking multi-rotor unmanned aerial vehicles for the automatic monitoring of riverine environments. While the surface vehicle benefits from the aerial vehicle to extend its field of view, the aerial vehicle benefits from the surface vehicle to ensure long-range mobility. This symbiotic relation between both robots is expected to enhance the robustness and long lasting of the ensemble. The hardware architecture includes a considerable set of state-of-the-art sensory modalities and it is abstracted from the perception and navigation algorithms by recurring to the Robotics Operating System (ROS). A set of field trials shows the ability of the prototype to scan a closed water body. The datasets obtained from the field trials are freely available to the robotics community.

Keywords: cooperative robots, unmanned aerial vehicles, UAV, autonomous surface vehicles, ASV, environmental monitoring, riverine environments

1 Introduction

The monitoring of riverine and maritime environments has been shown in the last years as one of the most important activities to reveal the negative impact of human activities in Nature [**1**], [**2**], [**3**], and increase the awareness of people regarding climatic changes. The unattractiveness and difficulty of monitoring remote aquatic environments by humans render the automation of the process highly valuable.

A fine spatiotemporal mapping of environmental variables across extensive water bodies hampers the application of typical fixed sensor networks. Furthermore, such a solution is unable to return samples for laboratorial analysis, which is a requirement for several monitoring procedures. Several projects had dealt with these limitations by introducing autonomous surface vehicles [**4**], [**5**], [**6**]. These projects, however, are still unable to cope with inherent limitations of a surface-level perspective of the environment. The major limitation concerns the ability to properly perceive the far field, which ultimately limits the autonomy of the vehicle when facing cluttered and shallow water bodies. Previous work capitalized on the benefits of multi-robot systems to overcome this problem by relying on a helicopter to provide the human operator with improved situation awareness [**6**]. The RIVERWATCH[1] experiment, a part of the EU funded FP7 project ECHORD[2], takes this idea up to the next level, i.e., without demanding the presence of a human operator. Concretely, RIVERWATCH considers an autonomous surface vehicle (ASV) with a multi-rotor unmanned aerial vehicle (UAV) piggybacked, which is deployed when a higher vantage point is required. Hence, the surface vehicle benefits from the aerial vehicle to extend its field of view. Conversely, the aerial vehicle benefits from the surface vehicle to ensure long-range mobility. Although the use of aerial images to help surface-level navigation has been explored in a parallel work, the actual acquisition process has not been considered [**8**].

This paper provides both an overview of the RIVERWATCH experiment and the details of the practical aspects related to the hardware and software architectures. Details regarding high-level software components, such as those enabling perception and safe navigation, will be published elsewhere.

2 Relationship to Collective Awareness Systems

We consider that the perception of the environment shared by both surface and aerial vehicles implements a form of collective awareness. The environment monitoring products generated by the system contribute to an ecological global awareness.

3 The RIVERWATCH Architecture

Fig. 1. Computational and communications hardware in RIVERWATCH., depicts the major computational and communications hardware components selected for the RIVERWATCH system. These have been selected in order to ensure large computational and communications capacity and, thus, openness to future demands. From the software perspective, this openness is ensured by the use of the Robotics Operating System (ROS) as backbone. ROS[3] offers a cross-language inter-process

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[1] RIVERWATCH homepage: http://riverwatchws.cloudapp.net
[2] ECHORD homepage: http://www.echord.info/
[3] ROS homepage: http://wiki.ros.org

communication system and several state-of-the-art software components freely available.

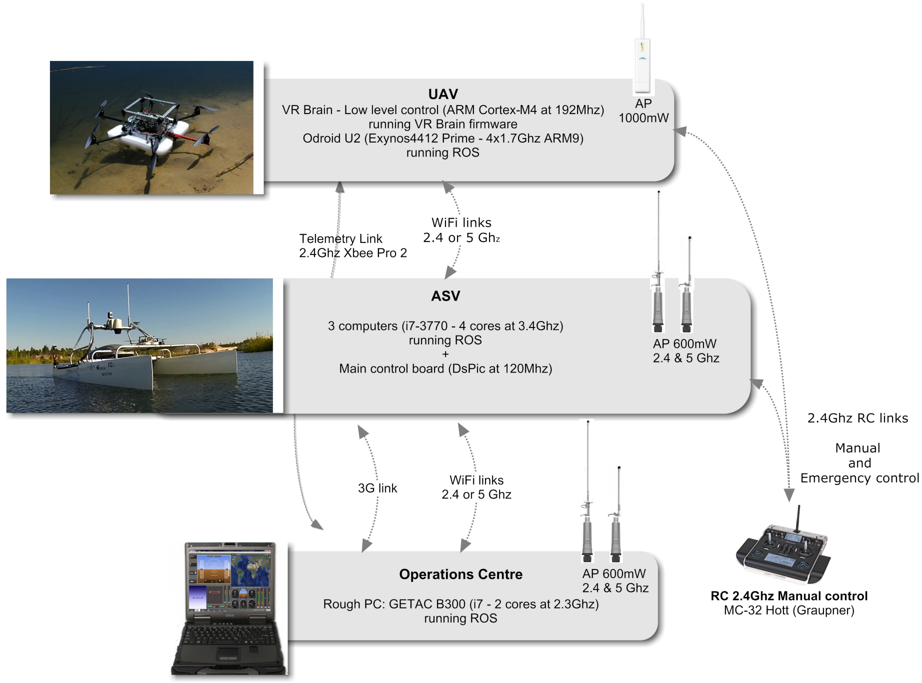

Fig. 1. Computational and communications hardware in RIVERWATCH.

3.1 The Multi-Rotor UAV

Several commercial multi-robot aerial platforms had been evaluated, namely, AirRObot, Asctec, Microdones, Draganfly, and Cyberquad. These products are patented and closed, which limits considerably their interest for research activities. This issue can be avoided by recurring to open source solutions, such as MikroKopter, Mikro's Aeroquad, NG-UAVP, UAVX, UAVP, OpenPilot, Arducopter, Multipilot 32, and VBrain. From these, the VBrain commercialized by the Italian company Virtualrobotix[4], was selected as the base for the RIVERWATCH's aerial platform. This solution is fully open sourced, including the mission control software and hardware, and it is provided with the most powerful microcontroller from all the evaluated possibilities.

[4] http://www.virtualrobotix.com/

Regarding the mechanical design, a six-rotor configuration was preferred to the common four-rotor solution. First, a six-rotor solution, a *hexacopter*, provides more lifting capability. Second, it endows the system with graceful degradation, as it is able to land with one motor off, without yaw control though. Moreover, it may still be able to fly with two motors off, provided that they stand on the neutral torque bar. Fig. 2, illustrates the designed *hexacopter* and its supporting hardware architecture.

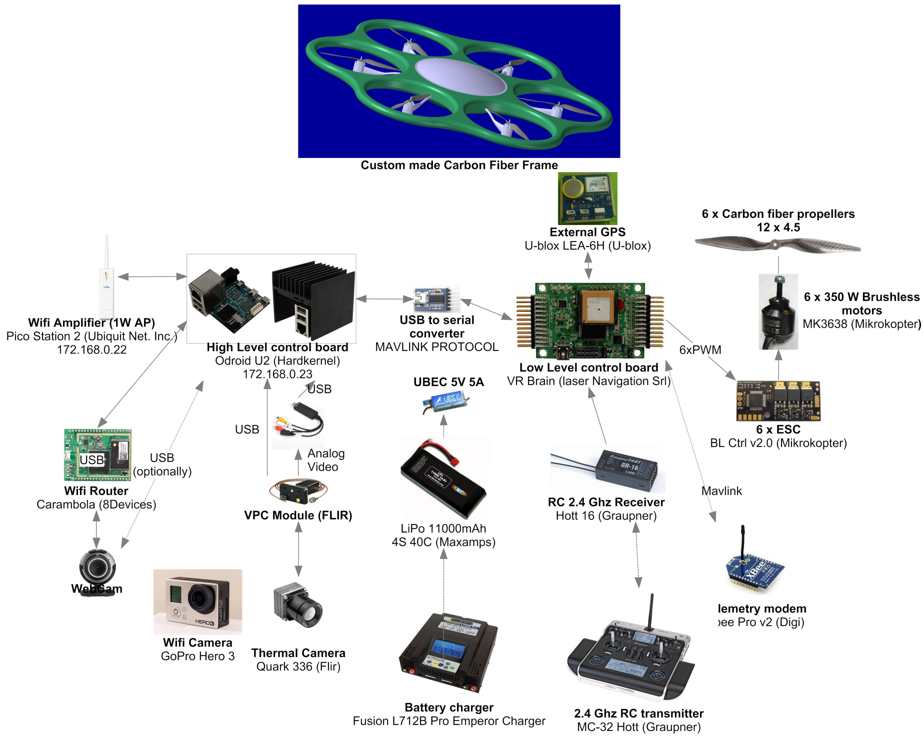

Fig. 2. The UAV's hardware architecture.

3.2 The ASV

The ASV is based on a 4.5 m *Nacra* catamaran, which has received special carbon fibre reinforcements for the roll bars and motor supports. The hulls have been filled with special PVC closed cells foam, making it virtually unsinkable. The trial testes here presented have been done with the propulsion in a differential locomotion configuration using a Haswing Protuar 2 Hp motor in each hull. The motors can be driven manually for safety reasons and if required for debugging purposes. A docking station with an H-marked for facilitated detection and tracking from aerial images taken by the UAV was fitted to the ASV's deck. A net was set around the docking station as lateral protections to the UAV when docked. Fig. 3 depicts the ASV's hardware architecture. Aiming at autonomous behaviour, the ASV is equipped with a set of state-of-the-art navigation-related sensors. Concretely, it is equipped with a GPS-RTK (Proflex 800 from Ashtec SAS), an IMU (PhidgetSpacial 3 axis from Phidgest Inc), a long range tilting laser scanner (LD-LRS2100 from Sick), a fixed underwater sonar (DeltaT 837B from Imagenex), and a multi-camera vision system (Ladybug3 from Pointgrey).

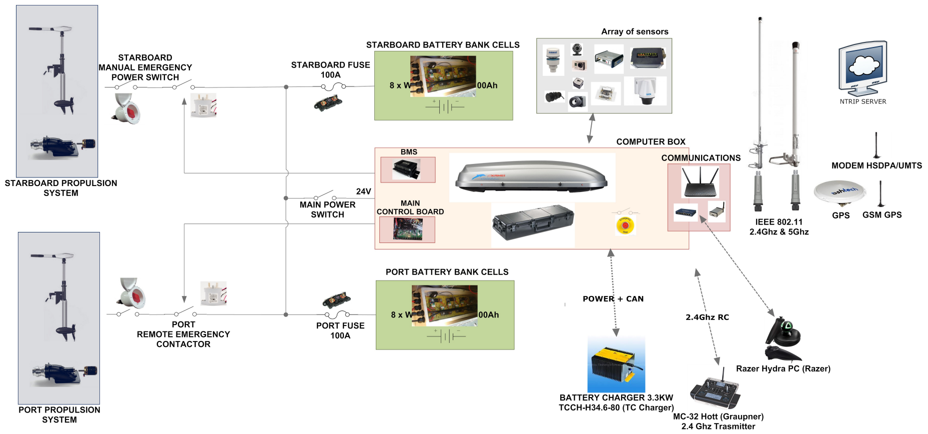

Fig. 3. The ASV's hardware architecture.

3.3 The Operations Control Centre

The operations control centre is a web-based application that allows the remote operator to perform offline missions planning and online missions execution monitoring. This section describes briefly the hardware and software aspects related to the maintenance of the communication channels between control centre and robots (see Fig. 4).

Two communications strategies were implemented. The first strategy assumes that the robots are relatively close to the control centre (roughly 1 Km radius in line of sight), which enables a direct wireless link and, consequently, high throughput communications. Hence, in this mode the operator is able to directly control the robots at the several levels of autonomy, from direct motor control up to mission specification.

The second strategy imposes neither range limit nor synchronisation between control centre and robots, provided that both are able to connect to the internet via, for instance, a GPRS or a 3G modem. In this case communications are done indirectly and asynchronously via a third-party file sharing service, such as DropBox. By not relying on peer-to-peer communications, accessing the products generated by the robotic system by remote clients becomes easily configurable and easily maintainable in the presence of communications dropouts.

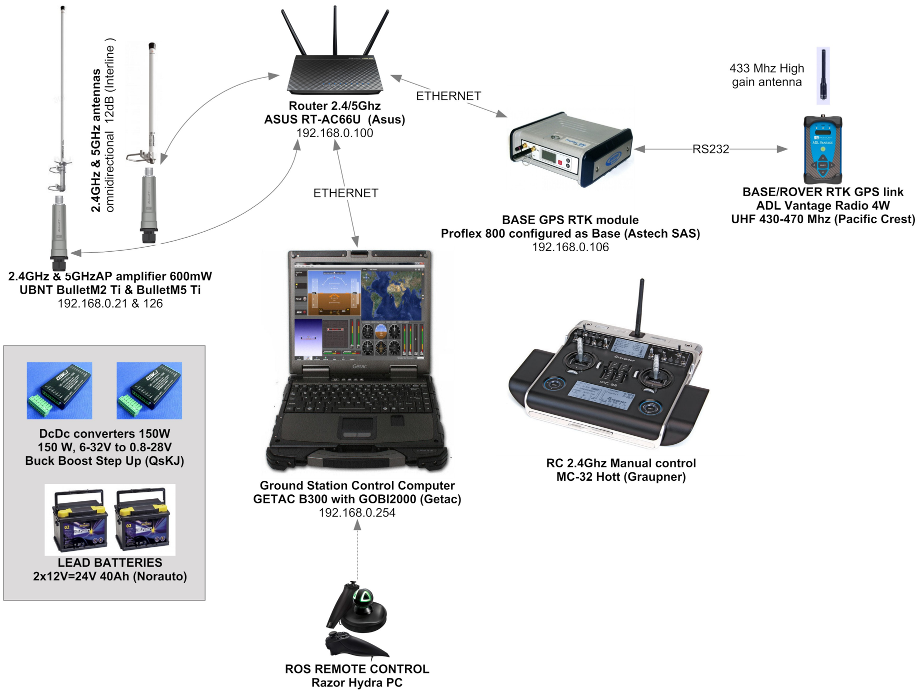

Fig. 4. Operations control centre's hardware architecture.

4 Preliminary Field Trials

To validate the proposed system, a large set of field trials was carried out with the robots in autonomous and tele-operated modes. The autonomous mode is based on a set of navigation and coordination algorithms. The goal of the tests, in what regards this paper, is to show that the hardware architecture and the robots mechanical design fits the purpose of robust navigation in riverine environments. The tests were carried out in a private lake in the Sesimbra region in Portugal, with an area of roughly 1.5 Km^2. This site offered in a single place most of the environmental traits that can be found in riverine environments, such as narrow passages, open space areas, deep and shallow waters, margins with disparate kinds of vegetation ranging from sander dunes to large trees passing by zones of extreme vegetation density.

Fig. 5, depicts several results obtained throughout the field trials. It highlights the ability of the described system to provide the reliability necessary for the perceptual and navigation algorithms to autonomously scan the environment that will be published in future articles. Fig. 6, also depicts a situation in which the UAV is taking off the ASV. All sensory data produced throughout the field trials are publicily available as ROS-enabled log files.

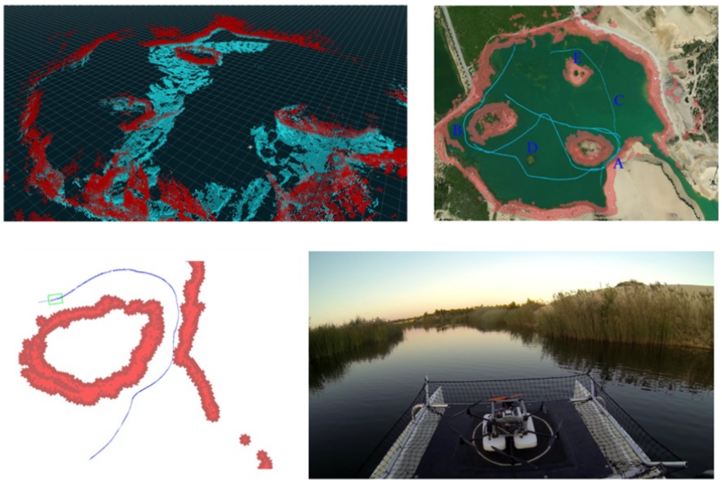

Fig. 5. Field trials: autonomous navigation. Top-left: Resulting occupancy grid from surface (red) and underwater range data (blue). Top-right: Cost map overlaid in red on satellite imagery of the trials site. Lines correspond to autonomous navigation paths. Bottom-Left: The path of the robot when navigating autonomously across a narrow passage. Bottom-Right: A view from the ASV of the narrow passage. **.**

Fig. 6. Field trials: UAV taking off the ASV. Left: moment right after the taking off takes place. Right: A few moments after the take off onset.

5 Conclusions and further work

Although the use of heterogeneous robots working as a collective is an old idea, only in RIVERWATCH it has been realised in the context of aquatic-aerial robotic teams for environmental monitoring. This approach serves the purpose of enabling long-lasting robust operation. Long lasting from using the ASV as energy supplier and robust from using the UAV to provide far field navigation cost information. This paper focused on the hardware and technological aspects of the RIVERTWATCH experiment with the expectation of fostering the development of new prototypes for the execution of related experiments. Our future work will be centred in making RIVERWATCH a full autonomous system, and so is necessary to solve problems as: Energy harvesting by the ASV and charge of the UAV; Full tests and evaluation of the landing algorithms; Full characterization of the innovative dual propulsion system; Consider seriously the development of a smart "catch" mechanism that is vital for safe landings in adverse meteorological conditions.

Acknowledgments

This work was co-funded by EU FP7 ECHORD project (grant number 231143) and by the CTS multi-annual funding, through the PIDDAC Program funds.

References

[1] Balog, J. D. (2008). Extreme Ice Survey. In *AGU Fall Meeting Abstracts* (Vol. 1, p. 0652).

[2] Church, J. A., & White, N. J. (2006). A 20th century acceleration in global sea-level rise. *Geophysical research letters*, *33*(1), L01602.

[3] Allison, I., Bindoff, N. L., Bindschadler, R. A., Cox, P. M., de Noblet, N., England, M. H., & Weaver, A. J. (2011). The Copenhagen Diagnosis: Updating the world on the latest climate science.

[4] Sukhatme, G. S., Dhariwal, A., Zhang, B., Oberg, C., Stauffer, B., & Caron, D. A. (2007). Design and development of a wireless robotic networked aquatic microbial observing system. *Environmental Engineering Science*, *24*(2), 205-215.

[5] Bhadauria, D., Isler, V., Studenski, A., & Tokekar, P. (2010). A robotic sensor network for monitoring carp in Minnesota lakes. In *Proc. of the IEEE Intl. Conf. on Robotics and Automation (ICRA),* pp. 3837-3842.

[6] Tokekar, P., Bhadauria, D., Studenski, A., & Isler, V. (2010). A robotic system for monitoring carp in Minnesota lakes. *Journal of Field Robotics*, *27*(6), 779-789.

[7] Murphy, R. R., Steimle, E., Griffin, C., Cullins, C., Hall, M., & Pratt, K. (2008). Cooperative use of unmanned sea surface and micro aerial vehicles at Hurricane Wilma. *Journal of Field Robotics*, *25*(3), 164-180.

[8] Heidarsson, H. K., & Sukhatme, G. S. (2011). Obstacle detection from overhead imagery using self-supervised learning for autonomous surface vehicles. In *Proc. of the IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS),* pp. 3160-3165.