Title: UniBZ-LSSU Collaborative Proposal for the 2022 RobotX Maritime Challenge

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Introduction

In collaboration with the students and faculty of Lake Superior State University (LSSU), advised by Prof. Edoardo Sarda, the students and faculty at the Libera Università di Bolzano (UniBZ), advised by Prof. Karl von Ellenrieder, propose to develop an Autonomous Maritime System (AMS) comprised of: a WAM-V unmanned surface vehicle (USV); an unmanned aerial vehicle (UAV); a ground control station (GCS); a guidance navigation and control (GNC) system; and a propulsion system. We plan to attend the 2021 Interactive RobotX Forum and to send a combined UniBZ-LSSU team to compete in the 2022 Maritime RobotX Challenge. A complementary proposal is being submitted by our team partners at LSSU, which is entitled "LSSU-UniBZ Collaborative Proposal for the 2022 RobotX Maritime Challenge." In this part of our joint proposal, those aspects of the collaboration to be led by UniBZ are highlighted, together with our plans for integrating the systems and software developed and for coordinating our activities.

Technical Approach and Justification

To simplify path/trajectory planning and control, we plan to configure the USV to be fully actuated. The PI's lab at UniBZ already possesses two VLP-16 and one VLP-32 LiDARs. Together with an existing camera system, the LiDARs will be set up for both long range and short-range distance measurements on the USV. High-level planning and control will be implemented in ROS on a Jetson TX1, or similar system. Long range WiFi will be used for communication with our GCS. Low level actuator control of the AMS and interfaces with sensors will be accomplished using PLCs. UniBZ will lead the development of planning and control algorithms and LSSU will lead the systems integration, mechatronic design, implementation, and testing of the AMS. We plan for the vehicle to reside at LSSU before the 2022 competition and to alternate the university at which it resides between subsequent competitions. In the sequel, our preliminary (ConOps) ideas for accomplishing each task are presented. Using a more rigorous systems engineering approach, our preliminary ideas will be reevaluated to develop a formal plan. This formal plan will then be refined as we gain additional on-water experience while developing our systems, and as further information is released about the specific details of each task by the competition organizers and on the RobotX forums. The UniBZ-LSSU team's joint schedule can be found in the complementary proposal submitted by LSSU.

Challenge Task 1 - Entrance and Exit Gates: We envision approaching this task in four phases: 1) The first phase involves localizing the acoustic pinger. A hydrophone will be placed at the fore end and aft end of each of the USV demi hulls (a total of 4 hydrophones) to create a long baseline system to localize the active underwater acoustic beacon. Using the hydrophone measurements, a dedicated signal processing system will be used to estimate the range and bearing of the pinger with respect to the body-fixed coordinate system of the USV. 2) After the acoustic beacon is localized, the vision system will be employed to identify in which of the three start/end gates the pinger has been positioned. The vehicle will align itself approximately perpendicularly to the plane of the gate, recording the colors of the buoys on either side, and proceed through the gate, while also searching for the location of the nearest black Buoy to Circle (B2C). To help ensure the integrity of its positioning, the USV will make a GPS positioning measurement as it passes through the gate. 3) Once the appropriate B2C has been identified the USV will transit towards the buoy until it is about 5 m away, at which point it will initiate a circular turn around the B2C using LiDAR to ensure it maintains a turning radius of about 5 m from the B2C until it is facing the start/end gate (the center of which is identified with the colors on either side now flipped and confirmed with a compass heading measurement of approximately 180° from the heading when the turning circle was initiated). 4) If these two conditions (gate colors and heading angle) are not met, the USV may need to perform small oscillations of its the heading angle to locate the correct start/end gate. If it is unable to reacquire the start/end gate visually, the system will rely on the GPS measurement as a last resort to make its way back to the gate (overshooting the GPS coordinate to ensure that it passes through).

Challenge Task 2 – Follow the Path: We plan to acquire a UAV-based LiDAR system, such as the YellowScan, which can produce an RTK GPS georeferenced LiDAR point cloud, super-imposed with images from a color camera (to determine buoy colors). Assuming that the UAV will not be permitted to return to the GCS on its own or be able to hover for the duration of this task, our approach includes four stages: 1) The UAV will take off from the USV and perform a lawn-mower shaped search pattern to produce a GPS referenced map of the buoys and course obstacles. 2) The USV will broadcast its RTK GPS position via wireless modem, which the UAV will use to locate the USV and to return to home after performing its survey of the buoy field. 3) Once on board the USV, the UAV will download its data to the USV. The data will be processed on board the USV to identify the positions of the buoys/obstacles and to plan a path for the USV to follow through the buoy field. It is anticipated that the black obstacle buoys will be hardest to detect, as they may not be visible in the color images but will hopefully produce clear point cloud images. A point-to-point motion planning approach will be taken using selected waypoints along the planned trajectory. 4) In the final stage of the task, the USV will follow the planned path using a nonlinear control technique. Based on the PI's experience with the WAM-V USV16 it is anticipated that sliding mode control techniques, which tend to be very robust to wind and current disturbances, will be employed. There may be obstacles or buoys, which were not identified in the aerial survey (in particular, the black buoys), but which are detected by the USV's on board LiDAR system. To avoid colliding with these, the controller will be programmed with a reactive behavior in which the Generalized Velocity Obstacles approach will be used to determine a kinematically feasible short-range trajectory that can be executed to move around an obstacle and then rejoin the originally planned path. It is noted that the PI and his colleagues at UniBZ have a significant amount of experience in path/trajectory planning and in the design of robust nonlinear control systems for trajectory tracking and path following.

Challenge Task 3 – Wildlife Encounter and Avoid: A UAV hyperspectral imaging camera will be acquired to enable us to perform this task. MAVTech S.r.l. (http://www.mavtech.eu/), one of our industrial team partners, has extensive experience in the development of UAVs and in their use for imaging and mapping, including the hyperspectral imaging of crops. The team will be able to draw on MAVTech's wealth of experience for technical advice when it addresses this task.

It is anticipated that this task can be accomplished in a way very similar to Task 2. The LiDAR system can be used to identify the positions of the field boundaries by locating the orange buoys. The images from the hyperspectral camera will be superimposed on the georeferenced LiDAR point clouds to determine the locations of the "marine life"[1]. Thus, the task will be conducted in four phases: 1) The UAV will take off from the USV and perform a lawn-mower shaped search pattern to produce a GPS referenced map of the wildlife. 2) The USV will broadcast its RTK GPS position via wireless modem,

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[1] It is respectfully noted that the platypus is a freshwater animal.

which the UAV will use to locate the USV and to return to home after performing its survey. 3) Once on board the USV, the UAV will download its data to the USV. The data will be processed on board the USV to identify the positions of the wildlife and to plan a path for the USV to follow. A point-to-point motion planning approach will be taken using selected waypoints along the planned trajectory, being careful to circumnavigate (a full 360º change in heading) the platypuses in the clockwise direction, the turtles in the counterclockwise direction, and avoiding the crocodiles. 4) As with Task 2, the USV will follow the planned path using a nonlinear control technique.

Challenge Task 4 - Scan the Code: The USV will enter the 40m x 40m test area and perform a spiral shaped search pattern starting from approximately the center of the test area until it locates the light assembly. Once the assembly is found, it will turn to face the assembly and maintain its position and orientation using a sliding mode station keeping controller. An RGB color camera on board the USV will be used to monitor the flashing lights and to determine the sequence of colors transmitted. The color pattern will be reported via the GCS and TD network.

Challenge Task 5 - Dock and Deliver: The USV will use a sliding mode station keeping controller to position itself in front of and with its bow facing the docking and delivery bays while searching for the assigned colored light using visual registration of the images from the on-board color camera. Once the light has been found and the correct bay has been identified, the images from the color camera will be superimposed on measurements from the short range LiDARs to determine the edges of the correct docking bay. The vehicle will enter the docking bay and a set-point heading and position controller will be used to maintain the heading and position of the USV within the docking bay while it is delivering the payloads (racquet balls). The LiDAR system will be used to measure the USV's distance to the face of the delivery bay and the heading will be fixed as that of the USV when it successfully entered the bay. A special purpose payload delivery system with its own targeting camera and azimuth/elevation control will be used to deliver the payloads.

Challenge Task 6 – UAV Replenishment: As with Task 5, the USV will use a sliding mode station keeping controller to position itself in front of and with its bow facing the center of the docking and delivery bays. The distance to the wall of the delivery bays will be measured using the LiDAR on board the USV. This value will be transmitted to the UAV. The UAV will take off from the USV and hover over the dock about 1 m from the vertical wall of the delivery bays, while searching for the assigned colored disc it must retrieve using visual registration of the images from its on board color camera. Once the correct disc has been identified, the UAV will use a custom-built system to pick up the disc. If each disc is light weight, solid and has a smooth surface, it is anticipated that a system using a semi-permanent attachment (i.e., strong double sided mirror tape) can be used to transport the disc to the helipad. If the UAV must release the disc at the helipad and return to the USV, without any human intervention, a pick up and release mechanism will be needed. It might be possible to use a servo- or solenoid-actuated suction cup. To deliver the disc to the helipad, the UAV will ascend to an altitude of about 10 m to locate the Helios UAV light beacon. According to the manufacturer's website, the Helios beacon is omnidirectional, can be configured to be continuously on, flashing off and on, and can also selected to use visual light (red, green, blue or white) or infrared. Our localization strategy will partly depend on the way in which the Helios beacon is configured for use in the competition. As the light can be seen from about 1500 m away, it is anticipated that by ascending to about 10 m and station keeping the beacon will be in the field of view of the UAV. The challenge will be correctly perceiving the beacon in an ocean of other flashing objects, such as wave reflections at the water's surface in the morning or early evening. If the light is on continuously, it may be easy to distinguish it from the background by averaging a series of rapidly recorded images (or through a more complex process of image registration using fixed objects in the image to correct for motion of the UAV before averaging) and then thresholding the average image to remove flashing or moving light sources.

It should be noted that retrieving objects from the ground with a UAV is not a trivial problem. As a UAV descends and comes to within a few centimeters of the ground, a pressure effect known as the wing-in-ground (WIG) effect modifies the lift generated by each UAV propeller making it difficult to accurately position the UAV over the object using continuous state feedback control. This problem is aggravated if the disc is placed at the edge of a dock, as the resulting pressure distribution under the UAV can be asymmetrical (lower over the water and higher over the dock, causing a pitch/roll moment that redirects thrust and drives the UAV towards the water). A common UAV strategy for avoiding WIG effects is to perform an uncontrolled drop with unpowered propellers (using autorotation to slow the descent) from a height of about 0.25 m above the target. Such an uncontrolled descent can be risky, especially near the edge of a dock. Using numerical modeling, the PI and his colleagues at UniBZ have explored an alternative approach, which uses a trajectory planner and switching controller that takes the WIG effect into account when a UAV approaches an object on the ground. We are very interested in exploring the practical implementation our proposed planner/controller to perform this task.

1. Other Considerations:

a) Obstacle Avoidance – as discussed above, we plan to explore the use of reactive behaviors and a LiDAR system to help avoid collisions with obstacles on the courses.
b) Autonomous Maritime System Heartbeat – we plan to implement a visual feedback system and heartbeat broadcast system. We also plan to provide our own wireless network for information exchange between the AMS and GCS.

Team Qualifications

Prof. Karl von Ellenrieder has extensive experience in the areas of the design and development of autonomous marine vehicles; navigation and control; and experimental measurement. He has developed and field-tested GNC and propulsion systems for several unmanned surface vehicle (USV) research platforms including a wing-sail propelled USV, an amphibious USV, a WAMV USV12, a WAMV USV14 and a WAMV USV16. He was the Faculty Advisor of FAU's AUVSI Roboboat Student Competition Team from 2008-2016 and the FAU Faculty Supervisor for the FAU-Villanova 2014 RobotX Maritime Challenge Competition Team. His research group has implemented robust nonlinear controllers on these systems, and they have been used in conjunction with high-level planners through implementation in ROS. At UniBZ Prof. von Ellenrieder teaches courses in automatic control, microcontroller programming and mobile robotics, he is on the Advisory Board of the UniBZ FabLab and is the Coordinator of the PhD Program in Advanced-Systems Engineering.

Prof. Helen Henninger has significant experience in the development of trajectory planning algorithms and has been teaching courses in the use of Python, ROS and mobile robotics.

Prof. Renato Vidoni has extensive experience in the development and implementation of mechatronic systems and teaches courses on motion planning for robotic systems. He is the Coordinator of the UniBZ MS degree program in Industrial & Mechanical Engineering.

Students: The team will consist of both undergraduate and MS graduate level students. When possible, PhD students will be encouraged to participate by formulating aspects of the RobotX challenges that can be executed as part of their dissertation research. While student participation in robotics competitions is rare in Italy, it is noted that our undergraduate programs include a broad range of hands-on experiences, such as microprocessor programming and control, use of sensors and mechanical projects. At the MS level students are also introduced to Python programming, automatic control, mobile robotics and the use of ROS. The course in Mobile Robotics taught by the PI includes field testing of unmanned ground vehicles and the implementation of control systems based on student-developed models and simulations.

The Facoltá di Scienze and Tecnologie (FaST) has six full-time permanent technical staff that can assist with the preparation of instrumentation and the logistics associated with the RobotX competitions. In particular, Mr. Matteo Malavasi is an electronics technician who can assist with the design and integration of vehicle instrumentation and Mr. Artur Weiser, who is a mechanical engineering technician, is available to assist with the CAD design and fabrication of mechanical systems. Additionally, the PI's lab is staffed by several post-doctoral researchers who can provide advice to students about the more advanced aspects of trajectory planning, nonlinear control and use of ROS.

Facilities

Prof. von Ellenrieder is the co-PI of the UniBZ Field Robotics South Tyrol (FiRST) Lab at the NOI Tech Park in Bozen-Bolzano (Prof. Vidoni is PI). Available facilities include 225 m^2 of lab space and a 200 m^2 open area test site. The lab already possesses extensive instrumentation for the development and testing of field robots, which can be made available for this project if needed. Facilities include several unmanned vehicles and robotic systems, including a 3DR Solo UAV, Husky UGV wheeled vehicle, a Mattro Bock ROVO2 UGV tracked vehicle, two custom built Losi Desert Racer based UGVs, a UniTree A1 walking robot, a SUP-based USV, UR5 robotic manipulator arms, a force-reflexive joystick, major navigation sensors (e.g., two VLP-16 and one VLP-32 LiDARs, RTK GPS, XSens MTi series IMUs), and a planned long range WiFi system, (see https://firstlab.projects.unibz.it for additional details). UniBZ, the UniBZ Bitz FabLab, and the NOI Tech Park possess machine shops and fast prototyping facilities for the design/fabrication of custom devices and interfaces. Nearby test venues include two small natural lakes with boat ramps and easy access via car, the Lago di Monticolo and the Lago di Caldaro. Both sites are about a 20-minute drive from the NOI Tech Park and include floating docks that can be used during testing. Several researchers in FaST perform frequent field work related to the ecology of mountain rivers and lakes. The infrastructure supporting this field work is available to all Faculty in FaST, and so is also available for use by the RobotX Team, including access to a four door off-road pickup truck (capable of transporting our SUP-based USV with its instrumentation), as well as on-water safety equipment (life preservers, etc.). These facilities will help the team to perform preliminary validation and testing of our planning and control algorithms, in parallel with the development/implementation occurring at LSSU.

Sponsorships and Partnerships:

Organization	Contact	Email	Phone
MAVTech Srl	Gianluca Ristorto	gianluca.ristorto@mavtech.eu	+39 349 1317855
NOI Tech Park	Sebastian Mayrgündter	s.mayrguendter@noi.bz.it	+39 0471 066 680
UniBZ FabLab	Kathrin Kofler	kathrin.kofler@unibz.it	+39 0471 015339

Management Approach: Students will be recruited via email, on the university electronic message board, UniBZ student club program and in class. Students from all areas of the university will be welcome to participate. However, recruitment efforts will initially focus on the Faculty of Sciences and Technology (which includes students studying mechatronics, automation, mechanical engineering, engineering management and logistics), the Faculty of Computer Science (including students studying cybernetics, software design and embedded processing) and the Faculty of Art and Design (in which students receive extensive hands-on training in industrial design and prototype fabrication).

The team will vote to select a UniBZ team leader, who will serve as the principal point of contact with the LSSU team leader for administrative and organizational issues. Individual UniBZ team members will be encouraged to directly consult/collaborate with their counterparts at LSSU to facilitate systems integration and joint development of the AMS. It is anticipated that the organization of the remaining team members will be formulated using a work breakdown structure (WBS) of the AMS (USV+UAV), in which team members are elected to lead different aspects of the effort according to their personal interests and academic specialty. In addition to addressing the technical aspects of the challenge, the team will be careful to ensure that adequate attention is paid to the systems integration, management, and logistics areas of the WBS, including aspects related to fundraising and communication/outreach.

To ensure a successful collaboration between UniBZ and LSSU, the team will hold regular Zoom meetings to discuss its progress and to coordinate the development and implementation of its systems. We will explore the use of Slack or Teams to rapidly exchange information related to the development of the AMS, to keep each other updated on our progress, and as a sharepoint site for important documents and presentations. We will use GitHub for the shared development of our system's software.

Rough Order of Magnitude Cost:

Item	Cost Euro
Airfare	24000
Hotel	10800
Shipping (Sydney-UniBZ)	6000
Team Uniform	1000
Posters	200
Food	7200
Local Transportation	1000
Instrumentation & Parts	15000
Equipment Insurance	1250
Total	**66450**

The estimated costs are shown at left (in Euros €). It is assumed that 12 team members from UniBZ will be participating and that they will be staying for a total of 12 days (including time to recover from travel and time to familiarize themselves with local suppliers of electronics, batteries, and other essential equipment that may be needed during the competition). A total of 15k€ is budgeted for the purchase of additional instrumentation. We plan to raise funds by applying for mobility grants from the EU and province, and by requesting donations from industry.

Summary: Through close collaboration the UniBZ-LSSU RobotX Team we will develop the hardware and software required for an AMS to successfully compete in the 2022 RobotX Maritime Challenge. The distributed teams will take advantage of online communication and organizational tools (with which we have all become too familiar with during the recent pandemic) to facilitate the tightly coupled, shared development of our AMS. For the 2022 competition LSSU will focus on developing the physical platform and UniBZ will focus on the development of planning and control algorithms, as well as the associated high-level software.

To Prof. Karl von Ellenrieder
Libera Università di Bolzano
Facoltà di Scienze e Tecnologie
Piazza Università 5
39100 Bolzano, Italy
E-mail: karl.vonellenrieder@unibz.it

Bolzano, 30th April 2021

Subject: Letter of support to UniBZ-LSSU 2022 RobotX Competition Team

Dear prof. von Ellenrieder,

with this letter, we would like to express our support for the UniBZ-LSSU 2022 RobotX Competition Team. MAVTech Srl is specialized in the development of UAVs and UAV imaging systems and would be excited to participate with the UniBZ-LSSU team as an industry partner.

If the team's application is successful, our participation would include providing technical feedback and advice about the methods and strategies the team considers as it addresses the competition challenges, in particular those related to the data processing of multispectral/hyperspectral sensors and to the autonomous take-off and landing of UAVs on moving platform.

We hope in the success of your proposal to start the activities with your Competition Team.

Best regards,

Eng. Fulvia Quagliotti
(President and CEO)

unibz fablab

To Whom It May Concern,

the BITZ unibz Fablab would like to express its support for the proposed UniBZ-LSSU 2022 RobotX Competition Team. The BITZ unibz Fablab is an open space where students and citizens can make models and prototypes, either through digital technology or manual work, from the hammer to the CAD-controlled laser cutter. In addition, BITZ offers introductory courses to the use of its fabrication machines, hands-on technical workshops on programming and the use of microcontrollers, and other events. In particular, the Fablab includes fabrication facilities often critical to the development of robotic systems, such as a laser cutter, CNC machines, electronics assembly and testing workstations, and 3D printers. The lab can also serve as a meeting place, if needed. The Fablab will be available to provide advice and support to the students in the UniBZ-LSSU 2022 RobotX Competition Team.

Official opening_	08th March 2018
Address_	Via Antonio Rosmini 9, 39100 Bolzano, Italy
Opening hours_	Tuesday till Friday: 12-8pm | Saturday: 11am-5pm
Phone_	+39 0471 015337 | +39 331 6742985
Homepage_	bitzfablab.unibz.it
Email_	bitzfablab@unibz.it
Social_	Facebook | Instagram
fablabs.io page_	click here
Events_	50 events in 2019: courses, workshops, presentations...
Administration_	BITZ officially belongs to the Workshops of the Faculty of Design and Art - unibz
BITZ regulations_	download here (Italian and German language)
Security regulations_	download here (Italian and German language)

For any further information do not hesitate to contact me.

Kind regards
Kathrin Kofler
BITZ unibz Fablab

Kathrin Kofler
Bolzano 29th April 2021