Boosting the Talent of New Generations of Marine Engineers Through Robotics Competitions in Realistic Environments: the SAUC-E and EuRathlon Experience

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Abstract— **This article summarizes the experience of the NATO Science and Technology Organization (STO) Centre for Maritime Research and Experimentation (CMRE) in the organization of the Student Autonomous Underwater Vehicle Challenge-Europe (SAUC-E) and euRathlon 2014 competitions. SAUC-E (http://sauc-europe.org/) started in 2006 in the UK and has been hosted by CMRE in La Spezia, Italy, since 2010. Each year SAUC-E challenges multidisciplinary University teams to design and build Autonomous Underwater Vehicles (AUVs) capable of performing realistic missions. The AUVs must perform a series of tasks autonomously in the CMRE sea basin which represents a realistic and challenging environment characterized by limited visibility and salt water. The aim of SAUC-E is to act as a driver to bridge the gap between theory and practice often affecting universities' studies. The success of SAUC-E also contributed to the European Robotics Athlon project - euRathlon (http://www.eurathlon.eu/). In October 2014 a marine robotics competition in the framework of euRathlon was organized by CMRE at its basin and in nearby waters, featuring challenges different than SAUC-E's and inspired by the 2011 Fukushima disaster. This experience will lead to the organization in Piombino, Italy, in September 2015, of the first world competition in which autonomous flying, land, and sea robots will work together to achieve a disaster response goal.**

I. Introduction

Encouraging young people today to participate in science, technology, engineering and mathematics (STEM) programmes is of critical importance to the development of the high-tech workforce of tomorrow [1]. Robot competitions can be one of the most effective driver to boost new generations of motivated and creative engineers. There is no better way to educate young and talented people in marine science and engineering than offering them challenging tasks to be solved at sea in novel and efficient ways. Adding the competition factor to it encourages young engineers to study innovative approaches to problems, thus creating new solutions. Student robotic competitions are a very good complement to coursework, as system engineering is applied to real-world underwater missions in a venue that is both competitive and collegial. The students not only can practice the concepts learned in the classes but also develop the so-called soft skills like management, team building and entrepreneurship. The NATO Science and Technology Organization (STO) Centre for Maritime Research and Experimentation (CMRE) is pushing the education of marine engineers and scientists through high profile robotics competitions. Namely, the Student Autonomous Underwater Vehicle Challenge-Europe (SAUC-E) which started in 2006 in the UK and has been hosted by CMRE since 2010. Each year SAUC-E challenges multidisciplinary University teams (consisting at least of 75% students members) to design and build Autonomous Underwater Vehicles (AUVs) capable of performing realistic missions. SAUC-E competition is proud of the newcomer teams that return, expand their involvement, and have shown improvement from one year to the next. Many teams around Europe and also overseas have participated in the nine editions of the competition with most of the teams coming back at least once and in some cases very regularly.

In 2014, for the fifth year in a row, CMRE hosted the SAUC-E competition from September 20 to September 26 in its sea basin in La Spezia, Italy. In the following week, from September 29 to October 3, CMRE also hosted the euRathlon 2014 sea robotics competition. euRathlon is a European project funded by the 7th Framework Programme which aims to organize outdoor robotics competitions along three years. While in the first year the competition was land-based and held in Berchtesgaden, Germany [2], [3], 2014 has seen the sea robotics competition taking place at CMRE [4] and in 2015 the euRathlon Grand Challenge will take place in Piombino, Italy, from September 17 to September 25. The experience of CMRE in organizing SAUC-E contributed to its participation in this project as the local organizer for 2014 and 2015 competitions. The 2014 sea robotics competition took advantage of the synergy with SAUC-E. The teams were in fact able to practice for euRathlon during the SAUC-E's week. There were differences between SAUC-E 2014 and euRathlon 2014. In euRathlon 2014 the tasks were more challenging and more focused on a scenario inspired by the Fukushima 2011 nuclear accident [5]. While SAUC-E is focused on student teams, euRathlon is open for companies and industry-based teams. In the following, descriptions of both competitions illustrate their goals, differences and outcomes.

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II. SAUC-E

The spirit of the annual Student Autonomous Underwater Vehicle Challenge-Europe (SAUC-E) [6] is that of a complement to coursework, a practical application based on real-world tasks and scenarios. The participants have to realize vehicles that must work in a challenging environment. All the technical aspects have to be considered for realizing a working and smart vehicle. The teams have to design systems by keeping in mind the maintainability and usability from a user perspective, to design robust and functional mechanical and electronic components and to write well-maintained software. These features are essential to deploy robust and reliable AUVs. SAUC-E teaches this to the teams by making them challenging the real environment, where all the flaws made during the design phase become clearly visible. This "learning by doing approach" promoted by SAUC-E helps filling the gap between theory and practice and forges the mentality of the participants for getting prepared to the work in companies and in real experiments at sea. The result is that SAUC-E encourages the design of original and reliable robots used for research also in other projects, and at the same time fosters the publication of scientific papers based on the developed algorithms [6]. Furthermore, other than technical skills, SAUC-E encourages students to develop their managerial skills, such as organizing their own teams, problem solving, fund-raising and crisis management. SAUC-E also helps brilliant students to get in contact with the organizations/institutions involved in maritime research and development, thus providing unique recruitment opportunities for sponsoring companies and agencies. These points are demonstrated by several publications including journal ones [7]–[10] and in the transformation of one of the winning vehicles in a commercial platform [11]. Moreover, several SAUC-E participants are nowadays employed in world class marine robotics companies and laboratories, including CMRE.

The main goals of SAUC-E can be summarized as:

- Advance the state of the art of Autonomous Underwater Vehicles by proposing new challenges to student teams.
- Create ties between young engineers and the organizations involved in marine technology.
- Promote a creative and excellent environment involving interdisciplinary interactions among young researchers.
- Get closer contact between the university teams and companies invited to participate in order to create an effective synergy between the main actors in the field.

The challenges that the teams are asked to solve include passing a validation gate, searching for a pinger positioned on the sea bottom, detecting a light, mapping a wall, inspecting an underwater structure and collaborating with an Autonomous Surface Vehicle (ASV) via acoustic communication. In the past, tracking an ASV from CMRE was another of the tasks proposed to the teams. The full description of the tasks to be accomplished can be found in [12]. These tasks must be done autonomously, with no control, guidance, or communication with the operator. In some tasks it is possible to get navigation help, but always through another robot and acoustic communication. All this must be done in a very challenging underwater environment, the murky CMRE marina, a salt-water basin open to La Spezia harbor (see Fig. 1). The teams must therefore face changing environmental conditions such as wave action, low visibility, salinity and tides which only a real environment can offer. Thanks to its special characteristics SAUC-E is considered as one of the most challenging realistic robot competitions in the world. The scenario is as close as possible to a real one. For instance, Fig. 2 shows the piping assembly underwater structure to be inspected.

Fig. 1. The CMRE water basin.

Fig. 2. The piping assembly structure.

The full arena is seen in Fig. 3. The arena was divided in two parts, one for the competition and one for practice. The practice arena included some of the setup used for euRathlon competition allowing the teams to practice one week before the competition. This clearly helped the teams to perform well during euRathlon as they had enough time to practice the more complex euRathlon tasks.

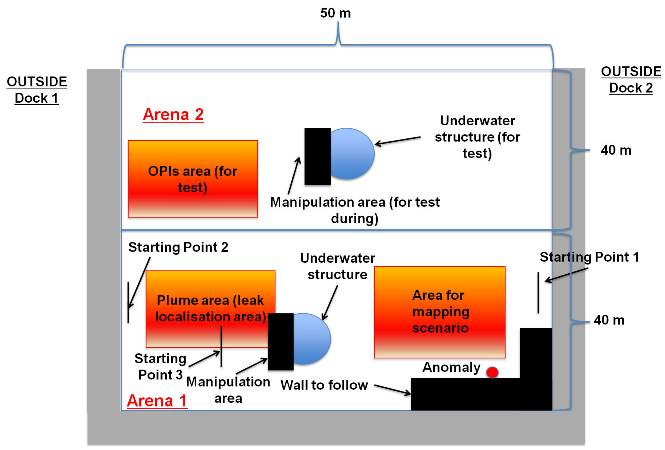

Fig. 3. The competition and practice arenas. The locations of the different areas of the proposed tasks are shown.

SAUC-E has had many participating teams along the years and has established as a standard competition in Europe. The SAUC-E's "hall of fame" includes Heriot-Watt University from UK (1st in 2008 and 2009 editions), the University of Girona from Spain (1st in 2010), the University of Lübeck from Germany (1st in 2011), the Canadian ETS Montreal team (1st in 2012) and the University of Cambridge from UK (1st in 2013), ENSTA Bretagne SAUC'ISSE team from France (1st *ex aequo* in 2014) and AVALON team from University of Bremen/DFKI in Germany (1st *ex aequo*). Many other universities from different countries participated including the University of Florence, the Polytechnical University of Marche, the University of Genoa, all from Italy, the University of Las Palmas de Gran Canaria (Spain), ESIEA Paris, ENSTA Bretagne, both from France, the University of the West of England, the University of Southampton both from the UK, among others.

This year, the following teams competed in SAUC-E: AVALON (from DFKI/University of Bremen, Germany), SAUC'ISSE and CISSAU from ENSTA Bretagne, France, and the rookie teams ROBDOS (mixed team Robdos company and Polytechnical University of Madrid, Spain), Scuola Superiore Sant'Anna from Italy and the University of Kiel, Germany. This year has seen the participation of three new teams, two of them with very limited or no previous experience in marine robotics. These teams could participate in the competition due to the loan of the SPARUS II AUV as it will be explained better in the next section. The results have been encouraging and two teams managed to accomplish, for the first time, inter-vehicle cooperation/communication. Teams with some years of experience in this competition classified better in the final ranking as expected. They also showed improvements with respect to previous years (including but not limited to the communication between different vehicles). We have been proposing challenges including multi-vehicle cooperation in the last years, since the development of effective multi-robot systems is one of the hot topics in research. Furthermore, the teams, by a smart cooperation between vehicles (e.g. between an underwater and a surface vehicle), can succeed in achieving good navigation performance also without having expensive sensor suites on board. This year, as collaborative task, we propose one trial which consisted in localizing a moored buoy at a depth of 1.5 m with a flashing lamp on its top. The searching AUV had to follow a wall and then detect the buoy/lamp. At that point, the AUV should call, via an acoustic link, a collaborator AUV/ASV by providing it with the position of the lamp. The collaborator vehicle had to localize the buoy/lamp communicating acoustically the state of the lamp (on/off) to the judges.

III. EURATHLON

The successful experience of SAUC-E led CMRE to participate in the FP7 euRathlon project [13]. euRathlon is a three-year effort, funded by the European Commission and coordinated by the University of the West of England. euRathlon's main goal is to organize competitions for autonomous robots. After a land robotics competition held in Berchtesgaden, Germany, in 2013, [2], [3] and a sea robotics competition held in La Spezia, Italy, in 2014, euRathlon will culminate with the organization of the Grand Challenge. The Grand Challenge, for the first time in the world, will see autonomous aerial, land, and marine robots working together to achieve a disaster response goal. The Grand Challenge will be held in Piombino, Italy, in September 2015 and will propose scenarios inspired by the 2011 Fukushima accident.

The aim of the project is to push forward the state of the art of autonomous heterogeneous robots capable to solve real world problems in dynamic environments through inter-robot cooperation and shared situation awareness. euRathlon aims to open a user-led process of defining standards for outdoor robotic vehicles through the multi-robot competition scenarios, to create research, industry and user-recognized benchmarks for robot performance measurement and comparison and to represent an opportunity of contact between the different communities of roboticists working in the marine, land and aerial domains.

In 2014, the sea robotics euRathlon competition took place at CMRE sea basin. Cooperation between marine surface vehicles and AUVs was encouraged and highly rewarded.

In euRathlon, industry partners and senior researchers are allowed to be part of the teams as opposed to student-based teams in SAUC-E. This is reflected also by the increased difficulty of euRathlon tasks. Moreover, teams coming from other domains or with limited experience were invited to participate and the euRathlon consortium loaned three SPARUS II AUVs (see Fig. 10), manufactured by the University of Girona [11]. One of the teams that got the loaned SPARUS II AUV was a mixed team from the Polytechnical University of Madrid and Robdos company. For 2015, another company-academia mixed team is participating with a loaned SPARUS II AUV, specifically a team composed of the University of Vigo and ACSM Subsea Services company, Las Palmas, Canary Islands, Spain. The same reliable and robust platforms were offered to different teams for several reasons. First, the idea is to attract teams that were not expert in the maritime domain, in order to cross fertilize the research communities. Second, by loaning equal platforms to several teams, it is easier to benchmark the results and the performance increase from one year to the next one. Last, the teams, by receiving an already operational platform, could shift their focus to cognition, intelligence, and autonomy instead of engineering and hardware problem solving. Developing benchmarking measures for a better comparison between the robots is another goal of the euRathlon competition. The benchmarking results for the euRathlon 2014 sea robotics competition can be found in [14].

The general scenario is inspired by the Fukushima 2011 disaster. A potent earthquake affected the area where a nuclear plant is located. In less than an hour of the initial earthquake a tsunami arrives and strikes the energy plant. A team of marine robots is deployed to inspect the disaster area. Based on this general framework, five different trials were proposed to the teams:

1) Long distance underwater navigation - reaching the disaster area.
2) Environmental survey of the accident area (mapping) - understanding the effects of the disaster.
3) Leak localization and structure inspection - localizing the leak.
4) Underwater manipulation - acting on the plant.
5) Combined scenario (to accomplish simplified versions of the cited tasks in sequence).

In each trial a team had to participate with an AUV and an ASV could be used as a collaborator vehicle to support the AUV's operations. The robots had to perform autonomous tasks in all the trials except for the manipulation task in which tele-operation was allowed.

The first trial, "Long range underwater navigation", took place in an area located just outside the CMRE basin. In this scenario the vehicles had to navigate autonomously for a path of about 1 km. This trial was completely new and never tried, neither partially, during SAUC-E.

In the "Environmental survey of the accident area" challenge, a wall of the CMRE sea basin had to be followed. Then the AUVs had to localize and inspect a buoy with a flashing light and map area where mid-water buoys (Object of Potential Interest - OPIs) were deployed (see Fig. 4).

For the "Leak localization and structure inspection" (see Fig. 5), a plume was simulated with white mid-water buoys (at the side of the plume) and orange (in the middle of the plume). Black numbers were painted on the buoys to indicate the proximity to the source of the leak. The vehicles had to follow the plume up to the underwater structure constituted of yellow pipes (see Fig. 2), inspect it and identify an orange valve.

For the "Underwater manipulation" the vehicles had to accomplish three different tasks interacting with a console containing different structures: stay into contact with the underwater structure, rotating a valve and grabbing a stick+ring structure bringing it to the surface. The valve and the stick with the ring can be seen in Fig. 6 and Fig. 7. The teams

Fig. 4. An OPI. The outer diameter of the sphere is 30 cm. The buoys were moored at 1.5 m from the bottom.

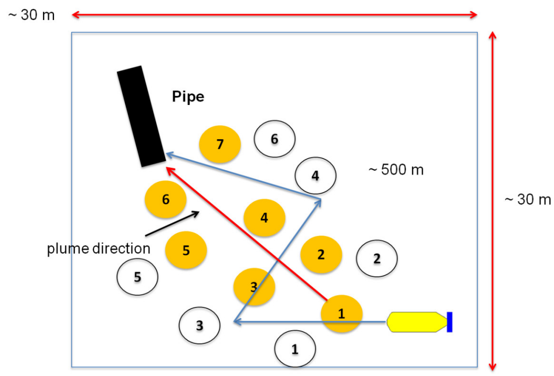

Fig. 5. Concept of the leak localization and structure inspection trial. Orange OPIs represent the plume with higher numbers closer to the source. White OPIs are positioned to the borders of the plume. The AUV had to follow the plume up to the source.

were allowed to tele-operate their robot via WiFi connection with a floating buoy connected to the robot with a cable. The judges were able to see in real-time the performance of the teams by observing their control station. Also this scenario was never tried before by the student teams of SAUC-E and was successfully accomplished by two participant teams.

Finally, for the "Combined scenario" (see Fig. 8), the vehicles started outside the CMRE basin and with autonomous navigation entered the basin, inspected the wall localizing the buoy with the flashing light, then mapped the area with mid-water buoys and finally grabbed the stick in the manipulation area.

Looking at the results, the performance of the teams was overall positive and encouraging. This is true also considering that some of the challenges were proposed in euRathlon for the very first time. Not all the teams participated in every challenge as in euRathlon each challenge had a dedicated day and it was a competition in itself. The University of Girona won the "Long range underwater navigation" challenge by completing the path with a precise DVL-based navigation. A different strategy was followed by SAUC'ISSE team. An ASV was used to support the navigation of the AUV (which was not equipped with a DVL) by using an acoustic modem to compute range measurements. The approach par-

Fig. 6. The console containing the object to be manipulated: an orange valve and the stick+ring structure. Low visibility conditions were present during the competitions in the CMRE basin area.

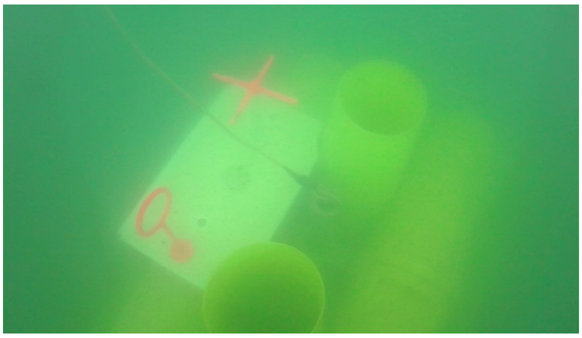

Fig. 7. Another view of the console for the manipulation task.

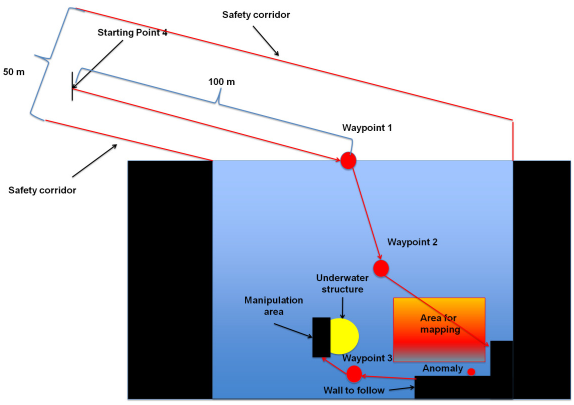

Fig. 8. The combined scenario. The AUV starts outside the CMRE basin and with autonomous navigation enters the basin, inspects the wall localizing the buoy with the flashing light, then maps the area with mid-water buoys and finally grabs the stick in the manipulation area.

tially worked but problems arose in the coordination of the navigation of the AUV and ASV.

In the “Environmental survey of the accident area” AVALON team won producing appropriate maps and a 3D optical reconstruction of the piping structure. In the last three scenarios the University of Girona classified first in the rankings providing accurate optical mosaics of the area and maps produced by a multi-beam sonar. In the manipulation task the University of Girona and AVALON succeeded

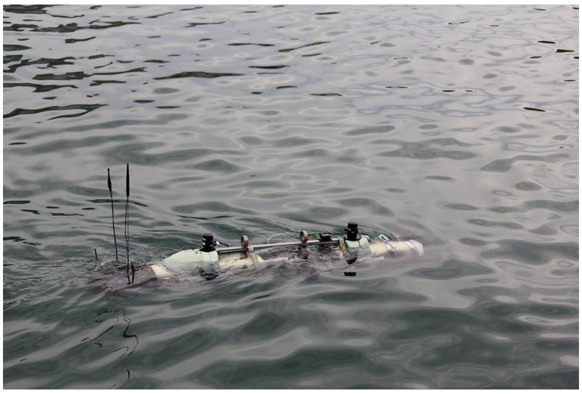

Fig. 9. AVALON vehicle at sea. The AVALON team from DFKI Robotics Innovation Center and the University of Bremen, participated both in SAUC-E (winning the first prize jointly with the team SAUC'ISSE of ENSTA Bretagne) and in euRathlon, winning the first prize in the Environmental survey challenge.

Fig. 10. SPARUS II AUV of the University of Girona team. University of Girona participated in euRathlon winning the first prize in 4 of the 5 proposed challenges.

in accomplishing the three tasks by using tele-operation. Autonomous manipulation is still an open research topic and more expensive vehicles (with robotic arms) are needed.

Results show how a combination of a good quality vehicle and a well-organized and motivated team is the key for success in this kind of competition. These two features allow a team to begin testing the vehicles at sea soon after the arrival at the competition site. From our experience, even if this is not common for participant teams which usually need some days to tune and prepare their vehicles, this is a key point to succeed. The more time at sea of effective practicing one team is able to get, the better the results will be in the competition.

The teams with the loaned SPARUS II AUV met difficulties in setting their vehicle up for trials at sea. This was essentially due to the lack of experience in the marine domain. More experience is needed to position/tune the sensors properly and above all to prepare and manage the robot during the frenetic days of the competition.

Fig. 11. SAUC-E 2014 award ceremony held at Cruise Terminal in La Spezia during the European Researchers' Night event.

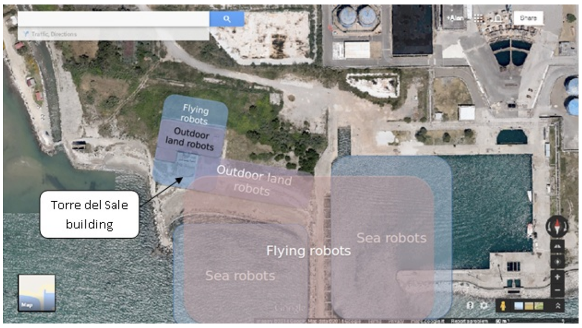

Fig. 12. Tor del Sale area in Piombino, Tuscany, Italy. The area, in front of the ENEL electric power plant, will host the euRathlon 2015 Grand Challenge from 17 to 25 September 2015. The area where the different kinds of robots will operate is shown in the picture.

IV. Conclusion and Future Work

Both events attracted good teams from around Europe, three of them coming for the first time to this kind of competition. Links were also created with other European initiatives. For instance, the award ceremony of SAUC-E was held during the European Researchers' Night event (see Fig. 11). This is to enlarge the interest in our educational activities.

From the technical point of view, the experience from this year is positive showing progress of the teams in terms of performance and approach to the competition. Scenarios never proposed previously in SAUC-E and introduced for the first time in euRathlon were successfully faced by the teams. An important lesson learned is that the teams that are non-expert in the marine domain need more time to practice and their performance is expected to improve in 2015.

These results are encouraging also thinking to 2015 events, in which we will propose the euRathlon 2015 Grand Challenge, a multi-domain (land, air and marine) competition inspired by the Fukushima 2011 accident. In 2015, SAUC-E will be part of the euRathlon Grand Challenge. euRathlon Grand Challenge will be held in Piombino, Italy, from 17 to 25 September 2015, in an area in front of an electric power plant (see Fig. 12). A ruined building will simulate the reactor chamber, while marine robots will operate in the nearby waters. Cooperation between the different domains will challenge teams with communication and coordination issues to achieve a common goal.

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