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Gabriele Ferri, Fausto Ferreira, Vladimir Djapic

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Multi-domain robotics competitions: the CMRE experience from SAUC-E to the European Robotics League Emergency Robots

Gabriele Ferri[1], Fausto Ferreira[1] and Vladimir Djapic[2]

***Abstract*— This paper details the experience of the Centre for Maritime Research and Experimentation (CMRE) in the organisation of several robotics competitions since 2010. In particular, the Student Autonomous Underwater Vehicle Challenge-Europe (SAUC-E) which started in 2006 in the UK and has been hosted by CMRE since 2010, the euRathlon 2014 and 2015 competitions and the European Robotics League (ERL) Emergency Robots 2017. SAUC-E started as a marine robotics competition for students. This paper explains the expansion towards multi-robot and multi-domain competitions such as euRathlon and ERL Emergency Robots. It was the success of SAUC-E, widely recognised by the community as the most realistic student competition for underwater robots, that led CMRE to participate in the euRathlon project and locally organise the first world competition, the euRathlon 2015 Grand Challenge, in which autonomous aerial, land, and marine robots worked together in an emergency scenario inspired by the 2011 Fukushima disaster. ERL Emergency Robots will be held in Piombino, at Tor del Sale site, 15-23 September 2017, and it is the natural follow-up of euRathlon. Some new twists will be presented to the teams to push for more autonomy and multi-robot cooperation. Results from previous competitions are presented and the evolution along time and different competitions is shown.**

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]. Robotics competitions are successful means to achieve this and are one effective driver to boost new generations of motivated and creative engineers. Proposing challenging tasks to solve efficiently and originally is a good way to educate young and talented people, bridging the gap between theory and practice often affecting universities' studies. Robotics competitions are perfect to train not only the technical skills of young engineers, but also to improve the so-called "soft" skills. Team working, marketing, interaction with possible stakeholders and working respecting deadlines are certainly improved by a participation in a competition. The team learns also how to work in a stressful situation. The in-field experience teaches the importance to consider the maintenance and robustness aspects in the design of both the hardware and software of a robot. This is the only way to have systems which are able to operate in realistic applications. The introduction of the competition factor is a key driver to encourage young engineers to study innovative approaches to problems. Furthermore, robotics competitions that present challenging tasks to solve such as the DARPA Robotics Challenge 2015 [2] add to the educational aspects a strong push to advance the state of the art. These events are great opportunities for teams of industrial and academic professionals to create innovative solutions to problems considered still "challenges" by the research community.

Competitions are also a perfect meeting place for the different robotics communities. The need to create meaningful scoring systems can push the research on robot benchmarking [3]. It remains an open research topic and is more and more important, since robotic systems are becoming mature and the need to evaluate and compare them increases.

The NATO STO Centre for Maritime Research and Experimentation (CMRE) has been pursuing this approach by organising robotics competitions. This article summarises the experience of CMRE in the organisation of robotics competition from 2010, when the first Student Autonomous Underwater Vehicle Challenge - Europe (SAUC-E) was held at CMRE. The success of SAUC-E led CMRE to participate in the euRathlon EU funded project [4], [5]. This gave us the opportunity to locally organise the first world competition in which autonomous aerial, land, and marine robots worked together in an emergency scenario inspired by the 2011 Fukushima disaster. euRathlon was more than a competition. There was involvment of the specialised and general public through visits to the competition area, stands of academia and industry and parallel robotics demonstrations. These aspects are a key driver to create awareness about robotics and to attract sponsors which make competitions sustainable. After the success of euRathlon, CMRE will locally organise the European Robotics League Emergency Robots (ERL-ER) which will be held in Piombino in September 2017 and is part of the European Robotics League supported by SPARC [6]. SAUC-E is described in the next section. Then, the euRathlon competition is described in Sec.III. The upcoming European Robotics League Emergency Robots will be presented in Section IV. Finally, Sec.V concludes the article with final remarks and future plans.

II. SAUC-E

The Student Autonomous Underwater Vehicles Challenge - Europe (SAUC-E) has celebrated 10 years of student

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[1]Gabriele Ferri and Fausto Ferreira are with NATO Science and Technology Centre for Maritime Research and Experimentation (CMRE), Viale San Bartolomeo 400, 19126 La Spezia, Italy Gabriele.Ferri,Fausto.Ferreira@cmre.nato.int

[2]Vladimir Djapic is with University of California, USA vdjapic@gmail.com

Fig. 1. The CMRE water basin.

innovation and inspiration. SAUC-E (http://sauc-europe.org/) started in 2006 in the UK at Pinewood Studios and after several editions in the UK and France, has been hosted by CMRE in La Spezia, Italy, without interruption since 2010 (except in 2015, in Piombino, Italy). Each year SAUC-E challenges multidisciplinary University teams to design and build Autonomous Underwater Robots (AUVs) capable of performing realistic missions, such as autonomous navigation, exploration of autonomous underwater structures and localisation of a "black box" on the seafloor. The student AUVs must perform a series of tasks autonomously in the CMRE sea basin, which represents a realistic and challenging environment (see Fig. 1). Students and realism are the SAUC-E keywords. Teams must consist at least of 75% students members. SAUC-E is the only underwater robotics competition in the world to present realistic operative conditions and is recognised as the most realistic underwater robotics student competition [7]. The changing conditions of low visibility, turbulence, salty water with waves, tides and sea currents have been faced over the years by the teams. This has resulted in a perfect training ground for the young engineers from all over Europe. In the last years, we have started to introduce cooperative tasks, since the effective coordination of different kinds of robots can allow to manage complex missions in real conditions. The teams have been encouraged to use not only a single Autonomous Underwater Vehicle (AUV), but also to deploy a companion Autonomous Surface Vehicle (ASV) to support the underwater survey. The companion vehicle can be from a different teams which fosters cooperation among the teams and creates a friendly competition environment.

SAUC-E [8] has always acted as a complement to coursework, a practical application based on real-world tasks and scenarios. The "learning by doing approach" promoted by SAUC-E fills the gap between theory and practice. This results in the creation of low-cost original robots by the students that eventually end up being used as research prototypes and continuously improved even up to the commercial phase. The use of student competition robots for research led in the past to many outcomes of success including journal publications [9], [10], [11], [12] and in the transformation of one of the winning vehicles in a commercial platform [13]. At the same time, SAUC-E represented an excellent training opportunity for the students that not only developed their managerial skills, such as organising their own teams, problem solving, fund-raising and crisis management. The participation in SAUC-E allowed students to enter in contact with some of the institutions and companies associated with the competition. Some students were hired by these institutions (including CMRE). SAUC-E tries to involve industry as much as possible not only through the form of sponsorship but also through attendance, providing unique recruitment opportunities.

In SAUC-E, the students' AUVs must perform a series of tasks autonomously, with no control, guidance or communication from a person or from any off-board computer including GPS systems. Tasks set in previous years have included underwater structure inspection, detection of a mid-water target, passing though validation gates and following a wall. This year, we added a new mission task: the search for a missing person underwater, represented by a realistic mannequin. The full description of the tasks to be accomplished can be found in [14]. In some tasks it is possible to get navigation help, but always through another robot and acoustic communication which adds extra complexity to the task.

This competition has had many participating teams along the years and has established as a standard competition in Europe. Of the eight participant teams in 2016, seven had previously participated in SAUC-E, showing how SAUC-E is today a fixed appointment for several European research groups. Moreover, two of the teams had been away from SAUC-E for 3 years and came back this year which highlights how SAUC-E can be a strong stimulus for research groups to continue working on underwater vehicle technology. The success of euRathlon 2015 has also played a role in this regard. For example, 5 teams that participated in the euRathlon 2015 Grand Challenge also took part in the competition this year.

As we did in the past, CMRE loaned, without charge, one AUV robotic kit to be given to a team. As in euRathlon 2015, the robotic kit was the basic version of a SPARUS II AUV without payload sensors. This initiative provides selected teams a sort of "jump start", since building an underwater robot is not a trivial task. This can promote rapid development and innovation, and makes the team to focus more on navigation, sensing and autonomy than on engineering problems. This year the chosen team was AUGA, a recipient of the loan also in 2015. Although this year the team had little time to practice with the robot (the AUV was sent in late April 2016), the performance was satisfactory and the team reached the 4th place in the final ranking. The SPARUS II is another success story of SAUC-E. The platform was designed and realised based on the experience matured in previous SAUC-E editions and is now commercialised by a University of Girona spin-off. This is the kind of technology transfer that we would like to encourage as an output of robotics competitions.

One of the interesting things we have noticed is the improvement of the teams performance over the different SAUC-E editions. Proposing similar tasks in the last years allows significant and steady progress over the years also for teams that have entered the competition more recently. Good examples are the AUV Team TomKyle or the AUGA team. In the latter case, this also means that loaning standard platforms can be a good idea to boost teams with little experience. In the last edition of SAUC-E, in 2016, the results were satisfactory with several teams able to handle the proposed tasks, achieving most of the task goals. Out of the eight teams registered, all tested their vehicles in the water and five classified into the Finals on the last competition day by fulfilling the "passing the gate" task during the first four competition days. This task, showing basic vehicle navigation capabilities, requested the AUV to navigate from a starting point through a gate composed of two buoys. Two teams managed to show collaboration between an AUV and ASV. Another team attempted and was successful during the practice runs but failed in the Finals.

Following the direction to increase the contacts between students and industry, this year's SAUC-E had several extras, transitioning the event into a true marine robotics forum. A new development for SAUC-E 2016 was the presence of exhibitors. For the first time, CMRE opened its doors to companies and institutions that wished to participate with an exhibition space. This attracted the CADDY FP7 project, the EXCELLABUST H2020 project, the Interuniversity Centre of Integrated Systems for the Marine Environment (ISME) and SBG Systems to set up stands and connect with the SAUC-E community. Besides the presence of exhibitors, a parallel presentation programme was prepared that included four invited talks. The presence of industry was witnessed by Subsea Mechatronics, which offered a paid internship, and VideoRay LLC which donated 4 x M5 thrusters to the best two teams.

In addition to the invited talks, a new twist for this edition was the connection with the ROBOCADEMY FP7 EU project [15]. ROBOCADEMY is a training network program and a parallel workshop was organised for the final day of SAUC-E with 13 international PhD students. These events opens SAUC-E more to the academic European world, with exposure of SAUC-E participants to theoretical talks. It was also a good opportunity for ROBOCADEMY PhD students for hands-on experience with underwater robotics and acoustics devices.

III. euRathlon

The success of SAUC-E led CMRE to participate in the European Robotics Athlon (euRathlon) project [16], [4], [5]. euRathlon (2013-2015) was a three-year effort, funded by the European Commission and coordinated by the University of the West of England, Bristol. euRathlon's main goal was to organise competitions for autonomous robots of the different domains (air, sea and land) in mock scenarios inspired by the 2011 Fukushima accident. The aim of the project was 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 competitions were also opened to teams coming from industry. The goal was to create opportunities of cross-fertilisation between academic and industrial worlds and among the robotics communities of different domains. A land robotics competition was held in Berchtesgaden, Germany, organised by the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE, in 2013 [17]. It was followed by a marine robotics competition organised by CMRE in La Spezia, Italy, in 2014 [1], [3]. 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 several proposed scenarios, in fact, cooperation between underwater and surface vehicles was a key point to achieve high scores. The 2014 edition was organised back to back with SAUC-E 2014 which allowed several teams to train for euRathlon 2014 during SAUC-E and perform better. This demonstrates how in marine robotics competitions time for practice on site is essential. Three of the teams participating in euRathlon 2014 had loaned three SPARUS II AUVs. The idea is that by offering reliable and robust platforms to teams that are not-expert in the maritime domain, research communities can be cross-fertilised. Teams can therefore shift their focus to cognition, intelligence, and autonomy instead of engineering and hardware problem solving, bringing their experience in the marine community.

The tasks of euRathlon 2014 were also preparatory for the marine part of euRathlon 2015 Grand Challenge. These included long range autonomous underwater navigation, environmental survey of the accident area, leak localisation and structure inspection, interaction with underwater structures and a combined scenario. Looking at the results, the performance of the teams was overall positive as it is described in [3], in which a rigorous analysis of the team performance is reported. For instance, a challenging scenario such as the interaction with underwater structures which involves manipulation and was not previously proposed in SAUC-E, was well tackled by all the attempting teams. Taking into account that they were mainly student teams with a limited budget, the innovative solutions for low-cost manipulators performed well with a tele-operation control. The teams with the loaned AUV had some issues during the competition and performed poorly. Both significant practice time and strong commitment are required for groups coming from other domains to enter a marine competition. The team from University of Girona, past winner of SAUC-E, won four out of the five scenarios thanks to their experience in at-sea experiments and, more in detail, with the SAUC-E competition format.

euRathlon culminated with the "Grand Challenge", locally organised by CMRE at Tor del Sale power plant site in Piombino, Italy, in September 2015 [5]. The Grand Challenge, for the first time in the world, saw a competition in which autonomous aerial, land, and marine robots worked together to achieve a disaster response goal. More than 130

Fig. 2. The euRathlon 2015 site, in front of Tor del Sale power plant, with the sea basin in foreground.

Fig. 3. The euRathlon 2015 Grand Challenge winners: Cobham team (Germany) - land, ISEP/INESC TEC (Portugal) - air, University of Girona (Spain) - sea.

participants divided in 16 teams with more than 40 robots from all the domains took part in the euRathlon Grand Challenge. The competition area was in front of ENEL Tor del Sale power plant: a sheltered harbour for marine robots, a beach and a ruined building for the land and air robots (see Fig. 2).

The proposed scenarios simulated an intervention mission in a nuclear plant after a tsunami. Robots were asked to survey the area, localise missing workers (i.e. mannequins), identify possible leaks and intervene to close stopcocks both underwater and inside the ravaged machine room (set up in the ruined building). After single-domain and two-domain challenges, the Grand Challenge took place in the last two days of the event. Six multi-domain teams participated in the Grand Challenge and tried to solve the proposed missions. The proposed tasks did not need to be tackled separately and could be accomplished in parallel. Strategy was important, as the teams were free to tackle the mission goals in parallel or in sequence and to choose the order. Cooperation between robots was essential in achieving the proposed tasks. For instance air and land robots cooperated to localise the missing workers, or the underwater robot had to communicate to the land vehicle which underwater pipe was leaking. While tele-operation was allowed in some tasks for aerial and land robots (and for the underwater robots only for manipulaton), full autonomy was largely rewarded by the scoring system. The scoring system is directly related to the benchmarking methodology and inspired by the Task Benchmarking of RoCKin project [18].

For the 2015 edition, the marine domain was the most represented as out of the 16 teams that participated in euRathlon 2015, 12 had a marine component (see Fig. 3). This reflects the interest of the marine robotics community in our competitions. Of the 12 teams, only three had not participated previously in any edition of SAUC-E and/or euRathlon and were new entries in the competition which highlights how well established is the SAUC-E brand. As in 2014, the euRathlon consortium loaned out three AUVs. One of teams kept their loan since 2014 which allowed them to train more time on the same platform. By loaning the same platforms to several teams along the two years, it was also easier to benchmark the results and the performance increase from one year to the next one. Indeed, AUGA team was a good example of performance increase from euRathlon 2015 to SAUC-E 2016. AUGA team was able to outperform more experienced teams after only few months of work with the robot. This team had previous experience with ROVs and this helped them in familiarising with the new platform. Team OUBOT had excellent performance considering the short time they had to practice with the loaned AUV. This team succeeded to partially accomplish the trials after only 6 months of practice with their vehicle and without any previous experience in the marine domain winning the Best Rookie Award provided by VideoRay Inc.

The competition offered a good view of the robotics trends. Robots are today effective and useful in tackling single-domain tasks in realistic outdoor scenarios. Nonetheless, we are still far from full autonomy. This is true in particular in the land domain and in autonomous multi-robot cooperation. In the land domain, we have seen the highest use of tele-operation, above all from professional end-users. In the future, search and rescue robotics systems need to increase the level of autonomy to effectively exploit multi-robot cooperation and the synergies the different types of robots can offer. Autonomy is necessary to overcome situations common in disaster response intervention, such as poor communication which does not allow a continuous link with the operator.

For what concerns the marine domain, the conditions were harsh with the low visibility (< 1 m) being the main challenge. Although the area is a protected harbour with shallow waters (~ 4 m), the visibility was very low due to a storm occurred few days before the event. Even though the objects to identify were bright orange, in some cases they could be hardly seen as visible in Fig. 4.

Nonetheless, the teams managed to perform the tasks under such difficult conditions by achieving many of the

Fig. 4. Orange buoy detection by OUBOT team in limited visibility conditions. Orange buoys were positioned to simulate a leak from an underwater pipe following, caused by the tsunami.

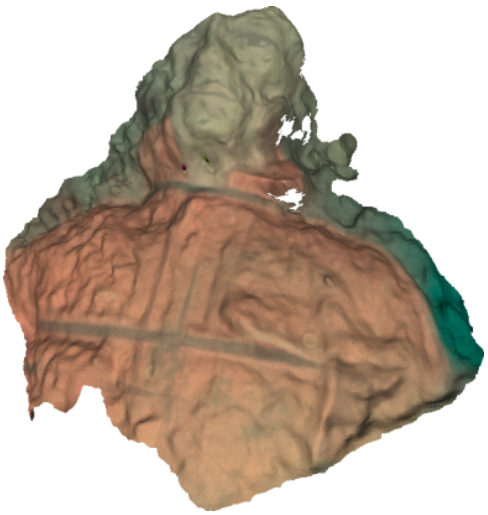

Fig. 5. 3D reconstruction of the head of a mannequin by University of Girona.

proposed goals. As an example, the object detection and recognition of the buoys by the OUBOT team is shown in Fig. 4. Fig. 5 presents an outstanding 3D reconstruction of the mannequin by University of Girona. The winning team for the marine trials (University of Girona) managed to accomplish over 85% of the achievements proposed in the two trials completely or partially. In all marine domain scenarios (Sea Trials, Subchallenge Sea + Land and Grand Challenge), three teams accomplished always at least 50% of the achievements and the winning team achieved 86% and 89% in the Sea Trials 1 and 2 respectively and 82% in the Grand Challenge. A less good performance occurred in the Subchallenge Sea + Land with 67% of achievements accomplished (which is still over two thirds).

euRathlon 2015 Grand Challenge was also a great opportunity to involve all the robotics community. Besides the competition itself, there were 12 exhibitors (six of them from the marine domain) and there were demos both for the technical public (which reached 300 people including judges, sponsors and participants) and for the general public (over 1200 people). The event became global with the presence of

Fig. 6. The KAIST DRC Hubo robot, winner of the 2015 Darpa Robotics Challenge during its exhibition at euRathlon 2015.

invitees from Japan, US and Korea (see Fig. 6) making sure that the whole world of robotics research could assist to the first competition in the world that required the three domains (marine, aerial and land) to come together and cooperate in a common realistic mission.

IV. European Robotics League Emergency Robots 2017

To continue advocating multi-domain robotics cooperation, CMRE takes part in the RockEU2 EU funded project coordinated by euRobotics AISBL. RockEU2 is a Coordination and Support Action (CSA) funded by the Horizon 2020 program from the European Commission. One of the goals of this project is the organisation of the European Robotics League (ERL), a novel pan-European competition format that aims to provide a platform for challenging, developing and showcasing robotics technologies, bridging the gap between Industry, Research and the general public [6]. The ERL is an international robotics competition set in three vibrant fields: Industrial, Service and Emergency robotics. Competitors engage in Local and Major Tournaments Europe-wide, that are organised at some of the most prestigious research institutes. Within this framework, CMRE will be the local organiser of the ERL Emergency Robots Major Tournament which will take place again in the Tor del Sale site, in Piombino, Italy, from 15th to 23rd September 2017.

ERL Emergency Robots 2017 will be again a multi-domain competition with land, aerial and marine robots cooperating in a Fukushima-like scenario. The tasks will be similar to the ones of euRathlon 2015 Grand Challenge but some changes were made to raise the competition level and difficulty. The feedback and performance from the teams in 2015 were taken into account when designing this year's scenarios but several novelties are being introduced to push the teams to their boundaries. For instance, the aerial vehicles

will have to pick and drop two emergency kits, close to one missing worker and nearby the land robot. The UGV will need to recognise the kit and transport it to the worker inside the building. In the marine domain, the missing worker will be trapped in an area with debris and several objects. Moreover, the AUV will need to surface on the top of the mannequin and signal it to the aerial vehicle that should take a picture of the location and geolocalise it.

The teams and sponsors's response has been very positive. From this year's competition, we are focusing more on the autonomy, which will be highly rewarded in the scoring system. We are also making the multi-domain aspect more central in the competition. Single trials, for instance, will not be awarded and will serve as practice. This aims to support the participants in preparing better the multi-domain challenges and to improve the synergy between the different team components. This was one of the lessons learned from euRathlon 2015, where previous experience in working together was strongly correlated with good multi-domain cooperation.

As in euRathlon 2015, ERL Emergency Robots 2017 will be the opportunity to gather industry and the different robotics communities to talk and discuss about search and rescue topics. The local community, with particular attention to schools, will be involved through parallel events such as talks and demos to increase the general awareness about European robotics.

V. Conclusion and future work

We firmly believe that robotics competitions are effective means to prepare young engineers and scientists to the "real" world, both to work in the industry and in applied research. Solving complex technical problems in teams under stress can only be achieved if technical skills are melded with soft skills and good problem solving capabilities. This is what our experience with SAUC-E from 2010 demonstrates. Along the years, we have witnessed the improvement of team performance. SAUC-E has been able to attract teams over the years and is today recognised as the leading marine robotics competition in Europe. This has been possible thanks to its real-world tasks and its friendly environment between participants and judges and organisation. We have seen that it is important for teams to repeat their experience at SAUC-E to increase their performance. This is evident not only from the technical point of view, but also from the competition management perspective. One good example is the AUV team Tomkyle from Kiel. They won the Rookie of the Year Award in SAUC-E 2014, got 3rd place overall for the marine domain trials of euRathlon 2015 and was 2nd in SAUC-E 2016. After good teams were mature thanks to the experience in SAUC-E, we have started to push on multi-vehicle tasks. For instance, we have devised a cooperation task between a surface and underwater vehicle to localise and inspect an underwater flashing light. Multi-robot, heterogeneous systems are instrumental to achieve complex tasks and young generations of roboticists ought think in this perspective. Multi-robot heterogeneous systems are also appealing for the participant education. Teams need to integrate different systems making the team work far more difficult. The push on multi-robot systems led us to participate in the euRathlon project and to locally organise the euRathlon 2015 Grand Challenge. This was the first world's competition in which autonomous aerial, land, and marine robots worked together in an emergency scenario inspired by the 2011 Fukushima disaster. euRathlon 2015 was more than a competition. It was a robotics event involving industry, researchers from different communities and general public. We think this is the direction to follow for cross-fertilisation among the domains and for community building. Creating public awareness on robotics is important for dissemination to the general public and decision makers. We will continue with this in the European Robotics League Emergency Robots 2017, which we will locally organise in Piombino, Italy, from September 15th to September 23th. The created public awareness has to be a lever for a deeper involvement of industry and robots end-users. Not only as spectators or sponsors, but also as collaborators in defining the tasks of interest for future competitions. This can be a way both to guarantee the sustainability of the competitions by their own funding and to create links between industry, academia and young engineers to prepare the skilled workforce of the future.

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Author(s)

Gabriele Ferri, Fausto Ferreira, Vladimir Djapic

Title

Multi-domain robotics competitions: The CMRE experience from SAUC-E to the European Robotics League Emergency Robots

Abstract

This paper details the experience of the Centre for Maritime Research and Experimentation (CMRE) in the organisation of several robotics competitions since 2010. In particular, the Student Autonomous Underwater Vehicle Challenge-Europe (SAUC-E) which started in 2006 in the UK and has been hosted by CMRE since 2010, the euRathlon 2014 and 2015 competitions and the European Robotics League (ERL) Emergency Robots 2017. SAUC-E started as a marine robotics competition for students. This paper explains the expansion towards multi-robot and multi-domain competitions such as euRathlon and ERL Emergency Robots. It was the success of SAUC-E, widely recognised by the community as the most realistic student competition for underwater robots, that led CMRE to participate in the euRathlon project and locally organise the first world competition, the euRathlon 2015 Grand Challenge, in which autonomous aerial, land, and marine robots worked together in an emergency scenario inspired by the 2011 Fukushima disaster. ERL Emergency Robots will be held in Piombino, at Tor del Sale site, 15-23 September 2017, and it is the natural follow-up of euRathlon. Some new twists will be presented to the teams to push for more autonomy and multi-robot cooperation. Results from previous competitions are presented and the evolution along time and different competitions is shown.

Keywords

Robot kinematics, Europe, service robots, industries, underwater autonomous vehicles

Issuing Organization

NATO Science and Technology Organization
Centre for Maritime Research and Experimentation

Viale San Bartolomeo 400, 19126 La Spezia, Italy

[From N. America:
STO CMRE
Unit 31318, Box 19, APO AE 09613-1318]

Tel: +39 0187 527 361
Fax:+39 0187 527 700

E-mail: library@cmre.nato.int