CIRTESU

Research Centre for
Robotics and Underwater
Technologies

GOOD PRACTICES REPORT

January 2018 – September 2021

UNIVERSITAT JAUME I

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GENERALITAT VALENCIANA
Conselleria d'Innovació, Universitats, Ciència i Societat Digital

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CIRTESU. Research Centre for Robotics and Underwater Technologies: Good practices report. January 2018 – September 2021.

Castelló de la Plana, September 2021

CREDITS

Universitat Jaume I

Co-ordinated by:

Office of the Vice-Rector for Research and Transfer

Produced by:

Research Centre for Robotics and Underwater Technologies and the Office for Cooperation in Research and Technological Development

With cooperation from:

Communication and Publications Service, FACSA Chair on Innovation in Integrated Water Cycle Management, Language and Terminology Service, Library, Rector's Bureau, Scientific Culture and Citizen Science Project, Technical Office for Construction Work and Projects

Design and layout:

Research Centre for Robotics and Underwater Technologies and Format G10

Photography:

Cover, pages 6, 8, 12, 14, 25, 30 and 35: Communication and Publications Service

Page 20: Research Centre for Robotics and Underwater Technologies

DOI: *http://dx.doi.org/10.6035/idifeder.2018.013.2021*

Document available in open access from the Universitat Jaume I Institutional Repository: *http://repositori.uji.es/*

The project is co-financed by the European Union through the Operational Programme of the European Regional Development Fund (ERDF) of the Valencian Community 2014-2020.

Photo: CERN

Contents

Good practices criteria

Introduction

Since it was founded 30 years ago, the driving force behind the Universitat Jaume I has been its intention to contribute to the sustainable development of the region through the generation and transfer of knowledge committed to social, economic and environmental progress.

And this outlook, which permeates all our scientific and academic activity, is what allows us to be closely aligned with the priorities and objectives of the European Regional Development Fund (ERDF), the aim of which is to promote innovation in order to strengthen the socio-economic cohesion of the European Union.

The correspondence between the lines of research of the Universitat Jaume I and the vision and mission of ERDF is reflected in our active participation in the ERDF Operational Plan of the Valencian Community 2014-2020, promoted by the Regional Department of Innovation, Universities, Science and Digital Society of the Valencian Regional Government.

One of the innovative initiatives promoted in this Operational Plan is the recently opened Research Centre for Robotics and Underwater Technologies, CIRTESU, whose good practice report 2018-2021 is presented below.

As reflected in this document, the launch of CIRTESU is the starting point of a new and decisive stage in achieving excellence, which makes it possible to provide innovative solutions to problems in the underwater environment (underwater robotics, integrated water cycle management, aquaculture, etc.).

CIRTESU is a high-impact scientific facility supported by a team of professionals from different research groups with renowned careers in complementary areas.

CIRTESU's high potential for transfer helps it have a wider outreach, as the results of the research will be extrapolated to a wide variety of sectors ranging from electromedicine or nuclear technology, thereby acting as a catalyst for new partnerships with companies, research centres and public agencies. I would like to finish this introduction with some well-deserved words of thanks to the whole team, research staff and administration and services staff for the courage and effort they have put into making this fantastic project a reality.

Jesús Lancis Sáez
Vice-rector for Research and Transfer
Universitat Jaume I

Executive summary

Purpose and description of the project

The Research Centre for Robotics and Underwater Technologies (CIRTESU) of the Universitat Jaume I was established to meet the need to boost R&D&I in the Valencian Community by generating new synergies between three interrelated areas: underwater robotics, aquaculture and the complete water cycle.

Between 2018 and 2021, a high-level centre was established in a purpose-built industrial facility which houses a water tank with a volume of 480 m³, in which real conditions are simulated. A G500 underwater vehicle has been purchased, and a robotic arm has been adapted to it.

This involved an investment of more than €750,000 by the European Fund for Regional Development (ERDF), the Government of the Valencian Community and the Universitat Jaume I.

Good practices

Within the framework of Responsible Research and Innovation, cooperation between various actors has enabled the CIRTESU to comply with the good practices criteria identified in the ERDF Operational Programme.

1. Dissemination

More than 30 activities of different types have been carried out. These have been aimed at the scientific community, businesses and the general public.

2. Innovation

The CIRTESU is the first centre of its kind in the Valencian Community, which enables the development of cutting-edge applications related to underwater technology.

3. Results

The initially established objectives have been met, increasing the capacity for validating hypotheses in scenarios that simulate reality.

4. Problem-solving

The CIRTESU has helped to improve the initial situation, providing an ideal forum for scientific and technological experimentation.

5. Level of coverage

The scientific community and companies in the sectors involved in the underwater field now have a specialised R&D&I centre.

6. Horizontal criteria

The CIRTESU promotes gender equality in science and technology, as well as environmental sustainability in its building, equipment and projects.

7. Synergies

Synergies are created in key areas of the university's work: R&D&I Projects, training (on bachelor's degree, master's degree and doctorate courses) and alignment with policies.

Outlook for the future

The results obtained show that CIRTESU is destined to become a benchmark in its field, after having attracted more than 80% of the initial investment in the three years that the project has been under way.

In addition to the initial research lines, new applications related to radiation protection in medical applications, the inspection of pipes in nuclear facilities and the identification of underwater threats are now being addressed for the Spanish Ministry of Defence.

Interview with the CIRTESU coordinator

Pedro José Sanz Valero

The researcher Pedro José Sanz Valero has coordinated the various phases of the CIRTESU – Research Centre for Robotics and Underwater Technologies project cycle at the Universitat Jaume I between January 2018 and September 2021.

Pedro José Sanz Valero is a Professor at the Universitat Jaume I, affiliated to the Department of Computer Science and Engineering. He is the coordinator of the IRS Lab – Interactive and Robotic Systems research group, which has been classified as a High Performance Group by the university. He has authored over a hundred international publications, coordinated various projects at the regional, Spanish and European levels, and held various positions in international organisations, including the Institute of Electrical and Electronics Engineers Systems Council.

His point of view as a researcher on the most significant experiences and results of the CIRTESU is set out below.

What is the background to the CIRTESU?

The research team that established the IRS-Lab group in 2009 entered the world of underwater robotics based on our extensive experience in human-machine interaction systems and multi-purpose robotic manipulation. The partnership with the Underwater Robotics Research Centre of the University of Girona and the University of the Balearic Islands enabled us to obtain a series of projects on the Spanish and European technology frontier, which were all coordinated by the IRS-Lab.

Because only the University of Girona initially had facilities for experimental validation (which were the only ones in Spain at that time), we gradually created the embryonic CIRTESU at the Universitat Jaume I. To do this, we started with a laboratory equipped with a small water tank and afterwards, the plot where the Centre is located today was transferred.

The year 2018 marked a turning point in our history, as we took advantage of this momentum and the CIRTESU was created by a consortium between the Universitat Jaume I and the Institute of Aquaculture Torre de la Sal (a Spanish National Research Council centre), which was joined by two UJI research groups – Design Engineering and Multiphase Fluids, as well as the IRS-Lab. The objective of this partnership was to be able to provide a common structure with shared resources for experimentation in all aspects of the underwater field.

This powerful partnership combined significant experience in European projects, increased the institution's critical mass and greatly expanded the applications of research in the underwater field.

What added value has the support from the European Regional Development Fund (ERDF) brought to your research career?

Because of the nature of the project and the difficulties that have arisen as a result of the COVID-19 pandemic, in both the construction work and in the mobility of research staff, we have not yet had enough time to quantify the impact of the new facilities since the recent launch of the CIRTESU (which was inaugurated in December 2020).

What we are already seeing today is an important achievement in terms of the support from the ERDF giving us a higher profile in Spain and internationally. This has been corroborated by colleagues who are leaders in robotics and underwater technologies who consider us ideal candidates for joint high-level projects, since in addition to our experience, we are backed by our unique facilities and equipment.

The likelihood of this cooperation will increase in the near future, when we have a pool of researchers receiving their training at the CIRTESU facilities, within the framework of the Erasmus Mundus Interuniversity Master's Degree in Marine and Maritime Intelligent Robotics[1] and the future UJI bachelor's degree course in Robotics Intelligence.

What are your main priorities in coordinating the CIRTESU?

We have an infrastructure that enables us to cover all the areas of interest in the underwater sphere (oceanography, fish farms, marine pollution, defence, underwater archaeology, off-shore industry, seaports, the complete water cycle, etc.) and as such, my greatest priority is to seek synergies with institutions working in these fields, in some of which we are currently working (such as the SIMBAAD project sponsored by the Spanish Ministry of Defence).

Another of my priorities is to reinforce our human resources, so we can make the most of using the Centre's equipment and facilities. Finally, as a more complex and long-term objective, we aim to give the CIRTESU a status in line with the University Institutes or Mixed Research Institutes, which would give the institution a conclusive boost.

How do you see the future of the CIRTESU, taking into account its local and global profile?

The CIRTESU is a project for the future that has already begun to bear its first fruits. At present, at the regional level we are the leaders in the Valencian Community in underwater robotics projects for intervention, and a benchmark in the research lines concerning the other groups involved, with extensive experience in aquaculture and the complete water cycle.

From now on, and at a Spanish level, we aim to occupy a prominent position in all these disciplines thanks to our unique facilities, which mean we can validate scientific hypotheses in a water tank equipped with aeration and current generation systems. These mechanisms mean we can model situations like those that we are going to come across in the sea or in wastewater treatment facilities, thereby overcoming the limitations involved in the static tanks that are usually used in experimentation.

These factors can be extrapolated to the international sphere, in which we have enhanced our relations with several European countries, Japan, Australia and the United States, giving our doctoral students the opportunity to prepare jointly supervised international theses, while we are taking part in various European projects.

In this sphere, we have had a cooperation agreement in place since 2018 with the European Organization for Nuclear Research (CERN) in Switzerland, the world's leading centre in the field. We are currently working with this organization on a four-year European project, El-Peacetolero, to which we are fully committed to a very interesting area: robotics for intervention in radioactive environments.

[1] https://www.master-mir.eu/

Finally, I would like to stress the importance of our partnerships with the research groups mentioned above, which are international benchmarks in their field, in our recent development. This cooperation has strengthened the synergies between interrelated disciplines, in a symbiosis that will undoubtedly contribute to our progress towards excellence.

«The CIRTESU enables us to apply the results of research that we have been cultivating for over ten years, and has become an ideal platform for excellence.»

Pedro José Sanz Valero, CIRTESU coordinator and Professor at the Universitat Jaume I.

Description of the project

Identification sheet

Project title	Research Centre for Robotics and Underwater Technologies
Acronym	CIRTESU
Location	Parque Científico y Tecnológico, parcela E Campus Riu Sec, Universitat Jaume I (Castelló de la Plana)
Convening agency	Ministry of Innovation, Universities, Science and Digital Society of the Government of the Valencian Community
Call	Grants for R&D&I infrastructure and equipment for the period 2018-2020 (PO ERDF Valencian Community 2014-2020). 2018 Call
Period	From 1 January 2018 to 30 september 2021
Principal investigator	Pedro José Sanz Valero
Institutions	Universitat Jaume I and Institute of Aquaculture Torre de la Sal – CSIC
Amount granted	€564,101.25
Total budget	€751,617.01
Website	http://www.irs.uji.es/cirtesu/
Video summary (Spanish)	https://youtu.be/5te_SciX7Qs

Project summary

Why is it necessary?

In the field of underwater technology, the creation of robots capable of working underwater is one of the greatest challenges the scientific community faces, especially if the robots are autonomous (without an umbilical cable connection to vessels on the surface or mother platforms) and they must act on a coordinated basis. Their development creates a vast array of opportunities to overcome existing needs in very diverse areas, such as archaeology, marine biology, oceanography, aquaculture, gas exploitation and underwater oil platforms, etc.

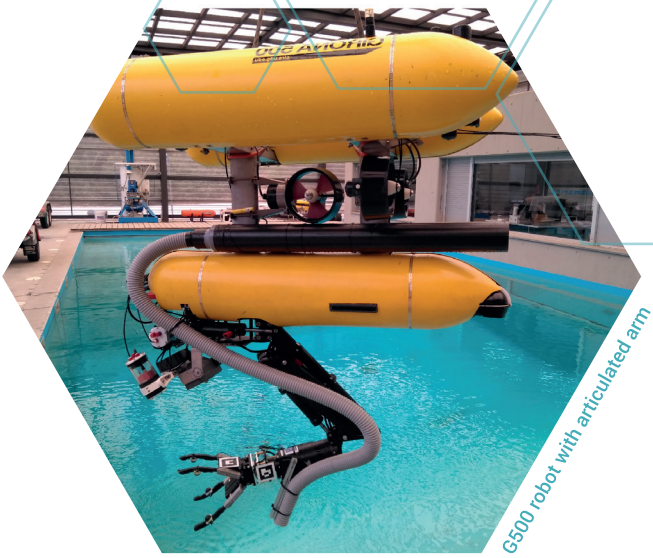
Furthermore, the complex conditions of the underwater environment create demands similar to those found in other hostile environments, such as nuclear power plants, health facilities with radiation hazards, and aerospace environments. In these situations, the risk to the integrity of our scientific-technical team is minimised by using remote control robotic platforms adapted to the environment, which are designed based on our experience obtained with underwater robots.

However, if science is to move forward in this field, research staff must have specific resources that are not always available to them, such as suitably equipped pools to test robots and their communication systems under real conditions. A further advantage is that these pools enable experimentation in research lines related to the complete water cycle, including the treatment and storage of drinking water and the purification and reuse of wastewater.

What is the response to the needs that are identified?

In order to contribute to the search for solutions in this area, the CIRTESU project at the Universitat Jaume I has the overall objective of creating a high level research centre that provide solutions to complex problems related to underwater

technologies. To that end, the investment made has been divided into three main areas:



G500 robot with articulated arm

1

The purchase and enhancement of the G500 robot, enabling integration of a manipulator arm, sensors and tools, as well as its networked interconnection with robots and sensors that are already available. This robot is vital for making progress in the design of cooperative intervention applications, such as those for use in drinking water tanks, wastewater treatment plants and fish farms in the sea.

Construction of the industrial facility

2

Construction of the infrastructure, consisting of an industrial facility with a floor area of 611.78 m² and a height of 8.35 metres, in which the main feature is a water tank with a volume of 480 m³ (half the capacity of an Olympic size swimming pool) designed for experimentation with underwater technology.

Control room

3

Devices for generating currents and studying oxygen in efficient water purification, necessary for simulating water management and purification environments directly related to aquatic, scientific and industrial applications in the complete water cycle and underwater robotics.

"The advanced design of the aeration and current generation tank means that underwater technology experimentation can take place under conditions close to reality, with very reliable results"

Rosario Vidal, researcher at the CIRTESU, Director of the Green Research and Development Group, and Professor at Universitat Jaume I

Who made it possible?

Because of the complexity and high profile of the project, an interdisciplinary working team was formed which included the following Universitat Jaume I research groups:

· **Robotic and Interactive Systems Laboratory**, which coordinated the project. The group's work focuses on human-machine interaction and the development of solutions (software/hardware) for robotics applications in real scenarios, especially underwater and in other hostile environments.

· **The Green Research and Development Group**, which works on environmental and social sustainability, life cycle assessment, ecodesign and the environmental quality of drinking water in treatment stations, storage tanks and distribution networks.

· **The Multiphase Fluids Group**, with research lines including knowledge of materials, nanotechnology, modelling and simulation of wastewater treatment plants (biochemical processes, neutralisation of odours and nitrates, etc.) and the management and reuse of treated water.

In addition to these research groups, the Institute of Aquaculture Torre de la Sal, a centre belonging to the Spanish National Research Council (CSIC), has been a member of the CIRTESU since its inception, and contributes to increasing the opportunities that the project offers in the optimisation of marine and freshwater aquaculture.

Its inclusive approach is one of the CIRTESU's strengths. It includes end users in the project, such as the company Fomento Agrícola Castellonense (FACSA), which specialises in the operation and maintenance of water treatment plants and desalination plants.

Creating new opportunities...

The CIRTESU will foster significant breakthroughs in both the underwater sphere and in other difficult-to-access environments. This is evidenced by the fact that the first strategic alliances were established during the execution of the project. These have already begun to bear fruit, including:

· Collaborations with the European Organization for Nuclear Research (CERN), thanks to the similarities between the radioactive and the underwater environments. Ongoing activities include the development of robots suitable for improved radiation techniques for medical applications and for the evaluation and maintenance of pipelines in nuclear facilities.

· New research areas for the management of marine crops, especially those carried out using cage devices, to achieve optimal working conditions.

· Design of small underwater robots for sampling oxygen in treatment plants, in partnership with the FACSA-UJI Chair.

· Cooperation with the Spanish Ministry of Defence to design and implement an integrated system for monitoring and searching for aquatic threats on the surface and at depth, using a wirelessly communicated autonomous underwater vehicle (AUV).

"The CIRTESU is a bridge that links underwater research with multiple applications in various areas of knowledge, such as health and engineering"

Raúl Marín, CIRTESU researcher and University Professor at the Department of Computer Science and Engineering at the Universitat Jaume I

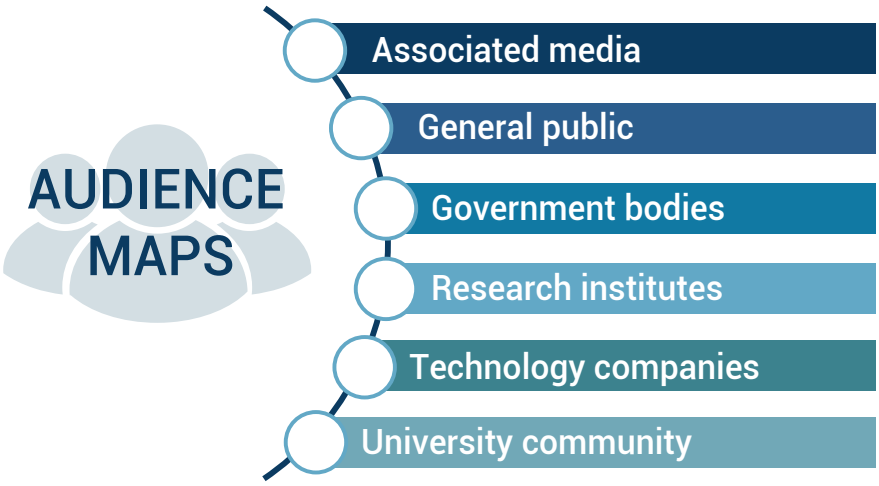
Projects like those mentioned above are in addition to the extensive experience that the CIRTESU team has built up in research projects, which makes the Universitat Jaume I as a benchmark in R&D activities in the field of robotics and other underwater technology.

Good practices criteria

In order to highlight the results achieved by the CIRTESU for other institutions, its compliance with the good practices criteria identified in the Communication Strategy of the ERDF Operational Programmes of the Valencian Community 2014-2020 is described below.

1. Dissemination

In order to undertake activities adapted to various groups, the first step in the communication strategy was to define an audience map, which identified the groups shown in the figure below.



The most appropriate communication objectives and channels for each group were then defined, leading to the actions listed below.

Official inauguration of the CIRTESU, with the participation of senior representatives from the political and educational spheres (3 December 2020)

1.1. Public events and activities

The main activities and public events where the project has been disseminated are presented in the following table.

ACTIVITY	PUBLIC	YEAR	SHORT DESCRIPTION
Press conference	Media	2019	Organised on the occasion of the arrival of the G500 underwater robot at Universitat Jaume I
Educational innovation	University students	2019	Participation in the Good Game initiative to inspire video game creation
Experiments	Scientific community	2019 2020	Experiments within the framework of projects such as El-Peacetolero (European Commission) and TWINBOT (Spanish Ministry of Science and Innovation)
Visits to the CIRTESU	Government bodies Scientific community	2019 2020 2021	The facilities have been visited on several occasions by political representatives and researchers (e.g. Automatic Conference 2021)
Presentations at international congresses	Scientific community	2020 2021	The project has been publicised at events including the European Robotics Forum and the World Congress of the International Federation of Automatic Control
European Researchers' Night	General public	2020	Presentation of the project and its links with gender equality in the "Expert voices" section
Official inauguration	Government bodies Scientific community Technology companies	2020	An event held at the Universitat Jaume I in which political and educational representatives inaugurated and visited the facilities

1.2. Dissemination in the media

Dissemination initiatives have been carried out aimed at both the university community and the general public throughout the project's life cycle, as listed in the table below.

ACTION	NUMBER	SHORT DESCRIPTION
Press release	2	Press releases by the Universitat Jaume I Communication and Publications Service sent to the media
News in **newspapers and magazines**	18	News reports published in newspapers and magazines, in paper and digital format (e.g. Europa Press, El Mundo, Levante, Mediterráneo, Castellón Diario, Castellón Plaza and Valencia Plaza)
Radio broadcasts	3	Interviews and news broadcasts on stations including Radio Nacional de España, À Punt Ràdio and Onda Cero
Scientific dissemination **videos**	3	Videos published on the Universitat Jaume I Science Portal and on YouTube
Posts on **social networks**	3	Information disseminated through the Universitat Jaume I, RUVID (Network of Valencian Universities) and IRS Lab Twitter, LinkedIn and Facebook channels

1.3. External publications

Bearing in mind the publications' suitability for sharing the results of the project with the research community, the project team has begun to transfer the progress it has made in the form of a series of scientific articles[2] , which are steadily increasing in terms of their number and impact. As well as the participation of personnel with extensive experience, the project has recruited trainee researchers, for whom the project has created new opportunities.

Likewise, this good practices report has been produced in open access format aimed at making science more accessible to the public, in line with the Valencian Community's Smart Specialisation Strategy in Research and Innovation.

1.4. Information on websites

Given the importance of the project, a website specifically for the project was created and hosted on the server of Universitat Jaume I, and a specific entry has been published in Wikipedia. The CIRTESU also appears in various sections of the Universitat Jaume I website, including the Science Portal, the Science TV Videoblog and the news and photo news archives, which provides the general public with access to the information.

1.5. Means of publicity

Various graphic items that enhance the project's visibility have been developed, including an information poster, explanatory posters, a roll-up banner and stickers for the equipment and the entrance to the building.

Graphic items that enhance the project's visibility

[2] Articles published while the project was being undertaken:

- de la Cruz, M.; Casañ, G.; Sanz, P.; Marín, R. Preliminary Work on a Virtual Reality Interface for the Guidance of Underwater Robots. Robotics 2020, 9, 81. https://doi.org/10.3390/robotics9040081

- de la Cruz, M.; Casañ, G.; Sanz, P.; Marín, R. A New Virtual Reality Interface for Underwater Intervention Missions. Proceedings of 2020 IFAC Conference.

- Pérez, J.; Bryson, M.; Williams, S.B.; Sanz, P.J. Recovering Depth from Still Images for Underwater Dehazing Using Deep Learning. Sensors 2020, 20, 4580. https://doi.org/10.3390/s20164580

- R. Pi, P. Cieślak, P. Ridao and P. J. Sanz, "TWINBOT: Autonomous Underwater Cooperative Transportation," in IEEE Access, vol. 9, pp. 37668-37684, 2021, doi: 10.1109/ACCESS.2021.3063669.

2. Innovation

Its innovative nature is one of the hallmarks of the CIRTESU project, as it encompasses the entire value chain, from the generation and use of knowledge to obtaining results that respond to existing needs.

2.1. Infrastructure and equipment

The experience of the research team involved in the CIRTESU, which specialises in areas such as underwater robotics, made it possible to identify the limitations associated with the lack of adequate infrastructure and equipment required to make scientific breakthroughs in this field and to obtain an in-depth knowledge of the specifications needed for the building that houses the CIRTESU.

In the purpose-built industrial facility measuring 30 x 15 x 8.35 metres, next to the water tank and the devices for simulating real situations, are the launch and recovery areas for robots, the control room, the gantry crane and the underwater technology design and construction workshop. The interior of the tank can be viewed through a large reinforced glass window located on one of its vertical sides.

The water tank has submersible beaters and an air blower unit that feeds removable grilles with diffuser units located inside the tank. This modular unit enables hydrodynamic phenomena and the aeration process of the biological reactors used in the wastewater treatment plants to be reproduced on a real scale, and is also very useful in experimentation with underwater robots.

In the field of underwater robotics, an autonomous robot able to do intervention work was acquired. It has been adapted based on the G500 robot, and equipped with a manipulator arm and a stereo camera, permitting a wide range of applications, such as seabed exploration, searching for and retrieval of objects, such as the black box of an aircraft. This is possible because the robot can submerge to a depth of 500 metres, as its lithium-ion batteries have an autonomy of around 6 hours.

Furthermore, as no umbilical cable connecting the robot to the surface platform or mother ship is required, this eliminates the risk of entanglement and cable breakage, which can lead to the equipment being lost. At another scale of intervention is the development of small low cost submersible robots for work in smaller installations, such as water treatment plants.

The CIRTESU's underwater robotics projects use the UWSim simulation program, developed and updated by the IRS Lab research group, as their basic medium. This open source tool, which can be accessed on the Universitat Jaume I website, enables users to view the reconstruction of a real intervention and to simulate underwater projects. Components such as underwater vehicles, surface boats, robotic manipulators and sensors can be included on the simulator screen. These have been created in previous projects, and the CIRTESU will increase their use and encourage further breakthroughs.

"The real-scale study of the hydrodynamic processes inside the biological reactors of wastewater treatment plants will lead to major breakthroughs in the optimisation of treatment processes"

Sergio Chiva, CIRTESU researcher, Director of the Multiphase Fluids Group and Professor at Universitat Jaume I.

2.2. Research lines and applications

The link between the generation of knowledge and its transfer is one of the CIRTESU's key areas. Taking into account the variety of difficult-to-access environments, the project enhances the potential related to intelligent robotics and the complete water cycle in multiple areas of knowledge. Some of these are summarised below.

Main research lines	Examples of application
Robotics underwater and in other harsh environments applied to real scenarios, including the development of software for the simulation, programming and control of autonomous and coordinated devices.	Evaluation and maintenance of polyamide pipes in **nuclear power plants**
	Access by robots to **drainage facilities** with a radiation hazard
	Monitoring of **underwater crops** in cages (self-cleaning of tanks, oxygenation, etc.)
	Gathering of information for **underwater cartography**
	Support for research on **underwater cultural heritage** by studying items submerged underwater
	Monitoring and search for **aquatic threats** (underwater mines, etc.) for the Spanish Ministry of Defence
	Checking and maintenance of facilities in seaports
Processes with **multiphase fluids** (air-water) used in **wastewater treatment plants** for the decomposition of organic matter by aerobic microorganisms in biological reactors.	Experimentation with a **biological reactor** in an **industrial wastewater treatment plant** on a real scale (hydrodynamic phenomena, aeration and mixing, modelling and computational simulation, etc.)
Design engineering of products, facilities and devices for **environmental sustainability** and the measurement and improvement of the **quality of drinking water.**	Water supply with **optimisation of water resources** using geographic information systems
	Development and validation of **drinking water quality models** for storage and distribution networks.

"The involvement of the Institute of Aquaculture Torre de la Sal (CSIC) in the CIRTESU opens up new ways to improve the management of marine cultures and to move towards a more sustainable aquaculture"

Ariadna Sitjà, Director of the Institute of Aquaculture Torre de la Sal(Spanish National Research Council centre)

2.3. Innovation aimed at the region and the target audience

The CIRTESU's infrastructure is unique in the Valencian Community, which constitutes a significant improvement in the region's position as an underwater technology research pole, and is very important for Universitat Jaume I, the province of Castelló and the Valencian Community.

The unique nature of the facility opens up multiple opportunities for scientific-technological collaboration with innovative contributions for the audience at which the project is aimed. Some parts of this audience are shown in the figure below.

Summary of the innovations that the CIRTESU provides for the target audience

Research staff

Pioneering space for underwater experimentation simulating real intervention conditions

Students

Relevant learning and high-level experimental practical sessions in underwater robotics

R&D&I centres

Application of knowledge for new developments applicable to various hostile environments

Companies

New opportunities for public-private collaboration in the field of artificial intelligence

Public Administration

Contribution to sustainable development policies based on R&D&I

Public

Participation in scientific progress and in the generation of a knowledge-based society

3. Results

As described below, the results achieved in the CIRTESU project have enabled the objectives defined in the initial application to be achieved, and the added value obtained is confirmed thanks to co-financing from the ERDF.

Objective 1. Cooperative Robotics, with capacity for supervision and intervention using sensor equipment and heterogeneous mobile manipulator robots, for applications in the aquatic and industrial field (the Internet of Things and offshore industry).

This objective was achieved with the acquisition of an AUV (Autonomous Underwater Vehicle) type robot, to which an articulated manipulator arm equipped with a claw enabling the use of tools has been adapted. In addition, progress has been made on designing small low cost mobile robots with handling capacity, and cooperative inspection tests have been carried out at the CIRTESU.

Objective 2. Experimentation in scenarios close to real conditions in the presence of currents and unforeseen situations.

The simulation of real contexts in the CIRTESU water tank has been enhanced by the design and implementation of a series of hydraulic control and current generation devices, and the adaptation of the UWSim submarine robotics simulator program. The first experiments have already been carried out, in which a robot has recovered the black box from an aircraft (full-scale model) at the bottom of the water tank, among other achievements.

Objective 3. Aquatic applications: Monitoring and optimisation of the drinking water system, inspection and improvement of water management in treatment plants, optimisation of irrigators for efficient water use, maintenance of fish farms and strategic underwater facilities.

The involvement with the CIRTESU of the Green Research and Development and Multiphase Fluids research groups, which specialise in environmental assessment, treatment and purification of water, has provided the Centre with the necessary facilities for the experimentation carried out to become useful innovations for companies and institutions in the public and private sector associated with the complete management of the water cycle.

Underwater robotics opens up new opportunities in water treatment and purification

Objective 4. Industrial applications: Cooperation of industrial robots in the fields of Industry 4.0, sensor networks (IoT), simulations and cooperative control interfaces of industrial robots.

The design of robots has contributed to the convergence of research on artificial intelligence with the experience of the Universitat Jaume I in innovation and transfer to the manufacturing sector, opening up possibilities for companies to improve their competitiveness through high technology. Examples of the CIRTESU's contributions to industrial robotics are sealing techniques for use in dusty environments and remote control of equipment with limited communication, such as in tunnels.

Objective 5. Scientific applications: Design of technology to safeguard underwater archaeological heritage in the Valencian Community, remote control of robotic intervention systems in dangerous scenarios (e.g. involving fire, radiation and water), fluid engineering research and improvement of construction systems in facilities in the water cycle, and breakthroughs in aquaculture techniques and efficiency in fish farms.

After identifying the interest of the target audience, the CIRTESU contacted various institutions to facilitate the use of the breakthroughs in R&D&I to solve specific needs. Relationships with companies, research centres and government bodies have led to the start of experimentation in areas including advanced irrigation control systems, underwater archaeology, purification and storage of drinking water, and hospital care in areas with radiation risks.

Objective 6. Crosscutting objective: Following the international guidelines on good practices in robot ethics and engineering, technology will be investigated and designed in order to serve people, to improve the quality of life and to promote employment and peace.

The CIRTESU's work seeks to contribute to the values of society while aligning with Responsible Research and Innovation (RRI). The specific measures to that end have included the promotion of scientific education with activities such as the European Researchers' Night, the promotion of open access to information, and joining the Strategy of Excellence in Human Resources for Researchers at the Universitat Jaume I.

Underwater robotics has vast potential for facilitating and enhancing underwater archaeology projects.

Photo: Juha Flinkman, SubZone OY, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

The work plan established in the project report has been followed in order to obtain these results, and the goals established in all phases of the report have been achieved in its life cycle. Some of the most significant achievements are as follows:

Phase 1. Simulation of robotic interventions in currents

Goals:

- Design of automated water current system plans
- Adaptation of the UWSim underwater robotics simulator program
- Empirical evaluation in simulation with robots

Phase 2. Fluid mechanics experiments and current tank design

Goals:

- Analysis of the results of the empirical evaluation
- Adaptation of the building plan to the final configuration of the system of currents, the robot launch and recovery areas, the control room, the gantry crane and the underwater technology design and construction workshop.

Phase 3. Cooperative inspection

Goals:

- Purchase of a G500 model type AUV underwater robot.
- Adaptation of the G500 robot handling system with the addition of an articulated arm equipped with a claw enabling it to use of tools in fish farms, wells, etc.
- Progress in the design of small low cost mobile robots with manipulation capacity for smaller underwater installations.
- Cooperative inspection tests in the project's provisional facilities (CIRS Girona).

Phase 4. Experiments in the current tank with a robot

Goals:

- Confirmation that the facilities operate correctly
- Preliminary tests of robots in the current generation tank.

Phase 5. Cooperative intervention experiments in a current tank. End of the project

Goals:

- Cooperative robotic monitoring and intervention under conditions similar to reality for the transport of underwater pipes.
- Transfer of software developed for efficient network cooperation for use in other areas of cooperative robotics.

Crosscutting phase

Goal:

- Preparation of a framework for integrating the CIRTESU research lines with the Smart Specialisation Strategy for Research and Innovation in the Valencian Community, the Sustainable Development Goals of the 2030 Agenda, and the international guidelines for good practices in robotics and engineering ethics.

4. Problem-solving

The CIRTESU's contribution to solving problems and weaknesses identified in the area of execution begins with a detailed analysis of the initial research situation in cooperative underwater technology and robotics in the Valencian Community. This situation is summarised in the SWOT matrix presented below, which analyses its Strengths, Weaknesses, Opportunities and Threats.

The matrix shows the main difficulties and possibilities associated with the project internally and externally, and is inspired by the Smart Specialisation Strategy for Research and Innovation in the Valencian Community (Government of the Valencian Community, 2016) and more specifically, by the SWOT included in that Strategy.

SWOT on research in underwater technology and cooperative robotics in the Valencian Community

INTERNAL ANALYSIS

WEAKNESSES

1. Lack of appropriate facilities to carry out experiments in which real environments are simulated.

2. High cost of the equipment and infrastructure required for applied research.

3. Imbalance in the access of women and men to studies in areas related to the CIRTESU (artificial intelligence, technology in hostile environments).

4. Difficulties finding technical personnel specialised in handling the CIRTESU's devices.

5. Medium-sized university with limited resources to invest in its own research plan.

6. Restrictions on the mobility of research staff aggravated by the situation caused during the COVID-19 pandemic.

STRENGTHS

1. A team with extensive research experience in robotic and interactive systems, water storage and purification and aquaculture.

2. Close collaboration between complementary research groups (e.g. the Multiphase Fluids and Green Research and Development groups).

3. High level of institutional support in the establishment and promotion of CIRTESU as a leading centre in its field.

4. High level of appeal to trainee research personnel.

5. Robust network of contacts with European and international centres, with which a relationship of trust has been established.

6. Bachelor's degree and postgraduate courses related to the project are taught at the university, providing trained people who can participate in the CIRTESU.

7. Production of the hardware and software (UWSim) required for the simulation and programming and control of underwater robots.

EXTERNAL ANALYSIS

THREATS

1. Small business fabric specialising in underwater technology in the province of Castellón.

2. Difficulties in access to external aid to co-finance the investment required in human and material resources.

3. Low investment in R&D&I in the project compared to other European regions and countries.

4. Difficult consolidation of careers of research staff, leading to the emigration of highly qualified people who have been trained in centres in the Valencian Community.

5. Economic crisis as a result of the consequences of the COVID-19 pandemic.

OPPORTUNITIES

1. Interest shown in underwater robotics by companies in various sectors.

2. Emergence of new applications for robotic technology in environments that are difficult to access, such as monitoring and control in radioactive environments.

3. Internationally renowned R&D centres such as the Higher Technical Institute of Lisbon have expressed interest in collaborating with the CIRTESU.

4. Regional, Spanish, European and international policies promote responsible research and innovation.

5. The region in which the university is located has a tradition of innovation and entrepreneurial culture.

6. Close links with the Mediterranean axis, with similar interests and concerns, facilitating the extension of the CIRTESU to similar environments.

7. Need to optimise the construction and management of drinking water treatment and storage facilities by experimentation and design.

Although reference is made throughout the report to how the project has approached the various aspects of the SWOT analysis, an overall vision that summarises the main relationships between its results and the CIRTESU is presented below.

Contributing to overcoming weaknesses

The construction of the facility housing the tank for the generation of water currents, the devices to simulate real environments and the acquisition and adaptation of the G500 underwater robot means that all kinds of experiments can be undertaken within the project, thereby avoiding difficult and expensive journeys to similar centres located outside the Valencian Community.

As for gender equality, the CIRTESU expresses its total commitment to the strategies and guidelines of the UJI, and especially with those stated in the II Equality Plan 2016-2020 of the Universitat Jaume I and the HR Excellence in Research European quality accreditation. For more details on the above, please see section 6.1. of this Report, on "Horizontal criteria: Equality".

Enhancing strengths

The implementation of the project would not have been possible without close collaboration between the research groups involved in it. Interdisciplinary work has created spaces for mutual knowledge and collaboration, and new projects, some of which have already started, have emerged. The opportunities that the CIRTESU offers for research have attracted young researchers who have joined the team and experienced a boost at the beginning of their scientific career.

Meanwhile, with a view to promoting training for the use and maintenance of the CIRTESU facilities, specific content related to the project's thematic areas has been taught on bachelor's degree and postgraduate courses at the Universitat Jaume I.

An example of application is the project's interest in the field of archaeology, where there is interesting potential for collaboration with institutions including the Centre for Law and International Relations Studies, a research group at the Universitat Jaume I with an extensive background in defending underwater cultural heritage.

Reducing the risk of threats

Companies from various sectors have been identified to expand the potential for applying the research carried out at the CIRTESU. Work to that end has been undertaken on a local, regional and European scale with various types of institutions which have expressed their potential interest in the field.

As for economic sustainability, a map of possible calls for aid has been produced, with special emphasis on the new European Union 2021-2027 framework programme, Horizon Europe, because of its capacity and priorities in the financing of R&D&I.

Aligning with opportunities

In order to enhance the project's potential, difficult-to-access environments similar to the underwater environment have been located, where there are many opportunities to transfer the results obtained from the research of robotic applications in hostile environments.

In this area, experimentation in the current generation tank has begun in order to validate or check scientific hypotheses for improving the construction and management of drinking water treatment and storage facilities. Likewise, the WATER UJI initiative, consisting of a Technological Hub in the water sector, which was created at the UJI in late 2020 thanks to a project financed by the Valencian Innovation Agency, will strengthen synergies with other research groups and business.

Collaboration has also begun with the Ministry of Defence on a project which aims to design an integrated system for monitoring and searching for aquatic threats using autonomous underwater vehicles.

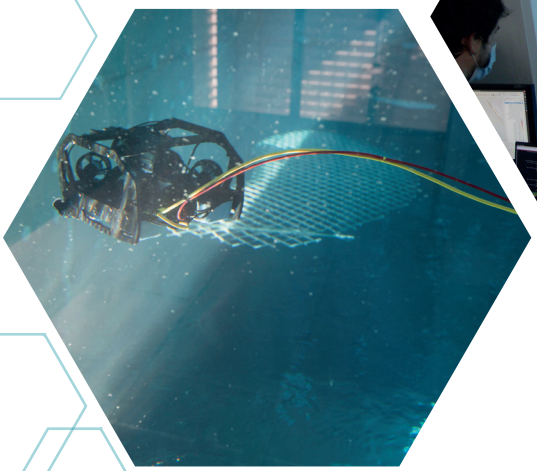
5. Level of coverage

When analysing the CIRTESU's level of coverage of its target population, we will take into account the research community in the Valencian Community and the companies in the main areas that could benefit from the project.

5.1. Coverage among the research community

The impact of the CIRTESU on the landscape of Valencian university research structures may be considerable, due to the unique nature of its facilities and equipment. It enables other universities in the region, with their own projects in related lines of work, to carry out experiments that allow them to make progress with their own R&D&I.

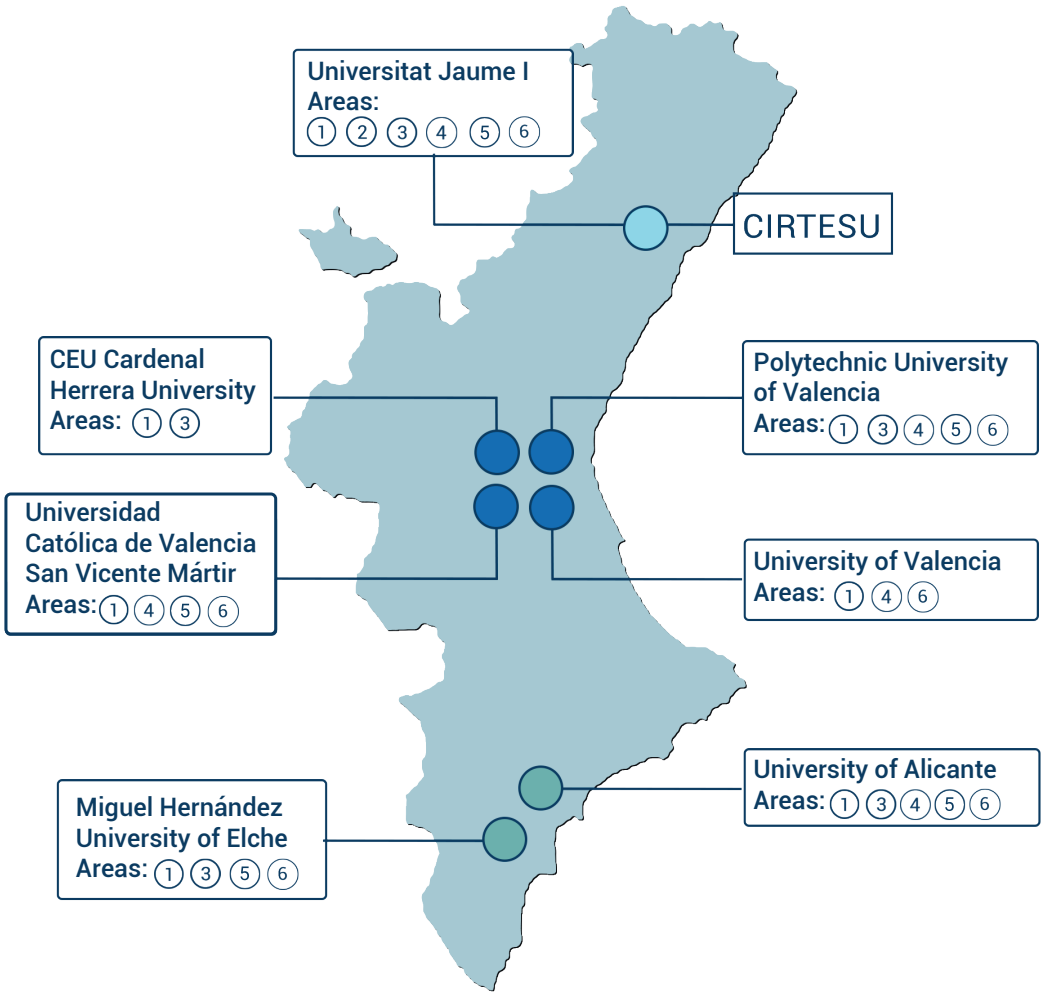
Photo: FMNLab, CC BY 4.0 <https://creativecommons.org/licenses/by/4.0>, via Wikimedia Commons



There are research structures carrying out projects related to the CIRTESU at all the universities in the Valencian Community.

The illustration below summarises some of the areas of experimentation of Valencian universities working with the CIRTESU.

Main areas of experimentation at Valencian universities working with the CIRTESU



① *Artificial intelligence*
② *Robotics underwater and in other hostile environments*
③ *Robotics for Industry 4.0.*
④ *Aquaculture*
⑤ *Purification and storage of drinking water*
⑥ *Wireless underwater telecommunications for data transfer*

As well as the scientific community working at universities, the Valencian Community is also home to other important R&D&I centres working in areas similar to those of the CIRTESU. Those working closely with the project include the following:

- Institute of Aquaculture Torre de la Sal of the Spanish National Research Council (CSIC), an active member of the CIRTESU.

- Information and Communication Technological Institute.

- Valencia Agricultural Research Institute.

- Valencian Cartography Institute.

5.2. Coverage among companies in related sectors

By way of an example, this section considers two important sectors in the region with particularly close links to the CIRTESU: aquaculture and water. There are also other scenarios with a short-term profile, including monitoring and maintenance of port facilities.

by the collaboration between the CIRTESU and the Institute of Aquaculture Torre de la Sal, a Spanish National Research Council (CSIC) centre, can contribute to improving this situation. This progress would have an impact on the region's economic progress, especially in the coastal area.

The use of underwater robots will contribute to improving production in the aquaculture sector

In aquaculture, world production amounted to 112 million tons in 2017, which is higher than the figure for extractive fishing (IVACE, 2019). According to the Economic and Social Committee (2020), the Valencian Community, which has more than 500 kilometres of coastline, is the leading producer of sea-raised fish in Spain. 28 marine farms were authorised in 2019, of which 16 were located in Alicante, 8 in Valencia and 4 in Castellón, in addition to 22 mussel rafts and 2 for oyster farming. They produced a total of 16,667 tonnes, with a value of 87.57 million Euros, with sea bream (6,528 tonnes), sea bass (4,561 tonnes), croaker (4,125 tonnes) and other species (1,453 tonnes) accounting for the highest production levels.

Despite this position, and the region's vast potential due to its privileged location, the commercial balance in the territory must be reinforced. As well as adopting other necessary administrative measures, the combination of the underwater robotics research lines with the aquaculture lines, which is facilitated

The water business sector in the Valencian Community is highly fragmented, with a clear predominance of small and medium-sized companies. With a population of almost 5 million people, the Valencian Community is subject to a fragile quantitative balance between its water resources and demands, with the risks increasing due to the effects of climate change (Cabezas, 2008). There are some problems related to the quality of the water, which can be clearly improved, especially in the province of Alicante. These problems are due to the overexploitation and salinisation of aquifers as a result of marine intrusion, pollution caused by agricultural activities and discharges, insufficient purification and limited reuse of wastewater.

According to a study by the Polytechnic University of Valencia (2019), the necessary innovation in the water sector in the Valencian Community is undertaken by 24 institutions and public companies (some of which are mixed), 40 private companies and 47 research units, including those at the

various Valencian universities. In this framework, the CIRTESU can contribute with experimentation in its current generation tank and reproduction of the behaviour of wastewater treatment plants on a real scale, thanks to its submersible grille system and the beaters system, and the implementation of a comprehensive instrumentation system (Climent et al., 2018). An example of this is the research on reducing the formation of trihalomethanes[3] in drinking water purification plants, which is already under way.

6. Horizontal criteria

The CIRTESU has been an opportunity to integrate the gender perspective and environmental sustainability in research and innovation on underwater robotics and technology, and a response to the priorities of Responsible Research and Innovation (RRI), to which both the team implementing the project and the Universitat Jaume I adhere.

6.1. Equality

Although it is true that progress has been made in recent years in terms of the participation of women and in conducting research with a gender perspective, a greater boost is still needed for this equality to be effective in the fields of science, technology, engineering and mathematics, as women account for less than 30% of the research staff in these areas (UNESCO, 2019).

This figure is a long way from the 40% participation level which is the proposed threshold for achieving gender balance in the European Commission's Horizon 2020 Programme. In the case of the CIRTESU, the overall composition of the research groups that make up the project (Universitat Jaume I and Institute of Aquaculture Torre de la Sal-CSIC), is 39.5% women and 60.5% of men, which is significantly close to this figure.

In order to consolidate equality in research teams and integrate the gender dimension in research and innovation, the CIRTESU team has participated in the guidelines, strategies and actions carried out by Universitat Jaume I.

First, the CIRTESU has fully adhered to the II Equality Plan of the Universitat Jaume I 2016-2020. Among other measures, the Plan calls for an absence of

The CIRTESU participates in the Researchers' Mediterranean Night, an exhibition of the scientific breakthroughs in its immediate environment.

[3]Trihalomethanes are the result of reactions between the organic matter present in water before it is disinfected, and the chlorine used to disinfect it. The World Health Organization considers that chlorine disinfection provides many more benefits than the additional risk caused by trihalomethanes (WHO, 2006).

discrimination on the grounds of sex, race, religion, beliefs, disabilities or sexual orientation. It also calls for the use of inclusive oral and written language in all communications, both within the university and those presented externally. It also stipulates that the images disseminated through the media may not represent stereotyped roles, in addition to maintaining a balance between the number of men and women that appear in them.

Another essential benchmark for the CIRTESU is the HR Excellence in Research quality accreditation, which the European Commission awarded to the Universitat Jaume I in 2020. This award acknowledges the alignment of the human resources policy with the principles of the European Charter for Researchers and the Code of Conduct for hiring researchers. In practice, the accreditation means that an Action Plan has been implemented which includes specific commitments, such as promoting gender balance in the composition of the personnel selection committees, guaranteeing access to calls and non-discrimination of the research staff through the university's Equality Unit.

The third area with which the CIRTESU team collaborates is the Scientific Culture and Citizen Science Project of the Universitat Jaume I, which has lines of work including scientific dissemination, the dissemination of research results and the promotion of citizen science initiatives. Among the dissemination actions that are directly related to equality are the International Day of Women and Girls in Science (February 11) and MEDNIGHT[4] – Mediterranean Researchers' Night.

In addition to the above, and taking into account that the gap is greater in scientific-technological research, the CIRTESU also participates in events in which specific activities are carried out in the field of robotics, such as the Girls in Control workshop, held at the 21st IFAC (International Federation for Automatic Control) World Congress, which took place in July 2020. The workshop, which is a pioneering initiative in this type of congress, focused on attracting the attention of girls aged between 10 and 15 years old to degree courses in science, technology, engineering and mathematics.

"On the path to equality in science we are achieving a society that is fairer, but also richer, more complete and effective research, by incorporating the gender perspective"

Lluís Martínez León, head of the Scientific Culture and Citizen Science Project (PC[4]) at the Universitat Jaume I

Another example is the Conference on Automatic at Universitat Jaume I (September 2021), with a round table on women in the professional automatic sector.

[4]The MEDNIGHT project is an event associated with the European Union Researchers' Night initiative, funded by the Marie Skłodowska-Curie actions.

6.2. Environmental sustainability

The starting point for this analysis is the building where the CIRTESU is located. As summarised in the following table, the construction of the facility that houses the current generation tank and its installations and annexes, carried out under the project management of the Technical Office for Construction Work and Projects of the Universitat Jaume I, followed criteria of energy efficiency and environmental sustainability.

ENVIRONMENTAL SUSTAINABILITY IN THE CIRTESU BUILDING

1. The facility has **thermal insulation on its roof** to avoid excessively high indoor temperatures in summer.

2. The micro-perforated façades provide the facility with **ventilation and natural lighting**.

3. The water tank has been made with **waterproof concrete** to reduce costs and to avoid using more materials that waterproof and protect the waterproofing, providing a more resistant finish to withstand the impacts that use will cause.

4. The **interior lighting is LED** in order to reduce consumption levels.

5. The **air conditioning system is based on INVERTER DC technology**, which enables the output of the compressor to be adjusted to changes in temperature detected in the room, providing greater efficiency, energy savings and comfort.

6. A **salt chlorination** system has been installed, which replaces chlorine with salt, and as such work is carried out with products healthier than chlorine.

7. The building's electrical switchboard comes straight out of the Espaitec 2 building, which has a **photovoltaic solar** installation on the roof that partially meets the demand from both buildings.

8. The building is connected through the service hall to the separation network on campus, where there are **separate wastewater and rainwater networks**.

9. The service hall allows **connectivity to be expanded** with other facilities in the building with no need to carry out any other work.

10. The building is connected to the **overall campus management system** which enables remote control, in addition to monitoring all the energy consumption.

Only electric power is used in the equipment and facilities, and all the robots used operate with high-performance lithium-ion electric batteries. There are therefore no greenhouse gas emissions, and practically no environmental pollution, including indirect pollution, as the electrical energy for recharging the robots' batteries can come from the photovoltaic energy from the panels installed on the roof of the Espaitec 2 building at the Universitat Jaume I.

As for the sustainability of the projects, coastal areas like the one affected by the project possess considerable natural wealth that will be enhanced by the breakthroughs anticipated in the underwater robotic-aquaculture convergence. In addition, a very positive outcome is to be anticipated for research in the area of health and quality of life as a result of projects to improve drinking water.

A highly beneficial complementary contribution is the possible reduction of the risk of maritime pollution by using underwater robots to monitor underwater structures, such as crude oil discharge unloading terminals and port facilities. This supports the objectives of Law 6/2014 of 25 July of the Government of the Valencian Community, on Prevention, Quality and Environmental Control of Activities in the Valencian Community, inspired by the European Directives in which the prevention of pollution has been prioritised as essential for the construction of European regulations.

7. Synergies with other projects

The impact of the CIRTESU has clearly been reinforced by the generation of synergies with the main tasks of the University, creating a multiplier effect in research projects financed with public funds (local, regional, Spanish and European), enhancing teaching in various knowledge areas and contributing to other public intervention policies and strategies.

7.1. Synergies with research projects

The current CIRTESU research team has specialised in study and experimentation in underwater environments (robotics, complete water cycle, etc.) and has experience dating back to the 1990s. This in turn has led to new projects in hostile environments (due to radioactivity, strong magnetic fields, etc.) as a result of their similarities with underwater robotics, especially in sealing and remote control techniques for equipment with reduced communication.

The timeline below shows some of the most important projects. Those considered as taking place prior to the CIRTESU being established were carried out before 2018, before the implementation of this framework, and acted as the foundation for it. In the following three years (2018-2021), the design and construction of the Centre was combined with the launch of new projects in complementary research lines, and the results of these may constitute a major scientific and technological breakthrough.

The official inauguration of the physical infrastructure in December 2020 saw the beginning of a period of continuity and progress in R&D&I, and the establishment of a starting point for the consolidation of the CIRTESU as a pole for attracting talent.

The consistency and maintenance of the work carried out over time have led the team's initiatives to receive support from various funds mentioned above, which enhances the Centre's sustainability in the medium and long term.

Main projects linked to the CIRTESU with external funding

2021

SIMBAAD – Integrated System for Monitoring and Seeking Aquatic Threats for Defence. Development of a prototype capable of autonomously detecting and recognising underwater threats with unmanned vehicles.
Financed by: Spanish Ministry of Defence

VIRAL – Development of the virtual reactor in wastewater treatment plants. Use of artificial intelligence and modelling with computational fluid dynamics programs for online management and control.
Financed by: FACSA

EL-PEACETOLERO – Embedded electronic solutions for polymer innovative scanning tools using light emitting devices for diagnostic routines
Financed by: European Commission

CERN-MEDICIS- Research on robots suitable for improved radiation techniques for medical applications
Financed by: European Organization for Nuclear Research (CERN)

ROBOT FOR ACCELERATORS – Human control field-supervisor of robot equipment for telemanipulation at the Large Hadron Collider (LCH) and other accelerators at CERN
Financed by: European Organization for Nuclear Research (CERN)

2018

CIRTESU – Research Centre for Robotics and Underwater Technologies
Financed by: Government of the Valencian Community and the European Regional Development Fund

TWINBOT – Twin robots for cooperative underwater intervention missions
Financed by: Spanish Ministry of the Economy and Competitiveness

MARINE ROBOTICS – Marine intervention robotics: manipulation, location, communications and HRI (Human-Robot Interaction)
Financed by: Government of the Valencian Community

COOPERATIVE ROBOTS – Multifunctional marine cooperative robots for intervention domains
Financed by: Spanish Ministry of the Economy and Competitiveness

WATER QUALITY – Design of a decision-making aid tool for optimising water quality in the supply and distribution network
Financed by: Grupo Wasser

TRITON – Underwater intervention using cooperative marine robots and multisensory perception
Financed by: Government of the Valencian Community

TRIDENT – Marine robots and dexterous manipulation for enabling autonomous underwater multi-purpose intervention missions
Financed by: European Union

RAUVI – Design, implementation and execution of validation experiments in the Rauvi coordinated research action on underwater autonomous intervention
Financed by: Spanish Ministry of Science and Innovation

2008

BEGINNING OF UNDERWATER ROBOTICS RESEARCH

The applicability of the CIRTESU's research to radioactive environments has led to experimentation at the CERN's Large Hadron Collider

7.2. Synergies with university education

The European Commission has defined a series of guidelines to achieve a European Education Area by 2025, which links training with job creation, economic growth and social cohesion. As stated in its Communication on the European Education Area (EC, 2020), the development of a talent pool in cutting-edge scientific and technological disciplines (such as those related to artificial intelligence) has been established as a priority for higher education, and there is an acute lack of experts in these fields.

Within this framework, the opportunity for university students to learn about and carry out practicums in cutting edge facilities such as the CIRTESU is undoubtedly an important educational innovation in robotics and other underwater technologies, and establishes synergies with new degree courses at the Universitat Jaume I that are currently being implemented. Apart from their autonomy, these degree courses provide a high level of specialisation in the academic track, structured in two stages. These are:

1. Multi-faceted initial training through the Bachelor's Degree in Robotics Intelligence, with a total of 240 ECTS credits (European Credit Transfer System) spread over four years. These studies are general in nature, and include content on cooperative robotics, autonomous vehicles (land, marine and underwater), drones, domestic robots, etc.

2. Specialisation in Robotics applied to underwater intervention missions, through the Erasmus Mundus Interuniversity Master's Degree in Marine and Maritime Intelligent Robotics, with 120 ECTS credits taught over four semesters. As well as the Universitat Jaume I of Castelló, the Norwegian University of Science and Technology, the University of Lisbon and the University of Toulon, which is the coordinating body, are involved as partners in the Master's Degree course. Twenty-five academic institutions and industrial partners from 21 countries are also involved.

The synergies obtained can be extended to the bachelor's and master's degree courses which have already been consolidated at the UJI, on which CIRTESU researchers teach. These are:

- Bachelor's degree courses in Computer Engineering, Computational Mathematics, Video Game Design and Development and Industrial Technology Engineering.

- University master's degree courses in Intelligent Systems, Industrial Engineering and Energy Efficiency and Sustainability.

Meanwhile, the close links between the CIRTESU and the doctoral studies are enabling trainee research personnel to carry out innovative experimental

studies and to participate in scientific networks at the European level. This is evidenced by the fact that four doctoral theses have been carried out at the facilities of the European Organization for Nuclear Research (CERN) during the project's life cycle. The first of these was publicly presented at the Universitat Jaume I[5].

7.3. Synergies with other policies and strategies

As mentioned elsewhere in this report, the CIRTESU has aligned itself with various policies, plans and strategies at the regional, European and international levels. This reinforces its impact, as it joins other organisations working under these guidelines, and favours the achievement of specific objectives, commitments and goals referred to below.

Within the Smart Specialisation Strategy for Research and Innovation in the Valencian Community (RIS3-CV), the CIRTESU shares specific objectives with the following areas:

AREA 1. Quality of life

- Food: Applying underwater robotics in aquaculture to support the production of safe and high quality food, facilitating the reduction of energy and water resources necessary. Developing advanced control systems for agricultural irrigation, in which ICTs play a fundamental role.

AREA 2. Innovative products

- Habitat: Improving the design, construction and management of treatment plants and drinking water storage tanks based on experimentation in the CIRTESU current generation tank.

AREA 3. Advanced manufacturing processes

- Capital goods: Reinforcing the developments of control systems with the incorporation of new ICT functionalities, applying them primarily to the development of robotics underwater and in other hostile environments.

The CIRTESU is contributing to achieving several of the United Nations Sustainable Development Goals established for 2030 in its research lines. These are:

• **Goal 2. Zero hunger:** Transferring the results of the CIRTESU's research to increase yields from aquaculture with savings of water and feed. Promoting sustainable agriculture, increasing productivity and food production with the implementation of irrigation control systems using low-cost ICT.

• **Goal 6. Clean water and sanitation:** Collaborating in the application of new construction and management techniques for drinking water purification and storage facilities, based on experimentation in the current generation tank.

• **Goal 14. Life below water:** Using underwater robotics to ascertain and use the resources of the continental platform (gas, oil, etc.), and to maintain off-shore facilities (such as oil platforms), minimising the risk of marine pollution.

• **Goal 17. Partnerships for the goals:** Increasing regional and international cooperation in R&D on underwater robotics, fostering the establishment of partnerships in the public, public-private and civil society spheres.

[5] Lunghi, G., Marín, R., Sanz, P, di Castro, M. (2020). Multimodal Human-Robot Interface for Heterogeneous Robotic Systems Control in Harsh Environment (Tesi doctoral). Universitat Jaume I, Castelló.

“The launch of the CIRTESU is a scientific milestone for the Universitat Jaume I. With this infrastructure, which is unique in the Valencian Community and one of the few of its kind in Europe, we will become an international scientific pole scope in underwater robotics”

Eva Alcón, rector of the Universitat Jaume I

The CIRTESU in figures

1st research centre
in underwater technology in the Valencian Community

+ 480 m³ capacity
in the water tank for experimentation with underwater technology (1/2 Olympic pool)

+ 10 environmental measures
implemented to ensure the building's sustainability

+ 10 areas of application
in which the R&D&I undertaken at the CIRTESU can be used

+ 20 researchers
have participated in its implementation

+ 1,100 students
have had access to new knowledge about underwater technologies

+ 30 outreach activities
including public events, news reports, publications and advertising media

+ 15,800 people
comprising the target audience for communication activities

+ €750,000 invested
in the construction of the CIRTESU and the acquisition of equipment

+80% of the initial investment
made at the CIRTESU has already been attacted in 3 years

Acknowledgements

The impact and profile of the Research Centre for Robotics and Underwater Technologies have been enhanced with the help of the following institutions.

UNIVERSITIES AND R&D&I CENTRES

Institute of Aquaculture Torre de la Sal

Ioffe Physical-Technical Institute of the Russian Academy of Sciences

Lisbon Technical Institute

Norwegian University of Science and Technology

Sorbonne University

University of Girona

University of the Balearic Islands

University of Toulon

GOVERNMENT BODIES

Government of the Valencian Community

Spanish Ministry of Defence

Spanish Ministry of Science and Innovation

COMPANIES

Arttic

Blue Print Lab

Electricité de France

Facsa

Forschungzentrum Jülich GMBH

Ingesom

IQUA Robotics

Mirsense

Narwhal

Port of Castelló

Robotnik

UTEK

EUROPEAN AND INTERNATIONAL BODIES

Comissaritat à lÉnergie Atomique et aux Energies Alternatives

European Regional Development Fund

European Commission Horizon 2020 Programme

European Organization for Nuclear Research

EU Robotics

Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V.

International Federation of Automatic Control

Institute of Electrical and Electronics Engineers-Section Robótica y Automatización

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