JERICO-S3

Proposal for Transnational Access

to Coastal Observatories

1st Call

2nd June 2020 - October 2020

Description of the project to be sent in pdf format to jerico.ta@marine.ie

Please consult access rules at http://www.jerico-ri.eu and contact the manager of the infrastructure/installation you wish to use before writing the proposal

The JERICO-S3 project is funded by the European Commission's
H2020 Framework Programme under grant agreement No. 871153
Project coordinator: Ifremer, France.

PART 1

1. GENERAL INFORMATION

Title of the project (255 characters max.)	**Fault detection, isolation and Recovery fOr uNderwaTer glIdERS**
Acronym (20 characters max.)	**FRONTIERS**
Applying Institution	**University College London, UK**
Host Institution	**SOCIB, ES**
Host facility(ies)	**SOCIB**

Have you or other members of your user group previously used the requested facility(ies)?		Yes	X	No
If yes, please indicate the EU Program(s), the name of the project(s) and year(s) you or other members of your user group have used such facility(ies)				
If you have received transnational access support from a previous JERICO project, please list resulting publications, conference contributions, patents. List only the ones that acknowledge the support of the European Commission and JERICO				

2. USER GROUP DETAILS

Indicate if the proposal is submitted by

☐ an individual

☒ a user group

Principal Investigator (user group leader)

First and last name	Enrico Anderlini					
Gender	X	Male		Female	**Nationality**	Italian, British
Institution	University College London					
Address	Roberts Engineering Building, London, WC1E 7JE					
Country	United Kingdom					
Email address	E.Anderlini@ucl.ac.uk					
Telephone	+44 7450272675					
Fax						
Previous user		Yes	X	No		

User group members

Member # 1

First and last name	Peng Wu					
Gender	X	Male		Female	**Nationality**	Chinese
Institution	University College London					
Address	Roberts Engineering Building, London, WC1E 7JE					
Country	United Kingdom					
Email address	Peng.Wu.14@ucl.ac.uk					
Telephone	+44 7459810890					
Fax						
Previous user		Yes	X	No		

(duplicate below for each member of the user group)

3. HOST INFRASTRUCTURE

Indicate the JERICO-S3 host facility(ies) offered in Chapter 1 (Observing systems) you are interested in

(Tick more than one boxes if it is useful for your project)

		Short name	Requested access time (UA*)
	Cabled observatory		
	Ferrybox		
	Fixed platform		
	Fishing vessel		
√	Glider	SOCIB/GLIDER	14 days
	Supporting facility		
	Special equipment		

**UA: please refer to the Infrastructure description in the JERICO-S3 website*

Modality of access

	remote	*the measuring system is implemented by the operator of the installation and the presence of the user group is not required*
√	partially remote	*the presence of the user group is required at some stage e.g. installing and un-installing*
	in person/hands on	*the presence of the user group is required/recommended during the whole access period*

If you wish to avail also of a support facility from Chapter 2, please fill in the table below

		Short name	Requested access time (UA*)
	Supporting facilities and specialized equipment		

**UA: please refer to the Infrastructure description in the JERICO-S3 website*

Modality of access

	remote	*the measuring system is implemented by the operator of the installation and the presence of the user group is not required*
	partially remote	*the presence of the user group is required at some stage e.g. installing and un-installing*
	in person/hands on	*the presence of the user group is required/recommended during the whole access period*

Explain briefly why you think your project will be best carried out at the specified host facility(ies)	Due to the deep waters available near the facility, SOCIB represents the most appropriate choice. We have also already been in touch with the hosts to ensure the feasibility of the project.
If possible, list other JERICO-S3 facility(ies) where you think your experiment could alternatively be carried out	Other glider facilities are also possible, even some changes to the project may be needed, e.g. CNRS/GNF, MI/SmartBay and TALTECH/Glider Mia + profiler.

Is there a facility similar to one/all those you wish to utilize in your country?	√	Yes		No
If yes, please indicate your reasons for requesting access to the JERICO-S3 facility(ies) you have chosen and also exist in your country	The UK National Oceanography Centre is a similar facility. However, finding funds for short projects is challenging. The SOCIB location near deep waters is also superior.			

4. REQUEST FOR A JERICO-S3 GRANT

(tick the box)

√	**Travel grant** (*)
	Shipment of your equipment, if applicable

(*) travel, hotel and meals

Please provide a detailed and realistic budget for the expenses you expect to incur, including the number of people and days required. Explain clearly the role of each person for which a travel grant is requested.

Please note that a base amount of 3000-6000 € has been set for each facility involved in a TA project. The effective grant assigned to a project will be considered case- by-case depending on the type of access, the types and number of facilities requested, the length of stay, and the costs in the visited country.

- Travel : 2 return flights from London to Mallorca, €1,000
- Hotel : 14 nights (& breakfast) in Mallorca for 2 people, €2,800
- Meals : 14 lunch & dinner meals in Mallorca for 2 people, €1,120
- Total: €4,920

PART 2

Note: This part contains material for the evaluation

1. SCIENTIFIC EXCELLENCE OF USER GROUP
(maximum score: 5)

Short biography of the PI ***(half a page)***

Dr **Enrico Anderlini** (**EA**) is a senior research fellow in the Marine Research Group at University College London (UCL) in the UK. His research focuses on the dynamic modelling and control of autonomous underwater vehicles and wave energy converters, with a special interest in data-based strategies. **EA** has collaborated with the UK National Oceanography Centre (NOC) on the automation of their underwater glider operations since January 2018. In particular, he has designed a recommender system to help pilots trim Seagliders correctly and select the parameters for their on-board flight model and a fault detection tool for underwater gliders, enabling round-the-clock operations. Both the recommender system and the condition monitoring tool are being included within the NOC's C2 software with the help of Marine Autonomous and Robotics Systems group.

The positive outcomes of his work have enabled **EA** to build capability through the award of a Lloyds Register Foundation: Assuring Autonomy International Programme (AAIP) grant to develop smart fault diagnostics solutions for marine autonomous systems in collaboration with NOC (£167,425.45) in addition to NOC co-funding a PhD studentship under his supervision (£53,496.58) Additionally, **EA** has already successfully completed a Transnational Access Scheme with EUMarineRobots (EC/731103) to investigate the impacts of biofouling on underwater gliders, in collaboration with the Oceanic Platform of the Canaries, which led to the development of innovative methods for the detection and characterisation of marine growth on underwater gliders.

Expertise of the user group in the domain of the application ***(half a page)***

The Marine Research Group (MRG) within the Department of Mechanical Engineering at UCL focuses on research in the areas of maritime engineering and naval architecture with international strength in ship design, alternative power strategies for transport, fluid mechanics, environmental challenges and low carbon shipping. To strengthen links with industry, support is given for the BMT Chair of Marine Engineering and a Ministry of Defence (MOD) professorship. This enables the department to stay at the cutting edge of some of the most challenging engineering problems.

The PI has recently created new avenues of investigation for the MRG in fault adaptive control and intelligent maintenance systems for marine autonomous systems. The user group is complemented by Co-I Dr **Peng Wu**, who is developing smart fault diagnostic systems for underwater gliders as part of project ALADDIN: "Assuring Long-term Autonomy through Detection and Diagnosis of Irregularities in Normal operation (ALADDIN)" (funded by the AAIP). Dr **Wu** recently completed his PhD on decarbonising coastal shipping using fuel cells and batteries at the MRG before joining the user group in July 2020. Additionally, Mr Davide Grande, who joined the group in April 2020 as a PhD student, will help with the preparation of the methods for the project.

A list of 5 recent, relevant publications of the user group in the field of the project

1) **E Anderlini**, D A Real-Arce, T Morales, S Woodward, C Barrera, JJ Hernandez-Brito, AB Phillips, and G Thomas, "Identification of the Dynamics of Biofouled Underwater Gliders", *IEEE OES AUV Symposium*, St John's, NL, Canada, October, 2020, accepted September 2020.
2) **E Anderlini**, CA Harris, G Salavasidis, A Lorenzo, AB Phillips, and G Thomas, "Autonomous Detection of the Loss of a Wing for Underwater Gliders", *IEEE OES AUV Symposium*, St John's, NL, Canada, October, 2020, accepted September 2020.
3) **E Anderlini**, CA Harris, AB Phillips, A Lorenzo-Lopez, M Woo and G Thomas, "Towards Autonomy: A Recommender System for the Determination of Trim and Flight Parameters for Seagliders", *Ocean Engineering*, 189, October, pp 106338, 2019, doi: 10.1016/j.oceaneng.2019.106338.
4) **E Anderlini**, CA Harris, M Woo, and G Thomas, "A new recommender system for determining trim and flight parameters of Seagliders", *29th ISOPE*, Honolulu, HI, USA, 2019.
5) **E Anderlini**, GG Parker and G Thomas, "Docking Control of an Autonomous Underwater Vehicle Using Reinforcement Learning", *Applied Sciences*, *Special Issue Underwater Robots in Ocean and Coastal Applications*, 9 (17), pp 3456, 2019, doi: 10.3390/app9173456.

2. SCIENTIFIC AND TECHNICAL VALUE OF THE PROJECT
(maximum score: 5)

Description of the project

Main objectives *(half a page)*

The aim of the project is to validate methods for the smart fault detection, isolation and recovery for underwater gliders. The project outcomes will help increase the reliability of these platforms and help over-the-horizon pilots continue deployments even after noncritical faults, thus contributing to the assurance of the operations of marine autonomous systems (MAS).

The project will be achieved through the following objectives:
O1 Introduction of data-driven methods for the fault diagnostics of MAS (as part of project ALADDIN funded by the AAIP);
O2 Creation of solutions for the over-the-horizon control of underwater gliders after noncritical faults, in particular considering the case studies of a glider
- suddenly losing one wing;
- being incorrectly ballasted and trimmed.

O3 Validation of the tools for both case studies with the actual field test of an underwater glider.

Scientific background and rationale *(one page)*

Whilst autonomous systems are predicted to become pervasive in the maritime industry [1], a fundamental problem operators face is difficulty in accessing them, e.g. MAS need to be self-reliant when at sea. MAS depend on limited sensor data to identify adverse vehicle behaviour, which may be caused by faults, e.g. mechanical failures, strong environmental disturbances, ocean eddies, or a combination thereof [2]. If the underlying cause cannot be correctly diagnosed and the situation remedied, the vehicle can be lost or present a hazard to other sea users. Hence, the vehicle must be recovered, which can incur in significant costs and delays to the mission.

Underwater gliders represent a type of autonomous underwater vehicles that can be deployed for months at a time thanks to their efficient propulsion system for the exploration, study and monitoring of the oceans [3]. Nowadays, to meet the scientific objectives of the deployment, pilots monitor and command the gliders to a new way point after each dive through dedicated over-the-horizon infrastructures [4]. However, commanding gliders in the presence of strong ocean currents or noncritical faults requires significant expertise, with novice pilots struggling. An example of a noncritical fault is the loss of one wing, as studied in [5]. In this case, to control the glider after the anomaly, pilots resort to either
- using the full setting on the variable buoyancy device (VBD), the means to control the glider's change in buoyancy, thus incurring high power expenditure and a dramatic shortening of the deployment duration, or
- retrieving the vehicle at sea, which is extremely expensive and would end the deployment.

An additional challenge that over-the-horizon pilots face is the incorrect ballasting and trimming of gliders. Although the vehicles are ballasted and trimmed in a dedicated tank before deployments, it is possible for modifications to be made at sea on the research vessels deploying the gliders or a glider may be recovered mid-mission and redeployed with a different sensory configuration.

Additionally, the oil bladder of the VBD may be positioned incorrectly, so that it extends outside of the hull mostly on only one side. In these cases, the net buoyancy and heel and trim angles of the glider at rest may be affected, causing the pilots challenges similar to the loss of wing in controlling and commanding the vehicles during a deployment.

Here, for the first time, a novel method will be introduced for the over-the-horizon control of underwater gliders after noncritical faults, including the selection of the settings of the VBD and pitch control system and the specification of the next waypoint. Hence, no changes will be made on the actual vehicles, whilst the system is designed to help pilots monitor gliders remotely within the existing infrastructure. In particular, the process will be split as follows:

- the dynamic model of the underwater glider [6], whose parameters will be estimated through system identification, is embedded in an unscented Kalman filter (UKF) and used to predict the emergence point after the dive given the input VBD and pitch control settings and the impact of ocean currents, whose magnitude and direction is estimated through the gliders' current and past measurements in addition to remote sensing data, e.g. by satellite;
- the multi-objective optimisation of the mission planning to maximise deployment time in the area of interest whilst considering energy expenditure and marine traffic avoidance by optimally selecting the next way points using deep reinforcement learning [7-8]. The competing objectives will be included in a single reward function.

The field test is instrumental for the validation of the algorithms as well as the validation of novel data-driven methods for the fault diagnostics of MAS based on generative adversarial networks [9], developed as part of project ALADDIN. The smart fault diagnostics and mission planning approaches will greatly simplify the pilots' tasks, thus enabling round the clock operations and the control of a greater number of gliders per pilot.

References:

[1] Department for Transport, "Technology and Innovation in UK Maritime: The case of Autonomy", London, UK, 2019.

[2] CA Harris, AB Phillips, C Dopico-Gonzalez, and MP Brito, "Risk and Reliability Modelling for Multi-Vehicle Marine Domains", *IEEE OES AUV Symposium*, 2016.

[3] DL Rudnick, "Ocean Research Enabled by Underwater Gliders", *Annual Review of Marine Science*, 8(1), pp 519–541, 2016.

[4] CA Harris, A Lorenzo-Lopez, O Jones, JJ Buck, A Kokkinaki, S Loch, T Gardner, and AB Phillips, "Oceanids C2: An Integrated Command, Control, and Data Infrastructure for the Over-the-Horizon Operation of Marine Autonomous Systems", *Frontiers in Marine Science*, 7, June, 2020.

[5] **E Anderlini**, CA Harris, G Salavasidis, A Lorenzo, AB Phillips, and G Thomas, "Autonomous Detection of the Loss of a Wing for Underwater Gliders", *IEEE OES AUV Symposium*, St John's, NL, Canada, October, 2020, accepted September 2020.

[6] L Merckelbach, A Berger, G Krahmann, M Dengler, and JR Carpenter, "A dynamic flight model for Slocum gliders and implications for turbulence microstructure measurements", *Journal of Atmospheric and Oceanic Technology*, 36, pp 281–296, 2019.

[7] **P Wu**, J Partridge and R Bucknall, "Cost-effective reinforcement learning energy management for plug-in hybrid fuel cell and battery ships", *Applied Energy*, 275, pp115258, 2020.

[8] **E Anderlini**, GG Parker and G Thomas, "Docking Control of an Autonomous Underwater Vehicle Using Reinforcement Learning", *Applied Sciences*, *Special Issue Underwater Robots in Ocean and Coastal Applications*, 9 (17), pp 3456, 2019.

[9] T Schlegl, P Seeböck, SM Waldstein, G Langs and U Schmidt-Erfurth, "f-AnoGAN: Fast unsupervised anomaly detection with generative adversarial networks", *Medical Image Analysis*, 54, pp 30-44, 2019.

3. QUALITY OF THE WORK PLAN
(maximum score: 5)

Experimental method and work plan

Describe below the proposed method and work plan for the project

(one page)

The project is subdivided into the following work packages:

WP1: Methods development. Timing: October 2020 to February 2021.

New solutions will be developed to control underwater gliders over the horizon, where the control outputs are the desired VBD volume in descents and ascents, the desired pitch angle in descents and ascents and the coordinates of the next waypoint. The gliders' current and past measurements in addition to remote sensing data, e.g. by satellite, will be used to estimate the disturbance caused by ocean currents over the water-column. The method will include model-based system identification and a deep reinforcement learning algorithm for optimal mission planning.

The algorithms will be developed building on UCL's existing dynamic models for underwater gliders and implemented in Python. The techniques will be trained and verified using data from many past underwater glider deployments available through the BODC [1].

WP2: Validation during the TNA field tests. Timing: February 2021 – three weeks.

To validate the performance of the algorithms in detecting and identifying faults and guiding underwater gliders optimally, the field tests will include the following experiments:

- Deployment of a healthy underwater glider to identify its specific model parameters – seven days duration;
- Retrieval of the glider at sea and redeployment after removing the right wing – two days
- Retrieval of the glider at sea and redeployment after reconnecting the right wing and removing the left wing – two days;
- Retrieval of the glider at sea and redeployment after reconnecting the left wing and adding a ring at the stern (in front of the rudder) with a mass on the right side to simulate a misballasted glider with an angle of heel and trim. The ring will be made of a snap tie coated with heat shrink to reduce friction and avoid the small mass from touching the gliders' hull. Calculations and measurements will be made to ensure that the glider is safe to operate even after the addition of the mass – three days;
- Retrieval of the glider at sea and redeployment after rotating the mass to the left side – two days.

Depending on the operational practices of SOCIB, the idea would be run three yos per dive, starting with a maximum depth of 200m and then moving up to 1,000m (after the initial set-up dives). For the waypoint selection, the pilot will enter the coordinates manually, selecting the recommended values provided by the algorithm. However, if the results are unrealistic or dangerous, e.g. due marine traffic, the pilot can override the system.

The success for the fault diagnostic will be quantified through the accuracy in detecting and identifying the fault, with a 95% accuracy of correct labelling within the first new dive expected. The measure of success for the mission planning algorithm is quantified through the energy consumption during each experimental stage and comparing it with the past missions data available through the BODC portal.

References

[1] BODC, "Glider inventory," 2019. [Online]. Available: https://www.bodc.ac.uk/data/bodc_database/gliders/.

Proposed time schedule

Provide below a clear schedule for your project including interruption, restarts and expected duration of access time

(half a page)

The field test would ideally run in February 2021 after discussions with the host, although we can be flexible with dates.

- Initial deployment of healthy glider – 7 days starting on a Monday – remote – **N.B.**: *It is possible to combine the project with an additional JERICO or other project, which runs before it. In this case, the previous deployment of the healthy glider is not required if the other users are happy to share the engineering data of the glider. This would save one week of tests in addition to the money required for two separate projects. A similar expedient was trialled successfully sby the PI as part of a field test for EUMarineRobots.*
- Deployment of the glider with no right wing – 2 days starting on the Monday of week 2 – in person;
- Deployment of the glider with no left wing – 2 days starting on the Wednesday of week 2 – in person;
- Deployment of the glider with angle of heel to starboard and trim to the stern – 3 days starting on the Friday of week 2 – in person;
- Deployment of the glider with angle of heel to port and trim to the stern – 2 days starting on the Monday of week 3 – in person.

The plan leaves an allowance of two days for unforeseen circumstances or bad weather.

Travel plan to the host facilities:

- Departure on Sunday of week 1;
- Return on Saturday of week 3.

Please specify your requests regarding the use of your chosen facility's equipment/instruments/sensors, including any additional services, data or other requirements

- Slocum underwater glider with standard CTD sensory suite – no preference on G2 or G3 types or pumped or unpumped CTD.
- Boat to deploy and recover the glider – preferably a RIB if the weather is mild.
- No preference on the deployment location, although major shipping routes should be avoided.

List all material/equipment you plan to bring to the facility (if any)

- Bespoke ballasting ring, which comprises a snap tie, heatshrink coating to increase friction, and a small mass (<50g) secured through fishing line. The mass and displaced volume of the ring will be accurately quantified to prevent causing serious concerns for the underwater glider. No transportation costs will be billed to JERICO.

Risks, contingencies and mitigation measures

Describe below the potential risks and contingencies that might occur during the project and how do you plan to avoid, mitigate or resolve them

#	Risk / Contingency	Prevention / Mitigation / Corrective action
1	Bad weather causes delays in the deployments	A margin of two days is included in the project plan. As the field testing includes symmetrical loading cases, only one case may be considered, giving precedence to the test with the loss of wing.
2	The mission planning algorithm returns unrealistic control input values (VBD and pitch control settings and next waypoint).	The algorithm will be extensively tested in a simulation environment before the field test. The expert pilots of the host facility can override the proposed control settings if they are seen as unfeasible or unsafe.
3	Risk of potentially damaging or losing the glider.	SOCIB have already been consulted on the project plans. The deployment areas and parameters, e.g. maximum depth, will be selected only in accordance with the host institution and listening to their suggestions. The PI has already undertaken training in the operation of underwater gliders (PLOCAN Glider School). The ballasting mass will be lower than 50g.
4	Risk of injury to the participants.	The user group will receive a safety induction by the host institutions. Deployments at sea will be made only if the host institution establishes that it is safe to do so.
5	Delay due to Covid-19	The timing of the field test is flexible and the user group are happy to agree on new dates with the host institution.

4. POTENTIAL FOR SEEDING LINKS WITH INDUSTRY
(maximum score: 5)

Do you think that this proposal has potential for seeding links with Industry? If so, how?

(half page)

By leveraging off the activities of project ALADDIN and its industrial stakeholders (Lloyds Register, Blue Ocean Monitoring and the UK Maritime Coastguard Agency), project FRONTIERS will have direct industrial impact. By validating the smart fault diagnosis and mission planning methods, the project will contribute to the assurance of MAS. The proposed methods are of high interest to Blue Ocean Monitoring, a private company specialising in the monitoring of the oceans with MAS. By being early adopters, Blue Ocean Monitoring will spark interest in the technology to other companies. Additionally, the outcomes of the project will inform Lloyds Register's, a global classification society, drafting of standards for marine autonomy.

The user group will include the project outcomes within the contribution to the Body of Knowledge on the assurance of Robotic and Autonomous Systems that form part of the deliverables of project ALADDIN.

5. EUROPEAN RELEVANCE AND INTERESTS FOR THE SCIENTIFIC COMMUNITY
(maximum score: 5)

Describe the relevance of your proposal at the European level and the potential interests for the research community

(half page)

This work feeds directly into the Blue Growth economy ambitions of the EC. In particular, the ability to conduct extensive and reliable underwater glider observations are an integral part of the Blue Growth visions of marine knowledge and integrated maritime surveillance.

The scientific use of underwater gliders is dependent on the vehicles operating reliably. Hence, the outcomes of project FRONTIERS are highly relevant not only for the fault detection, isolation and recovery community, but especially for the oceanography community. To reach both research audiences, the project results will be disseminated in a journal article in the highly ranked Engineering Applications of Artificial Intelligence (intelligent maintenance systems community) and presented at the IEEE OES Oceans 2021 international conference (oceanography community). Additionally, the project outcomes will be shared by the user group directly with their European collaborators, which include the National Oceanography Centre and the Oceanic Platform of the Canaries and by the host institution through JERICO.

GDPR Consent:

Personal data : I hereby understand that the JERICO-S3 project - through the Marine Institute, acting as the Work Package Leader for TransNational Access has needed to collect some of my personal information and data for the means of processing my application for Funding under the Jerico S3 project TransNational Access funding call.

Application processing: The Marine Institute will gather and securely store your data. Access will be restricted to required personnel as well as selected qualified external evaluators who will determine successful applicants. Data will be stored on Marine Institute servers onsite at the Marine Institute, Rinville, Oranmore, Galway, Ireland for the duration of this project which should last 4 years. The data will be deleted thereafter. Your data will not be used for any other purpose without your consent.

1. Privacy Policy: *JERICO-S3* is the data controller pursuant to article 28 of the EU GDPR (EU 2016/679), – *Ifremer Brest Centre, CS 10070 29280 Plouzané France, the Project Coordinator is Laurent DELAUNEY. MAIL Jerico-S3@ifremer.fr JERICO-S3: If you change your mind at any time, you can unsubscribe by contacting us at mailto: Jerico-S3@ifremer.fr. We will treat your information with respect.*

2. *TYPES OF DATA PROCESSED Personal and identification data - Personal data, any information relating to an individual, identified or identifiable, even indirectly, through reference to another piece of information, including a number of personal identification; Identifying data, personal data that includes the direct information of the interested party (such for example name, surname, e-mail address, address, number of telephone, etc ...). Defence in court - The User's Personal Data may be used for defence purposes on the part of the Owner in court or in the preparatory phases to his possible establishment, from abuse in the use of the same or the connected services by the User.*

Date of compilation	24/09/2020
Signature of the PI	Enrico Anderlini — Digitally signed by Enrico Anderlini Date: 2020.09.24 16:31:11 +02'00'
Signature of an appropriate authorised person (e.g. Head of Department, Research Office)	Professor Giles Thomas, Chair, Marine Research Group, UCL

This section is reserved to the JERICO-S3 TA Office	
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Signature of receiving officer	______________________