

# Autonomous Biomimetic Robot-Fish for Offshore Wind Farm Inspection “RoboFish”

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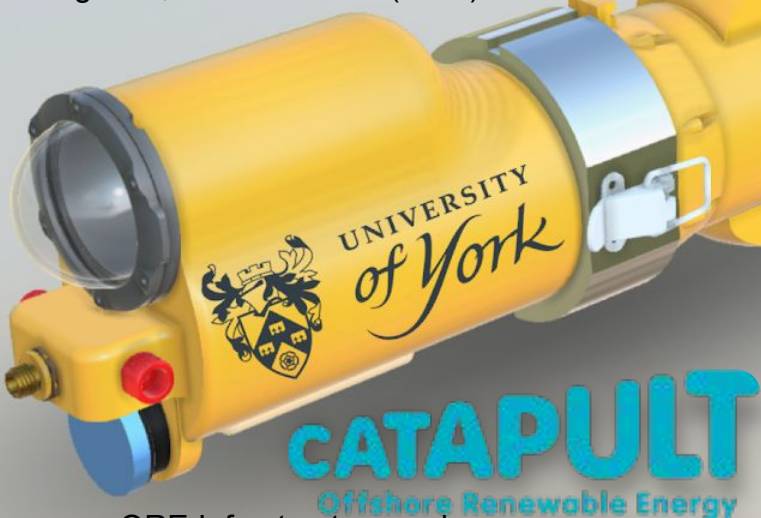


# Introduction



UNIVERSITY  
*of York*

Project Coordination; Robotic  
System Design; Sensing and  
Navigation; Outdoor Trials (Lake)



ORE Infrastructure and  
Requirements Guidance; Industry Connections

Supergen



Offshore  
Renewable  
Energy

R&D Funding; Links to ORE  
Applications; Stakeholder  
Meetings



University of  
**Strathclyde**  
Glasgow

**PICSEA**

Ocean Data Automation

High-Fidelity  
Modelling;  
Mechanical  
Design/Sim;  
Movement Control;  
Validation &  
Optimization

EC-OG



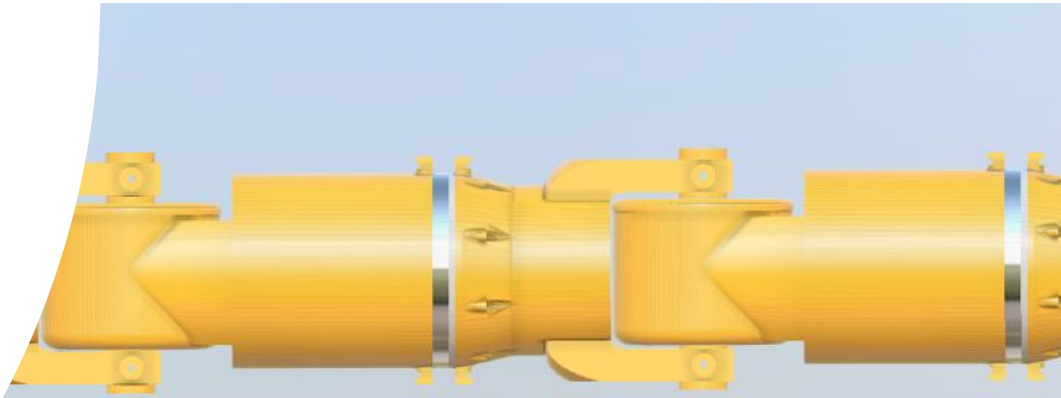
Power & Energy Storage; Subsea  
Engineering & Interfacing/Docking

Technical Expertise;  
Subsea imaging;  
Marine Operations;  
Logistics;

# Why Bio-inspired AUV?

Offshore wind farms provide clean, reliable and commercially viable energy. To ensure reliable production, regular Inspection Maintenance and Repair (IMR) tasks at high sea up to 100m depth need to be performed in a **cost effective** and **safe** manner. To extend Autonomous Underwater Vehicle (AUV) intervention time and perform IMR tasks the AUV needs to be efficient and flexible in operation.

A biomimetic AUV, capable of autonomous navigation about dense and moving underwater structures, can continuously and autonomously locate and monitor structural damages **in limited spaces**. A fish-like AUV with a **modular design** can provide higher specific thrust efficiency at low swimming velocities and higher **manoeuvrability** in critical spaces during sensor data acquisition.



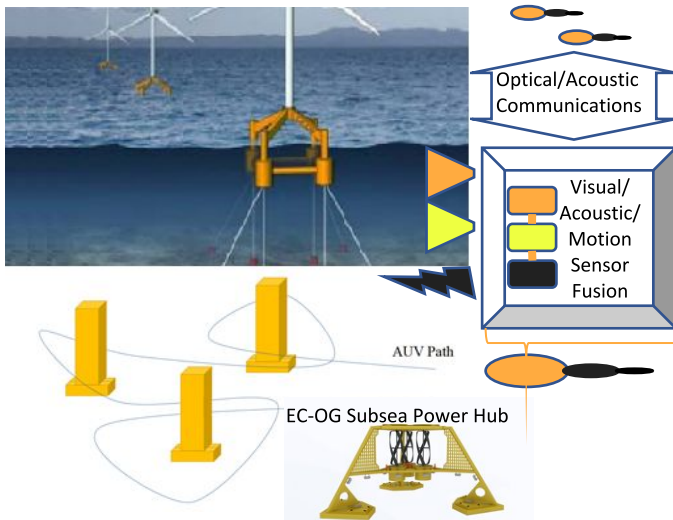
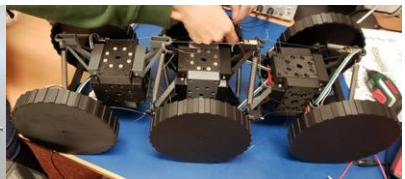
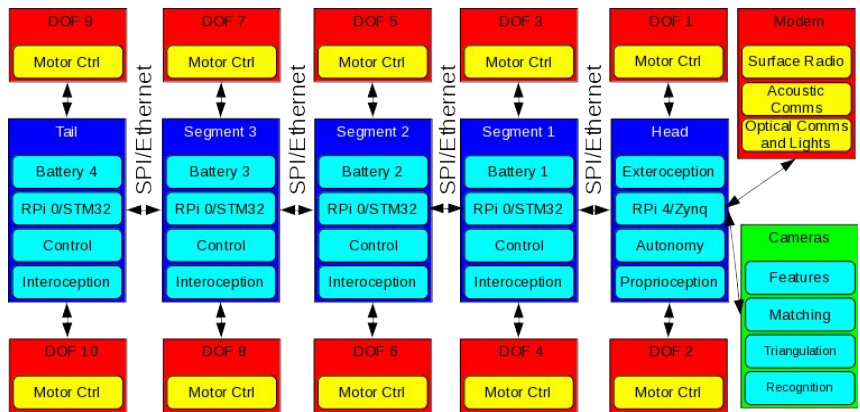
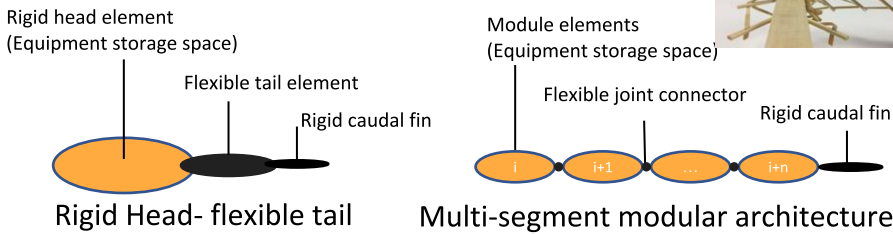
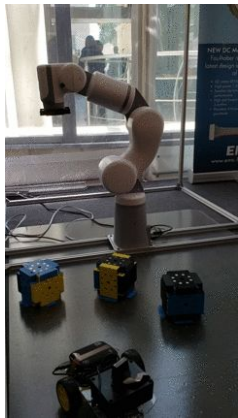


**Modular, Self-Aware, and Self-Configuring Autonomous Systems**

- RoboFish will build on a self-configuring modular architecture
- Segments will be autonomic cellular elements that operate in unison as a complete “organism” and are fault tolerant

**Adaptable, Bio-Inspired, Robust Robots for Harsh Environments**

- RoboFish will maneuver and dock using a flexible, adaptable body
- Designs include the use of “biotensegrity” and smart materials



**Robofish** is a biomimetic AUV capable of self-sufficient navigation about underwater structures

- It is intended for the purpose of locating and monitoring structural damage to wind farms.
- It moves like an eel/trout through full-body movement, allowing high agility in proximity.
- Its first 3D printed prototype could be spun out to a successful commercial product.

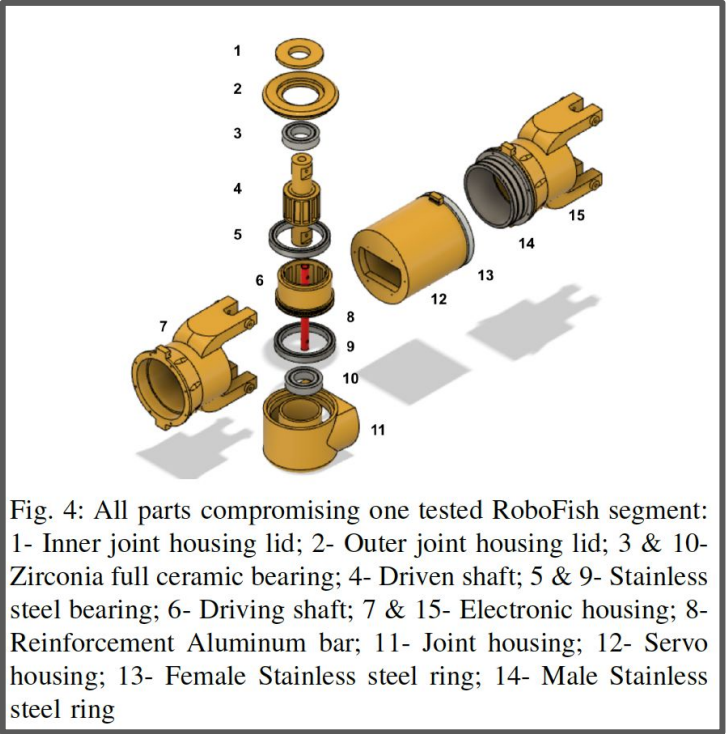
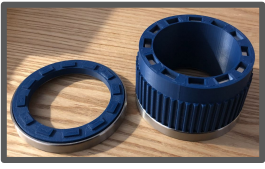
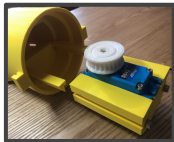
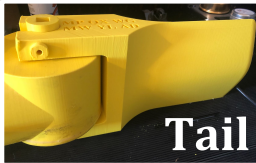


Fig. 4: All parts compromising one tested RoboFish segment:  
1- Inner joint housing lid; 2- Outer joint housing lid; 3 & 10- Zirconia full ceramic bearing; 4- Driven shaft; 5 & 9- Stainless steel bearing; 6- Driving shaft; 7 & 15- Electronic housing; 8- Reinforcement Aluminum bar; 11- Joint housing; 12- Servo housing; 13- Female Stainless steel ring; 14- Male Stainless steel ring



**Magnetic**

**joint**

technology

was

developed as a solution for a watertight jointed and 3D printed body.

- The design avoids dynamic interfaces and rotary seals.
- Magnetic blocks bond a free rotating inner shaft and a driven outer shaft for the joint to work.
- To provide 3D printed parts with the toughness and tolerance that O-rings need, two stainless-steel rings are incorporated in each segment as an intermediate connection and to allow disassembly.

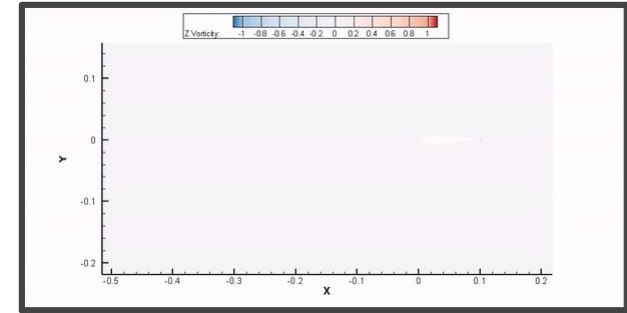
**Modular System** RoboFish uses a modular software and hardware architecture.

- Each segment is self-contained and includes self-managed battery power, and actuator control using a low-cost microcontroller.
- Communications and power transfer between segments is through Ethernet and ZeroMQ messaging.
- The head segment contains a powerful Xilinx Zynq SoC that serves as a master control node, communications router, and FPGA-accelerated vision platform
- An acoustic rangefinder adds obstacle and target ranging to monocular vision.
- An acoustic modem provides low-rate communications at medium range for remote control, telemetry, and inter-vehicle coordination.

EC-OG Halo Energy Gateway

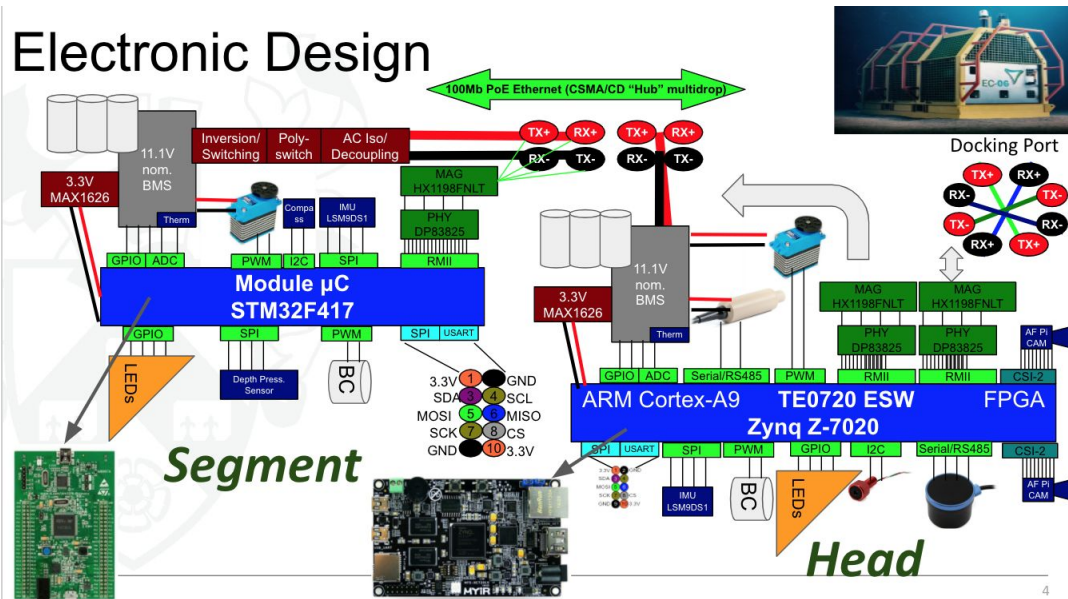


Wind Farm



CFD/FSI model of bio-inspired robotic fish created in the project

## Electronic Design



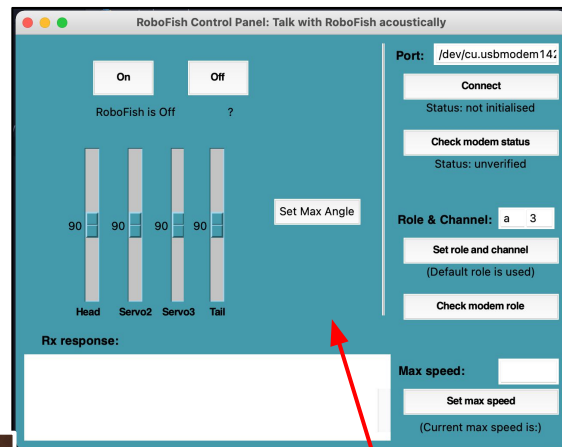
**Hydrodynamic Control** is accomplished through control derived from CFD/FSI study of swimming movement.

- Various swimming gaits are possible
- High agility, mitigates risk of fouling
- High efficiency in placement of the head can be achieved for docking

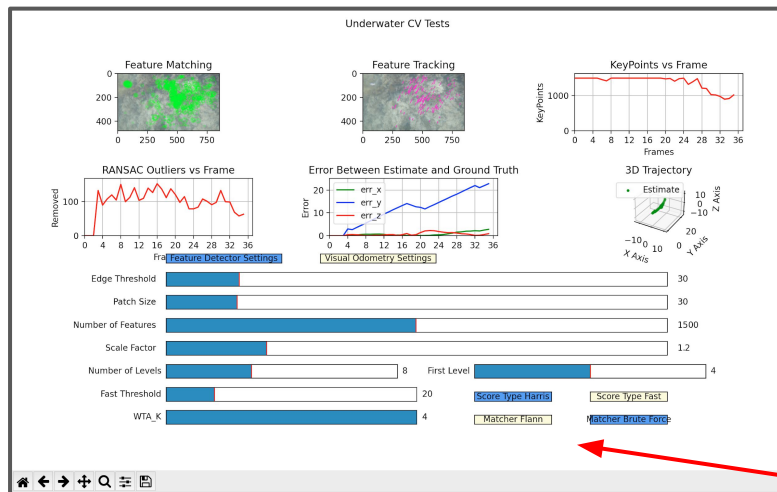


## Acoustic Communication & Computer Vision

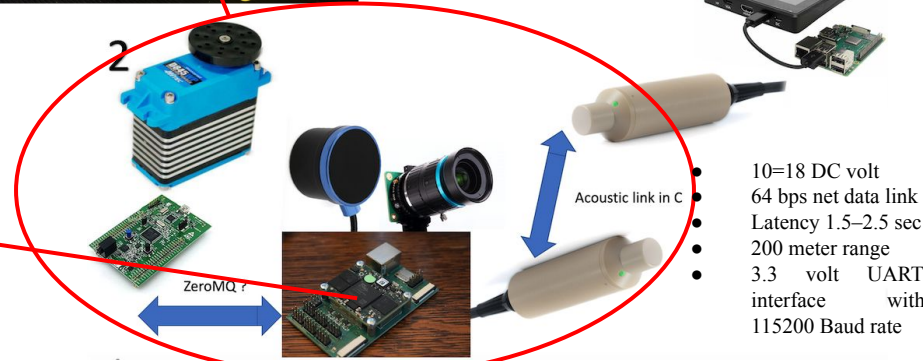
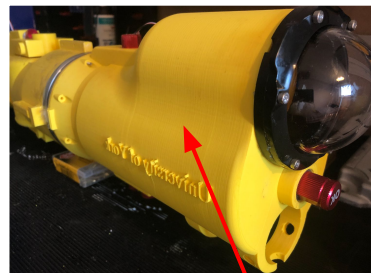
- The RoboFish-specific powerful Xilinx Zynq SoC is designed to serve as a master control node, communications router, and FPGA-accelerated vision platform and convert various range of DC voltages to the modems, rangefinder and camera..
- A half-duplex 64bps acoustic modem, called M64, provides low-rate communications at medium range for remote control, telemetry, and inter-vehicle coordination. A working Python GUI has been developed to run the RoboFish manually from a distance over the acoustic link. The modem has a configurable data link and can be used to implement other MAC protocols.
- Another working Python GUI, running a computer vision algorithm based on pattern recognition has been created. It trains a computer on a massive amount of visual data, labels objects on them, and finds patterns in those objects.



GUI to acoustic modem interface for manual remote control



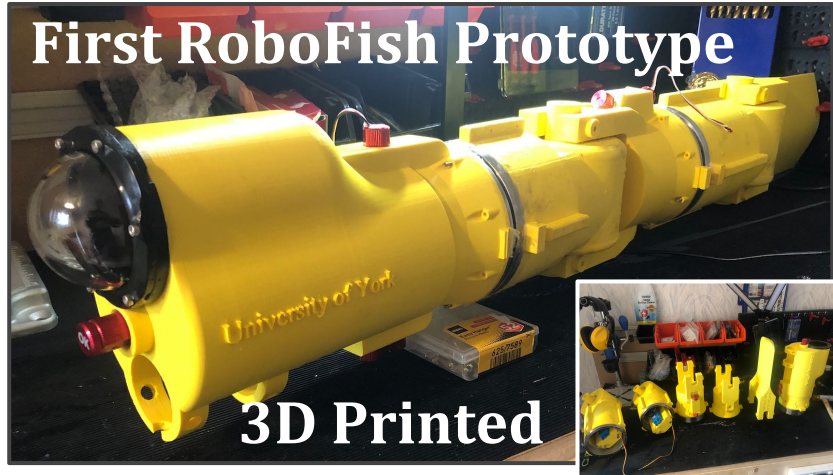
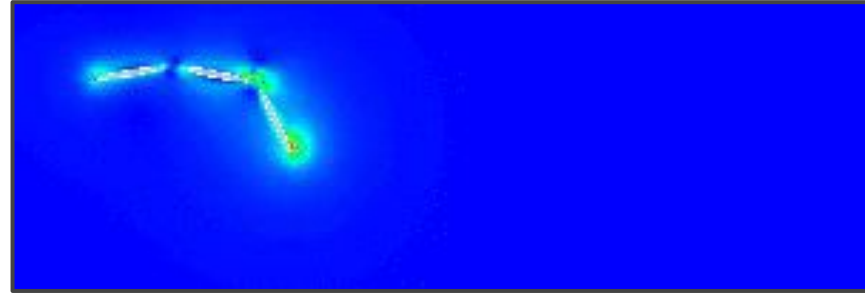
Testing an accelerated visual perception for underwater environments (YORK\_UNI\_DATASET)



**Initial Lake tests** proved water-tightness, joint functionality and body propulsion. Acoustic communication and rangefinding worked successfully in a tank. FPGA-accelerated visual software & hardware, and the rest of electronic system have all been designed & put together ready for field tests.

**Future:** The use of modular electronics & actuation, networking architecture, 3D printing approach, and most of all the magnetic joint design are novel contributions to the state of the art that will enable new opportunities and future research projects.

New versions of a smaller size RoboFish, with particular focus on modularity, provide a flexible platform for numerical data validation & experimental investigation within a towing tank, providing further insight to disseminate the hydrodynamic performance under different flow conditions, to especially support the targeted underwater docking.



Initial functionality trial at Uni of York lake; body is watertight & actuating with slow propulsion



# RoboFish Impact

RoboFish established itself as a vibrant, dynamic, manufacturing collaborative endeavour, and is already delivering significant benefits that represent just a fraction of its long-term potential. It has brought together leading university researchers, technological companies and future-focused businesses, and generated further fundings, contributions to knowledge & society.

## Collaborations

- Several partners including [University of York](#), [University of Strathclyde](#), [Supergen](#), [PicSea](#), [Catapult](#) and [EC-OG](#)
- Partners are from both industrial and academi
- Collaborations with other researchers and PhD students from robotics, communication, hydrodynamic research groups

## Contribution to knowledge

- Two conference papers were published
- Two journal papers are well underway
- An EPSRC Impact Case study was made
- An larger EPSRC industrial Impact Case study is underway
- Successful studentship projects completed
- RoboFish G drive research resource

## To use with RoboFish

- Python/C
- Fusion360
- EAGLE/kicad
- STM32CubeIDE
- Circuit Design
- System Assembly
- Acoustic Communication
- Computer Vision
- Navigation
- Autonomy
- Control
- 3D printing
- Fluid dynamics

## Further funding

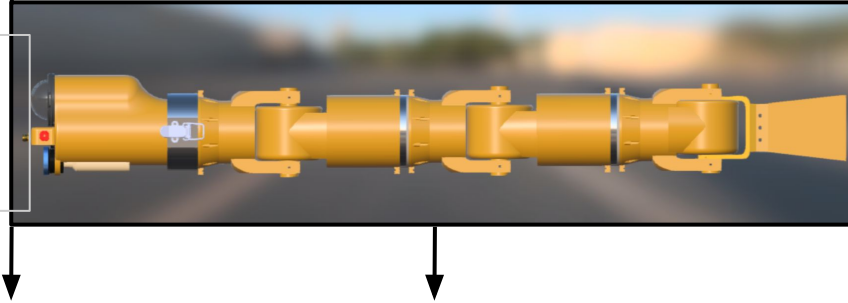
- White Rose Collaboration Fund of £11,000
- EPSRC IAA fund application has been made
- The eventful consortium Skype channel has created a think tank that has suggested numerous useful ideas that helped some of our partners in securing further funding.

## Contribution to Society

- Financial contribution to RA role
- Financial contribution to PhD studies
- Financial contribution to RA role
- [RoboFish webpage](#)
- [outreach lectures](#)
- [group seminar](#)

## Opportunities

- Innovative mechanical & Electronic designs are novel contributions to the state of the art that will enable new opportunities
- Potential future versions of a smaller size RoboFish, with particular focus on the modularity providing a flexible platform for experimental investigations within a towing tank



- [RoboFish WebPage](#)
- [IEEE AUV 2020 RoboFish Paper 1](#)
- [IEEE AUV 2020 RoboFish Paper 2](#)
- [Impact Case Study](#)

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<sup>2</sup> University of Strathclyde, 16 Richmond St, Glasgow G1 1XO

This is a short case study aiming at demonstrating the impact that our emerging RobuSub project has had to enable research that could not have happened without the initial investment from the Flexible Funds, made by the Superfund Remedial Energy Hub. The RobuSub project is concerned with the development of an "Autonomous Underwater Vehicle (AUV) for Offshore Wind Farm Inspection". Inspection tasks of offshore wind farms are currently being done by divers or using "Underwater Remotely Operated Vehicles (ROVs)" which are generally used tothers and a human operator and are limited in their accessibility and maneuverability. The RobuSub project is aimed at developing an autonomous underwater vehicle (AUV) that is able to mimic propulsion techniques observed in nature and exploiting these advantages to facilitate autonomous inspection of offshore infrastructure. Being an agile and efficient biomimetic, this AUV can continuously inspect the structures and components of offshore wind farms, such as nacelles, nacelle yaw, maintenance and operation constraints. It replicates the full-body movement of an eel or trout allowing greater agility in close proximity to structures and better energy efficiency of movement with higher specific thrust efficiency at low swimming velocities.

The Robofish project has established itself as a vibrant, dynamic, collaborative endeavor, and already delivering significant benefits that represent just a fraction of its long-term potential. It has brought together leading university researchers, technological companies and future-focused businesses, and generated further funding, a postdoctoral research associate job, financial contribution to two PhD studies as well as contributions to knowledge and society in the form of publications and outreach activities. The benefits of the Robofish project are not just an economical, efficient means of ORE infrastructure inspection. Lessons learned from the Robofish project range from how to improve the quality of underwater 3D printing, to how to make robotics navigate visually and acoustically underwater. The project outcomes also include new software for control of bio-inspired AUVs.

Pedra, [Caramazza](#) and [Dici](#). Most of these project partners, which are from both business and academic communities, are engaged in a weekly basis or more frequently using a dedicated Skype channel, serving as an on-line resource for the project, media, and communication. The project partners have been also involved in the research, feeding a dedicated open-access [Blog](#) ([http://blogs.ox.ac.uk/oxford-oxford](#)). The project has forged a very strong and collaborative relationship with the [Oxford University Press](#), which has been instrumental in the dissemination of the project by not only attending all meetings but providing a continuous daily flow of new design ideas and suggestions via the consortium Skype channel. D-Ox has also been active in discussions regarding the project with the systems and the design communities. The project has been also very active in the involvement and media, and test field facilities. In support of continuing the research mentioned by [RoboFid](#), [Mark Peck](#) and the consortium members have successfully obtained a [Yahoo! Research Collaboration Fund Grant](#) for the project titled "Intelligent Design: The Oxford-oxford Project". The project has also been awarded an "Inspiration Inspection". This new collaborative project connects the Yorkshire University of [Leeds](#), [Stratford](#), and the [RoboFid](#) project partners in a series of activities aimed at advancing several related researches in the field of intelligent evolution and design. The project has also been instrumental in the development of the interdisciplinary nature of this resulted collaboration.

inspired fish like robot with  
action (FSI) analysis has been  
of material properties and  
hydrodynamic performance and  
design process with focus on  
in CFD control. Bio-inspired

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The detailed investigation of the caudal fin is motivated by the high importance to the maneuverability and thrust generation of the overall design. In [2] Kelassi et al. presented significant thrust improvement and potential power savings provided from a passive caudal fin. Benefits of a

**II. METHODOLOGY**

Computational Fluid Dynamics (CFD) is a powerful tool used in the analysis of fluid problems. It provides a means of solving the Navier-Stokes equations using numerical data to enhance analysis capabilities for optimization in engineering designs. Coupled with the use of a genetic algorithm, the design space can be explored over various structures. In this study, an in-house developed finite volume based CFD solver is coupled with the finite element based structure solver **ANSYS**, using the coupling interface **HyperMesh**. The design optimization is performed using the capabilities of a global optimization tool. The propulsion performance of a subalinal design with certain flexible rigidities. Added PID control to the FSI simulations is to shed light upon the required actuator deflection for the desired swimming speed. The detailed analysis is used to predict swimming speeds. The closed loop controller is used to adjust the generated thrust to equal the incoming velocity and overcome the loading. The design optimization aspects of the actuator parameters are directly related to the power consumption, which provide insight into the power requirements of the robotic fish. The design process, including the optimization design, is shown in Fig. 1.

sh, 3D Printing

reliable and  
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### "Autonomous in Inspection"

Physical Sciences

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model for partition on RedoLog -

Figure 2 Process diagram showing CFD FSI Simulation in overall.

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# Thank You

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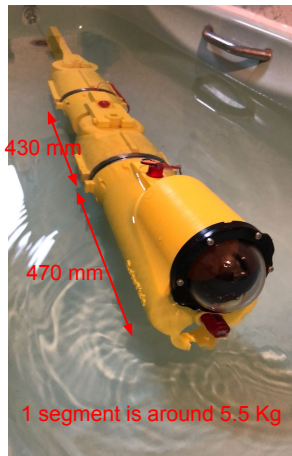


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## Technical Information (Optional)



Echosounder

»WEIGHT  
227.0 g | 8.00 oz

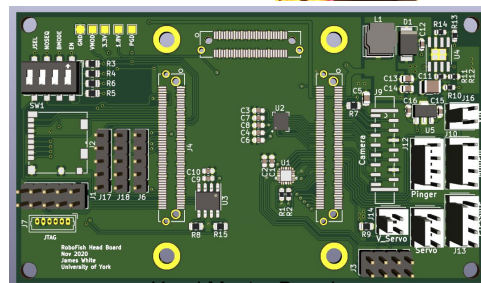
»MAX TORQUE  
50.0 kg/cm | 695.0 oz/in



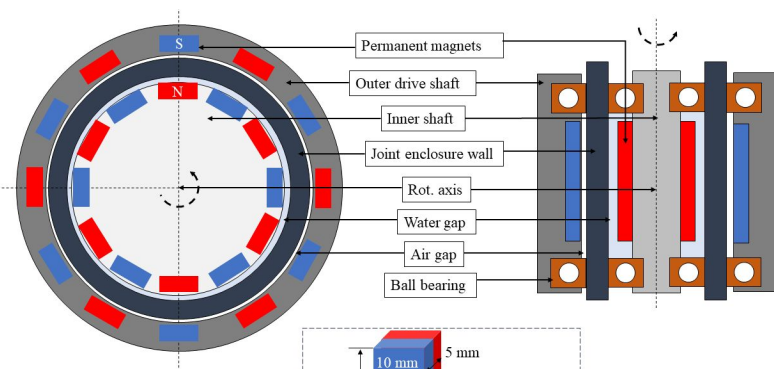
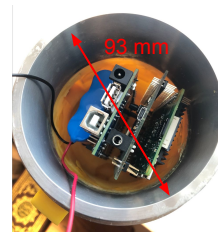
Acoustic Modem

30 mm

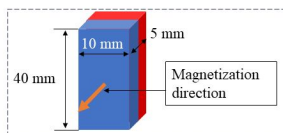
112 mm



Head Master Board



The schematic of the general arrangement of the designed clutch.



The tested joint uses 12 magnetic blocks of (40 mm \* 10 mm \* 5 mm) on the outer shaft and an equal number on the inner shaft of grade N42. With a 100 mm lever, the magnetic coupling appears to break at around 10 Kg load.

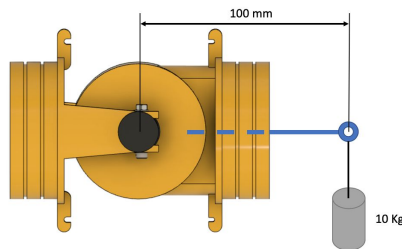
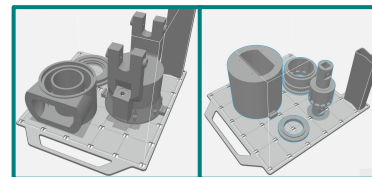


TABLE II: List of the 3D printer parameters

Parameter	Value	Comment
Layer height	0.254 mm	Standard
extrusion width	0.5mm	Standard
Wall thickness	2.032 mm	To print more perimeters per layer
Solid infill	Enabled	To help preventing water ingress
Variable width fill	Enabled	To fill any small gaps
Room temperature	25°	Enclosure

## 3D Printing



## Sanding



## Acetone treatment



## Water-tightness test

