Smartrawl 3.0 Final Report

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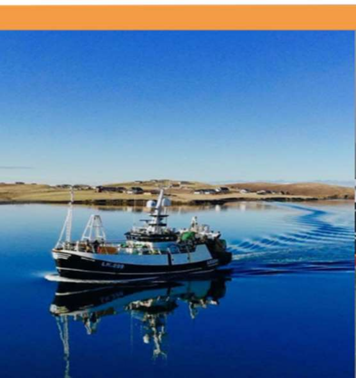

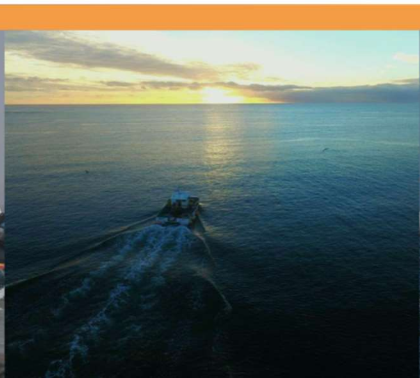


SMARTRAWL 3.0
Final Report

22 MARCH 2022

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UNIVERSITY OF ABERDEEN

by: **Paul Fernandes, Vivek Chacko, and John Polanski**

Front cover. *An image taken in June 2021 of the Smartrawl gate being loaded onto the Atlantia research vessel in Scalloway harbour, Shetland.*

Executive Summary

Smartrawl 3.0 was part of a series of phased projects, to develop a selective device to operate in a demersal trawler allowing for fish to be released in-situ underwater, thus allowing the skipper of the vessel to comply with the landings obligation.

The main objective of Smartrawl 3.0 was to design and build a gate which would allow fish to escape from a trawl if they were not required and retain fish if they were required. Gate designs went though 5 prototypes designs, 3 and 4 of which were built during Smartrawl 3.

Version 4 of the gate was built to full scale and tested at sea in discrete catch and release modes in June 2021.

System integration, whereby the camera, the gate and an underwater modem could communicate was not possible due to the nature of computing requirements. A more sophisticated computer is required to process the image analysis artificial intelligence algorithms to detect and size fish on the stereo camera images. A suitable computer has nonetheless been purchased, and system integration is being carried out in a subsequent phase (Smartrawl 4.0).

Additional data from the stereo camera system was gathered during deployments at sea on the fishing vessel Ceol na Mara. Almost 200,000 images have been collected from a total of 5 deployments of the stereo camera system on fishing vessels in the North Sea.

Analysis of all stereo camera images collected to date was carried out to determine passage rates which is vital for other components of the Smartrawl system. Passage rates varied but were typically low, with 1 organism passing by the camera every few seconds. On occasion when they were high (1 every 0.5 seconds) they were dominated by juvenile fish. Juvenile fish are almost certain to be selected by the cod end mesh size.

A patent for the gate and the rest of the system was submitted. A detailed system description was drafted to support the application. The outcome of the patent search, and therefore any likelihood of it being granted, is due in May 2022.

Contents

Introduction

The Smartrawl is a technological development designed to avoid discards and bycatch in demersal fishing trawls, ensuring that only fish and shellfish that are intended to be landed are caught at sea. The system consists of a stereo camera with lighting in the trawl extension to obtain high quality images of fish traversing into the cod-end through the trawl net. These images will be analysed by an onboard computer to determine the size and species of the fish. A signal is then sent to a 'gate' located in the trawl extension to catch or release the fish: if an unwanted fish is identified, a signal is sent to open the gate and the fish is released back into the wild; if the fish is wanted, a signal is sent to close the gate and the fish passes into the cod end to be captured. This was originally designed to be self-contained without information being passed to the bridge of the vessel. However, an interim modification involves the transfer of information from the stereo camera to the bridge via an underwater communications device (modem).

This report describes Phase 3.0 of the project funded under FIS0 which lasted from April 2020 to December 2021. This phase had the following objectives:

Smartrawl Phase 3.0 objectives

O1 To conduct design analysis and optimisation of the gate mechanism
- 1.1 To conduct detailed CFD flow analysis
- 1.2 To optimise the structural design
- 1.3 To prototype this refined design

O2 To integrate the 3 Smartrawl subsystems: i) camera; ii) gate; and iii) modem
- 2.1 To integrate the camera system, gate mechanism and modem
- 2.2 To test this system in a tank
- 2.3 To deploy on a fishing trawler(s) operating in the North Sea or west coast of Scotland

O3 To enhance and analyse stereo image data
- 3.1 To enhance the stereo camera image library
- 3.2 To analyse previous data to determine fish passage rates in support of O1.3 above.

O4 To patent the invention.

Objective 1: Gate optimisation

The Smartrawl prototype Gate Mechanism for a self-powered mechanical bycatch reduction device was developed based on the discussions carried out with the fishing community as part of Smartrawl 2.0, which connects with the preliminary proposal in FIS011B (Marshall et al. 2017). Two previous phases, namely Smartrawl 2.0 and 2.5, have concluded prior to this phase of the project. As part of Smartrawl 2.0, scale models of the Smartrawl Gate Mechanism (versions 1 and 2) were developed using Computer Assisted Design (CAD); analysed using Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD); and prototyped using a combination of conventional and rapid prototyping techniques. A stereo-camera frame was also developed, fabricated, tested, and deployed successfully. This development process is outlined in Figure 1.

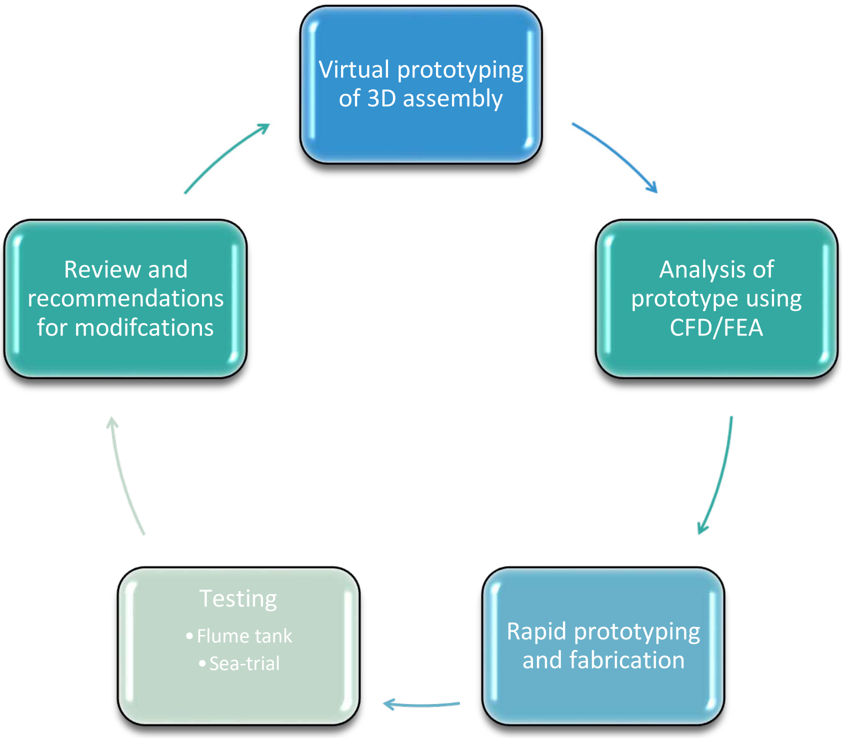

Figure 1 Design development process for the Gate Mechanism

The phases of the Smartrawl project with corresponding versions of the gate prototype are outlined in Figure 2, which demonstrates the iterative process of design refinement.

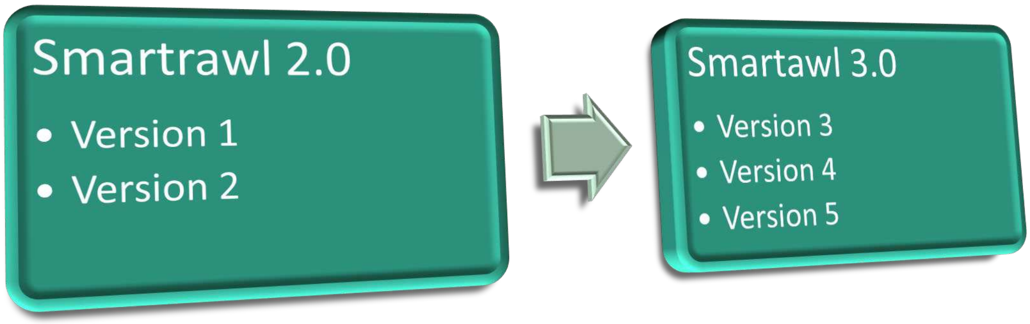

Figure 2 Prototype versions of Gate Mechanism corresponding to the phases of Smartrawl

Objective 1.1. Computational fluid dynamics analysis

Computational fluid dynamics (CFD) was carried out using SolidWorks Flow Simulation to simulate the flow through blade assembly, door, and assembled device. CFD analyses was also used to estimate drag created by the door (e.g., 649.52N) as well as torque generated by flow through the blade (e.g., 54.33Nm). Flow analyses were conducted at a range of speeds from 2.5 – 4knots. Based on the simulation of flow through the circular flat end, it was proposed to modify the profile of this component in version 5 which would reduce the influence of the component in reducing disruption to flow through it which would lead to better flow through the door and consequently, better response times.

Figure 3 shows an example of the CFD analysis conducted for a trawl speed of 4knots. In this figure, water flows along the z-axis (from left to right) at a velocity of 2.058m/s or 4kn and generated a torque of 66.69Nm. As expected, the flow velocity reduces in the vicinity of the cone but remains sufficiently high along its surface, which ensures that marine entities travel in the appropriate direction in catch and release positions. This has been corroborated by the video footage captured during the deployment of version 3 in June 2021. Detailed analysis will be published after the time restrictions in place due to the patent application, and this is estimated to be in Q3 2022.

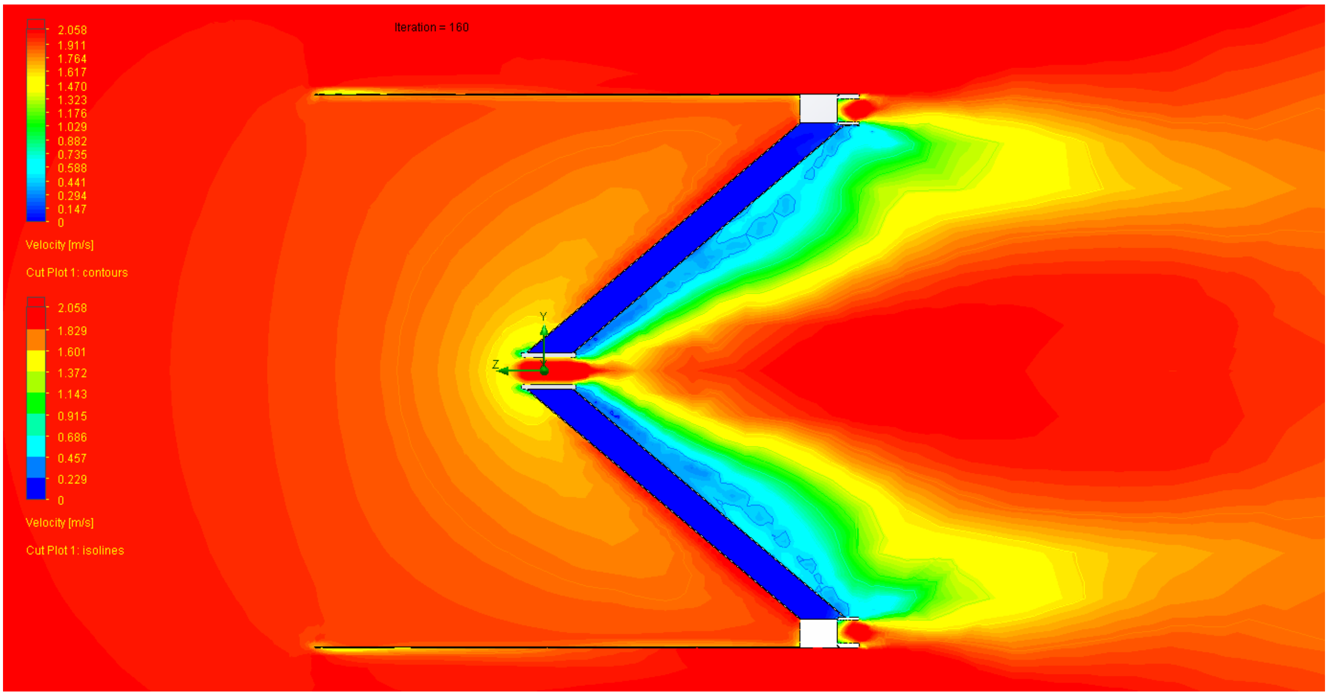

Figure 3 CFD analysis showing the cross-sectional side view of the door

Objective 1.2 Gate design optimisation

The early prototypes were tested successfully in flume tanks located in the University of Aberdeen campus (version 1) and the Marine Institute of the Memorial University, Canada (version 2) as part of Smartrawl 2.0. These tests successfully demonstrated proofs-of-concept for the Gate Mechanism (Figure 4 and Figure 5), in that the device could operate using hydrodynamic power generated by the flow of water as the trawl is dragged through the water.

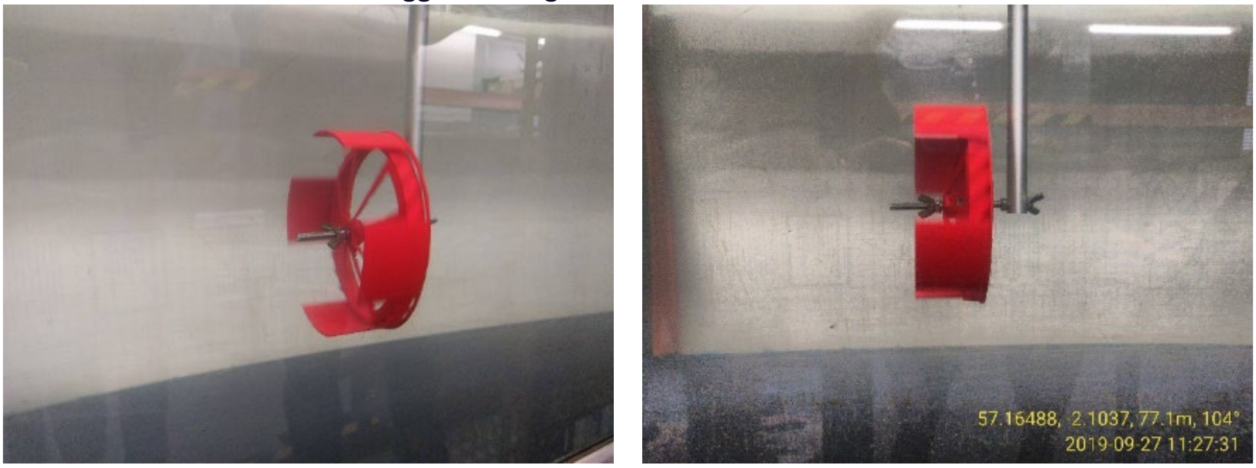

Figure 4 1:8 scale prototype tested in the flume tank in the Meston building of the University of Aberdeen

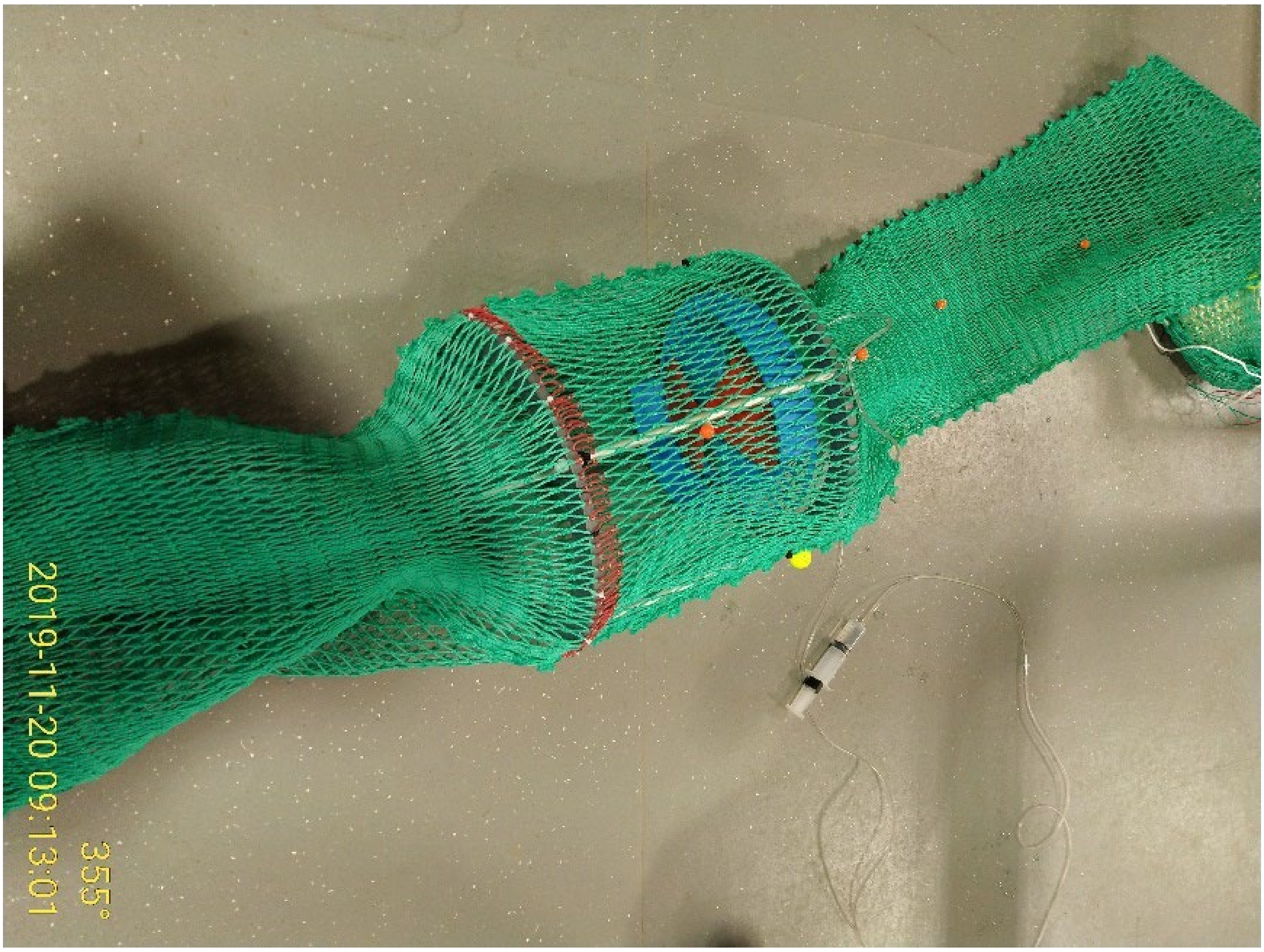

Figure 5 1:4 scale prototype readied for testing in the flume tank in Marine Institute, Memorial University, NL, Canada

In phase 3.0, mechanical design refinements were applied to the 3D prototype assembly generated in CAD to create the 1:1 scaled prototype (version 3). CFD analysis was carried out to study the flow through the device which revealed how the marine entities entering the trawl net would travel through the device which operated in two modes: catch and release positions. Marine entities entering the trawl travel to the cod end of the trawl in the catch position, and to the outside of the trawl net through openings in the net in the release position. Based on the observations from the deployment of version 3, version 4 was designed to operate using the torque generated from hydrodynamic forces. An electromechanical latch mechanism was designed with a mechanism to control operation of the door of the gate assembly, which, ultimately, will operate using a triggering signal from the stereo camera . Version 5 of the Gate Mechanism was designed to address the drawbacks of the previous version and new methods of fabrication were identified.

The development of the Gate Mechanism carried out in this phase of the project and their corresponding features are shown in Figure 6.

Figure 6 Development of the Gate Mechanism in Smartrawl 3.0

Table 1 Shows the summary of prototype deployments

Ver.	Date	Scale, mode	Field tests (when, where)	Comments
1	2019.09.21	1:8	Armfield flume tank, Meston Building, University of Aberdeen	https://www.abdn.ac.uk/engineering/research/armfield-flume-212.php
2	2019.11.19-22	1:4	CSAR flume tank, Marine Institute, NL, Canada	https://www.mi.mun.ca/facilities/flumetank/
3	2021.06.07-09	1:1, static	Fishing Vessel, Shetland	Videos provided evidence of meeting requirements in catch and release positions

The 3D assembly of version 3 is shown in Figure 7 and *Figure 8*. Some parts of the assembly such as the cowling plate and conical segments were fabricated in-house. Other components of the gate such as the flat circular ends and door and barrier frames were fabricated by an external supplier using waterjet cutting in addition to conventional machining and joining processes such as welding. The prototype version 3 (Figure 9), was fabricated in the University of Aberdeen's National Decommissioning Centre facility. Given the possibility of larger organisms entering the trawl net, the overall length of the device was increased during assembly to prevent entanglement. Video footage captured during the deployment showed that marine entities behaved as expected in both catch and release positions of the gate, except for some flat fish that tended to stick on the trawl net near the door of the gate.

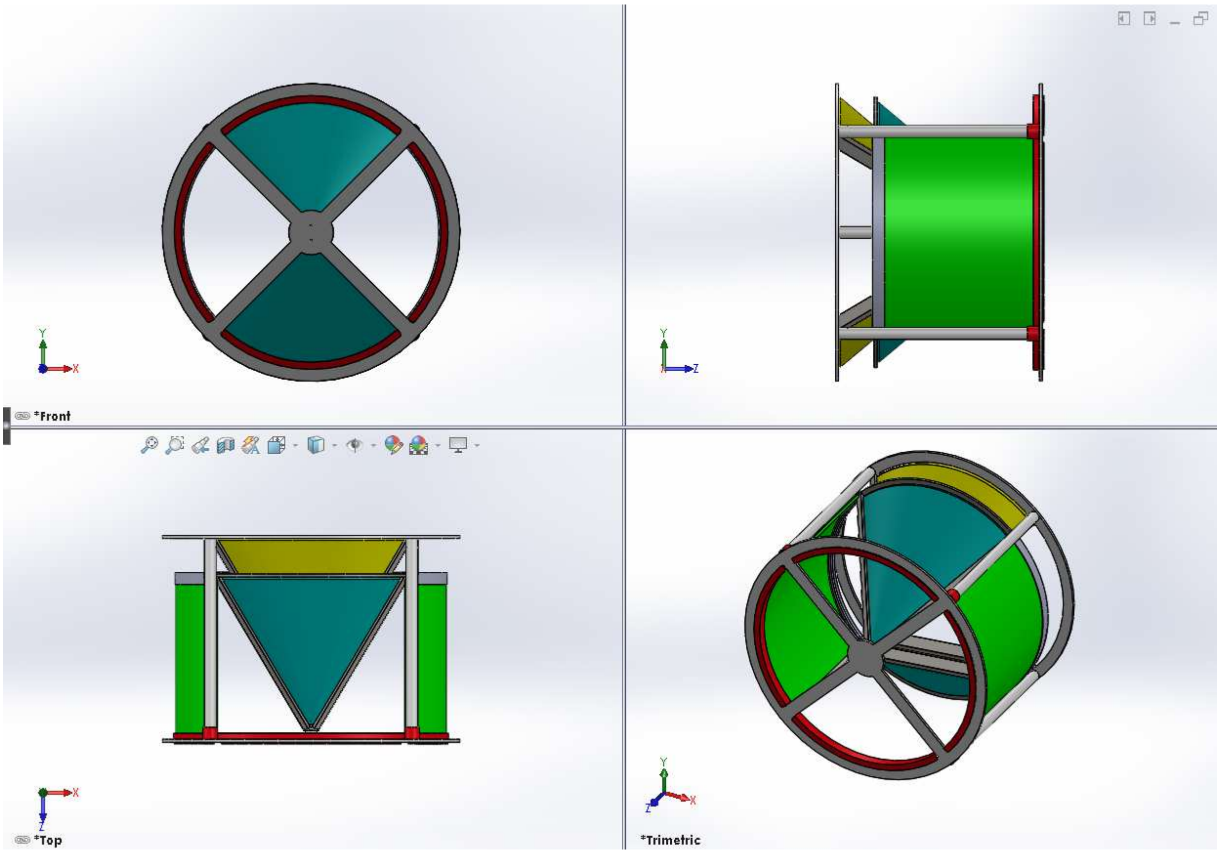

Figure 7 Version 3 of the gate in catch position

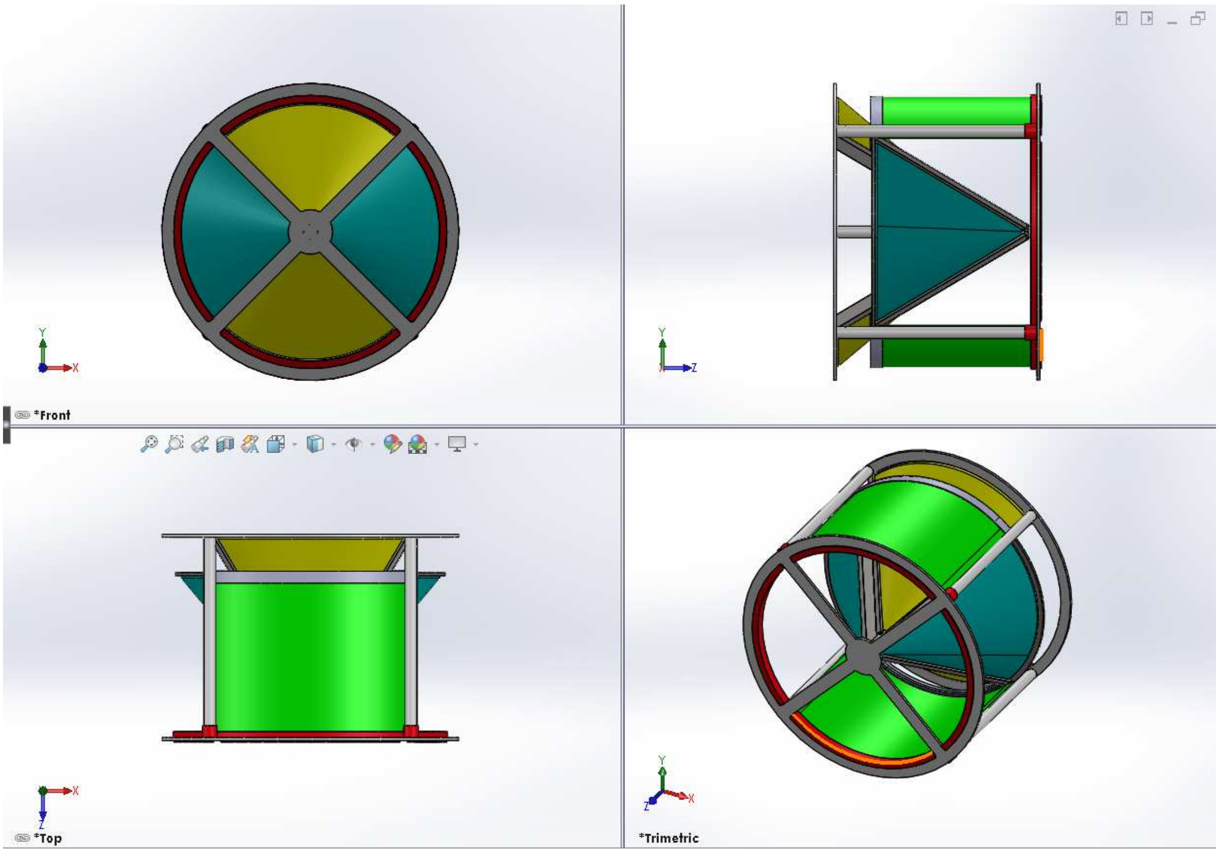

Figure 8 Version 3 of the gate in release position

Table 2 Shows the different types of analysis carried out and their purpose

Analysis method/tool	Component analysed	Purpose
CAD assembly	• Geometric creation and assembly of parts structure of the Gate Mechanism • Open and closed configurations	• Prototype without requiring a physical model • Calculate mass properties e.g., 9.83 kg for the door, moments of inertia etc by applying material properties to the parts • Shows assembly in virtual space
CFD analysis	• Different blade configurations • Flow in Catch and release positions • Different porosity • Flow around different outer frame profiles	• Flow pattern and velocity around the structures in different configurations, • Torque generated by the blades, • Loading data for conducting FEA
FEA analysis	• Different blade configurations • Shaft loading • Door assembly in flow conditions	• Insight into the mechanical performance characteristics under loading

Figure 9 Version 3 of the prototype in release position (cones closing off the cod end which would be to the right-hand side of the left image and beneath the lower part of the right image). The conical sections (in green) and doors (in grey) were made from high density plastic.

Objective 1.3 Prototype of refined design: version 4

Version 4 improved upon the previous version through the introduction of a rotating door with blades in place of the static door that could be locked in two positions. Figure 10 shows this version in the catch position and Figure 11 shows it in the release position. Components were retained from version 3, which enabled a quicker turnaround for completing the assembly of the Gate Mechanism particularly in the light of delays created by the pandemic. This version of the device also used aluminium alloy for the door frame which led to a weight reduction (Al 6082 has a density of 2.7g/cm^3 and SS316L has a density of 7.99g/cm^3, which makes it almost three times heavier than the aluminium alloy). The blades were fabricated in 8 sections of Acrylonitrile Butadiene Styrene (ABS) using a 3D printer recently acquired by the engineering workshop. The assembled prototype is shown in Figure 12.

An electro-mechanical latch mechanism that can control the gate movements between catch and release, was also designed. The operation parameters such as timing frequency can be controlled by programming an Arduino microcontroller which also allows the gate to receive signals from the acoustic modem or stereo-camera in the future. The mechanical components for this latch are currently being fabricated further to the completion of electronic component design and preliminary testing. The Gate Mechanism has been assembled and is ready for deployment based on weather conditions, the availability of the fishing vessels and assembly of the latch mechanism.

Sea trial and tow tank trials of version 4 were not possible because of the time limitations involving fabrication process limitations and delays, unavailability of technician and facility, delays caused by adverse weather conditions which hampered the assembly process as well as boat availability in addition to the pandemic constraints that were introduced due to work from home restrictions and closures.

Version 5 of the Gate Mechanism shown in Figure 13 (catch) and Figure 14 (release) improves on version 4 and it is proposed to use a redesigned set of components that can be produced using a combination of rapid prototyping and conventional fabrication by incorporating the modifications based on future observations which result from the deployment of prototype 4.

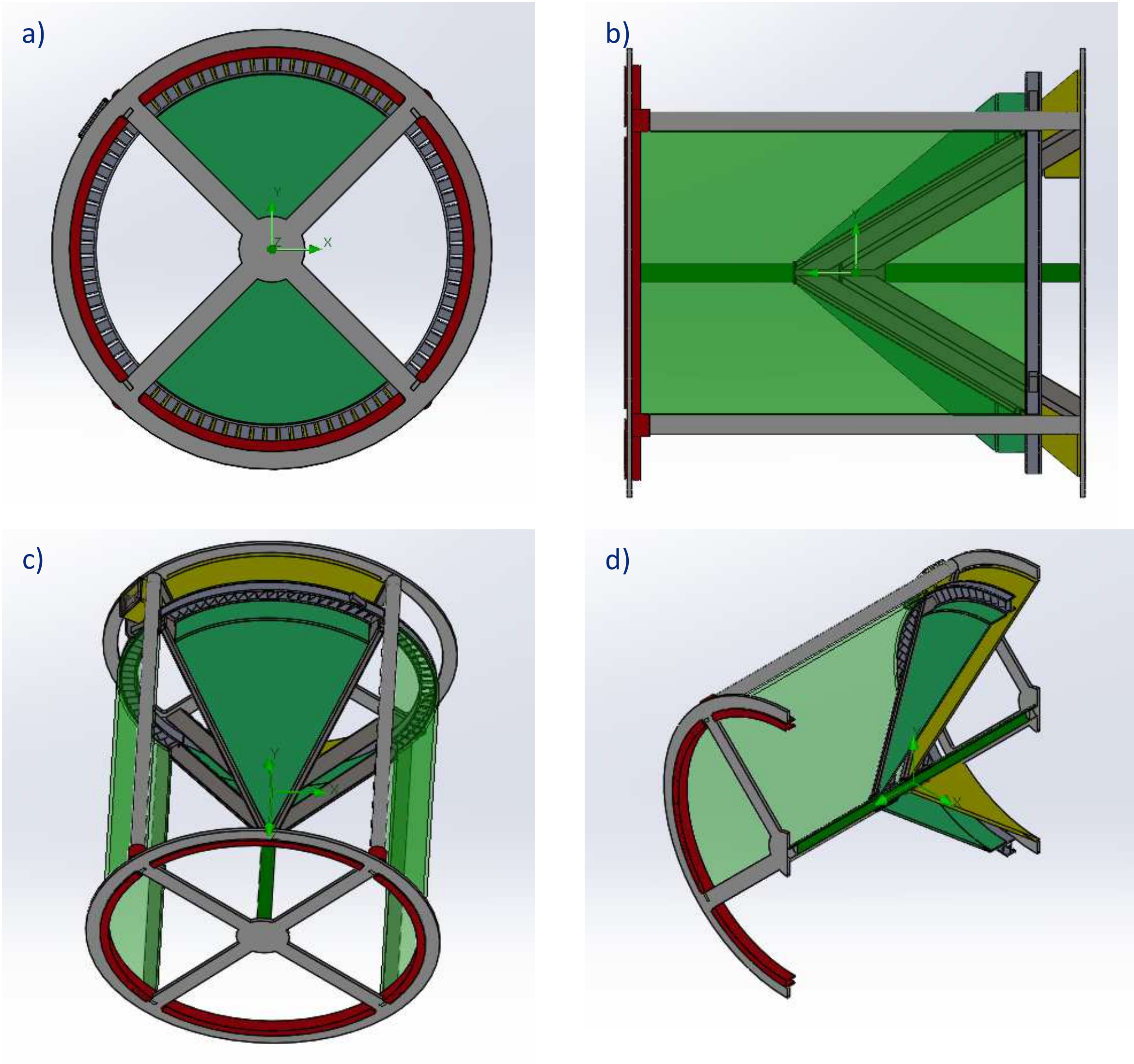

Figure 10 Version 4 of the prototype in catch position: a) Front view b) side view: c) 3D view d) 3D isometric section view

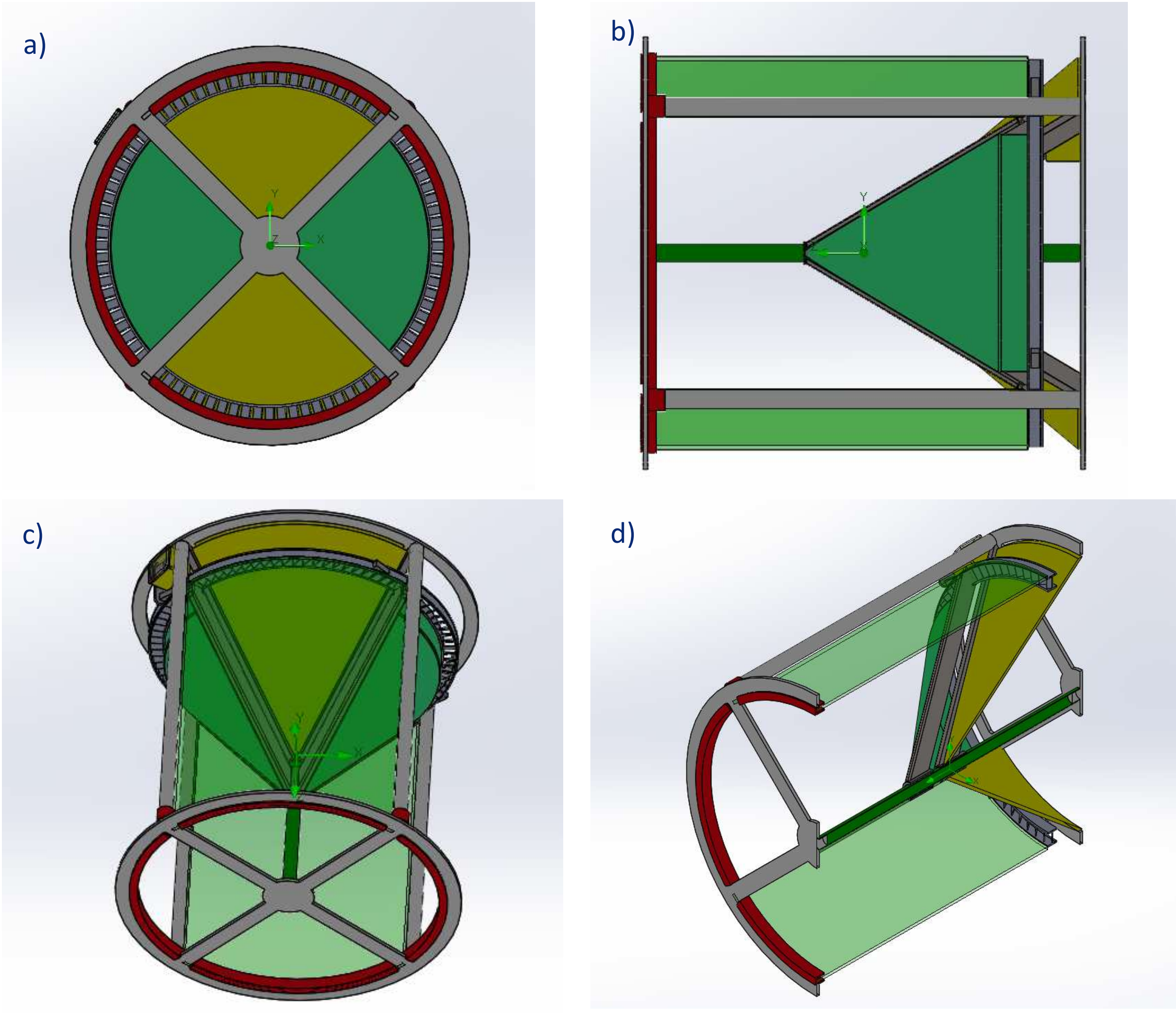

Figure 11 Version 4 of the prototype in release position: a) Front view b) side view: c) 3D view d) 3D isometric section view

Figure 12 Version 4 of the prototype with new aluminium cone sections and hydrodynamically operated blades (in blue).

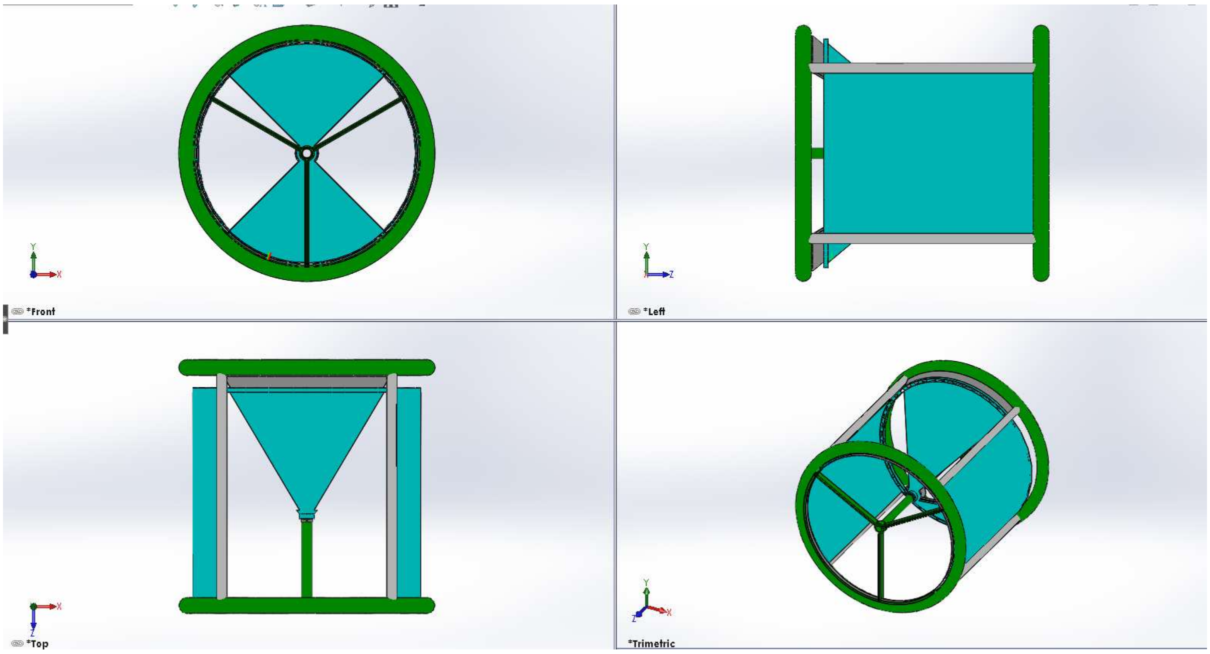

Figure 13 Proposed version 5 of the prototype in catch position: (clockwise from the top) Front view, side view, isometric view, and top view

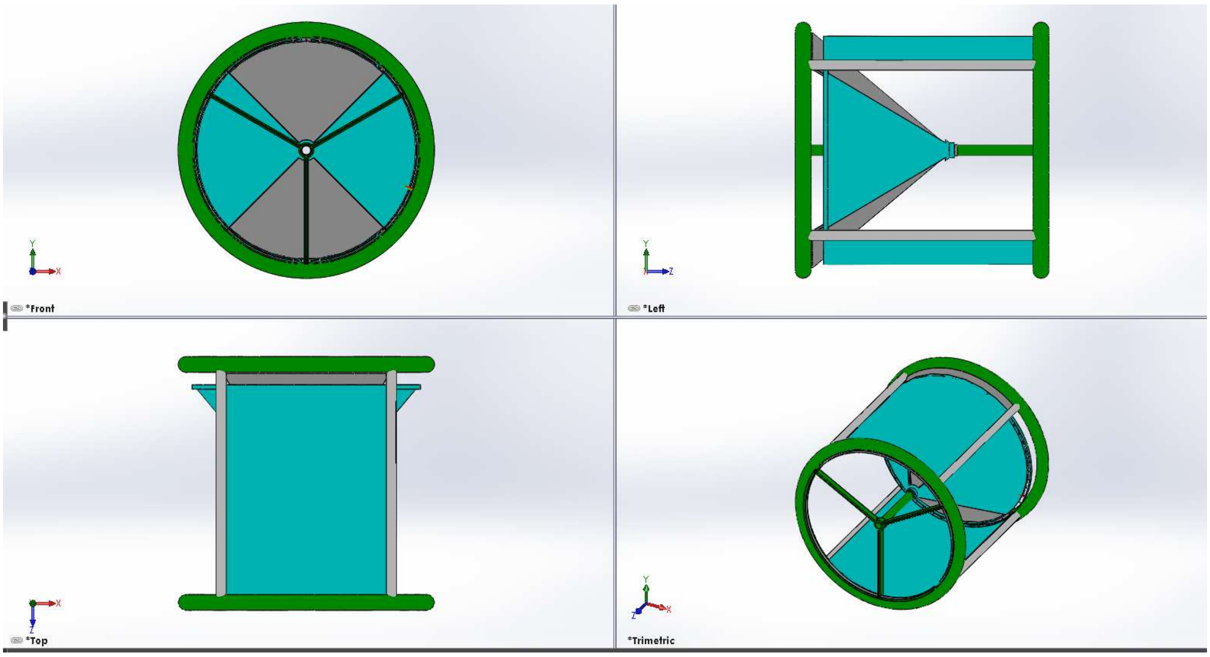

Figure 14 Proposed version 5 of the prototype in release position: (clockwise from the top) Front view, side view, isometric view, and top view

Future work

This gate demonstrates the possibility of bycatch and discards reduction using a simple self-powered mechanical device. Version 5 of the gate involves a complete redesign as shown in the previous section. Therefore, the techniques required for manufacturing are also different. A supplier with the capacity to print large 3D components (1m*1m*1m) in Polyethylene Terephthalate Glycol (PETG, a thermoplastic polyester commonly used in manufacturing) or polylactic acid (PLA) has been identified. A supplier for providing tube bending services should be identified to fabricate replacements for the flat circular ends. The newly proposed bladeless design (detailed in the patent description) can also be investigated in a future phase of the project. A low friction thrust bearing can be incorporated into future designs to reduce the effect of friction generated due to drag load on the rotational speed or response for the door mechanism, if required. Replacing conventional non-biodegradable materials into the design would ensure that the devices are in line with requirements for plastic and environmental targets following COP26. Dissemination of simulation and deployment results through publications can be made after the publication of the patent application in mid-2022.

Objective 2: System integration

Integration of the camera system, gate mechanism and modem were not possible due to the complex nature of the image analysis. This requires a more sophisticated on Single Board Computer (SBC) with an integrated graphics card, than was originally supplied in the stereo camera system. An upgraded SBC is needed to carry out the artificial intelligence algorithms required to detect fish and size them based on the images from the stereo camera. The fundamental issue that would enable this to take place is swapping the current SBC for another as described in the previous (Smartrawl 2.5) report. A suitable SBC was, however, procured – an Nvidia Jetson Nano, but not in time for the additional integration development which requires modification to the internal control boards and power supply (batteries) of the stereo camera system. System integration is being addressed in Smartrawl 4.0.

Objective 3: Analysis of stereo images

Analysis of stereo images was achieved using student BSc and MSc projects during the project. This allowed for the time-consuming process of processing hundreds of thousands of images to be carried out.

Objective 3.1 Enhancing the stereo camera image library

Over the course of Smartrawl 3.0, only two sea trials were conducted to add to the collection of stereo camera data. This was largely because the project took place during the Covid 19 pandemic when field work, including working at sea was largely prohibited. Once the pandemic eased, difficulties were encountered in securing vessels, but eventually two trips were carried out in December 2020 on the mixed demersal trawler Ceol na Mara (Figure 15).

The total amount of data collected to date in the various phases of the Smartrawl projects is summarised in Table 3. The project has now collected over 200,000 images, of which 140,000 have been inspected and catalogued. These images will form the basis of the image analysis algorithms and studies of fish passage rates which are important for other parts of the Smartrawl system.

Figure 15. The fishing vessel Ceol na Mara used during trials of the stereo camera system in December 2020.

Table 3. Details of all sea trials conducted during the Smartrawl project phases. IP is Internet Protocol which is a number unique to each of the two Smartrawl stereo cameras.

Vessel	Date	Location	Camera IP & lens	Duration	Number images	Catch	Weight (kg)
Sparkling Star	19 Jul 2019	Moray Firth	192.168.10.10 6.2mm narrow	4 hr 2 min	29120	Whole prawn Tailed prawns monk haddock	95 31 7 15
Sparkling Star	22 Aug 2019	Moray Firth Shot. 57°54N 2’12W Hauled 58°06N 2’04W	192.168.10.10 6.2mm narrow	4 hr 38 min	33412	Whole prawns Tailed prawns Haddock	38 25 31
Sparkling Star	13 Feb 2020	Moray Firth Shot 57°54’N, 002°09W Hauled 58’03.n 1’50w	192.168.10.10 4mm wide	5 hr 36 min	40366	Prawns Haddock Monkfish Plaice	32 640 45 40
Ceol na Mara	15 Dec 2020	Moray Firth 57° 38.7'N, 002° 48'W	192.168.10.10 4 mm wide	4 hr 22 min	31484	Squid Prawns Haddock Haddock disc Plaice disc	0.75 4 10 315 30
Ceol na Mara	16 Dec 2020	Moray Firth 57° 38.7'N, 002° 48'W	192.168.10.234 4 mm wide	8 hr 56 min	64383	Squid Prawns Haddock Haddock disc Plaice disc	0.25 2 2 45 60

Objective 3.2 Determination of fish passage rates.

Analyses of the data collected on several trips have been analysed to determine passage rates. These rates are critical to determine the operating requirements of the gate system. For example, if fish pass the camera every second, then the gate may have to operate at the speed to react to those fish, should they wish to be selected or not. Passage rates were determined based on the slope of the cumulative number of fish per unit time (number of animals per second, which can be converted to animal per n seconds, see e.g., Figure 16). These slopes were determined by segmented regression (e.g., 3 slopes, with 3 equivalent passage rates in Figure 16). Passage rates were generally low, with occasional high rates for juvenile fish which is to be expected as these present the highest numbers in the population prior to death by natural and fishing mortality.

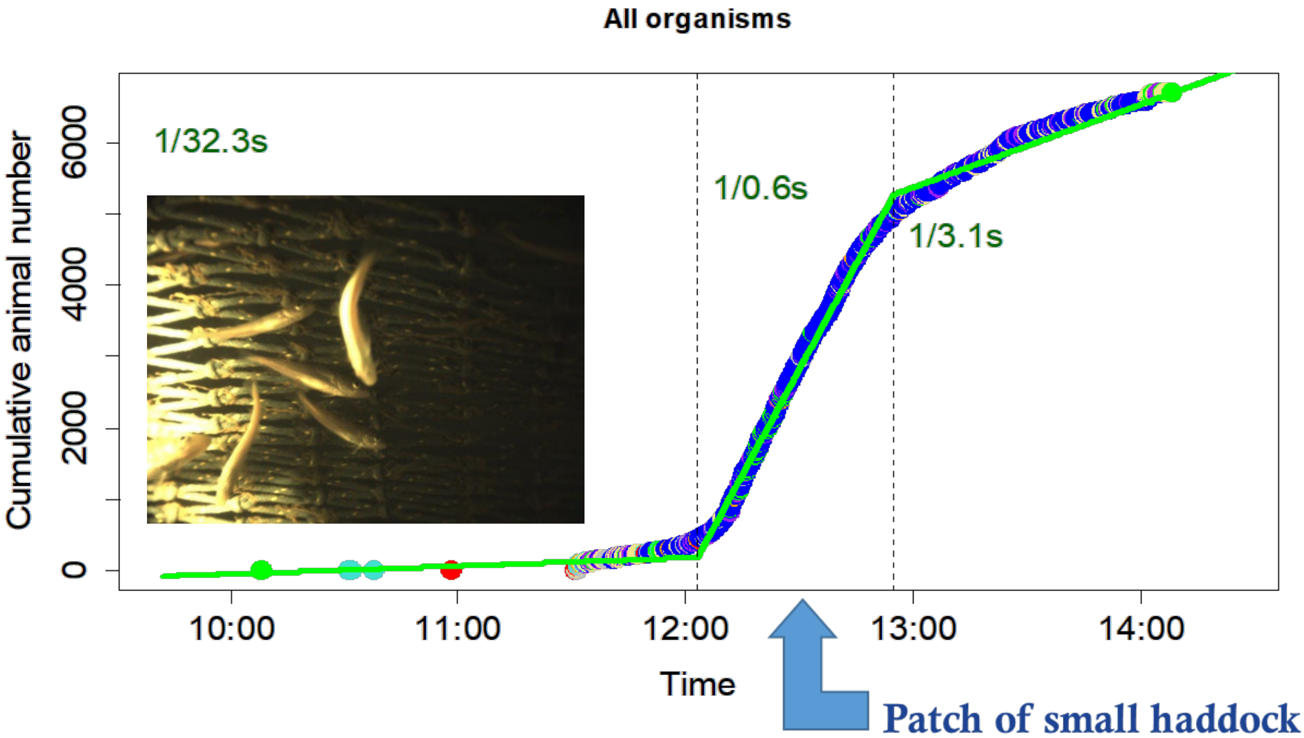

Figure 16. Cumulative animal number (y axis) against time (x-axis). Over the course of this deployment, which took place on 22 Aug 2020, over 6000 animals were observed in the time period (4 hours 38 minutes). Three different passage rates were detected: one animal every 32 seconds from ~09:30 to ~12:00; one animal every 0.5 seconds from ~12:00 to ~13:00; and 1 animal every 3 seconds from ~13:00 to ~14:20. The high rates of passage between ~12:00 and ~13:00 were of small haddock (inset image), most if not all of which would have passed through the meshes of the cod end.

Passage rates were also variable, by species and by time, both between trawl hauls and within trawl hauls and reflect the patchy nature of fish on the grounds. In one case (13 Feb 2020) passage rates were 1 fish every, 16.7 s, then 5.3 s, 2.9 s, 16.4 s, 25.6 s and finally 9.7 s. The highest passage rate detected was 1 fish every 0.5 s (Figure 16). The gate has, therefore, been designed to operate at that speed, although as mentioned above, it would not ever need to act on small fish going by, as these would be selected out of the gear by the meshes in any case. A scientific paper detailing these passage rates will be prepared in due course as they are relevant for selectivity studies as well as informing fish patch sizes.

Objective 4: Patent.

Based on the initial conversations that took place during Smartrawl 2.0, meetings were conducted in January 2020, to lay the foundations for filing a patent application to protect the Gate Mechanism which is a novel device. Based on the advice received from the patent attorney, documentation - including text and images relating to the gate mechanism - was prepared for the purpose of filing the patent. Formal terminology for the various components of the device was also created in this step. The patent search application was filed in November 2020 (GB2017670.7) and the patent application was filed in November 2021 following the prescribed timeline. An additional novel embodiment of the gate mechanism was included as part of this application, which paves the way for future development. This step ensures the protection of intellectual property created at the University Aberdeen using public funding received through FIS. This objective proved to be challenging due to (i) the IP arrangement where FIS held the IP; and (ii) due to a prior art exposure (FIS011 report which is online). It was, however, completed successfully during the stipulated period.

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