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Development of an underwater robotic tool for fish-farm net repair.

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Resumen

La inspección y reparación autónoma de redes de acuicultura es un reto importante en la piscicultura moderna, ya que los daños no detectados pueden provocar escapes de peces, pérdidas económicas e impactos ambientales. Aunque los ROVs y los avances en visión por computador han mejorado la detección de defectos, la reparación física sigue siendo limitada por sistemas de parcheo poco adaptables. Este trabajo presenta el diseño inicial de un efector final submarino para reparar roturas en redes mediante bridas (zip-ties), montado sobre una plataforma BlueROV2 de bajo costo. El mecanismo combina una Newton Gripper y un servomotor submarino SER2020 para permitir una manipulación coordinada bajo el agua. Los resultados preliminares muestran una correcta colocación y cierre de la brida sobre redes dañadas, validando la viabilidad del enfoque. La validación futura se realizará en el tanque CIRTESU con redes reales en condiciones submarinas semi-realistas.

Palabras clave: Acuicultura, BlueROV2, diseño mecánico, herraminetas de manipulación, ROS2.

Abstract

Autonomous inspection and repair of aquaculture nets remains an important challenge in modern fish farming, as undetected structural damage can lead to fish escapes, economic losses, and environmental impacts. Although ROVs and advances in computer vision have improved defect detection, physical repair is still limited by patching systems with low adaptability and predefined geometries. This work presents the initial design of a new underwater end-effector for repairing tears in aquaculture nets using zip-ties, mounted on a low-cost BlueROV2 platform. The mechanism combines a Newton gripper and a SER2020 servomotor to enable coordinated underwater manipulation. Preliminary results show successful placement and closure of the zip-tie on damaged nets, validating the feasibility of the approach. Future validation will be carried out in the CIRTESU tank using real nets under semi-realistic underwater conditions.

Keywords: Aquaculture, BlueROV2, mechanical design, manipulation tools, ROS2.

1. Introduction

Aquaculture, the commercial breeding of aquatic animals in controlled environments, has become a pivotal solution to meet the surging global demand for dietary fish protein without risking the collapse of wild fisheries. As the industry expands—recently surpassing wild capture fisheries as the primary producer of aquatic animals (FAO, 2022) it has become indispensable to integrate modern technology. Specifically, the use of underwater robots working in close collaboration with human operators is essential to monitor and maintain the farm infrastructure. A critical focus of this human-robot collaboration is the continuous inspection and repair of net enclosures (Vasileiou and Vlontzos, 2025). If these nets break,

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the resulting openings can allow natural predators to enter or farmed fish to escape, which not only causes significant financial losses but also severely compromises the surrounding marine ecosystems (Forseth et al., 2017). Escaped farmed fish threaten wild populations through genetic interbreeding (Glover et al., 2017) and the spread of parasites. From a corporate perspective, escape events represent substantial risks, including direct biomass loss, reputational damage that can hinder access to production sites, and the possibility of regulatory penalties or even criminal prosecution when negligence is involved or incidents are not properly reported (Norwegian Ministry of Trade, Industry and Fisheries, 2008). These risks further emphasize the importance of robust monitoring and rapid intervention strategies in aquaculture operations.

In current practice, inspection and repair tasks are still largely performed by professional divers, who operate in hazardous underwater conditions and face significant safety risks while attempting to seal damaged nets. In parallel, Remotely Operated Vehicles (ROVs) are increasingly being introduced into this field (Amundsen et al., 2024), providing capabilities for net inspection and assisting in the detection and preliminary treatment of structural damage. However, fully autonomous and reliable repair of net breaches remains an open challenge, requiring further advances in perception, manipulation, and human-robot interaction in underwater environments.

1.1. ROV inspection

In the case of a ROV inspecting aquaculture nets, the detection of structural damage represents a challenging perception problem due to harsh underwater conditions such as high turbidity, low illumination, and significant biofouling on the net surfaces. These environmental factors can severely degrade image quality and complicate reliable feature extraction.

To address these limitations, modern ROV systems integrate Artificial Intelligence techniques with advanced image processing pipelines. Among the most widely adopted approaches for real-time optical detection are Convolutional Neural Networks (CNNs), with particular emphasis on object detection architectures such as YOLO (You Only Look Once). These models enable fast inference while maintaining high detection accuracy, making them suitable for embedded deployment on robotic platforms. Once trained on large datasets containing examples of both intact and damaged net structures, these systems are capable of identifying anomalies in mesh geometry, including holes, tears, and localized deformations. This enables near real-time detection and localization of structural faults, supporting subsequent intervention strategies such as targeted inspection or repair operations (Fu et al., 2024).

1.2. Fixing nets

After detection and recognition, some ROVs are equipped with patching tools capable of repairing breaches in aquaculture nets. These repair systems typically deploy patches made of real netting material attached to custom 3D-printed components designed for underwater operation and compatibility with robotic manipulators. In some implementations, the patches are secured using four pins that penetrate the net structure to ensure mechanical stability, while alternative designs rely on a spring-loaded two-jaw mechanism that allows the patch to hook onto and remain attached to the mesh.

Despite these advances, current systems still present notable limitations. In most cases, the robot is only able to perform a single repair operation before requiring resurfacing or manual reloading of patches. Additionally, the patches are generally available in predefined sizes, which restricts their adaptability to different damage geometries. As a consequence, when a detected hole exceeds the dimensions of the available patch, the system is unable to perform an immediate repair, requiring either multiple interventions or manual assistance from operators.

2. Methodology

2.1. ROV platform

The robotic system is based on a BlueROV2 platform (Figure 1) which provides the physical foundation for underwater operations and integrates propulsion, sensing, and manipulation capabilities. The vehicle is equipped with 8 thrusters, enabling full 6-DOF motion control (surge, sway, heave, roll, pitch, and yaw), which is essential for stable positioning in dynamic underwater environments such as aquaculture farms. This configuration allows precise maneuvering near net structures, where hydrodynamic disturbances and limited visibility significantly increase operational complexity.

Figure 1: BlueROV2 platform used as base system.

Onboard computation and system integration are handled by a Raspberry Pi 4, which acts as the central processing unit for high-level control, communication, and coordination of all subsystems. The ROV is further enhanced by the integration of two actuated tools: a Newton Gripper and a SER2020 underwater servo (Blue Trail Engineering), which extend the platform's capabilities from pure navigation to active intervention tasks such as grasping and net repair.

2.2. System communication

Internal communication is based on a ROS2 architecture named SURA (Surface and Underwater Robotic Architecture), that CIRTESU itself is developing, it will be described in a future article. The onboard Raspberry Pi 4 enables teleoperation of the ROV and real-time monitoring through ROS2 nodes and a Blue Robotics Navigator interface.

The control hierarchy follows a modular multi-layer structure. At the highest level, the operator sends teleoperation commands using either a joystick interface or custom code. These commands are propagated through the SURA architecture and distributed to dedicated ROS2 nodes responsible for low-level control of thrusters, lighting systems, cameras, and actuator modules.

The system publishes telemetry data, including battery status, actuator states, and system diagnostics, through ROS2 topics. This allows continuous feedback and full situational awareness during operation. Each subsystem is designed to both publish and subscribe to relevant data streams, ensuring modularity and facilitating the integration of additional sensors or tools without modifying the core architecture.

After integrating the servo motor for the gripper system, the platform remains fully operational and supports coordinated control of both navigation and manipulation tasks.

The Newton Gripper, (Figure 2), operates as a linear actuation system driven by a servo motor configured in continuous rotation mode. Its motion is controlled through timed actuation: a high-level command triggers motor rotation, and after a fixed interval of 0.3 seconds, the signal is reset to zero, stopping the movement. This stepwise control strategy enables precise incremental actuation suitable for controlled gripping operations.

Figure 2: Newton Gripper, used for closing the jaw.

In contrast, the SER-2020, Figure3,operates in position control mode. Thanks to its Hitec servo configuration, it can execute up to three full rotations while maintaining accurate positional movement. This capability is exploited to generate the required zipper-like motion used in the fastening mechanism.

Figure 3: SER2020, used for the zip-tie pushing system.

2.3. *Development of repair tools*

To evaluate different approaches to net repair, this research investigates multiple mechanical concepts for sealing breaches in aquaculture nets, progressively moving from temporary fixation systems to fully functional repair mechanisms. Each mechanical component is designed in SolidWorks and manufactured using 3D printing (PLA, Bambu Lab X1 Carbon).

The first design, shown in Figure 4, is inspired by bag-sealing clips and adapted to clamp over damaged regions of the net. This solution provides a fast and simple temporary fixation, intended to stabilize the structure until a permanent repair can be performed by a human operator. While effective in terms of deployment speed, its main limitation lies in the lack of durability under long-term exposure to underwater currents and biological interactions.

The second iteration, Figure 5 is based on a clothes-pin-inspired mechanism, designed to improve clamping stability and resistance to hydrodynamic loads. This approach aims to provide a more robust semi-permanent solution, capable of maintaining attachment even under strong currents and interaction with marine organisms, while still relying on a relatively simple mechanical structure.

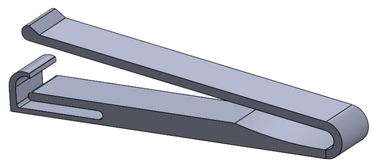

Figure 4: First design: clip-based temporary sealing concept.

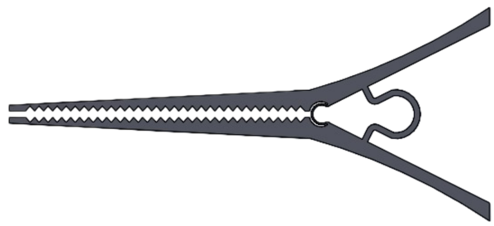

Figure 5: Second design: clothes-pin temporary sealing concept.

The design transitions toward a zip-tie fastening system. In Figure 6, the PAT2S Cable Tie Tool Head is shown as an example of an industrial cable-tie fastening gun. This tool uses compressed air to drive cable ties along a guided path around the target object. Once the tie completes the loop, it automatically engages with its locking mechanism, allowing it to self-lock. The system then applies the required tension and cuts the excess portion of the tie, completing the fastening process.

Figure 6: Panduit PAT2S, cable tie tool head.

This operating principle served as inspiration for the development of the underwater zip-tie fastening mechanism proposed in this work.

3. System design

The gripper mechanism consists of two main subsystems: a front section, responsible for mechanical interaction with the net, and a rear section, which houses the actuation and transmission components. As shown in Figure 7, the front assembly includes a rotating upper jaw and a fixed structural interface connected to the Newton Gripper. The rear section integrates the transmission chain linking the servo motor to the gripper mechanism, ensuring controlled motion transfer.

The system operates using two zip ties with distinct roles: one acts as a pushing element for guiding the fastening process, while the second is responsible for closing and locking the mechanism. This dual-element approach enables controlled and repeatable actuation during underwater repair operations.

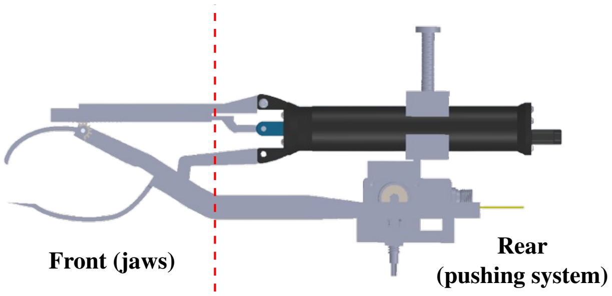

Figure 7: Gripper CAD model, side view.

The system is designed to be compatible with different types of cable ties (zip-ties), provided they satisfy specific geometric and mechanical constraints. In particular, the zip ties must not exceed the width of the guiding track, their length must remain within the allowable trajectory defined by the gripper geometry, and they must be sufficiently long to engage and lock with their own fastening head. Otherwise, structural modifications of the mechanism would be required to ensure compatibility.

All components are rigidly mounted onto the gripper assembly, as shown in Figure 8, ensuring mechanical stability and repeatable operation during underwater manipulation tasks.

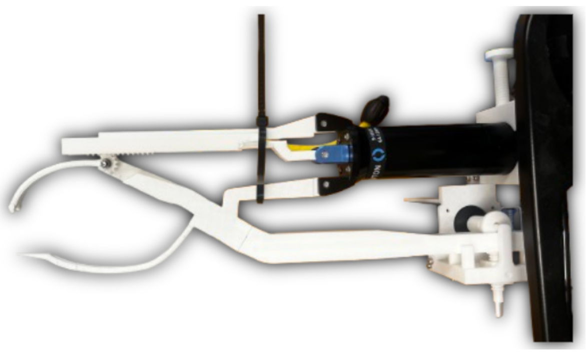

Figure 8: System mounted on Newton gripper.

4. Functioning

4.1. Repair procedure

The automated net repair procedure is composed of a sequence of coordinated stages that integrate perception, manipulation and actuation. Initially, the robotic system detects the presence of a tear and localizes the damaged region. Once the target is identified, the ROV performs a controlled approach maneuver and stabilizes its position in front of the net structure.

The end-effector then aligns with the rupture and inserts its jaws at one extremity of the damaged area. Specifically, the jaws are positioned by engaging two intact mesh nodes adjacent to the tear, one located above and the other below the opening, Figure 9a. This configuration ensures mechanical anchoring of the tool to the net structure, providing stability for the subsequent repair operations.

Next, the primary actuation phase is executed. Driven by the Newton Gripper's internal linear actuator, the upper jaw transitions from its initial configuration (posStart) to a predefined intermediate alignment (pos1), Figure 9b. This motion creates the necessary clearance and alignment for the insertion and guided motion of the fastening element.

Figure 9: a) Tool's head reaching the net rupture (posStart), b) the upper jaw closes at a predefined position (pos1).

Once this configuration is reached, the SER2020 motor is activated and advances a larger carrier zip-tie, which is responsible for feeding the primary fastening cable tie through the net meshes. The zip-tie is guided along a predefined track within the end-effector, ensuring controlled motion and minimizing misalignment during insertion. The fastening element continues its trajectory until it reaches a mechanical stop (Figure 10), which acts as a physical constraint ensuring repeatable positioning.

Figure 10: Zip-ties reaching the mechanical stop.

This stopping mechanism is essential to guarantee proper alignment before the locking phase. Additionally, a specialized pass-through hole (Figure 11, label 3) on the top surface allows the tail of the zip-tie to exit cleanly, as shown in Figure 11.

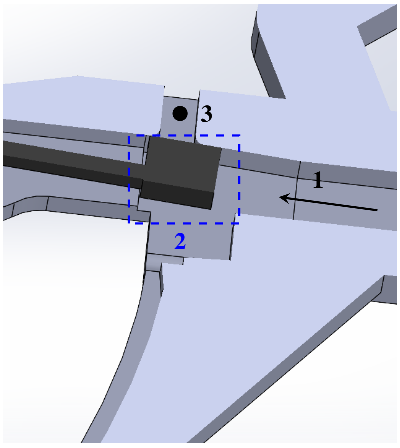

Figure 11: (1)Detailed section-view of the the zip-tie feeding track, (2) zip tie in the mechanical stopper, (3) the top-surface pass-through hole.

Once the zip-tie has fully encircled the damaged region, the Newton Gripper resumes its linear motion to push the fastening element into its locking head (pos2), thereby securing the mesh and closing the gap.

Subsequently, the upper jaw is opened to release the tool from the fastening element, allowing the zip-tie to detach from the guiding mechanism. At this stage, the system ensures that no mechanical interference remains between the tool and the newly formed closure. A full sequence of the zip-tie being closed can be seen in Figure 12.

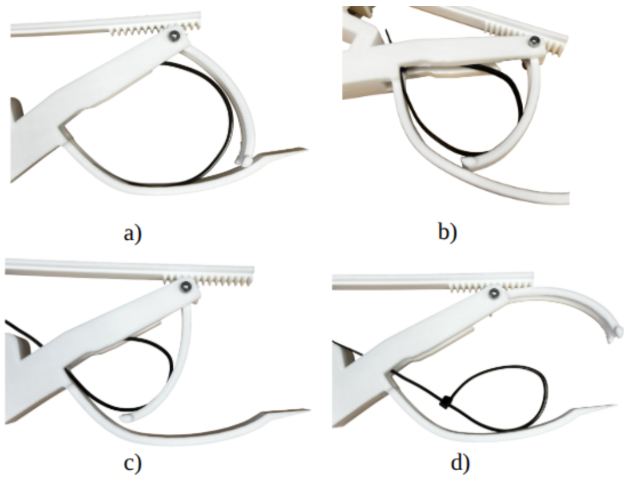

Figure 12: Zip-tie closing sequence. a) The zip-tie is fed into the track using the SER2020 motor, b) the zip tie reaches the stopper and the Newton gripper begins pushing the zip-tie into its locking head, c) the upper jaw reaches its maximum range, d) the upper jaw is released leaving the zip-tie closed and engaged in the locking head.

Finally, a third actuator (not currently implemented) is needed to perform the tightening phase, permanently securing the repair and increasing the mechanical stability of the closed net structure, as shown in Figure 13.

Figure 13: Zip-tie ready to be tightened.

5. Conclusions

We have presented a new underwater tool intended for future application in the repair of holes in aquaculture nets. Although the current gripper design is still under development and requires further optimization in terms of robustness, reliability, and system integration, the preliminary bench-top tests have shown promising results.

At the current stage, the prototype is capable of correctly positioning and closing a zip-tie around the net structure in a stable and repeatable manner under laboratory conditions. These initial tests validate the feasibility of the proposed mechanical concept and demonstrate the potential of performing controlled fastening operations using the developed end-effector.

However, the system has not yet been validated in underwater environments. Experimental trials in water, including tests under realistic aquaculture conditions, are planned as future work. These experiments will be necessary to evaluate the behavior of the mechanism under hydrodynamic disturbances and interaction with deformable net structures.

The current prototype also does not yet include an automated zip-tie feeding mechanism, meaning that manual reloading is required after each repair cycle. Future developments will therefore focus on the integration of an automatic feeder capable of supplying a new zip-tie after every operation, improving the autonomy and operational continuity of the platform.

In addition, the implementation of a dedicated actuator for automatic tightening of the zip-tie represents another important future step toward a fully autonomous repair system. Combined with future underwater validation campaigns, these developments will contribute to transforming the prototype into a reliable robotic tool for autonomous inspection and maintenance operations in aquaculture environments.

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