# Final report

## 1. Project details

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| **Project title** | EUDP 2022-I: Fuel savings and emission reductions in the shipping industry through innovative propeller polishing robot technology |
| **File no.** | 64022-1009 |
| **Name of the funding scheme** | EUDP |
| **Project managing company / institution** | SubBlue Robotics ApS |
| **CVR number** (central business register) | DK37932205 |
| **Project partners** | CoGrow ApS, Odin Diving A/S, Syddansk Universitet |
| **Submission date** | 18-02-2022 |

## 2. Summary


### Project summary:

**The purpose of the project**

The project addressed the high fuel costs and $CO_2$ emissions in shipping by developing and demonstrating a robotic propeller polishing technology that replaces divers. It improved fuel efficiency, reduced emissions, and enhanced safety through an innovative, automated underwater solution.

**Results, conclusions and perspective** A fully functional robotic propeller polishing system was developed, tested, and deployed in pilot operations.

- Reliability tests and certifications (e.g., Rotterdam) were achieved.
- Advanced control software, computer vision modules, and a debris collection system were implemented.
- The robot demonstrated up to 17% fuel savings and reduced $CO_2$ emissions
- The service is already commercially deployed and has performed multiple successful jobs.

**Future use:** The technology will be scaled to international ports, targeting shipowners and service providers. It will reduce operational downtime (“off-hire”), cut fuel costs, and support global shipping decarbonization goals.

**Expected effects:** Significant emission reductions, lower operational costs for shipping companies, and improved harbor safety standards.

## Projektresumé:

**Formålet med projektet**

Projektet adresserede høje brændstofomkostninger og $CO_2$-udledning i skibsfarten ved at udvikle og demonstrere en robotteknologi til propolering, som erstatter dykkere. Løsningen øgede brændstofeffektiviteten, reducerede emissioner og forbedrede sikkerheden via en innovativ, automatiseret undervandsløsning.

**Resultater, konklusioner og perspektiv**

- Et fuldt funktionsdygtigt robotbaseret propolering-system blev udviklet, testet og implementeret i pilotoperationer.
- Pålidelighedstests og certificeringer (bl.a. Rotterdam) blev opnået.
- Avanceret styringssoftware, computer vision-moduler og et opsamlingssystem blev implementeret.
- Robotten viste op til 17 % brændstofbesparelse og reduceret $CO_2$-udledning
- Servicen er allerede kommercielt i drift med flere succesfulde opgaver.

**Fremtidig anvendelse:** Teknologien skaleres til internationale havne, målrettet redere og serviceudbydere. Den vil reducere driftsstop, sænke brændstofomkostninger og understøtte globale klimamål.
**Forventede effekter:** Markant emissionsreduktion, lavere driftsomkostninger for skibsindustrien og forbedrede sikkerhedsstandarder i havne.

# 3. Project objectives

The project aimed to address one of the major operational and environmental challenges in global shipping: high fuel consumption and associated $CO_2$ emissions caused by propeller fouling, corrosion, and surface damage. The main objective was to develop, test, and demonstrate an automated, commercial-grade robotic propeller polishing solution that:

- Replaces traditional diver-based propeller cleaning, which is often restricted or unsafe in many ports.
- Reduces fuel consumption by maintaining optimal propeller surface conditions, typically improving fuel efficiency by up to 4–5% per half year for medium-sized vessels.
- Minimizes downtime (“off-hire”) by enabling faster, safer, and more convenient propeller maintenance directly in port.
- Enhances maritime safety by eliminating diver risks and complying with emerging environmental and operational regulations.

The technology developed is a robotic propeller polishing system that combines:

- Advanced robotic hardware: A durable underwater robot with upgraded joints, a kardan-led arm for precision polishing, hydrodynamic thrust control, and robust power and communication systems (CAN-based).
- Automated orientation and force control: Enabling the polishing disc to maintain correct angle and pressure on complex propeller surfaces.

- Debris collection and filtration system: Certified for use in regulated ports (e.g., Rotterdam), preventing biofouling particles from contaminating harbor water.
- Computer vision and neural network modules: Real-time orientation estimation and positioning of the polishing disc.
- Remote operation capabilities: Allowing the robot to be deployed and controlled without human divers, even during cargo operations in certain ports.

Through this project, the technology evolved from a laboratory-level prototype to a pilot-ready and commercially operational system, successfully deployed in multiple ports and already performing paid polishing services.

# 4. Project implementation

The project progressed over a three-year period, transitioning from initial prototype refinement to full-scale pilot testing and early commercial deployment.

**Evolution of the project:**

- **Year 1 (2022–2023):** The consortium established project governance, signed partner agreements, and initiated recruitment of key technical staff (robotics engineer, research assistant). A functional prototype was built and tested in Aarhus Harbor, demonstrating successful propeller polishing on a commercial vessel. Key challenges included unstable communication protocols in the robotic arm and power supply imbalances, which were resolved by switching to a CAN-based control system and redesigning stronger joints.

- **Year 2 (2023–2024):** The robot achieved pilot-level robustness with over 100 hours of operation without major failures. The control software was enhanced with safety functions, a cardannian joint for the polishing tool was introduced, and thrust control was tuned to prevent instability. A disc swapper prototype was developed but experienced issues with magnetic retention under high suction loads. A debris collection and filtration system was implemented but required pump upgrades (from 200 to 250 bar) for simultaneous polishing and collection. Pilot testing began in December 2023, with the first full propeller polishing completed in February 2024.

- **Year 3 (2024–2025):** Final reliability tests (equivalent to 10,000 hours corrosion of critical components) were conducted on joints. The debris collection system received certification in Rotterdam, and several pilot jobs were successfully completed. Computer vision modules for real-time orientation were developed and partially integrated, though full C++ software migration was delayed due to the departure of a key software engineer. Remaining upgrades were integrated into the existing robot rather than producing a second unit.

**Risks and challenges:**

- **Harbor certification and regulatory approval delays**: Obtaining authorization for in-water propeller polishing in key ports (e.g., Rotterdam) was a major dependency.

- **Hardware reliability**: Early-stage joints and thrusters experienced intermittent failures, requiring redesign and reinforcement.

- **Software continuity risk**: The planned migration from LabView to C++ ROS2 was delayed due to loss of a critical software engineer.

- **Resource overruns**: Budget and hours were exceeded (approx. 132% of planned resources) due to unforeseen material costs, component replacements, and additional testing requirements.

**Milestone achievement:**
Most planned milestones were met, including the go/no-go pilot test milestone (D4.1) and certification-related deliverables (D5.1, D3.2b). Some deliverables, such as the disc swapper (D3.2c) and full software integration (D3.6), remain in progress but do not compromise the core project objectives.

# 5. Project results

The main objective - to reduce fuel consumption and CO2 emissions in shipping by developing and demonstrating a robotic propeller polishing system was achieved. A fully functional, pilot-ready robot was developed, certified for use in key ports, and successfully deployed in commercial operations. While some deliverables (e.g., full C++ software migration, disc swapper optimization) were delayed or not fully implemented, these did not prevent the project from meeting its core goals.

**Technological results (including unexpected outcomes):**

- A robust robotic propeller polishing system was designed, built, and demonstrated, capable of withstanding >100 operation hours without major failures.
- Joints underwent extended reliability testing (43-day saltwater test, equivalent to 10,000 operating hours).
- Control software was upgraded with safety functions and partial C++ migration, though the final full integration was delayed due to loss of a key software engineer.
- Advanced computer vision modules were developed and validated, enabling real-time propeller edge detection and orientation estimation (accuracy within a few degrees in <1 second).
- A debris collection and filtration system was developed, certified in Rotterdam, and integrated into the operational workflow.
- A disc swapper prototype was designed but requires further refinement to prevent detachment during high-suction polishing.
- Unexpected positive result: Simulation-based operation assistance was successfully integrated, helping operators visualize arm position in real-time.

**Commercial results (including unexpected outcomes):**

- The robotic service was launched commercially during the project and performed several successful polishing jobs (e.g., for Danish and other European shipping companies).
- Initial paid service
- Certification processes in European ports (notably Rotterdam) improved market access
- The service attracted significant interest due to rising bunker fuel prices and increased regulatory focus on emissions, expanding the market potential beyond initial expectations.

**Target group and added value:**

- **Primary target group:** International shipowners and fleet operators seeking to reduce fuel consumption and emissions.
- **Secondary target group:** Ship service companies and franchise operators interested in offering automated propeller polishing services.
- **Added value:** Reduced off-hire time, compliance with environmental regulations, improved safety by eliminating diver operations, and documented fuel savings (up to 4% per polishing).

**Dissemination:**

- Results were disseminated through:
    - White papers (e.g., "PP4  Propeller Polishing Rule of Thumb Matrix" linking polishing to up to 4% fuel savings).
    - Multiple scientific publications and conference contributions (corrosion resistance results, computer vision articles, PortPic24, SMM Hamburg...)
    - Reports to EUDP, shipping partners, and certification bodies.
    - Presentations to shipping stakeholders

# 6. Utilisation of project results

The robotic propeller polishing technology developed in this project has transitioned from prototype to commercial readiness and will now be scaled to multiple international ports. A new generation of robots is already in production planning, with components integrated into an ERP system for easier ordering and assembly. Lessons learned from pilot operations (e.g., thrust control tuning, disc swapper optimization, pump upgrades) will inform the next iteration of the system. The computer vision modules developed during the project will be further integrated into the control software to enhance autonomous operation, and the certified debris collection system (e.g., Rotterdam) will be applied in all new deployments.

The service is already commercially active and has performed multiple paid propeller polishing operations in Denmark and Europe, already reducing fuel consumption and emissions of select ships significantly. SubBlue Robotics will commercialize the technology primarily through direct service contracts with shipowners and licensing/franchising to ship service providers. Expansion to high-traffic ports (Rotterdam, Antwerp, Hamburg) is the immediate next step, with plans to scale to 8 new ports per year. The business model combines one-time service fees and long-term service agreements.

**Economic impact:**

- **Turnover & revenue:** The project has already generated initial sales and is expected to significantly increase turnover as the service scales.
- **Exports:** First international jobs are completed in Northern Europe

- **Employment:** The project led to new hires (robotics engineers, software specialists) and is expected to create further jobs in production, service, and sales as operations expand.

- **Private investments:** The owner consortium has already injected additional capital to cover unforeseen material costs and will continue to finance expansion.

The market for automated underwater propeller polishing is in its infancy. Existing solutions rely largely on divers, which face increasing regulatory restrictions and safety concerns. Few robotic alternatives exist, and none are as integrated (debris collection + certified operation + remote control). Main competitors are traditional diving service providers and emerging hull-cleaning robots (which do not cover propellers).

**Entry and sales barriers:**

- **Harbor certification requirements** (e.g., water sample documentation, BIMCO “Approval Procedure for in-Water Cleaning Companies”). This barrier is being overcome via successful certification (Rotterdam achieved).

- **Trust and demonstration barrier**: Shipowners require proof of savings and reliability—addressed through pilot demonstrations and white paper publication.

- **Scaling capacity**: Production capacity is being increased via standardized components and ERP integration.

The project directly supports EU and Danish climate goals by reducing fuel consumption and emissions in shipping—an industry responsible for ~2.9% of global $CO_2$ emissions.

Three scientific articles on computer vision and control were produced and will be used in future teaching at SDU. The project has also generated white papers and guidelines (e.g., PP4 Rule of Thumb Matrix) that will be shared with industry stakeholders.

# 7. Project conclusion and perspective

The project successfully transformed a prototype into a commercially operating robotic propeller polishing system, achieving significant fuel savings (up to 4%) and $CO_2$ reductions while improving safety by eliminating diver operations. Despite budget overruns and delays in full software migration, key milestones—including reliability testing, debris collection certification (Rotterdam), and pilot jobs—were achieved.

**Next steps:** Complete C++ software integration, finalize disc swapper optimization, expand certifications to additional ports, and scale production to meet growing international demand.

**Perspective:** The technology is expected to become a standard in shipping maintenance, enabling more frequent, cost-effective, and environmentally responsible propeller upkeep across global ports.

# 8. Appendices

- Add link to relevant documents, publications, home pages etc.

subbluerobotics.com

CoGrow ApS, White Paper "*PROPELLER POLISHING As a means to avoid a 4% fuel penalty*", 2025

Y. Qu, T. Ebel, M. Hermansen, "*Attitude Estimation for Cardan-Connected End-Effector of an Underwater Robot by Integrating SAM-based Segmentation and Neural Network*", ICECET V. International Conference on Electrical, Computer and Energy Technologies, 2025

Y. Qu, T. Ebel, M. Hermansen, *"Evaluation of Corrosion Resistance of an Underwater Robot Joint through Accelerated Testing in Simulated North Sea Marine Conditions",* 9th International Conference on Advanced Manufacturing and Materials (ICAMM 2025), Oxford, UK during July 8-11, 2025

M. Hermansen, "*From Divers to Robots: Evaluating a Novel System for Underwater Propeller Polishing*", 5$^{th}$ Port In-Water Cleaning Conference PortPIC'24