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Initial Project Report

Enhanced Underwater Imaging With Machine Vision-Based Anti-Backscatter Lighting System for Unmanned Underwater Vehicles

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4th Year Initial Project Report for Degree of
MEng in Electronic and Computer Engineering

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Ethical Considerations

After consideration of the University of York's code of practice and principles for good ethical governance, I have identified no related issues in this project.

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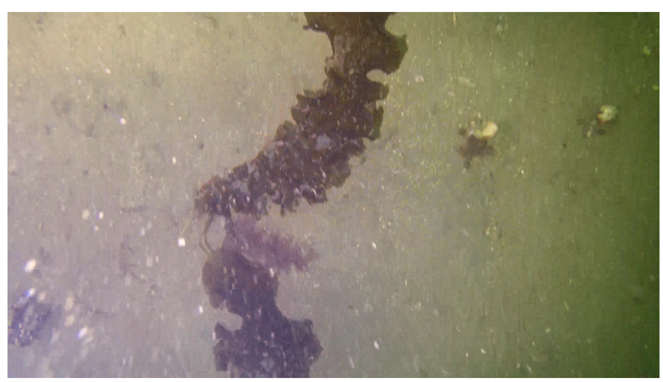
1 Introduction

Underwater imaging has long been crucial in various fields, from marine research to environmental monitoring, underwater archaeology, and offshore industries. For example, scientists use underwater photography with quadrats to audit the abundance of coral over time at several reef locations or to examine phenomena such as hydrothermal vents, underwater volcanic eruptions and gas seepages from the sea floor [1]. Unmanned Underwater Vehicles (UUVs), a type of submersible vehicle, are pivotal in advancing underwater imaging capabilities. These autonomous or remotely operated vehicles, often housing vast arrays of sophisticated sensors, enable the end user to explore and analyse underwater environments with unprecedented accuracy and efficiency. Their autonomous or remote-controlled nature advocates the ideal platform for conducting missions of extended duration in hazardous conditions, impossible for direct human presence and intervention. With the benefits of UUV deployment, they have become common as a safer and cheaper alternative to manned vehicular operations in the vast range of underwater imaging-related industries and applications, such as intelligence surveillance and reconnaissance in defence, inspection and identification of defects or foreign objects in maritime, and oceanography and hydrography in marine research [2].

(a)



(b)

Figure 1: (a) Backscatter is formed as the particles of sand drift between the aquatic animal and the camera [3]. (b) A captured frame in GoPro footage from a UUV of the seabed with backscatter formed as the propellors disrupt the sand.

Despite its importance, underwater imaging faces numerous challenges that hinder its effectiveness, from developing an air-tight camera housing to working around the lack of light attenuation at greater sea depths. An external high-power light source is often tied to a camera to ensure a well-lit imaging scene. However, this produces the most sovereign of all challenges: backscatter, shown in Figure 1, where suspended particles in water scatter light in an inhomogeneous manner. The most detrimental form of backscatter originates from particles reflecting the light emitted by the light source back into the camera, creating exponentially bright spots and often saturating the image and degrading the quality. Universal techniques exist to eliminate backscatter in underwater imaging [3]: (a) Reduce the space between the camera and the subject to lower the number of backscatter particles in the space between, (b) Fine-tune the light source positioning by altering the angle such that only the edge of the light cone illuminates the subject without illuminating the space in front of the camera, (c) By achieving perfect buoyancy, a diver can minimise creating clouds of sand and debris when ensuring stability underwater. While these techniques are straightforward, they lack viability for UUVs due to the erratic backscatter formation from the continuous and arbitrary motion of the propellors and general vehicular movement.

The ultimate goal of this project is to develop a cutting-edge light source system capable of aiding the generation of high-quality underwater images, mainly the seafloor, from UUVs without backscatter interference. Achieving this ambitious goal requires a multi-disciplinary approach encompassing efficient machine vision technologies and innovative hardware integration. This project first aims to research systems and develop reliable backscatter detection and elimination capabilities, with a specialised projector serving as a dynamic light source of tailored light patterns for selective scene illumination to mitigate backscatter effects. The second research aim will look into architectures and methodologies to optimise the system for real-time to ensure adherence to stringent requirements for predictability, stability, efficiency, and reliability, ultimately allowing for control of computational parameters to maximise imaging performance in dynamic underwater environments whilst maintaining requirements. The final research aim is delving into the engineering of a predictive system for anticipating the future positions of detected backscatter particles, enabling proactive elimination strategies without the need for continuous, computationally intensive machine vision processing, for efficient and preemptive adjustments to the light projection patterns for optimal backscatter suppression. These three aims represent critical trade-offs that must be carefully balanced to achieve the overarching objective, which this research project aims to establish through systematic exploration and optimisation to lead towards a novel framework for enhancing underwater imaging capabilities.

2 Project Objectives

A dive into machine vision technologies is a requirement to achieve the first research aim, the autonomous segmentation of backscatter. The system must be able to accurately and reliably pinpoint the location of backscatter particles as well as map out the shape of the outline, enabling the perfect segmentation of each particle for elimination. Whilst driving a specialised light source projector, the system must utilise the particle centre location and outline mapping to project holes in the light beam in addition to the implementation of position calibration, which is crucial to minimise the parallax effect, the displacement of the target from the perceived position in the video capture, ultimately ensuring accurate backscatter elimination.

When trying to achieve a system for autonomous backscatter particle segmentation, it is worth noting the vast range of machine vision-based technologies to harness, both in combination or in isolation, each with differing use cases and potential trade-offs. For example, the work of the previous student on this project [4] outlines the backscatter detection and elimination system revolving around a simple blob detection algorithm. However, much industry-related literature refers to an edge-detection algorithm as the industry standard for bubble detection and characterisation systems for underwater environmental analysis. While both of these machine vision-related options are viable solutions to this system, each has differing trade-offs and characteristics which need exploration, and more technologies exist to enhance the system further, requiring additional research.

The work of the previous student on this project discusses the hindrance to the successful operation of the blob detection-based backscatter elimination software due to the effects of the Linux operating system (OS): Linux's ability to run tasks in the background while the program is running, interfered with the execution of the program, making the camera image buffer and freeze [4]. A more controllable OS-level task-switching prioritisation functionality is vital to reducing system latency, thus boosting the performance of the backscatter elimination implementation. Unlike a general-purpose OS such as Linux, a real-time OS (RTOS) ensures compliance with stringent and fixed timing specifications to provide a highly deterministic reaction to any external event.

An RTOS provides an apparent solution to the jitter issues experienced by Shepherd [4] from a non-deterministic response handling by the general-purpose Linux OS. However, an RTOS implementation is more common in specialised embedded systems dedicated to a single functionality, such as single-core microcontrollers. Therefore, there will be a severe system simplicity trade-off when implementing an RTOS due to the dissimilarities of involved hardware and software architectures. Exploration of these trade-offs is crucial to improve the predictability and stability of the backscatter elimination system performance, with the ultimate goal being to strike a balance between these improvements without sacrificing system simplicity by requiring the engineering of low-level customised microcontroller implementations.

High-resolution images consist of high dimensionality with tremendous number of pixels, each containing numerous colour channels and meta-data. Applying machine vision technologies to these images can prove a monumental task to process the vast dataset for even the most perceivably simple functions such as edge detection, segmentation, or filtering. In many cases, machine vision algorithms must consider the entire image data rather than a small, finite subset of pixel values within the image to process frames. Although reducing the resolution of frame captures is viable to reduce the computational overheads, it often trades off object detection and segmentation accuracy. A predictive system approach can mitigate the computationally intensive requirement of machine vision application to every frame of an input video feed.

A system that can accurately predict backscatter particle movement and future locations eliminates the requirement to apply machine vision-based technologies to every frame in the video feed to identify and segment the particles. There are two main approaches to consider when working towards a predictive system: (a) an artificial intelligence (AI) approach, harnessing supervised machine learning (ML) methods with a potential to incorporate unsupervised methods for greater accuracy, or (b) a non-AI/ML interpolative approach with an application of either a linear or polynomial interpolation algorithm to predict future positions concerning the tracked locations in a finite count of previous frames. Again, there are significant trade-offs concerning accuracy, speed, and computational overheads for each approach that requires exploration.

References

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