Safe Steps: Underwater Terrain Reconstruction for Walking Robots

Description

Imagine a miniature amphibious robot standing on a riverbank, preparing to cross a shallow stream. To take a safe step, it must clearly see the terrain underwater—identifying stable rocks and avoiding deep holes. Our goal is to give the robot the ability to "see through" the water surface and accurately map the riverbed.
For a robot, the water surface is a chaotic visual barrier. Reflections (glare) blind the cameras like a mirror; Refraction bends light, making underwater stones look closer than they are; and Waves constantly distort the geometry. Standard computer vision algorithms assume air is the only medium and fail completely in this scenario.
We are developing a hybrid hardware-software solution to break this optical barrier. By combining Optical Filtering (using physics to kill glare) with Geometric Correction (using algorithms to fix distortion), we aim to reconstruct a clear, accurate 3D map of the underwater world.

Background

Amphibious robots are designed to bridge the gap between land and sea. While they are agile on solid ground and efficient in deep water, the shallow transition zone remains a dangerous blind spot. Standing at the water's edge, looking down at slippery rocks, uncertain depths, and moving currents, represents one of the most challenging moments for an autonomous system. Without reliable perception, a robot is likely to misjudge a step and fail before its mission even begins.

To a standard camera, the water surface acts as a deceptive lens. Reflections from the sky often mask the bottom completely. Even when the bottom is visible, Refraction bends the light rays at the air-water interface, causing significant errors in depth estimation—a rock might appear centimeters away from its true position. To make matters worse, Dynamic Waves act as a fluctuating distortion field, making static underwater objects appear to wobble and shift unpredictably.

Solving this problem is about robustness. Most computer vision algorithms work perfectly in the stable, uniform medium of air but collapse the moment they encounter water. By tackling this "Cross-Media" perception challenge, we aim to transform the robot from a fragile lab prototype into a rugged explorer. Giving a robot the "superpower" to see through optical interference is the key to enabling true autonomy in unstructured natural environments, from mountain streams to flooded disaster zones.

Technische Universität München

TUM School of Computation, Information and Technology

Lehrstuhl für Robotik, Künstliche Intelligenz und Echtzeitsysteme

Supervisor:
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Advisor:
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Type:
MA,SA,BA

Research area:
Computer Vision, 3D Reconstruction, Robot Perception, SLAM

Programming language: C++ and Python

Requirements:
High self-motivation and passion for computer vision; At least six-month working time; (Optional) With experience on computer vision algorithm.

Language:
English

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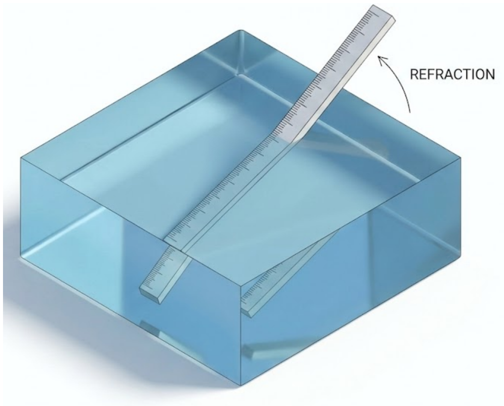

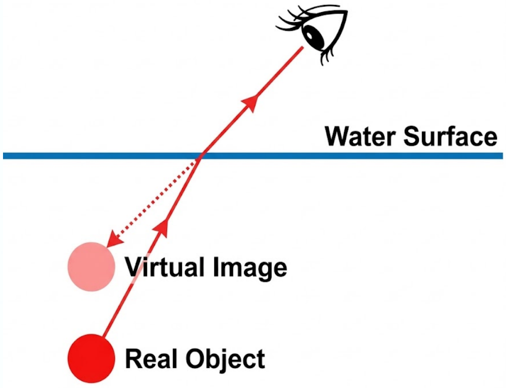

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Tasks

You will build a vision system that bridges the gap between air and water. The project follows a logical, three-phase structure:

Phase 1: Optical Filtering (The Hardware Setup)

Construct a stereo camera data collection rig.

Experiment with Polarizers (CPL filters). Your task is to find the optimal physical setup to passively remove surface glare and reflections, ensuring the camera captures the light coming from below the water, not the sky above.

Phase 2: Geometry Correction (The Algorithm)

Study the principles of light propagation at the air-water interface.

Design a correction algorithm that "undistorts" the refracted images. You will teach the robot to calculate where the underwater rock actually is, rather than where it appears to be.

Phase 3: Stable Mapping (The Integration)

Tackle the challenge of dynamic waves.

Develop a temporal fusion method (combining information from multiple frames) to filter out the noise caused by ripples, generating a stable and clean height map of the riverbed.

What You Will Gain

Hands-on Experience: You will move beyond simulation, setting up real cameras, playing with optical filters, and collecting your own datasets.

Computer Vision Mastery: Gain a solid intuition for 3D reconstruction, multi-view geometry, and image processing in non-standard environments.

Problem Solving: Learn how to tackle the messiness of the real world ("Unstructured Environments") where clean classroom assumptions don't apply.

Mentorship & Support

We believe that great research comes from curiosity and open discussion.

Onboarding: We will provide you with the necessary literature and a conceptual introduction to get you started on the right foot.

Responsible Supervision: You will not be left alone. We offer regular meetings to discuss your progress, brainstorm ideas, and troubleshoot challenges together.

Creative Freedom: This is an open research topic. While we have a roadmap, we strongly encourage you to bring your own ideas and proposed solutions to the table. We are here to guide your exploration, not just dictate tasks.

For further discussion on specific tasks, welcome to direct contact me via email.