Human-Robot Collaboration System Setup for Weed Harvesting Scenarios in Aquatic Lakes

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***Abstract*— Artificial Water Bodies (AWBs) are human-made and require continuous monitoring due to their artificial biological processes. These systems necessitate regular maintenance to manage their ecosystems effectively. Unmanned Surface Vehicle (USV) offers a collaborative approach for monitoring these environments, working alongside human operators such as boat skippers to identify specific locations. This paper discusses a weed harvesting scenario, demonstrating how human-robot collaboration can be achieved, supported by preliminary results. The USV mainly utilises multibeam SOund NAvigation and Ranging (SONAR) for underwater weed monitoring, showing promising outcomes in these scenarios.**

I. INTRODUCTION

AWBs are created by humans for different reasons such as water retention in dam construction, urban development, rainwater storage, or leisure activities. Unlike natural lakes, AWBs lack an established ecosystem, making them prone to environmental issues like ecological degradation and the spread of diseases if not properly monitored and maintained [1]. Managing AWBs, including artificial lakes, presents unique challenges due to their reliance on continuous human intervention, given the unnatural balance of their ecosystems and the potential for disturbances in biological processes [2].

This paper focuses on Maschsee Lake in Hannover, Germany; an artificial lake where rapid weed growth poses a significant problem, requiring continuous harvesting. Effective monitoring could reduce human labour and improve the efficiency of maintaining the lake's ecosystem. The proliferation of weeds negatively impacts the lake's biological life, affecting fish and other aquatic species, and disrupting leisure activities such as kayaking. Weeds can obstruct the propellers of small boats, posing risks to humans and equipment.

A heterogeneous approach involving collaboration between human operators and USVs offers a promising solution for managing the lake environment. The USV can autonomously survey designated areas of the lake, providing real-time data to the boat skipper to facilitate advanced planning. This approach aims to reduce the skipper's workload, increase operational efficiency, and contribute to energy conservation and environmental sustainability.

While optical cameras have been employed for monitoring of aquatic vegetation [3], SONAR and backscatter strength data are often more effective for underwater vegetation detection [4], [5]. SONAR is particularly advantageous due to its ability to scan larger areas at greater depths compared to optical cameras, though it requires specialised expertise for operation and data interpretation. By leveraging SONAR, we can achieve more efficient monitoring of underwater vegetation.

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Fig. 1. Weed Harvester boat and USV collaborating in Maschsee Lake.

II. METHODOLOGY & MISSION SETUP

The mission aims to support the weed harvesting process in Maschsee Lake by adopting a human-robot collaboration approach. This collaboration combines the advantages of USVs with human operators, to identify and map underwater weed clusters as depicted in figure 1. The USV performs a comprehensive survey of the lake using multibeam SONAR, resulting in high-resolution maps that provide boat skippers with detailed information on the location and extent of weed growth. This approach allows for more energy-efficient and targeted harvesting operations, improving both operational efficiency and environmental management.

Before harvesting, a preliminary survey of the lake is performed using the iWBMS multibeam SONAR from Norbit,[1] which provides a comprehensive scan of the underwater environment and high-resolution bathymetry. This process generates detailed maps, providing insights into the distribution and density of weed growth. The SONAR generates a bathymetric map, enabling accurate measurement of depth and the mapping of weed distribution throughout the lake. Additionally, backscatter data analysis allows for distinguishing between different underwater targets, such as weed clusters, the seabed, and other objects.

The multibeam SONAR operates at a mean frequency of 400 kHz, with an 80 kHz wide chirp forming 256 beams,

[1]https://norbit.com/subsea/products, accessed on 13-09-2024

each with a beam resolution of $0.9°$. The upper gate is set to $1.0\,\mathrm{m}$, and the lower gate to $5.0\,\mathrm{m}$, with a swath of $150°$. These parameters allow for a detailed and accurate mapping of the underwater environment. The average survey speed was $3\,\mathrm{knots}$.

The USV communicates directly through the interface used by the boat skippers. The map generated by the USV is updated in real-time, allowing the skippers to visualise weed locations on their displays. The interface bridges the communication between the USV and the skippers. As the USV performs the survey, it provides continuous updates to the map with the latest location of weed clusters. This real-time feedback allows the boat skippers to plan their harvesting routes efficiently. The USV transmits georeferenced acoustic images to the interface, which are overlaid with the lakes' topography to create a clear visual representation of weed distribution as shown in figure 2.

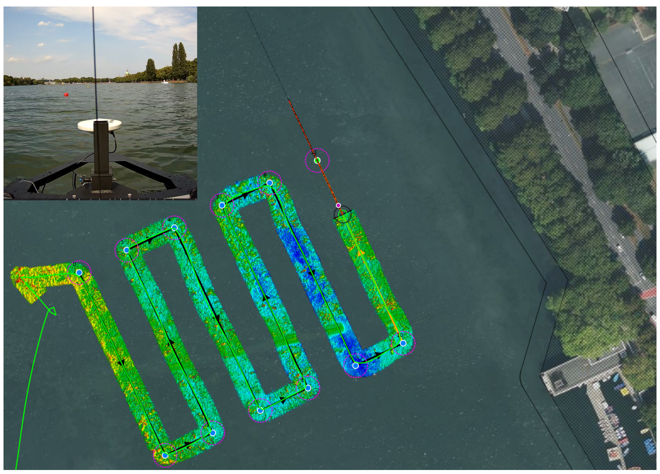


Fig. 2. Georeferenced map of Maschsee Lake with RGB image captured by the USV's camera overlaid. The SONAR data, visualising detected underwater features, is displayed along the predefined path of the USV. The map shows the surveyed areas and the nature of the detected features - whether underwater vegetation, the seabed, or other objects - requiring further analysis

Figure 1 shows the heterogeneous mission setup, in which the USV follows the weed harvester boat. The mission is structured so that the USV first scans a defined area using its multibeam SONAR to map the underwater weed clusters before harvesting begins. Once the area has been fully scanned, the weed harvester boat follows the path of the USV, mowing and collecting the weeds. To evaluate the impact of the harvesting process, the USV scans the same area again after the harvester passes, enabling a comparison of the pre-harvest and post-harvest conditions of the lake.

In addition to SONAR data, visual images captured by a GoPro camera attached to the USV provide a more comprehensive representation of the underwater environment. These images provide additional information than the acoustic data, improving the visibility of areas where SONAR data may be insufficient for precise interpretation.

Furthermore, an oceanographic instrument enhances the mission by collecting essential environmental data. The AML-3 LGR sensor, manufactured by AML Oceanographic,[2] is used for precise water column profiling during the mission. Equipped with a lithium-ion battery and onboard memory, the sensor stores collected data, which is transferred via WiFi or USB. The AML-3 sensor provides data for multibeam SONAR correction, including sound velocity and pressure profiling, ensuring accurate underwater mapping. It also monitors environmental conditions such as turbidity and dissolved oxygen levels, which influence weed growth. This additional information provides an understanding of the lake's ecosystem, providing valuable insights for monitoring and maintaining the artificial lake.

III. PRIMARY RESULTS & FINDINGS

The preliminary survey, conducted using multibeam SONAR, successfully mapped the underwater vegetation in Maschsee Lake. Data processing was performed with Auto Clean (BeamworX) software. The resulting multibeam bathymetry SONAR data revealed significant weed growth throughout the lake.

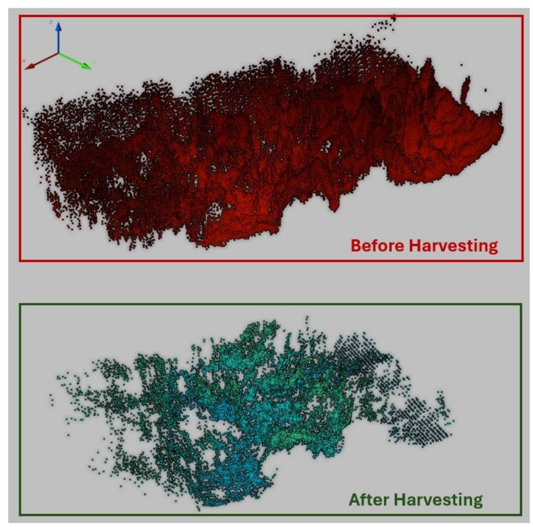


Fig. 3. 3D view of SONAR point cloud data from an inspection area, showing the height difference in weed distribution detected by multibeam SONAR **[Top]** before mowing and **[Bottom]** after mowing.

In an experiment, a designated area was first scanned with the USV equipped with the SONAR, followed by harvesting the weeds with a boat. A subsequent scan by the USV showed notable changes in the weed distribution. Figure 3 illustrates the weed distribution using multibeam SONAR bathymetry data before and after the mowing process. The average height difference between pre- and post-harvest was found to be $80\,\mathrm{cm}$.

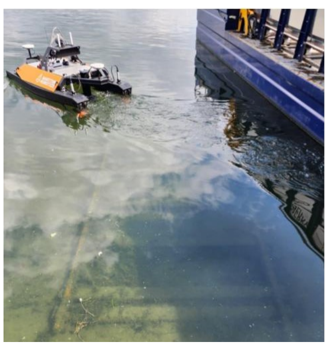
Underwater footage captured by a GoPro camera further validated the SONAR findings for the same area. Figure 4 displays these images, demonstrating the effectiveness of our system in detecting underwater vegetation and the benefits of the heterogeneous setup. The USV collaborates with the

[2]https://amloceanographic.com/aml-3-flexible-oceanographic-instrument, accessed on 13-09-2024

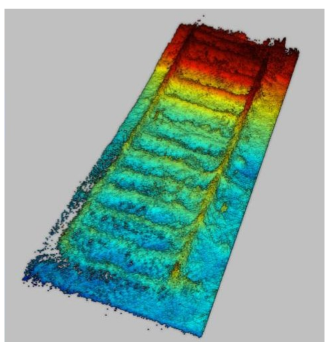
Fig. 4. Underwater image showing weed at Maschsee Lake captured using GoPro camera.

operator by providing a map that guides the mowing process, and it can estimate weed height, using the lake's depth map to determine the vegetation density.

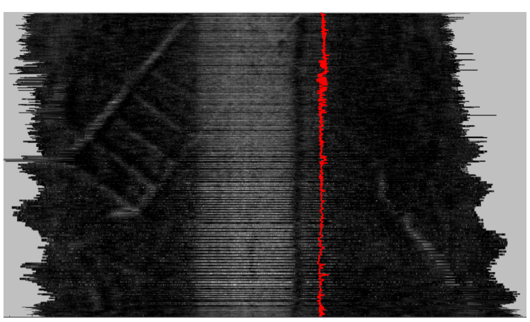
Furthermore, the multibeam SONAR detected a submerged ladder, demonstrating the USV's capability to identify and guide operators away from hazardous or inaccessible areas. Figure 5(a) presents a camera image of the ladder, figure 5(b) shows SONAR 3D point cloud, and figure 5(c) displays SONAR backscatter data.



(a)



(b)



(c)

Fig. 5. Submerged Ladder [**a**] Camera image above water [**b**] Multibeam SONAR 3D point cloud data [**c**] SONAR Backscatter data.

IV. FUTURE WORK

Future work will focus on several key areas to enhance the weed harvesting process. One important aspect is the detailed analysis of backscatter data from the SONAR to correlate it with weed volume and distribution across the lake. This analysis aims to refine our understanding of how SONAR backscatter reflects weed density.

To validate these findings, we plan to incorporate additional data sources, such as satellite imagery, to detect shallow water bathymetry [6]. Additionally, deploying a Remotely Operated Vehicle (ROV) equipped with an underwater camera and an acoustic positioning system will allow for precise location tracking of the ROV, providing ground truth for weed distribution.

Currently, weed detection relies on manual visual inspection by human operators, which is time-consuming. In the future, we will implement Artificial Intelligence (AI) techniques to automate weed detection. Techniques such as image segmentation, as demonstrated in [7], will be explored to enhance detection efficiency and accuracy.

Another critical area for future development is designing and implementing a path-planning algorithm to optimise the weed harvesting process. This algorithm will calculate the most efficient route for the boat, assisting the skipper in navigating through the weed clusters and harvesting them efficiently. It will also ensure that the conveyor belt capacity ($15\,\mathrm{m}^3$) is not exceeded, allowing the boat to reach the unloading station at the optimal time. Additionally integrating dynamic updates based on real-time data from the USV will enable the algorithm to adjust the route in response to newly detected weed clusters during the mission. Developing this functionality will significantly enhance the efficiency and adaptability of the harvesting process.

ACKNOWLEDGMENT

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