Developing an automated zooplankton identifying microscope

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Introduction

Traditional manual methods of collecting plankton data are very time-intensive, costly, and prone to human error. However, plankton are the backbone of aquatic ecosystems, and measures of their diversity serve as important indicators of environmental health. Recent advancements in low-cost (< $1,000) microscopy and image recognition offer promising solutions for automating monitoring. The fully automated OpenFlexure Microscope (~$300) enables high-resolution imaging using 3D-printed components and Raspberry Pi control systems (Collins et al., 2020). Additionally, the potential of artificial intelligence for ecological monitoring has been demonstrated with multiple machine learning approaches for phytoplankton classification (Liu et al., 2025).

This project integrates automated microscopy with machine learning detection models to improve the efficiency and accuracy of plankton monitoring at the Anita C. Leight Estuary Center research pier. Focusing on zooplankton (predatory plankton), they will be divided into three general groups: cladocerans, copepods, and rotifers, and provide the Estuary Center with valuable data on plankton populations and diversity, which are vital to assessing ecological health. This project aims to develop an automated microscope to count the total number of cladocerans, copepods, and rotifers on a microscope slide.

Methods and Materials

This project was developed in two separate pipelines: the microscope and the zooplankton detection model. First, a thorough dataset of zooplankton images across all seasons was acquired. Overall, the model was trained on a dataset of over 1,600 images. Each image was manually annotated in Label Studio, then used to train a YOLOv26 object detection model (Figure 1). The YOLO model is unique because it provides object detection and classification, which is necessary since many images contain multiple zooplankton.

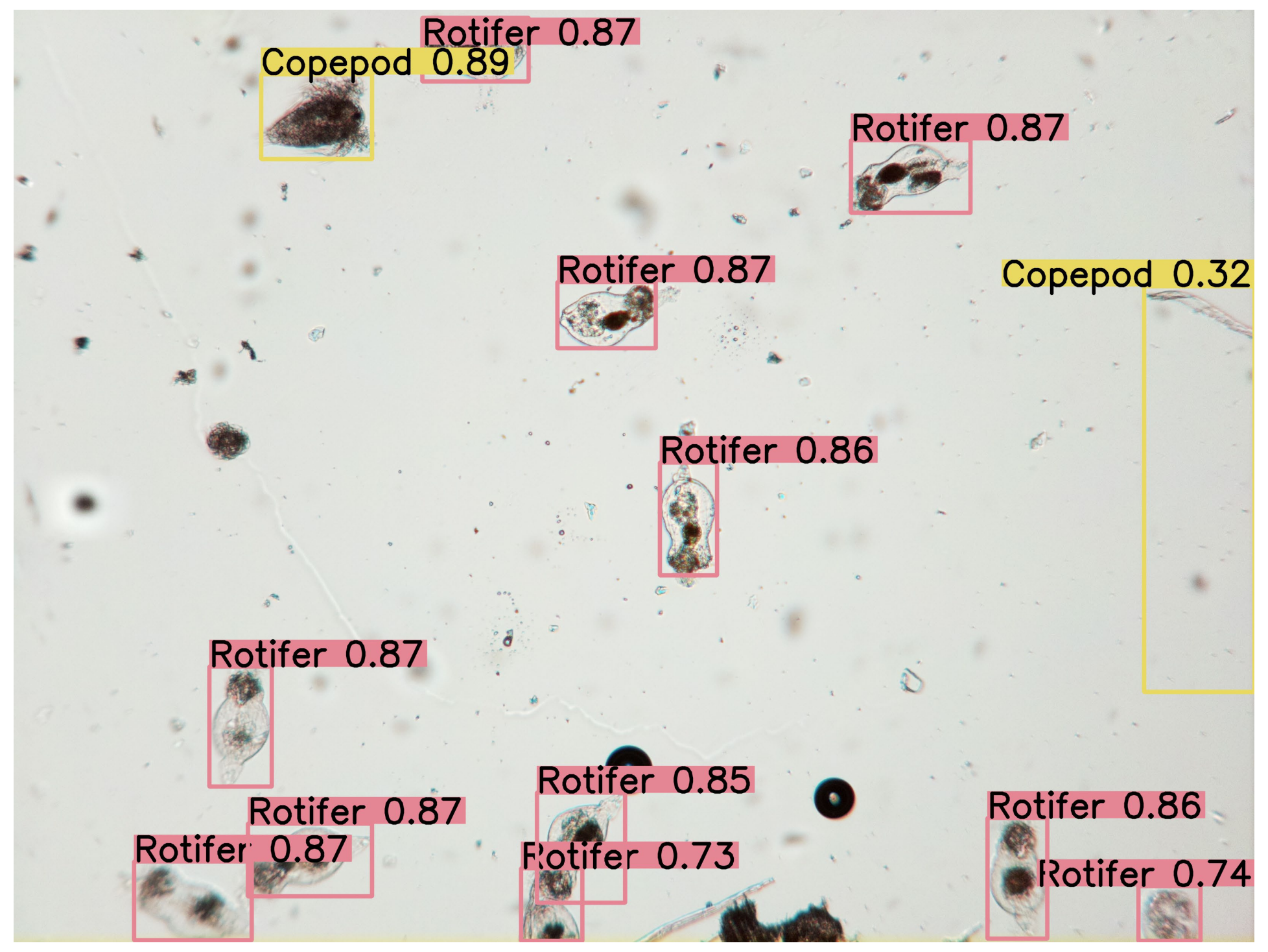


Figure 1 (left): The results of the YOLO model on an image of winter zooplankton. The model correctly drew bounding boxes around the zooplankton in the image while ignoring the surrounding marine debris. The model also correctly identified each detection, with relatively high confidence scores (the number between 0 and 1). The model has around an 88% accuracy for its detections.

Methods and Materials (continued)

The OpenFlexure Microscope assembly kit was purchased, and the 3D printed parts were produced using the provided .stl files. The microscope (Figure 2) was assembled according to the manufacturer's specifications and operated via wireless computer connection to the internal Raspberry Pi. Zooplankton samples were mounted on microscope slides, and then the microscope completed a raster scan to ensure complete field coverage.

Images collected during scanning were processed using a custom Python pipeline. First, the YOLO model was applied to each image, and all detections were compiled into a list. Each image was assigned microscope stage coordinates derived from stepper motor positions, and YOLO detections were mapped into the same coordinate space. This spatial mapping prevented duplicate counting of zooplankton appearing across multiple overlapping images.

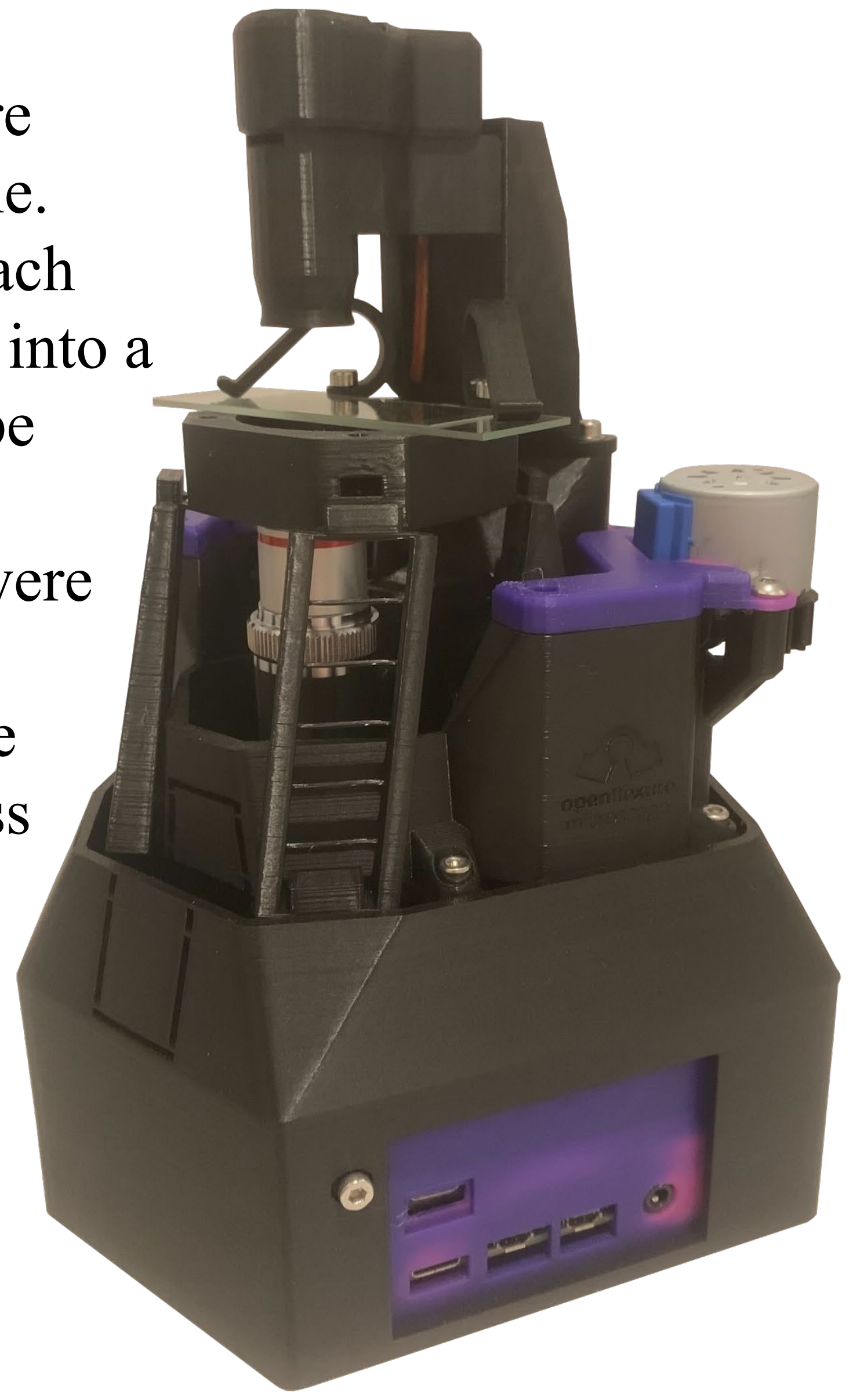


Figure 2 (right): The OpenFlexure Microscope is controlled by the stepper motors in the back, and has the objective lens and camera underneath the sample. The electronics drawer is printed in thermochromic filament to warn of potentially dangerous heat. Dimensions are approximately 145 × 132 × 256 mm.

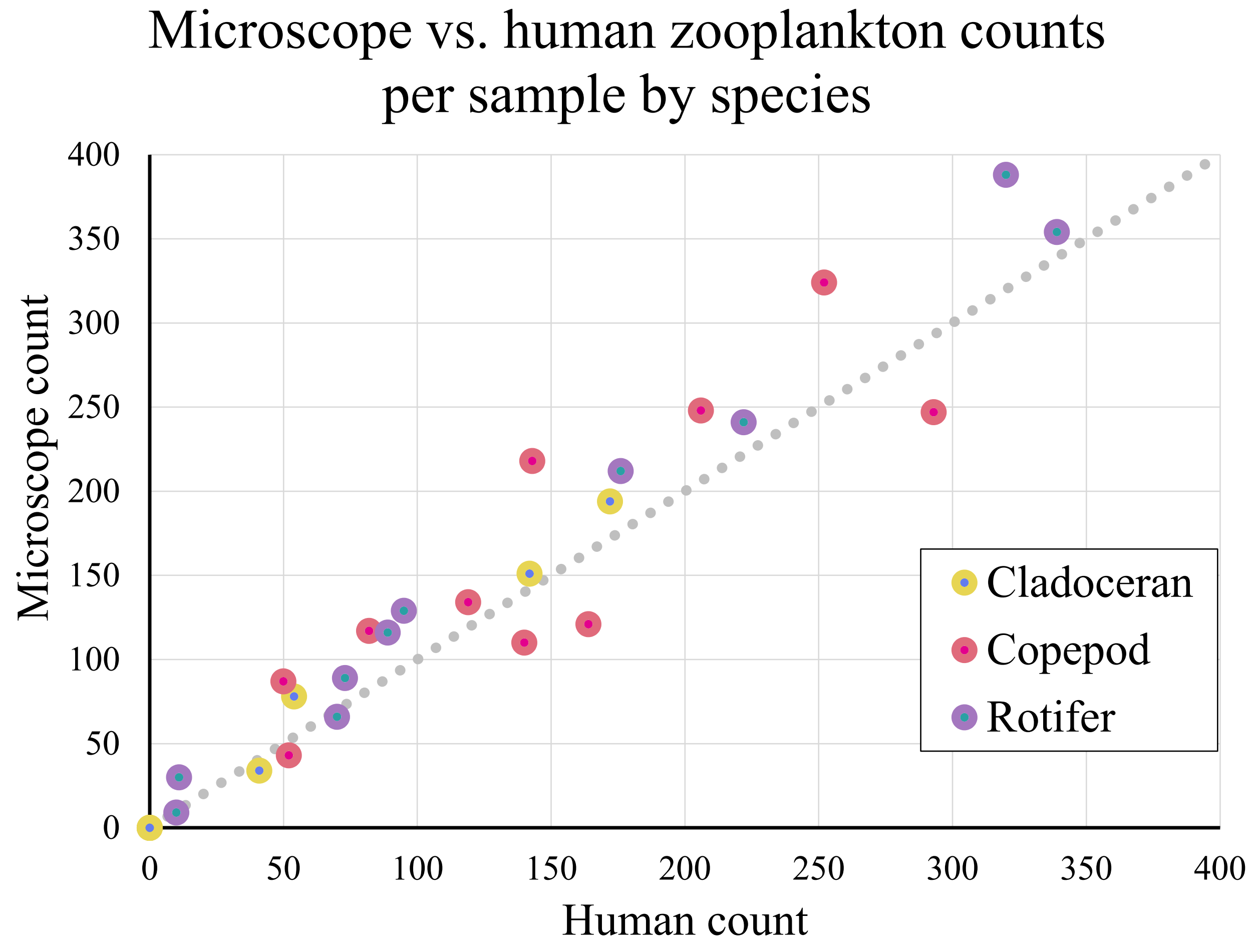
Results

The automated microscope's performance (Table 1) was evaluated using Pearson correlation analyses comparing microscope-generated zooplankton counts with human-verified counts across 10 samples. The scatterplot (Graph 1) showed data points aligned with the $y = x$ line, indicating a strong positive correlation between automated and manual counting methods ($r(22) = .958$, $p < .001$). Each scan required ~45 minutes, with an additional 3 minutes for image analysis, whereas previous manual procedures required 2–3 hours. Overall, the automated microscope demonstrated accuracy and reduced analysis time.

Table 1 (right): The results of the Pearson correlation test for each zooplankton group, showing correlation coefficient (r-value), p-value, and sample size (n).

Zooplankton group	***r*-value**	***p*-value**	***n***
Cladoceran	.984	< .001	4
Copepod	.879	< .001	10
Rotifer	.991	< .001	10

Results (continued)



Graph 1 (left): A scatterplot comparing the microscope and human-verified counts for each sample, separated by species. Ideally, both counts should be the same, and fall on the $y = x$ line, shown as the dotted gray line.

Conclusion

This project developed an automated microscope capable of accurately quantifying zooplankton counts, showing a strong correlation with human-verified counts. The integration of the OpenFlexure microscope and the YOLOv26 model demonstrated that affordable, open-source tools achieved high-precision plankton monitoring. The slightly reduced accuracy in copepod detection suggests that further refinement of the training data and model may enhance reliability. Additionally, optimizing the microscope's autofocus function will improve image clarity, increasing model detection accuracy. This automated data collection pipeline demonstrated potential for increasing efficiency across many fields, such as medicine and biology. The automated microscope and analysis program will be donated to the Anita C. Leight Estuary Center, reviving their zooplankton monitoring program, and aiding in their continued monitoring of ecosystem health.

References

Collins, J. T., Knapper, J., Stirling, J., Mduda, J., Mkindi, C., Mayagaya, V., Mwakajinga, G. A., Nyakyi, P. T., Sanga, V. L., Carbery, D., White, L., Dale, S., Lim, Z. J., Baumberg, J. J., Cicuta, P., McDermott, S., Vodenicharski, B., & Bowman, R. (2020). Robotic microscopy for everyone: the OpenFlexure microscope. *Biomedical Optics Express*, *11*(5), 2447–2460. https://doi.org/10.1364/BOE.385729

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