Marine Video Cloud: A Cloud-Based Video Analytics Platform for Collaborative Marine Research

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***Abstract*—With the increasing attention and corresponding developments of data collection of underwater surveying/diving videos, a large number of underwater videos have been yielded for different purposes. However, it is time-consuming and requires the corresponding expertise to yield a hierarchical and comprehensive biological analysis report based on the collected underwater videos. The development of the underwater video analysis platform is an emergency and users of such a platform should not be limited to some specific groups (*e.g.,* biological experts). The existing VIAME provides an intelligent solution for fishery and marine organism analysis with an installable platform. Differently, in this paper, we develop a novel cloud-based underwater video analysis platform, which focuses on more diverse marine species such as coral reefs and sea urchins. The proposed platform could provide hierarchical and comprehensive services for a wider user group. We aim to build a one-stop platform, which could allow every user to upload their surveying or diving videos and build a centralized database for more robust and accurate data analysis.**

***Index Terms*—Online platform, Video analysis, Marine study, and Biological analysis**

I. Introduction

The Marine ecosystem is the most productive of all ecosystems and shares immense ecological, social, and economic value. Performing marine study plays a significant role in protecting the marine environment and understanding marine science. Most existing marine studies highly depend on describing and analyzing the collected image/video data based on *in-situ* underwater surveying approaches. There are two main issues for this line of studies: 1) they cannot support a very large scale data collection and data scarcity has become one of the important factors that hinder the further development of the marine study; 2) further data analysis procedure still requires many human labors, time costs, and is also limited to some specific biology users. For the former data collection issue, Unlike taking in-the-air videos, it is more challenging to collect satisfactory underwater observations in the underwater setting due to various challenges (*e.g.,* the underwater color distortion, water force, visibility, dynamic object, and *etc*). There is a keen requirement for collecting underwater image/video data based on advanced digital devices. As for the latter marine data analysis, recent research [1] proposed to perform more effective **marine study** by utilizing advanced computer vision techniques, performing the classification, detection, segmentation, and quantification of objects of interest, which were typically performed by domain experts in the previous marine science study. The automatic object recognition and analysis model is customized to increase efficiency and effectiveness to obtain a comprehensive biology report. To tackle these concerns, we aim to propose an advanced online platform used for video analysis for studying marine observations in this work.

The proposed one-stop online data analysis web platform could effectively alleviate the data scarcity problem. Besides, every user of our platform could share their underwater videos for marine data collection and further analysis. The platform can build a marine video database and share data among different stakeholders (*e.g.*, the general public, researchers, government, and industry sectors for their research, education, and promotion purposes). Furthermore, our platform has integrated popular machine learning models and evaluation algorithms for speedy marine video annotation and analysis. To generate a more robust qualitative or quantitative analysis, we have also provided pre-processing algorithms (*e.g.*, denoising, compensating color attenuation, de-hazing, contrast enhancement, and color restoration) to promote underwater image quality to address underwater image issues. Finally, the auxiliary annotation refinement procedure is designed to refine the data labeling and prediction refinement for robust, versatile, and user-friendly analysis.

The abundance statistics, distribution visualization, and percentage coverage of objects of interest have been generated from uploaded videos. The users simply need to use an underwater camera such as GoPro to capture video clips and upload the video to our online analysis website. In this way, the participation of wider users could be heavily promoted. For detailed data analysis, the object detection [2], segmentation [3], counting, and post-processing will be conducted for generating

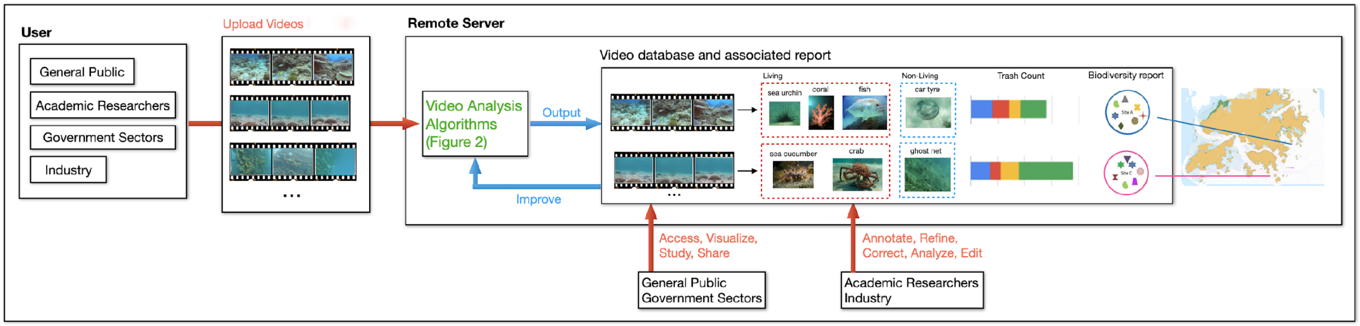

Fig. 1. Framework overview of the proposed platform. We propose a novel cloud-based platform for AI-based analysis of uploaded surveying or diving videos. It also allows experts to provide and correct data annotations and serves as a central database storing the growing dataset of marine videos obtained from different users. Users can access, visualize, obtain, and download the analysis outputs.

the biological report, including the species recognized, species richness (alpha diversity), abundance, coral coverage, etc. The generated biological report will be sent to the video uploader through a user-friendly interface providing better visualization. Besides, the report will be recorded permanently for long-term monitoring purposes. The uploaded videos will also be utilized as further training data for progressively enriching the data diversity. Finally, our platform summarizes the distribution of uploaded videos based on provided geographical information and video metadata.

We finally summarize the three key components of our platform as follows:

- The platform automatically recognizes pre-defined object categories, including the coral reefs and major benthic organisms. As coral reefs are regarded as one of the most significant and diverse ecosystems beneath the ocean surface, we perform the dense pixel-level semantic segmentation for coral reefs, recognizing their distinct biological features and topology. The platform will yield a standard biological output, which covers the result of marine organism detection, dense segmentation of coral colonies, and a report summarizing important statistics.
- It is important to validate the accuracy of the generated biological report by our platform and find out any case of missing detection or wrong detection. For evaluation, we rely on the field data and the interactive assessment by marine biologists, thereby validating the accuracy and robustness of the platform interactively.
- We will release our platform for general access, facilitating the public and scientific community to be involved. The significant increase in underwater video contribution will facilitate the scientific community in marine science. With abundant data collected, we also allow domain experts to refine the generated biological report (*e.g.*, correcting wrong labels, or adding missing correct labels). Thus, the analysis algorithms will be guaranteed to be improved through progressive retraining. The above-developed algorithms and frameworks can be deployed to not only standalone machines but to a remote cloud server for remote processing.

The significance of the proposed platform is threefold. First, the deployed algorithms in our platform can be efficiently executed in the cloud. Second, users can upload data to enrich the database and also download the data analysis output for their marine research. Third, the collaborative efforts (data and annotation contribution) from different users will continuously expand the database, making our platform very valuable for both academic and industrial applications.

II. Related Work

A. *Marine Study*

The existing marine studies mainly focus on static coral reef monitoring [4]–[6] and marine organism detection [7], [8]. A comprehensive and robust coral analysis is crucial for understanding and monitoring coral reef ecosystems. CPCe [9], a famous tool widely used in the coral research community, was the first software designed for benthic coral analysis based on still images. The sparse points are randomly sampled and annotated by the biologists for obtaining the coral coverage statistics. To reduce human labor, the patch-based Convolutional Neural Networks (CNNs) are then integrated to automatically determine the sparse point annotation as demonstrated in CoralNet [10], which could achieve high accuracy on patch-based coral classification [11]. The further variants [12] could achieve more reasonable prediction. Besides, the sparse point labeling, recent advancements have utilized dense semantic segmentation techniques on the benthic images to automate the spatial distribution annotation of coral reef surveying images [13], [14]. TagLab [15] is proposed as a software tool that utilizes CNN-based segmentation networks for agnostic or semantic recognition of corals to facilitate the labeling and mining of statistical information from ortho mosaic images of benthic communities. These advancements have significantly improved the state of the art in coral segmentation analysis, contributing to more efficient and accurate monitoring of coral reef ecosystems. The underwater detection algorithms have also been designed for detecting marine organisms (*e.g.*, sea urchin, sea cucumber, starfish, scallop, and *etc*). The data analysis of such marine organisms could help repair and maintenance of sub-aquatic structures and marine sciences.

B. Marine Dataset

To boost the marine data analysis, various underwater image/video datasets have been collected. [16] proposed to collect the realistic fish-habitat observation to perform underwater visual analysis. The camera is static and the main challenges come from the underwater distortion and visibility problems. Islam *et al.* proposed an underwater dataset and benchmark for evaluating the performance of underwater semantic segmentation. The coral datasets [17], [18] have been captured under some ideal conditions with very close-range and satisfactory visibility, which cannot fully express the diversity and complexity of coral images in the wild. The most recent Marine Video Kit (MVK) dataset [19] consists of 1379 underwater videos taken in 36 different locations worldwide at various times throughout the year. The videos vary in length, ranging from 2 seconds to 4.95 minutes, with each video having an average duration of 29.9 seconds and a median duration of 25.4 seconds. More importantly, those videos are collected under various sites with a large range of illumination, viewpoint, water turbidity, and condition changes. This MVK dataset ultimately contributes to the advancement of knowledge in marine research and the development of effective strategies for the management and conservation of marine resources.

III. Proposed Web Platform

Our web-based platform is developed for supporting scalable and efficient account and user resources management. Pre-trained machine learning models and evaluation algorithms are embedded into our cloud-based platform for speedy marine video annotation and analysis, which provides users with a seamless and efficient online method for analyzing their uploaded videos. It allows users to save time and computing resources when generating data analysis results. Moreover, our platform enables data sharing of uploaded videos and annotations and encourages users' collaboration and also the exchange of ideas, fostering a sense of marine research community among various researchers. Our platform is a promising solution for both individuals and organizations seeking to automate their video content management and analysis processes. In contrast to real-time mode, the proposed web platform could facilitate a more exhaustive and in-depth biological analysis and can be used to refine, enhance, validate, and correct the generated analysis.

A. Platform Implementation Details

We develop our web-based platform by utilizing **Express.js** [20], which is a robust web backend framework for

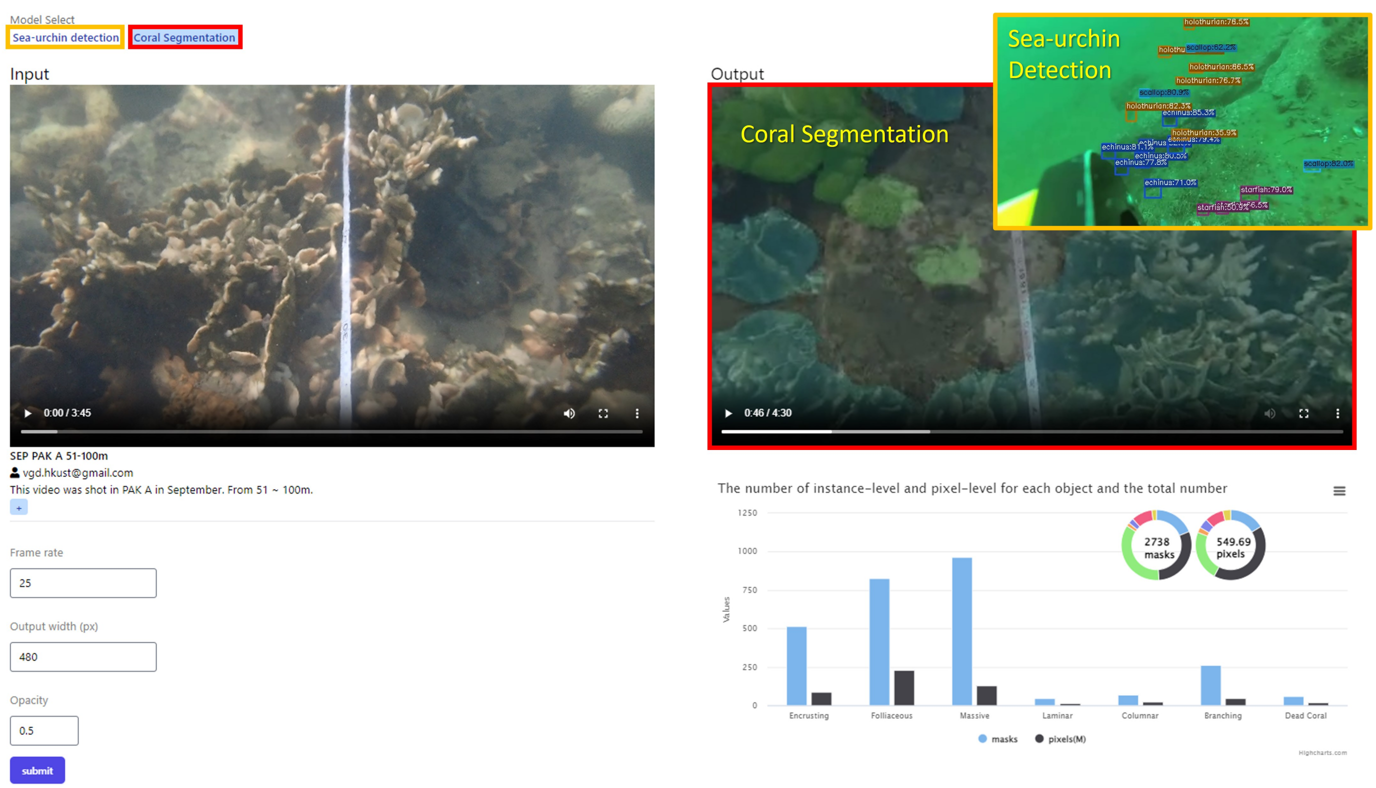

Fig. 2. Online video detection and segmentation, and data analysis. For each uploaded video, the uploader could run an annotation model in the cloud and the minimalist user-interface design enables users swiftly fine-tune the parameters as shown on the left. Online statistic analysis and annotation evaluation are reported with visualization right afterward as shown on the right.

Node.js [21] offering scalability and efficiency. The readers could check Figure 3 for more details. The Model-View-Controller (MVC) pattern is a software architecture pattern that separates an application's data model (M), user interface (V), and control logic (C) into three distinct components. In our backend, we manage to implement the MVC pattern by utilizing Express.js [20] and MySQL [22]. Following this software design, we could create scalable and maintainable applications with a well-defined separation of concerns, which can improve code quality and make it easier to add further features. Moreover, we utilize Tailwind CSS [23] for front-end design. Tailwind CSS provides a set of pre-defined CSS classes for creating custom designs. Based on the Tailwind CSS, we can create user interfaces that are intuitive and user-friendly, promoting their user experience. In addition, the in-memory data store framework Redis [24] is integrated to provide the task queue mechanism to optimize hardware resources, while the media and related information are stored in the reliable and scalable relational database MySQL. Please note that these data are also restored in the local file system for cost-effective and efficient storage. Finally, our software is containerized based on Docker, providing a streamlined deployment process and also improved scalability.

Our platform has been meticulously crafted to attain three crucial criteria as described below:

- **Efficiency**. The application is aimed at providing a fast and efficient user experience. This has been accomplished by optimizing performance through the use of lightweight frameworks: Node.js and Redis.
- **Maintainability**. The application is designed to be easily maintainable and modular. This has been achieved through the use of the Model-View-Controller (MVC) architecture and Docker [25] containerization.
- **Scalability**. The application is intended to handle heavy traffic loads and be able to expand as necessary using the aforementioned technology stack and software architecture.

The high hardware resource demands of machine learning models can present challenges for the efficient handling of large volumes of requests. To overcome this challenge, our implementation has installed a task queue mechanism to manage the scheduling of different user tasks and optimize resource utilization, ensuring stable handling of the requests from users. This mechanism prioritizes tasks based on their level of importance and schedules their execution in a manner, which minimizes delays and downtime. The task queue mechanism plays a critical role in ensuring the stability and reliability of the system, particularly in the context of processing machine learning requests. Its efficient management of resources enables our implementation to provide reliable and efficient machine learning services to users while minimizing the impact on system performance.

B. Core Features

As a cloud-based platform, our platform supports data sharing, online video annotation and analysis, and data assessment collaboration.

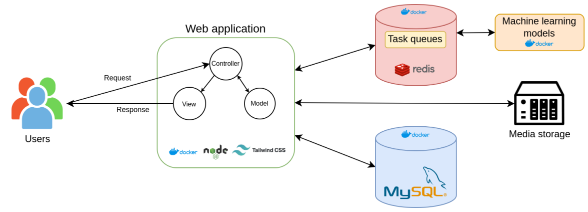

Fig. 3. The adoption of modern technology stack in application architecture involves using the latest software technologies and tools, including containerization with Docker. Containerizing web applications and machine learning models allow for seamless scaling and efficient deployment in cloud computing environments.

Shareable Video Uploading. In our platform, every user registered can upload personalized videos that have been grouped and customized with features, including but not limited to capturing time, location, and species. These uploaded videos can be shared publicly or kept private. The shared videos that are analyzed have the potential to alleviate data scarcity issues in the field of marine studies.

Integration of Existing Marine Analysis Models. Our platform supports online marine video analysis for popular species in marine data analysis with existing pre-trained AI machine models, such as sea-urchin detection [26], [27], fish segmentation [28], [29], *etc*. Users can feel free to customize model prediction parameters for analysis models (Fig. 2 on the left). Our platform runs video analysis online for each video and displays analysis results with analyzed video such as resultant annotation and visualized statistics of the analyzed video (Fig. 2 on the right).

Auxiliary Annotation Refinement. The auto-annotated and analyzed video can be exported in annotation formats in popular annotation platforms such as LabelMe [30] and CVAT [31]. Users could be redirected to the annotation platform for data labeling refinement and later back to our platform for quality assessment.

C. Specialized Features

Building upon prior work [15], [32], our platform advances marine study by harnessing the capabilities of contemporary machine learning techniques, thereby providing researchers with an innovative and robust tool for their investigation. Online data analysis and reports would be automatically generated for each user, featured with customized groups and tags.

Coral Segmentation Analysis. Coral segmentation analysis encompasses the employment of modern computational methodologies, including machine learning and image processing algorithms, to accurately discern and demarcate individual coral formations and characteristics within subaqueous images or videos. This analytical approach empowers researchers to examine coral ecosystems with enhanced precision, enabling the quantification of parameters: coral abundance, species diversity, physiological health, and growth dynamics. Moreover, coral segmentation analysis substantially contributes to the advancement of knowledge in marine ecosystems, conservation

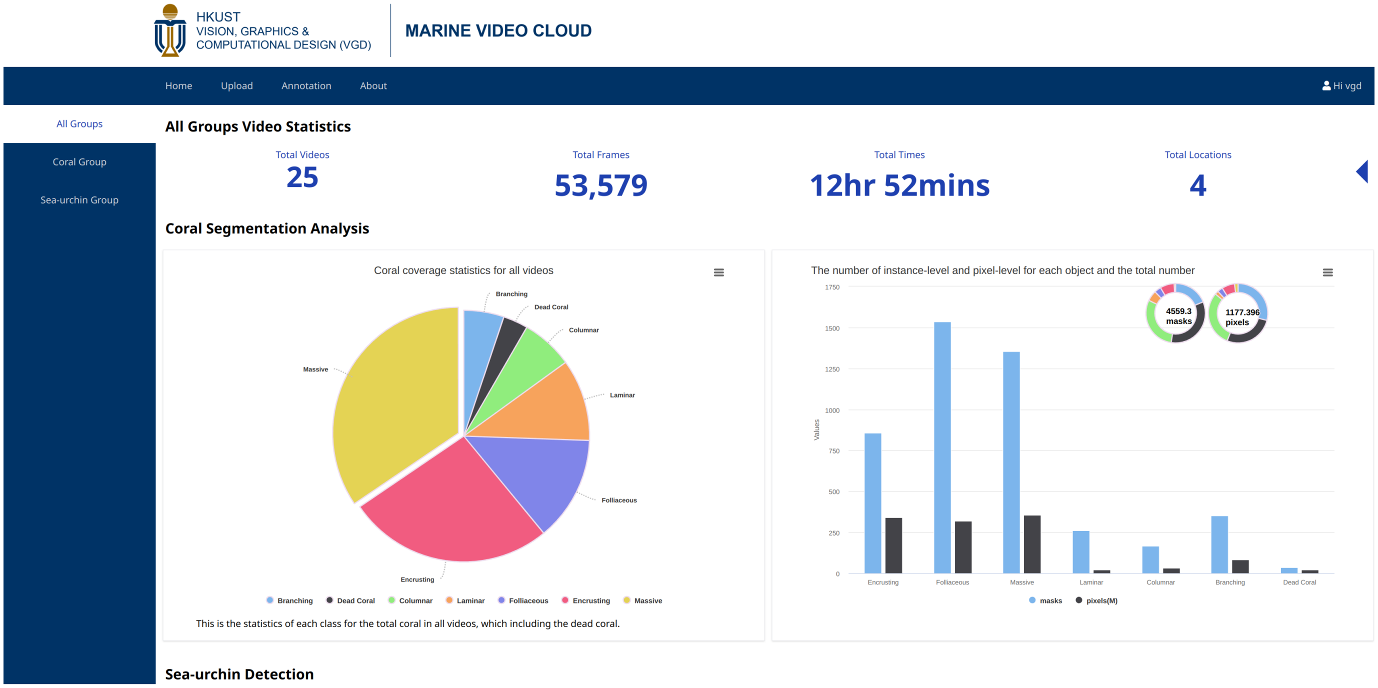

Fig. 4. Author dashboard for data analysis and visualization. Each user can view summarized data statistics and annotation evaluation and get insights from interactive visualization charts. Dashboard arranges analysis reports into customized groups and categorizes data in terms of marine species and evaluation metrics with interaction. For example, the user can hide or cover different coral species to compare coral coverage.

initiatives, and the elucidation of climate change repercussions on coral reef communities. By leveraging state-of-the-art machine learning models, we adopt coral segmentation analysis for the scientific community. This platform enables researchers to upload their videos and effortlessly utilize our artificial intelligence algorithms to perform in-depth analysis. Users are granted the capability to customize key parameters of the model, thereby ensuring an optimal and tailored experience for their specific research needs. Please refer to Fig. 2 for the single video analysis and Fig. 4 to see a summarized coral segmentation analysis among videos.

One-Stop Reporting Dashboard. We aim to provide a user-friendly interface for the efficient and effective analysis of marine video datasets. This interface combines essential data and analytical findings to provide a comprehensive summary of submitted underwater video materials, which can aid in the monitoring and conservation of marine environments (Fig. 4). With advances in underwater imaging technology, the importance of analyzing marine video datasets has been widely recognized, and the interface developed by our team represents an important step forward in this regard. It has the potential to facilitate the use of marine video datasets in diverse situations, including the assessment of coral reef health and the identification of marine species, and thus contribute to the conservation and management of marine environments.

IV. Discussions and Future Work

Considering the escalating requisites of the whole marine research community for the incorporation of machine learning models of the collected video analysis, the proposed platform has been diligently designed to accommodate the seamless combination of further models. Our prescient design ensures that the proposed platform remains agile and adaptive to the ever-evolving demands of researchers, enabling the effortless assimilation of avant-garde machine learning innovations, and fostering a perpetually enhanced analytical experience. Besides, the 3D reconstruction and Simultaneous Localization and Mapping (SLAM) will be further integrated into our platform, providing the 3D scene understanding.

V. Conclusion

The proposed user-friendly interface and cloud-based underwater video analysis platform represent a significant step forward in the field of underwater and marine video analysis. The increasing collection of marine video datasets has created a need for efficient and effective processing tools for analysis and interpretation. The user interface proposed in this work enables the combination of essential data collection and analytical findings to provide users with a comprehensive summary of the submitted underwater video materials, facilitating the evaluation and understanding of outcomes derived from marine video datasets. Additionally, our cloud-based underwater video analysis platform focuses on a broader range of marine species and provides hierarchical and comprehensive services to a wide user group. Our goal is to create a centralized database for more robust and accurate data analysis that is accessible to all users, regardless of their expertise in the field. By simplifying and streamlining the analysis of marine video datasets, these tools have the potential to contribute significantly to the monitoring and conservation of marine environments, which is crucial for the sustainability of the oceans of our planet.

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