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A research tool for long-term and continuous analysis of fish assemblage in coral-reefs using underwater camera footage

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ABSTRACT

We present a research tool that supports marine ecologists' research by allowing analysis of *long-term* and *continuous* fish monitoring video content. The analysis can be used for instance to discover ecological phenomena such as changes in fish abundance and species composition over time and area. Two characteristics set our system apart from traditional ecological data collecting and processing methods. First, the continuous video recording results in enormous data volumes of monitoring data. Currently around a year of video recordings (containing over the 4 million fish observations) have been processed. Second, different from traditional manual recording and analysing the ecological data, the whole recording, analysing and presentation of results is automated in this system. On one hand, it saves the effort of manually examining every video, which is infeasible. On the other hand, no automatic video analysis method is perfect, so the user interface provides marine ecologists with multiple options to verify the data. Marine ecologists can examine the underlying videos, check results of automatic video analysis at different certainty levels computed by our system, and compare results generated by multiple versions of automatic video analysis software to verify the data in our system. This research tool enables marine ecologists for the first time to analyse long-term and continuous underwater video records.

1. Introduction

One of the new challenges in today's data-driven world is how to make sense of enormous amounts of data (Kelling et al., 2009). To gain a better understanding of a complex environment such as a coral reef, collecting data for long-term monitoring of these environments is essential. Long-term monitoring of a coral reef environment can however be labour intensive, requiring divers to identify and count the fish species in a certain area (Pattengill-Semmens and Semmens, 2003). A number of disadvantages of the data collected by divers have been discussed in the literature (Hill and Wilkinson, 2004), including that the presence of divers may affect the fish assemblage, and that divers differ in their experience and ability to identify species.

Fixed underwater cameras can be used continuously to record the coral reef environment during the daytime. Compared to diver-collected data, camera collected data avoids some of the disadvantages of diver collected data. For example, fish activities are not influenced by the sensing equipment, the recorded video footage can be reused by multiple interested parties and video footage can be analysed by different kinds of automatic software as well as different marine ecologists. More importantly, continuous recording may capture trends and developments in the environment that may be missing from divers' observations. On the other hand, data collected by underwater cameras also brings new challenges both in creation (Jan et al., 2007) and analysis (Ebner et al., 2009) of this kind of data.

Analysis of this kind of data requires either a lot of human effort (Ebner et al., 2009) or automatic video analysis technologies. Advances in automatic video analysis technologies (Huang et al., 2012a; Spampinato et al., 2010) yields new solutions to address the above challenges. The goal of this research is to develop a system that allows marine ecologists to access and analyse the video content. In this case, the system is able to automatically find and recognise certain fish species in the video. This information is then organized and presented to users with a web interface for further analysis. This allows the users (marine ecologists) to analyse statistical summaries of the fish species count determined by automatic video analysis technologies. Users can create and verify hypotheses based on this data by checking the videos or performing additional diving expeditions. Currently, our dataset consists of video footage collected by up to 10 cameras that have been recording during 12 daylight hours for the last 3 years.

The contribution of this research can be summarized as follows. First, this is the only system that is able to *analyse of underwater video recordings for the presence of fish*, which makes these results no longer only dependent on the work of divers. An advantage of video recording is that the data becomes reusable, it also allows other marine ecologists to analyse and verify the results afterwards. Second, it is the first system that

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gives marine ecologists *a user interface to analyse and explore the output of automatic video processing software*. Third, the amount of analysed data by the system is unique, where we already have around *4 million observations of fish from around 1 year of continuous videos of multiple cameras*.

This paper describes the first prototype that is able to perform the challenging task discussed above. After the related work (Section 2), an illustrative example of the output of the system is given in Section 3 showing the ability to analyse and present new trends in marine ecology. In particular, we focus on three key aspects of the system: (i) data-intensive processing of underwater video footage (Section 4); (ii) fish detection and species recognition (Section 5) and (iii) visualization of the data (Section 6). Evaluation of video/image processing software is presented in Section 7 and an example is given how to verify observations with the user interface in Section 8.

2. Related work

To our knowledge, this is the first research that aims to analyse multiple years of underwater video data as described in the previous section. A number of research lines are relevant to the type of work described here. These research lines include: studies in analysing large ecological datasets; projects that use underwater cameras to monitor certain aspects of the underwater environment; and computer vision methods developed for recognizing fish species.

Large data collections for scientific purpose have received much attention in recent years. Most of these data collections are developed with human-observers inserting data or observations. One of the most well-known projects is Galaxy Zoo[1], where human volunteers can classify galaxies into different shapes. Research on large data collection, more related to ecology is ebird[2] (Sullivan et al., 2009), where volunteers upload their observations to a website, which allows scientists to look at location-based biological patterns of birds using large numbers of observations. Similar projects exist for flora observations (Auer et al., 2011; McGuire et al., 2008), where both projects couple observations to physical locations. To monitor the coral reef, there is a similar project[3] allowing divers to share voluntarily their observations online. As already discussed, human observations in this case share the same disadvantages as in other diver-collected data. All these current systems rely on human volunteers to insert data, while our system is fully automatic.

Instead of using diver observations, video recording can be analysed which avoids some of the disadvantages of diver observations. In Table 1, a comparison between the pros and cons of using video recording and diver observation is given. An overview of underwater camera systems for monitoring this kind of environments is given in (Shortis et al., 2009). Different camera setups are used for fish observations: cameras with and without bait (Watson et al., 2005), different kind of bait (Dorman et al., 2012), stereo vision (Cappo et al., 2006) and high-resolution rotating cameras (Pelletier et al., 2012). Most previous work uses short term video recordings, where our system used video data that continuous monitors the coral reef (Jan et al., 2007). The analyses of videos are often still performed by human observers except for the size of the fish which is usually a combination of human annotation and stereo vision (where 3D depth of the scene is determined with two cameras). A related research topic to fish identification is plankton identification. Plankton is much smaller than fish, so specialized sensing equipment is necessary. Software has been developed to classify up to 10–20 taxonomic classes with an accuracy of around 70–80% (Benfield et al., 2007). Examples of software for plankton classification are Visual Plankton (Davis et al., 2005), PICES (Luo et al., 2004) and ZOOSCAN[4].

Table 1
Table containing the pros and cons of diver observations versus video recording.

	Diver observations	*Video recording*
Fish activities:	Changed due to present of divers	Go back to normal after installation/maintenance of equipment
Mobility:	Divers swim around	Camera often static
Visibility	Larger field of view	Smaller field of view
Time:	Diver are limited by oxygen (hours)	Camera are limited by maintenance (weeks)
Recognition:	Human recognition (most cases better)	Automatic fish recognition
Consistent:	Human has attention span	Very consistent
Repeatable:	Diver observations cannot be verified	Video recording can be double checked by expert

While the literature and software of automated plankton identification are voluminous, software and literature on fish recognition are less common. One of the possible reasons for this might be that fish in a natural environment are more difficult to classify, because the difference between fish species are more subtle and there are more taxonomic classes in comparison to plankton. Another reason might be that no expert equipment is necessary, so for small numbers of fish humans can easily perform the analysis themselves, however for larger datasets this becomes impossible. Automatic fish species recognition has been developed for different purposes, both for commercial applications like fish farming and fishery and for environmental monitoring. There is research on automatically measuring fish size and estimating their biomass using stereo vision (Ruff et al., 1995; Strachan, 1993a; Strachan et al., 1990). Early work in fish recognition (Strachan, 1993b; Strachan et al., 1990) is focussed on fish on conveyor belts and classifies fish based on shape and colour. Classification of fish in aquariums and tanks (Lee, 2004; Toh et al., 2009) is more challenging than classification of dead fish (Larsen et al., 2009). The first research in unrestricted natural environments (Rova et al., 2007) is able to classify between two different species, where Spampinato et al. (2010) classified 360 images of ten different species (which is one of the largest datasets mentioned in literature). Extensions of the work of (Spampinato et al., 2010) are used in this paper for fish detection and tracking and species classification. Until recently, fish recognition software dealt with very small datasets. In this work, the system made more than 4 million observation of fishes in the video recordings (however many of these are resident species so are frequently re-observed). These observations are stored in a database, where a web interface allows different visualization options to explore this data, giving marine ecologists the ability to look at trends in fish count over time (i.e. hours in a day, fluctuations in a year).

3. Illustrative example of system usage

By using a scenario, we show how this system (webinterface) can be used for instance to explore temporal patterns in fish counts. The system provides users a webinterface http://f4k.project.cwi.nl/data1/ui/ that allows user to select counts of different species over years, hours in week, camera sites, etc. While observed patterns may not have an obvious association with an existing biological/ecological explanation, such information may be useful in providing entry points for marine ecology researchers to conduct further investigation, e.g., in terms of formulating hypothesis and design diving experiments.

3.1. Data exploration scenario

While looking at the counts of different fish species throughout the different daylight hours, we notice that the count distribution of *Chromis*

[1] www.galaxy-zoo.org.
[2] www.ebird.org.
[3] www.reef.org.
[4] www.zooscan.com.