



Clicks classification of sperm whale and long-finned pilot whale based on continuous wavelet transform and artificial neural network

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ABSTRACT

Passive acoustic observation of whales is an increasingly important tool for whale research. Clicks are the predominant vocalizations of toothed whales, such as sperm whales and long-finned pilot whales. Classifying clicks of sperm whales and long-finned pilot whales is an essential task for the passive acoustic observation of the two whale species, especially in the case that both whale species vocalize in the same observed area. In this paper, we proposed a method performing the automated classification of clicks produced by sperm whales and long-finned pilot whales. First, the two types of whales' original sounds were denoised using a wavelet denoising method. Then, a dual-threshold endpoint detection algorithm was utilized to detect and pick out all clicks from the denoised sounds. The continuous wavelet transform was applied to decompose the picked clicks, and a wavelet coefficient matrix can be obtained for each picked click. Focusing on the energy distribution and duration difference between the two types of whales' clicks, we proposed a feature-vector extraction algorithm based on the wavelet coefficient matrix. For each picked click, scale (frequency) features and time feature were obtained respectively and they were used to form the feature vector. Finally, a back propagation (BP) neural network was designed as a classifier of feature-vector to output final classification result. The experiment results show the proposed method can obtain high classification performances. The effect of training dataset size, and the number of training features on the classification performance was also examined in the experiments.

1. Introduction

In recent years, passive acoustic observation has gained more and more attention in the field of whale species research [1]. Passive acoustic observation, which only captures sounds from the surrounding environment of the observation instrument, can be used to monitor whales in a non-invasive manner [1]. Compared with visual observation methods, passive acoustic observation has a better monitoring performance. In addition, it can continue at night, in poor weather, and under other conditions in which visual observation cannot. The method can be used to measure the range and seasonal occurrence of whale species [2], to estimate the abundance of a species in a given area [3], to determine the population structure [4] and so on. For the above applications, a necessary precondition is to identify which species produce a given sound, particularly under the conditions that the target species are difficult to identify visually [5]. Correctly classifying various

whale sounds into corresponding whale species, which is an essential and primary task for passive acoustic observation applications, can assist observers to determine the species composition of the observed whale and further to determine whether or not the observation instrument turns towards the target species or continues to observe the target whale [6].

Generally, whale sounds can be classified into many sub-categories, such as whistles, pulses, and clicks [7]. Whale clicks are important vocalizations that are widespread in a variety of whales [7,8]. Moreover, whale clicks are considered as the predominant vocalizations of toothed whales [7,9]. Sperm whales (*Physeter macrocephalus*) and long-finned pilot whales (*Globicephala melas*) are two typical toothed whale species that can produce multiple clicks which can be applied for navigation, prey detection, and communication. [7,8,10–12]. Due to the unique physical structures of vocal organs, sperm whales are thought to produce only clicks [7,13]. Moreover, according to the

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different behavioral purposes (such as echolocation, communication) of sperm whales, clicks can be divided into usual clicks, creaks, slow clicks and codas [12]. Long-finned pilot whales are an extremely vocal species, using a combination of clicks, whistles and pulsed calls for echolocation, and communication [11,14].

Furthermore, sperm whales and long-finned pilot whales are abundant in quantity and widespread in distribution [7,8,14,15]. Sperm whales, which are relatively abundant and can be found in all the oceans, are the most widely distributed marine mammal species. Long-finned pilot whales can be found in temperate to subpolar marine waters especially in the North Atlantic and the Southern Hemisphere [14]. Therefore, there is a wide range of overlapping distribution area between sperm whales and long-finned pilot whales. Previous evidence has shown that both whale species may be present in the same area, such as Ireland's Atlantic Margin [16] and Arcipelago Campano Margin [17]. One of the sound files used in this paper also recorded the situation in which the sounds of the two whale species (sperm whales and long-finned pilot whales) appeared together.

However, for achieving the independent passive acoustic observation of the two whale species in the same area, it is a priority, necessary and vital to first distinguish and identify their own click from the mixed clicks composed of different clicks produced by the two whale species (namely Sperm whale and Long-finned pilot whale). In other words, it is critical to distinguish and classify own clicks of the two whale species, especially in the case that the two whale species appear together in the same observed area and their sounds are mixed when recorded by observation equipment [1].

Considering that the two types of whale clicks (the clicks of sperm whales and the clicks of long-finned pilot whales) are transient and have similar impacts on human hearing [18], there are errors and uncertainty in manual whale clicks classification. An efficient and automatic whale clicks classification method with high performance is requisite and vital. However, due to the variations of whale clicks, the uncertainty of ocean environment and impact of non-target sounds, it is still a challenging task to detect and correctly classify various whale clicks into their corresponding whale species, and more work needs to be done in this research field.

Several methods have been proposed to detect and classify clicks produced by whales or dolphins at species-level. Roch et al. presented a species classifier system to locate and classify echolocation clicks from three species of odontocetes [19]. The cepstral analysis was used to construct the feature vectors for clicks. The classification performance of Gaussian mixture model (GMM) and Support vector machines (SVM) was compared. H Klinck & DK Mellinger presented an energy ratio mapping algorithm which was tested for detecting clicks of Blainville's beaked whales while rejecting echolocation clicks of Risso's dolphins and pilot whales [9]. The algorithm correctly identified 81.6% of clicks in the evaluation dataset. Gillespie & Chappel introduced a system for automatically detecting the vocalizations of Harbour Porpoises [20]. The relative amplitudes of signals in different frequency bands and the shape of each detected pulse were used to classify clicks automatically. Roch et al. presented a system for classifying echolocation clicks of six species of odontocetes in the Southern California Bight [5]. Echolocation clicks are represented by cepstral feature-vectors that are classified by GMM. The system achieves a mean error rate of 22% across 100 randomized K fold cross-validation ($K = 3$) experiments. Jarvis et al. presented a novel SVM based methodology for species-level classification of small odontocetes [21]. A class-specific SVM was trained to identify click vocalization from four odontocetes species. Madhusudhana S et al. proposed an automatic detection method of echolocation click based on Teager-Kaiser energy operator (TKEO) and Gabor model [22]. The detection algorithm is well suited for processing continuous input audio samples which contain a variety of echolocation clicks. Luo W et al. proposed an automatic odontocetes species recognition methods by detecting and classifying echolocation clicks based on TKEO and k nearest neighbors (kNN) method [23]. The

average accuracies of species identification were 92.38% and 99.30% respectively. Frasier KE et al. presented an algorithm to classify dolphin echolocation clicks [24]. They used spectral shape and inter-click interval distributions of clicks as click characteristics, and developed an automated unsupervised network-based classification method.

Further, the majority of the research on the clicks classification of sperm whale or long-finned pilot whale focused on the classification of different sub-types of clicks from the same whale species, such as the classification of usual clicks, slow clicks, creak and coda [18]. Features extraction methods, such as Gabor function [25], wavelet packet transform [25,26], Teager energy operator [27] and classification methods, such as artificial neural network [26,28], SVM [29], were presented to recognize different sub-types of sperm whale clicks. However, these methods do not focus on the clicks classification between sperm whales and long-finned pilot whale at species-level, and therefore do not work well in the classification task between clicks produced by different whale species.

In this paper, we first analyzed the different characteristics between clicks produced by sperm whales and long-finned pilot whales in terms of energy distribution and duration. Further, considering those different characteristics, as well as their non-stationary and transient properties, we proposed a click features extraction and classification method based on both continuous wavelet transform (CWT) and artificial neural network (ANN). This method is applied to detect and classify clicks produced by sperm whales and long-finned pilot whales.

A novel features extraction algorithm based on the wavelet coefficient matrices from whale clicks was developed to extract features of whale clicks. In the algorithm, we first proposed a method to calculate the effective coefficient area (ECA) of each wavelet coefficient matrix. Then, scale features and time features of each picked click were obtained respectively from the ECA and formed a feature-vector. The feature-vector was classified into its corresponding whale species (sperm whale or long-finned pilot whale) by a back propagation (BP) neural network. Compared with the existing methods of whales' or dolphins' clicks classification presented above [5,9,19–21] the method proposed in the paper shows a better classification performance. Moreover, even in the case of a small training dataset size or a small number of features, a satisfactory classification performance can also be obtained from the proposed method.

The paper is structured as follows: Section 2 describes the characteristics of the whale clicks and the details of the sounds used in this paper. Section 3 describes the algorithms used for denoising, detection, feature extraction and classification; Section 4 describes the experimental process and the assessment method of algorithm performance. The experimental results are also presented and discussed in Section 4. Section 5 concludes the contents of this paper.

2. Characteristics of sounds

Clicks are a series of transient, powerful, highly directional, non-stationary broadband signals [7,8,29]. The frequency of sperm whale clicks ranges from 100 Hz to 30 kHz, with major energy emphasis in the 2–4 kHz and 10–16 kHz frequency ranges [8,29]. Compared with the sperm whale clicks, long-finned pilot whale clicks have a significantly broader bandwidth which can range from 1 kHz to 100 kHz and its energy distribution is more uniform in the frequency domain [18]. The duration of sperm whale clicks range from 100 μ s to 20 ms depending on the size of whales (most of the click distributions are within 10 ms) [29], while the duration of long-finned pilot whale clicks are significantly shorter with a range from 20 μ s to 75 μ s [18].

All the sounds used in this paper have been manually confirmed that they can be classified to sperm whale sounds or long-finned pilot whale sounds. The record location and sound quality are varied. Table 1 lists the detailed properties of the sound for both whale species.

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