Classification of a Large Collection of Whistles from Indo-Pacific Humpback Dolphins *(Sousa chinensis)*

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Abstract - **The whistle repertoires of some dolphin species have been characterised and classified both qualitatively and quantitatively [1, 2, 3, 4, 5]; however, given the extensive range of the species relatively little is known about the acoustic repertoire of the Indo-Pacific humpback dolphin, *Sousa chinensis* [6, 7], particularly those in South-east Asia. Quantitative classification methods have been developed using sub-sets of *S. Chinensis* whistles [8, 9, 10] but research aimed at classifying a more complete whistle repertoire of *S. Chinensis* through quantitative classification methods has not been reported. To address this, whistles produced underwater by six Indo-Pacific humpback dolphins kept by Underwater World Singapore Pte. Ltd. at Dolphin Lagoon, Sentosa, Singapore were recorded. The acoustic recordings were de-noised and the whistles 'traced' from the spectrogram time/frequency representation. They were then classified using PCA and *k*-means clustering.**

I. Introduction

Cetaceans produce a wide variety of sounds many of which are termed 'vocalisations' but those believed to be used for con-specific communication are frequency-modulated (FM) tones often referred to as whistles. This type of vocalization can be heard by humans both above and below water, as can other types of noise produced by cetacean behaviours such as tail-slapping that are also believed to signal information [11,12]. That said, the majority of vocalisations are produced and heard underwater. Dolphins can produce a huge variety of complex, whistle-like sounds along with 'moans, squeals, wails, grunts squarks and barks' which have been linked with communication [13]. Several cetacean species, such as sperm whales and blue whales, produce signature sounds that help identify individuals within a group.

Indo-Pacific humpback dolphins (*Sousa Chinensis*) are dark grey in colour at birth but as they mature their skin colour gradually lightens through patchy grey on pink, to completely pink (the pink colour being particularly striking in warm, equatorial waters), and the fatty hump on their back around the dorsal fin becomes more prominent. The dorsal fin is small and triangular and positioned near the centre of the ventral surface. The Indo-Pacific humpback dolphin grows to approximately 2.5 to 2.8m in length and can weigh up to 260kg. Frequently seen in coastal waters in Singapore, its range extends around the Indian Ocean, South China Sea and as far south as northern Australia and South Africa. Relatively frequent sightings are made in coastal waters of the western Pacific including southern China (particularly well studied in Hong Kong and Taiwan where it is called the white dolphin), Thailand, Borneo, Singapore, The Philippines, Indonesia, Vietnam and Australia.

Although there is doubt that bottlenose dolphins (*Tursiops truncatus*) produce individually distinctive 'signature whistles' in contexts of social isolation [14], there is evidence to support the concept that as part of their normal behavior growing up within a group, bottlenose dolphins develop distinctive signature whistles that identify an individual and help maintain cohesion within the group [15, 16] and that this is a learned behavior. There is also evidence of vocal matching in wild bottlenose dolphins [17]. Janik et al. [18] reported "Dolphins are the only animals other than humans that have been shown to transmit identity information independent of the caller's voice or location." It is therefore of considerable interest to study different dolphin species but a knowledge of acoustic vocalizations can also be helpful in assessing the number of animals in a population which is an important element of wildlife conservation [7].

Sousa chinensis might produce individually identifiable signature whistles when isolated [8], and a study of Pacific humpback dolphins off eastern Australia suggested that whistles might be used as contact calls [9].

Some of the authors of this paper began a cognitive research study with a group of six Indo-Pacific humpback dolphins kept by Underwater World Singapore Pte. Ltd. at their facility in Singapore. The project aimed to study the vocalizations of the dolphins with the aim of exploring whether it was possible to train the animals to associate synthetic dolphin-like whistles with an object, an action or an agent (usually a person or another dolphin), and then to mimic the sounds and ultimately to reproduce them with the long term aim (and hope) of establishing acoustically mediated 2-way exchange of information. During the course of this study, a large number of whistles were recorded. However, limitations on access to the dolphins meant it was not possible to incorporate a specific sub-study of 'signature whistle' production at that time. Furthermore, since there have been no previous reports of classification of a large set of whistles produced by Indo-Pacific humpback dolphins from South-east Asia which is the first step on which to base other studies, this paper concentrates on describing quantitative classification of the data set.

II. METHOD

A. Data Collection

The whistles (FM tones) used in this paper were recorded from a group of Indo-Pacific humpback dolphins (*Sousa chinensis*) kept by UnderWater World Singapore Pte. Ltd. in their facility called 'Dolphin Lagoon'. Our subjects comprised six dolphins of various ages: a four year old juvenile male; two female young adults (approximately 14 years old); and 3 mature adults (2 males and one female). The adult female was the mother of the juvenile and other family relationships existed within the group. The dolphins were housed in a semi-natural environment – a large man-made, sand-based, seawater lagoon divided into separate but connected enclosures that were not acoustically isolated. Noise from snapping shrimp found in many tropical coastal waters tended to dominate the acoustic environment. Recordings were made during experimental sessions (usually between 1 to 6 sessions per week, and 45 minutes per session) for a related project on dolphin communication and cognition that took place over a period of approximately one and a half years. A hydrophone (Model B & K Type 8103) was positioned in the enclosure that housed the dolphin subjects (either our adult male subject, or the juvenile male according to the study protocol). The dolphins were given the opportunity to become accustomed to the experimental process and an experienced trainer with whom the dolphin was familiar was present throughout the research work. For logistical and possibly behavioral reasons, whistles from the two young female adults in the adjacent enclosure were also often recorded and whistles from the other two mature adults are believed to have been recorded less frequently. However, during most experimental sessions the dolphins that were not directly engaged in the research were in enclosures further from the recording hydrophone. Their amplitude would have been lower in most but not all cases.

The data set of whistles was recorded *via* the hydrophone connected to a digital video camera (Model: DSR-PD150P) with an audio sampling rate of 48 kHz. Audio data was extracted from the DV tape by connecting the digital video camera via audio cables to a desktop computer running Adobe Audition software.

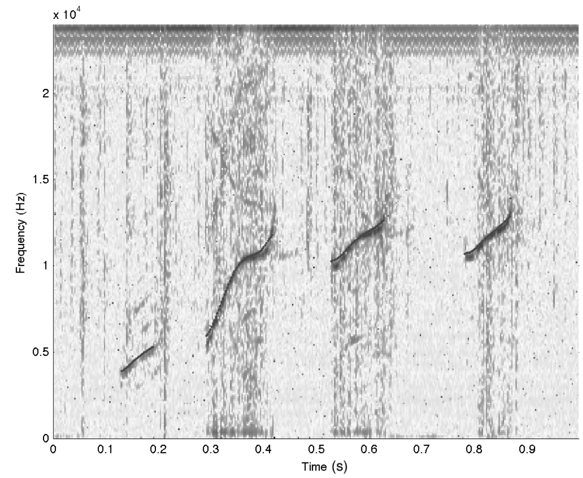

Figure 1: Spectrograms of a series of four *Sousa Chinensis* whistles.

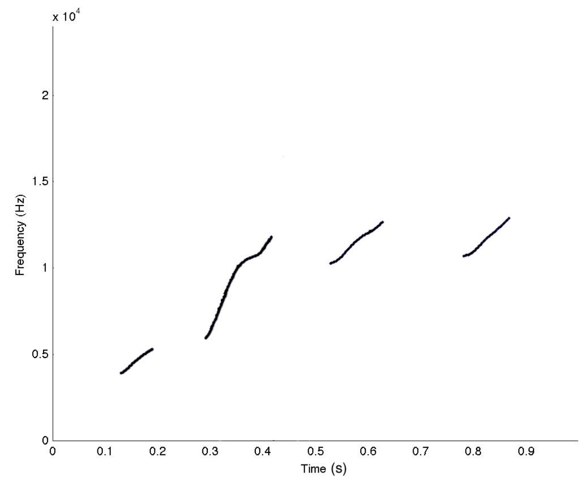

Figure 2: Traced whistles.

B. Whistle Tracing

Whistles are often best visualized and described by their time-frequency plane (spectrogram) characteristics [19]. Fig. 1 shows an example spectrogram of a series of four whistles.

Rather than extract a feature vector from the whole time-frequency plane, the whistle was 'traced' from the spectrogram following de-noising. A method based on the hybrid regional maxima method described by Halkias [20] was developed to trace the whistle. The result was a set of the time/frequency coordinates representing the smooth curve of the whistle. Fig. 2 shows the result after whistle tracing.

Since the audio recordings were made in a seawater lagoon, the recordings are complicated by a significant amount of transient broadband noise caused by snapping shrimp. While the whistle-tracing algorithm was generally robust against ambient noise and the snapping shrimp 'snaps', a high amplitude snap of a shrimp's claw near to the hydrophone could cause the whistle trace to be broken. Hence, a wavelet based de-noising algorithm [21] was used to specifically reduce the amplitude of broadband transients before each whistle contour was traced. This improved the quality of the tracing to an acceptable degree. From the recordings, 1400 whistles were traced and extracted and were manually checked for consistency against the original spectrograms. Poorly traced whistles where discarded resulting in a set of 1166 whistle traces.

C. Feature extraction

Given that the whistle extraction process produced a set of time/frequency coordinates for each whistle, the data was interpolated to give constant length feature vectors for 30 uniformly spaced samples. The frequency was normalized by the mean frequency of each whistle. Both the mean frequency and original length of the time series could be included in the feature vector. This approach is a modification of McCowan's method of obtaining feature vectors [22].

Although the method based on dynamic time warping [12] on which one of the authors (E. Taylor) is working with the co-authors of the original paper appears to be very promising, but for a large data set normalization with respect to the overall mean frequency and the length of a whistle is a simple method to minimize variations of these factors that might arise between vocalizations produced by individual animals or for variation in whistles produced by any given animal.

D. Feature vector reduction

Principal component analysis (PCA) was performed on all feature vectors. Four principal components that explained more than 80% of the variances were obtained and these were used as input for subsequent classification of whistles. Examination of the PCA transfer matrix shows components that explain most of the variance is those corresponding to the beginning and end frequency of the whistle, and also the fundamental/dominant frequency occurring at approximately two thirds of the duration of the whistle.

E. Classification

In order to determine the likely number of classes, *k*-means clustering was performed. This technique tends to increase the number of classes and therefore the average intra-class variance was measured for each *k*-means clusterings and is shown in Fig. 3. The graph shows no definitive indication of an exact number of classes. However, since 90% percent of the variance could be explained by using 5 classes of whistle types, and 95% percentage of the variance explained when using 8 classes, initially 8 classes were used for the *k*-means classification. These classified whistles were plotted and then manually verified by five independent researchers, and five whistle classes were consensually established. In total, 1166 whistles were successfully traced and 955 were successfully classified into five whistle classes. The remaining 211 contained vocalizations that were too short or too infrequent to form distinct classes.

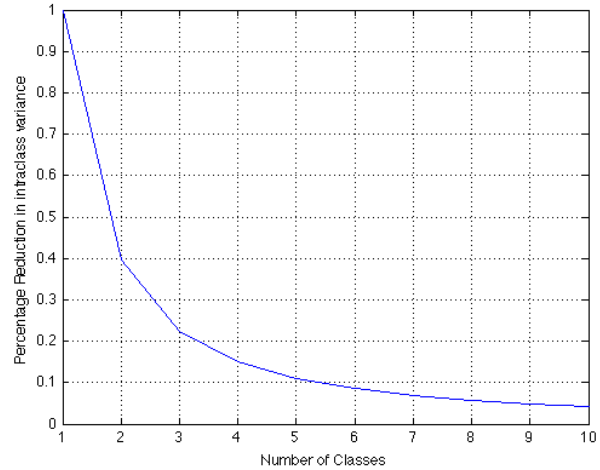

Figure 3: Percentage of intra-class variance with respect to the number of classes.

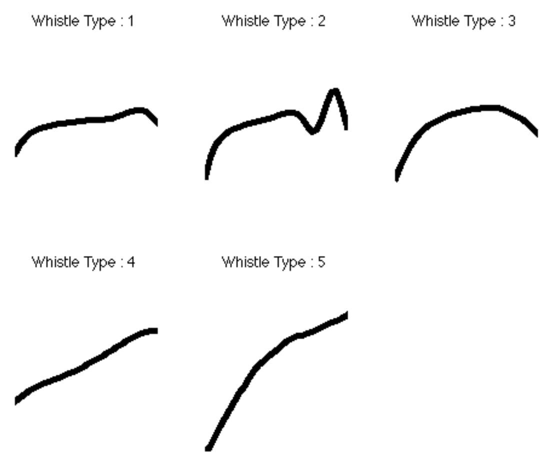

Figure 4: Five main types of whistles after classification.

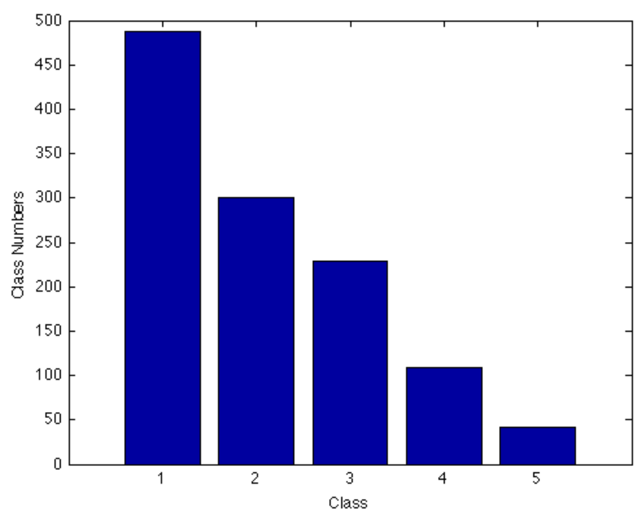

Figure 5: Number of whistles in each class of whistles.

III. RESULTS AND DISCUSSION

Figure 4 shows the typical whistle shapes classified, ordered in terms of their frequency of occurrence. The method by which the whistles were recorded does not permit a formal statement about the type of whistle produced by any particular dolphin especially with reference to 'signature whistles'. However, since there were family ties between members of this group and the group had been living together for a considerable number of years, the small number of whistle classes most commonly observed might not be surprising. In particular, it is interesting to observe the similarities between Class 1 and Class 2, and also between Class 4 and Class 5. The frequency of whistling did appear high during experimental sessions, especially those in which the calf was temporarily moved to an enclosure adjacent to his mother.

These spectrograms appeared quite different from the set of 329 whistles produced by Pacific humpback dolphins in east Australian waters described by van Parijs & Corkeron [9] which might reflect regional differences.

Figure 5 shows the distribution of centre frequencies. Most whistles were of lower frequency than those reported in [9] with the most common centre frequency being approximately 3.8 kHz.

Figure 6 shows the distribution of whistle durations. Whistles were of short duration – almost all being less than 1 second which agrees with the duration previously reported [9].

In addition to whistles (FM tones) a variety of other sounds made by the dolphins was recorded, many of which were vocalizations. High frequency broadband echolocation click trains were frequent and clearly directed at a given target object with most activity directed at previously unseen targets.

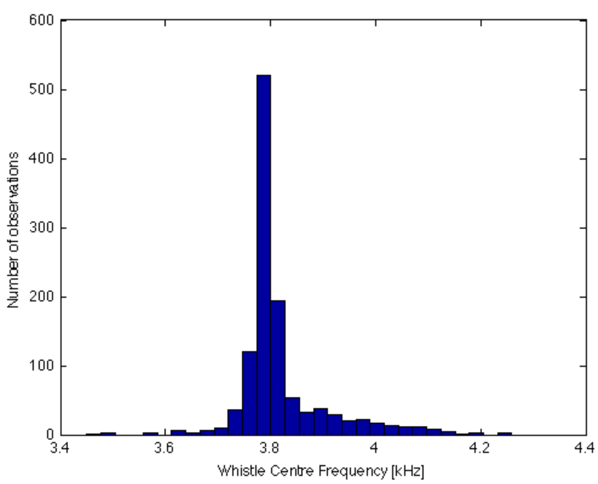

Figure 5: Distribution of whistle centre frequencies (kHz).

The PCA analysis suggested that the 'start' and 'end' frequency of whistles, plus the frequency occurring about two thirds through the duration of a whistle are the most important factors from a human analytical point of view and these are the points that contribute most to differentiating between classes of whistles.

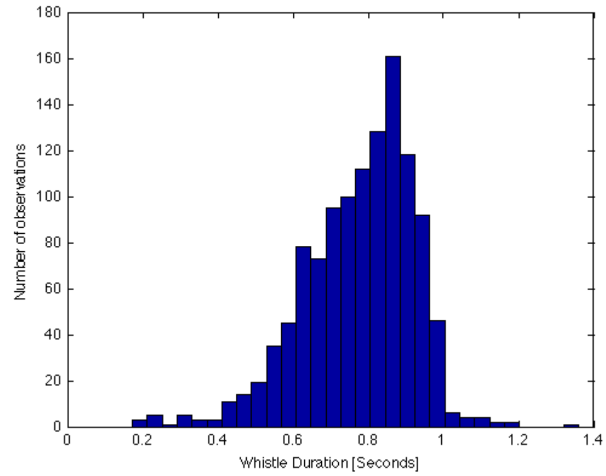

Figure 6, Distribution of whistle durations (seconds).

There was a particular 'bark'-type of sound (a well-defined, short duration burst pulse composed of harmonics similar to that reported in [9]) made by our adult male dolphin which appeared closely related in time with our experimental procedure for the study of cognition. However, these fall outside the scope of the current paper.

To provide the ability to classify new examples, a back propagation neural network has been trained, based on the classification discussed here. Typically it is trained with half the data from each class of whistles, and tested using the other half. Typical classification rates are around 80% for both training and test data.

IV. CONCLUSION AND FUTURE WORK

A large data set of whistles produced by a group of Indo-Pacific humpback dolphins was acquired during an exceptional opportunity to study this species in a semi-natural environment. With the aim of contributing to a range of studies of vocalizations produced by this species, the data was analysed using PCA and *k*-means clustering, and initially classified into 8 classes and then manually by combination of classes into 5.

Since our work showed there was no definitive number of whistle types, in future a hierarchal classification could provide an informative depiction of the different classes of whistles and their relationship to each other.

We are currently working towards combing our different analytical methods into one user-friendly method to both de-noise and quantitatively classify dolphin vocalizations.

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REFERENCES

[1] W.W. Steiner, "Species-specific differences in pure tonal whistle vocalizations of five western North Atlantic dolphin species," *Behavioral Ecology and Sociobiology*, vol. 9, pp. 241- 246, 1981.

[2] S.O. Murray, E. Mercado, and H.L. Roitblat, "The neural network classification of false killer whale (*Pseudorca crassidens*) vocalization," *J Acoust Soc Am,* vol. 104, pp. 3626-3633, 1998.

[3] W. Ding, B. Wursig, and S. Leatherwood, "Whistles of boto, Inia geoffrensis, and tucuxi, *Sotalia fluviatili*," *J Acoust Soc Am,* vol. 109, pp. 407-411, 2001.

[4] C. Bazua-Duran, "Differences in the Whistle characteristics and repertoire of Bottlenose and Spinner Dolphins," *Annals of the Brazilian Academy of Sciences*, vol. 76, pp. 386-392, 2004.

[5] L. J. May-Collado, and D. Wartzok, "A characterization of Guyana dolphin (*Sotalia guianensis*) whistles from Costa Rica: The importance of broadband recording systems," *J Acoust Soc Am*, vol. 125, pp. 1202-1213, 2009.

[6] K.W. Schultz and P.J. Corkeron, "Interspecific differences in whistles produced by inshore dolphins in Moreton Bay, Queensland, Australia," *Canadian Journal of Zoology*, vol. 72, pp. 1061-1068, 1994.

[7] S.M.van Parijs, J. Smith, and P.J. Corkeron, "Using calls to estimate the abundance of inshore dolphins: a case study with Pacific humpback dolphins *Sousa chinensis*," *J. Appl. Ecol.*, vol. 39(5), pp. 853-864, 2002.

[8] S.M.van Parijs and P.J. Corkeron, "Evidence for signature whistle production by a Pacific humpback dolphin, *Sousa chinensis*," *Marine Mammal Science*, vol 17(4), pp. 944-949, 2001.

[9] S.M.van Parijs and P.J. Corkeron, "Vocalizations and Behaviour of Pacific Humpback Dolphins *Sousa chinensis*," *Ethology,* vol. 107, pp. 701-716, 2001.

[10] Mallawaarachchi, M. Chitre, and E. Taylor, "A Method for Tracing Dolphin Whistles," in *Proceedings of OCEANS 2006- Asia Pacific*, pp. 1-5, 2006.

[11] S.C. Nanayakkara, M. Chitre, S.H. Ong, and E. Taylor, "Automatic Classification of Whistles Produced by Indo-Pacific Humpback Dolphins (*Sousa chinensis*)," in *Proceedings of OCEANS 2007 - Europe (Aberdeen)*, pp. 1-5, 2007.

[12] R. Gao, M. Chitre, S.H. Ong, and E. Taylor, "Automatic Template Matching for Classification of Dolphin Vocalizations," in *Proceedings of OCEANS 2008 (Kobe)*, pp. 1-6, 2008.

[13] K.S. Norris and J.H. Prescott, "Observations on Pacific cetaceans of Californian and Mexican waters," *University of California Publications Zoology*, vol. 63, pp. 291-402, 1961

[14] K. Norris, *The Hawaiian Spinner Dolphin*. University of California Press, 1994

[15] L.M. Herman, "What the dolphin knows, or might know, in its natural world," in *Dolphin Societies*, K. Pryor and K. S. Norris, Ed., University of California Press, Berkeley, pp 349-363, 1991

[16] B. McCowan and D. Reiss, "The fallacy of 'signature whistles' in bottlenose dolphins: a comparative perspective of 'signature information' in animal vocalizations," *Animal Behaviour,* vol. 62 (6), pp. 1151-1162, 2001.

[17] V.M, Janik, "Whistle matching in wild bottlenose dolphins (*Tursiops truncatus*)," *Science*, vol. 289 (5483), pp. 1355-1357, 2000.

[18] V.M, Janik and P.J.B, Slater, "Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls," *Animal Behaviour*, vol. 56 (4), pp. 829-838, 1998.

[19] V.M, Janik, "Pitfalls in the categorisation of behaviour: a comparison of dolphin whistle classification methods," *Animal Behaviour*, vol. 57, pp. 133-143, 1999.

[20] X.C. Halkias and D. Ellis, "Call Detection and Extraction Using Bayesian Inference," *Applied Acoustics, Special issue on Marine Mammal Detection*, vol. 67(11-12), pp. 1164-1174, 2006.

[21] P. Seekings, J. Tan, J. Potter, M. Hoffman-Kuhnt, A. Pack, and L. Herman. "Denoising dolphin click series in the presence of tonals, using singular spectrum analysis and higher order statistics," in *Proceedings of OCEANS 2006 - Asia Pacific*, pp. 1-6, 2006.

[22] B. McCowan, "A new quantitative technique for categorizing whistles using simulated signals and whistles from captive bottlenose dolphins (delphinidae, *Tursiops truncatus*)," *Ethology* vol. 100, pp. 177-193, 1995.