Development of an automatic discrimination method of the bio-sonar clicks of Irrawaddy dolphin (*Orcaella brevirostris*) from various types of boat noises

Harumi Sugimatsu[1], Junichi Kojima[2], Tamaki Ura[3], Rajendar Bahl[4], Sabro Tomuro[5]
(1) Institute of Industrial Science, The University of Tokyo, Tokyo, Japan, harumis@iis.u-tokyo.ac.jp
(2) KDDI R&D Laboratories Inc., Fujimino, Japan
(3) Kyushu Institute of Technology, Kitakyushu, Japan
(4) Indian Institute of Technology Delhi, New Delhi, India
(5) TOA OIL KOGYOSHO Co., Ltd., Yachiyo-shi, Japan

***Abstract*—Long-term acoustic monitoring of the Irrawaddy dolphins using a PAM (passive acoustic monitoring) system has been conducted since 2011 at the stationary observatory in the middle-river district of the Mahakam river in Borneo. For statistical data analysis using a large amount of data of both Irrawaddy dolphin clicks and a variety of boat noise pulses acquired by the long duration monitoring, applying the click train based ICI (Inter-click Interval) change rate and CF (Centroid Frequency) / frequency component analysis, a new integrated automatic discrimination method of the dolphin clicks from various types of boat noises pulses was developed. For evaluation of the proposed method, the analysis results using the method were compared with the manual analysis results. Similar trends were shown in both analysis results of the daily/monthly dolphin's appearance frequency (Ad), and the differences of the Ad values were within an acceptable range. It can be said that the proposed method could capture the overall trends of the dolphin's appearance frequency in a long-term span. From this, the effectiveness of the proposed method was demonstrated well.**

Keywords-Irrawaddy dolphin, Passive Acoustic Monitoring (PAM), Bio Sonar Click, Boat noise pluse. Click Train, Inter-click Interval (ICI), Centroid Frequency (CF).

I. Introduction

Irrawaddy dolphins (*Orcaella brevirostris*) are widely distributed in Asian rivers, lakes, lagoons and coastal areas. The animal belongs to the small toothed whale family (dolphin). Like other dolphin species, the Irrawaddy dolphin uses bio-sonar clicks for echolocation and the returning echoes to understand its surrounding environment and capture prey [1], [2]. As their habitat areas are easily accessible to humans, the dolphins are threatened owing to ongoing human activities. For example, in Borneo, only about 90 number of the Irrawaddy dolphins (adults and calves) remain in a 180km stretch of the middle-river district of the Mahakam river (c.f. Fig. 1) [3]. They are classified as threatened species with "CR: Critically Endangered" status on the IUCN red list (http://www.iucnredlist.org/). For understanding their underwater activities and migration behavior for their conservation, therefore, field studies in the wild are required.

The authors have been developing various types of Passive Acoustic Monitoring (PAM) systems using arrays of hydrophones that can provide position information of the click sound source with its acoustic parameters such as waveform, frequency, apparent source level (ASL), and inter-click interval (ICI) and have conducted several field observations since 2006. One of these studies has been targeting the Irrawaddy dolphin groups (adults and calves) that frequently migrate between Semayang Lake and the river through the tributary and the confluence in the middle-river district of the Mahakam river. In order to monitor their migration in a wide extent of the river, the stationary observatory using a PAM system that has been deployed from a private floating house was developed in December 2011 in Sangkuliman village (c.f. Fig. 1). The long-term real-time acoustic monitoring has been conducted since then with periodic improvements of the monitoring system to sustain the real-time monitoring over a long-term span in the difficult river environment [4], [5].

The dolphin position and location data with other parameters such as ICI and Spectrogram are transmitted to the host server in real-time through a data card using the available mobile network link and automatically uploaded to the database for further analysis every one hour except when internet connection is terminated. Analysis results using acoustic data have shown that some dolphin groups migrate from Semayang Lake to up/down-stream of the river through the tributary and the confluence. However, migration of the dolphins passing through the observatory was not seen every day, as on some days, dolphin clicks could not be extracted from the acoustic data. On the other hand, a variety of boat noise pulses have been recorded almost everyday during the monitoring period (c.f. Fig.2). Therefore, not only for understanding their migration trends from the lake to and from the river, but also for evaluation of increasing boat noise effect on their migration behavior, comparison of the trends of dolphin appearance using quantitative analysis is necessary. Statistical data analysis using a large amount of data (both dolphin clicks and boat noise pulses) acquired by the long duration acoustic monitoring and uploaded to the database, requires extraction of parameters to discriminate the dolphin

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clicks from various types of boat noise pulses (Sugimatsu et al., 2015) [6].

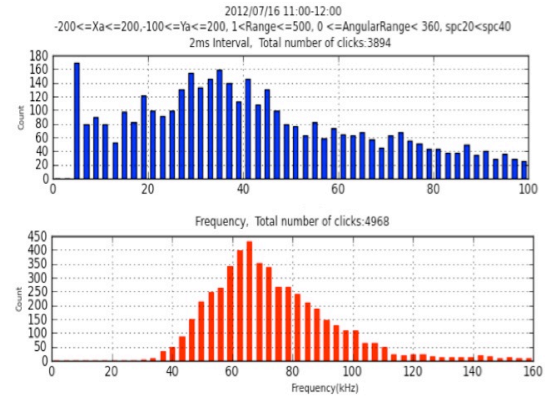
Our previous analysis of the dolphin clicks and the boat noise pulses based on the value of ICI and CF (Centroid Frequency) indicated that the ICI and CF distribution of some types of boat noise pulses overlapped with that of the dolphin clicks (c.f. Fig. 2) (Sugimatsu et al., 2013) [7]. Hence, ICI and CF based analysis is not sufficient to discriminate the dolphin clicks from such types of boat noise pulses. For the next step of automatic discrimination of dolphin clicks from the boat noises, therefore, we have focused on the differences of the “Click Train” characteristics (ICI change rate, click number, CF, frequency component) between the dolphin’s click train and the boat noise pulses. Applying the “Click Train” based analysis considering these parameters, a new automatic discrimination technique of the dolphin clicks from various types of boat noises was developed for the statistical data analysis. In this paper, details of the proposed method are reported.

(a)

(b)

Figure 1. Experimental site map (a)The Irrawaddy dolphins habitat areas in the middle-river district of the Mahakam river in Borneo (b) Stationary observatory with one SSBL-unit system

(a)



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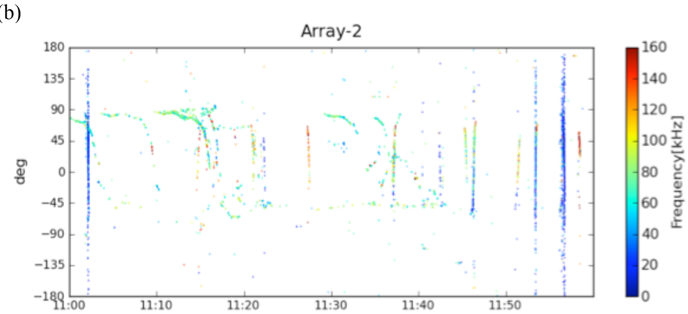


Figure 2. ICI and CF distribution and direction data of dolphins and some types of boat noise pulses (11:00-12:00 16 July 2012) (a) ICI and CF distribution were overlapped. (b) Direction data of dolphins and some types of boat noise pulses

II. MATERIALS AND METHODS

A. Statistical analysis using the data sets uploaded to the database

A database has been produced for the statistical analysis of a large amount of the data acquired from the long-term monitoring. Direction data (both dolphin clicks and boat noise pulses) of the click/pulse sound source with acoustic parameters acquired by the long duration acoustic monitoring phases using one SSBL-Unit recording system (c.f. Fig. 3, Table 1) were stored as for further analysis. The long term monitoring data uploaded to the database and used for the statistical analysis are as shown in Table II. For statistical data analysis to understand the diel/daily/monthly/seasonal migration trends of the dolphins passing through the observatory from the lake to up/down-stream of the river, the time series data was set in one-hour time units. In addition, the database has a function to display the direction data and other acoustic parameters such as ICI, frequency component and CF with time series can be displayed in 24/6/1 hour scale on GUI (Graphical User Interface) (c.f. Fig. 2).

Selecting data sets within the above database, then, the appearance frequency of the dolphins (Ad) and boats (Ab) in every one-hour are counted using the following definitions.

- If Ad/Ab counted in one hour of a day is 0, Ad/Ab in the hour is counted as 0 (min. number of Ad/Ab in one day is 0).
- If Ad/Ab counted in one hour of a day is more than 1, Ad/Ab in the hour is counted as 1 (max. number of Ad/Ab in one day is 24).

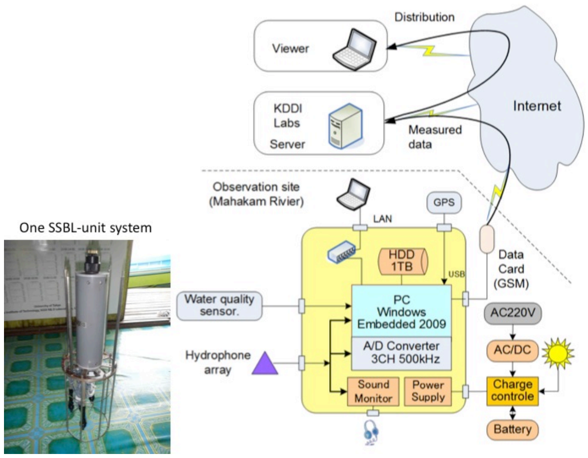


Figure3. One SSBL-unit system and schematic diagram of the recording system

TABLE I. SPECIFICATION OF ONE SSBL-UNIT SYSTEM

Items	Specification
Array of Hydrophone	Orthogonal arrangement
Length of Baseline	0.1m
Number of Hydrophone of one SSBL- unit	3-hydrophone
Frequency Range	10kHz – 200kHz
A/D Converter	16bit 500kHz 3ch simultaneous sampling
Processor	Intel Atom Z530 (1.6GHz)
OS	Windows Embedded Standard 2009
Communication	GSM/3G data card
Storage	2.5" USB HDD (Max. 1TB)
Water quality sensor	pH, Dissolved oxygen, Turbidity, Temperature, etc.
Electromagnetic velocity meter	Under contemplation
Peripherals	GPS, Magnetic compass

TABLE II. DATA ACQUIRED BY THE MONITORING PHASE 1 TO 4

Monitoring phase	Period	Recording hours / Total hours of the monitoring period
The first phase (Phase one)	From 13 June to 11 October 2012	2807/2904
The second phase (Phase two)	From 26 May to 22 October 2013	3497/3600
The third phase (Phase three)	25 December 2013 to 31December 2014	7207/8807
The forth phase (phase four)	1 January 2014 to 21 April 2015	1988/2664

B. ICI and Frequency characteristics of the Irrawaddy dolphin's click train

In the initial stage, discrimination the dolphin clicks from the boat noise pulses was made manually based on consideration of the ICI and CF histogram of the sound source and a double-check of the wave file data [6]. However, for quantitative analysis, discrimination of the dolphin clicks from the boat noise pulses should be made using fixed parameters for selection of clicks. As indicated in Section I, ICI and CF based analysis, i.e. ICI and CF histogram analysis is not sufficient to discriminate the dolphin clicks, because it was found that the ICI and CF distribution of some types of boat noise pulses overlapped with that of the dolphin clicks (c.f. Fig. 2). Therefore, then we have focused on the "Click train" of the dolphin clicks from the boat noise pulses and investigated the ICI and frequency characteristics to distinguish the Irrawaddy dolphin clicks from the boat noise pulses.

Similar to the ICI characteristics of the Ganges river dolphin (Sugimatsu et al., 2014) [8], the click train of the Irrawaddy dolphin showed these ICI characteristics: the ICI changed sequentially between approximately 10 ms and 100 ms, a click sequence of three echolocation phases (search, approach and terminal) was observed. Fig. 4 shows an example of ICI change rate of the Irrawaddy dolphin's typical click train. Therein, the ICI change rate was within 30% in a click sequence, and the number of clicks in a click sequence that fulfilled the above condition (the ICI change rate within 30%) was larger than approximately 7 (a number of ICI is 6). On the other hand, the boat noise pulses in which ICI and CF distribution overlapped with that of the dolphin clicks showed two types of ICI characteristics (type A and type B). Type A boat noise pulses showed the trend: the ICI change rate fluctuates much more than 30% (c.f. Fig.5), however, type B boat noise pulses showed the trends: the ICI change rate of some click sequences converged within 30% and its click number was larger than 7 (c.f. Fig. 6).

To discriminate the Irrawaddy's click train accurately from such boat noise pulses (type B), the difference in frequency characteristics between the Irrawaddy dolphin and the boat noise pluses was also analyzed. Frequency characteristics of clicks of the Irrawaddy dolphin's click train showed the trends: CF distributed from approximately 50kHz to 100 kHz (c.f. Fig. 4), the frequency component "10kHz to 20kHz" was mostly larger than that of "20kHz to 40kHz" (c.f. Fig. 7). On the other hand, CF characteristics of the type B boat noise pluses showed the trend: CF distributed from approximately 50kHz to 200kHz and its average value was higher than 120 kHz (c.f. Fig. 6). In addition, the CF values higher than 120 kHz were frequently seen from the clicks of the click sequences of type B boat noise pulses in which ICI change rate converged within 30% as shown in Fig.6 (c) (d).

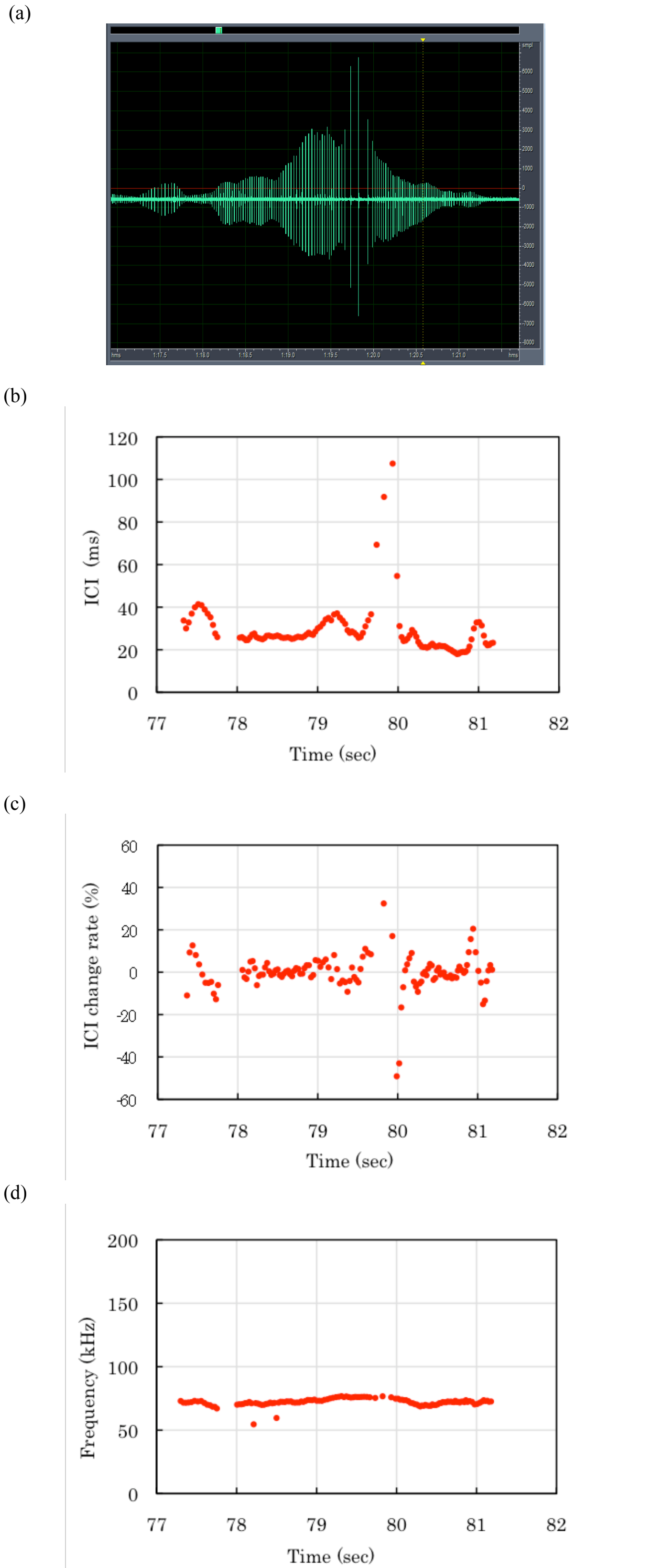


Figure4. Irrawaddy dolphin's typical click train (a) a click train (2009.12.21.14:40:40-14:40:51), ((b) ICI disribution of the click train, (c) ICI change rate of the click train (d) CF value changes of the click train

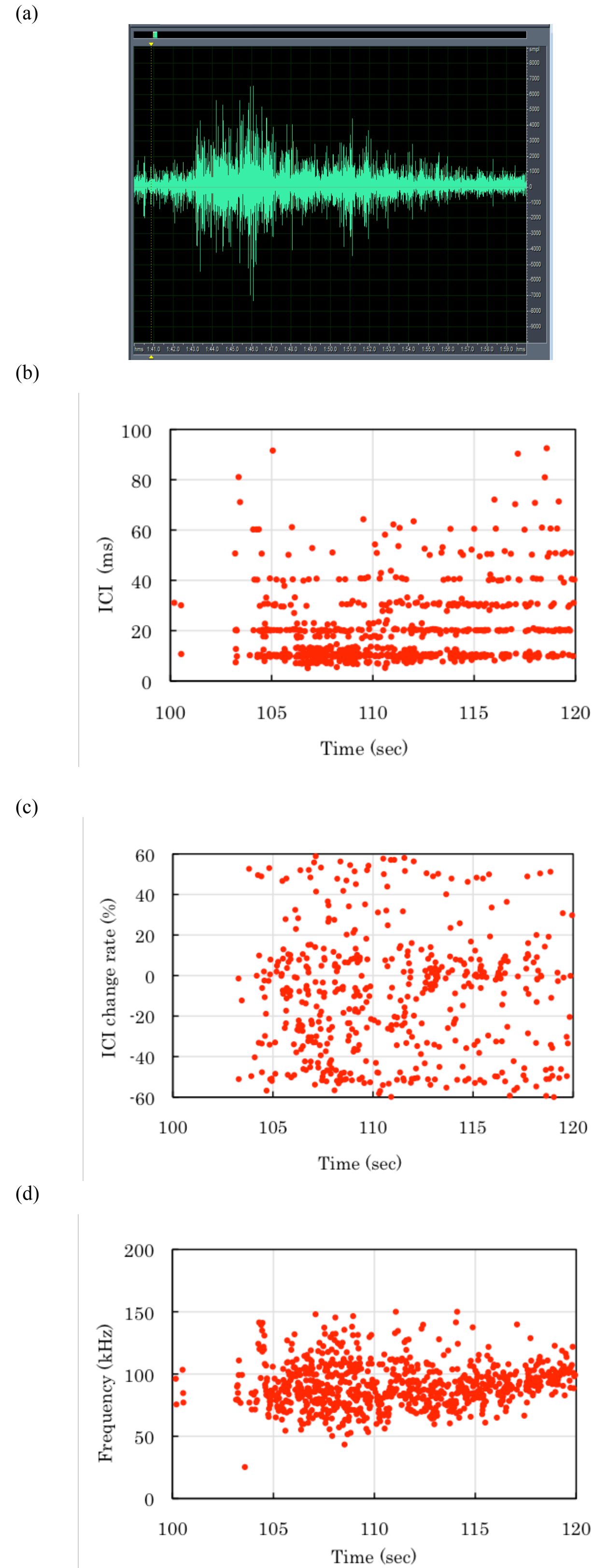


Figure5. An example of type A boat noise pulses (2012.7.23.04:20:05-04:20:26), (a) a series of the sequences of the boat noise pulses, (b) ICI of the sequences, (c) ICI change rate of the sequences, (d) CF value changes of the sequences

(a) (b) (c) (d)

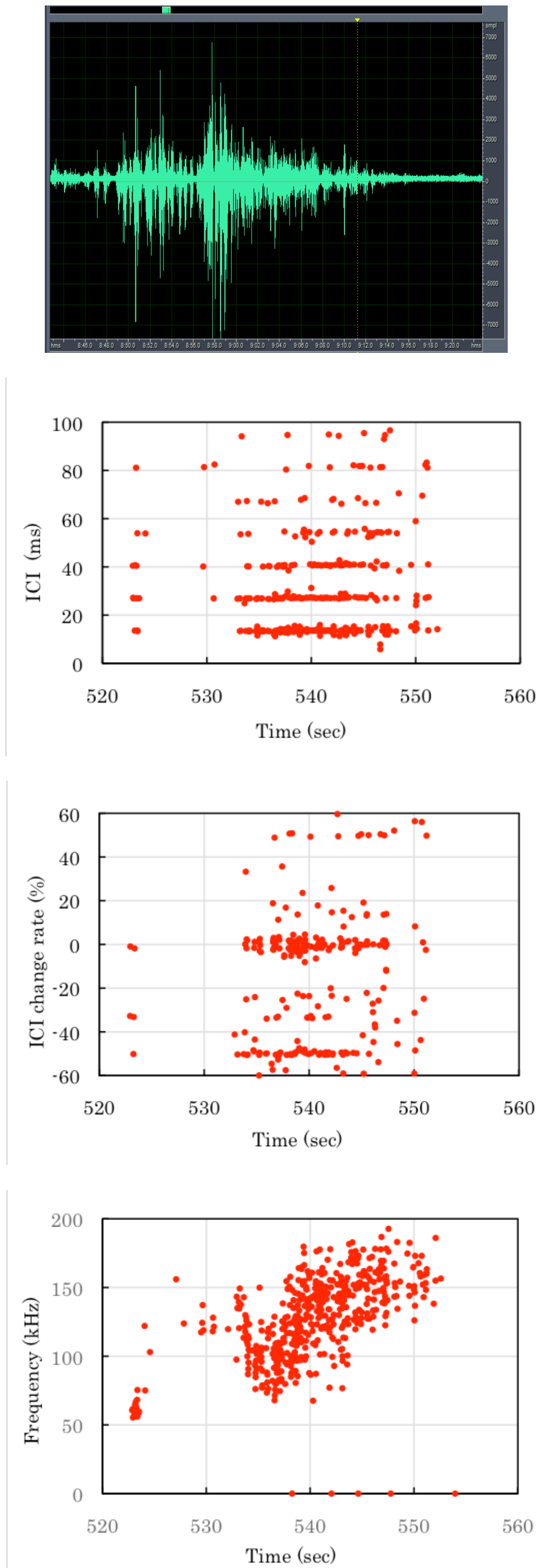


Figure6. An example of type B boat noise pulses (2012.07.16.08:19.50-08:20:26), (a) a series of the sequences of the boat noise pulses, (b) ICI of the sequences, (c) ICI change rate of the sesuences, (d) CF value changes of the sequences

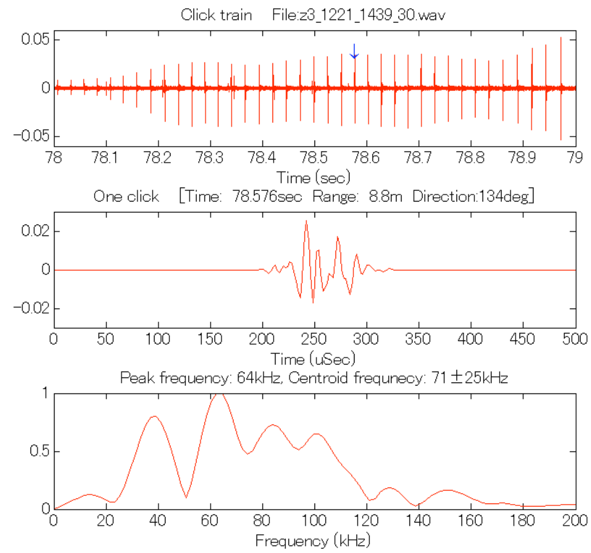


Figure7. Frequency characteristics of clicks of the Irrawaddy dolphin's click train as shown in Fig.4. The frequency component "20kHz to 40kHz" is larger than that of "10kHz to 20kHz" in the selected click.

C. Proposed method

Re-considering the ICI change rate and the difference in the frequency characteristics between the dolphin's click train and the boat noise pulses as indicated in Section II, a new integrated automatic discrimination method of the dolphin clicks from various types of boat noises pulses was developed. Fig. 8 showed the flow-chart of the algorithm. Data of appointed time (one hour data) was analyzed for selecting the click train of "Irrawaddy dolphin" that could fulfill the values of selected parameters. To delete the type B boat noise pulses, CF value of a click of the click train was included as a parameter in addition to the frequency component parameter. Parameters used for the selection of the click train of "Irrawaddy dolphin" and default values are listed as follows;

Parameters:

First step: ICI analysis

1. Time interval: one hour: 1
2. Start time: (yyyy/mm/dd/hh)
3. Termination time: (yyyy/mm/hh)
4. ICI distribution min. (ms): 10
5. ICI distribution max. (ms): 100
6. ICI change rate of a click sequence: min. (%): 0
7. ICI change rate of a click sequence: max. (%): 30
8. Number of clicks of a click sequence min.: 7

Second step: Frequency Spectrogram analysis

9. CF distribution of clicks in a click sequence: min. to max. (kHz): 0 to 120
10. Frequency component of a click of a click sequence "20kHz to 40kHz" larger than that of "10kHz to 20kHz": (%): 90

11. Number of clicks in a click sequence: min.: 7

For statistical analysis of the dolphin's appearance frequency (Ad) in long-term duration, in addition, the following calculations were added. Calculation results of the dolphin's appearance frequency (Ad) were recorded in a csv. file.

12. If the dolphin click train counted in an appointed one-hour is 0, Ad in the hour is counted as 0 (min. number of Ad in one day is 0).
13. If the dolphin click train counted in an appointed one-hour is more than 1, Ad in the hour is counted as 1(max. number of Ad in one day is 24).

Along with the algorithm development, an additional function that can display the selected dolphin click trains with their direction data in an appointed hour was added to the existing database to demonstrate the calculation results in the GUI.

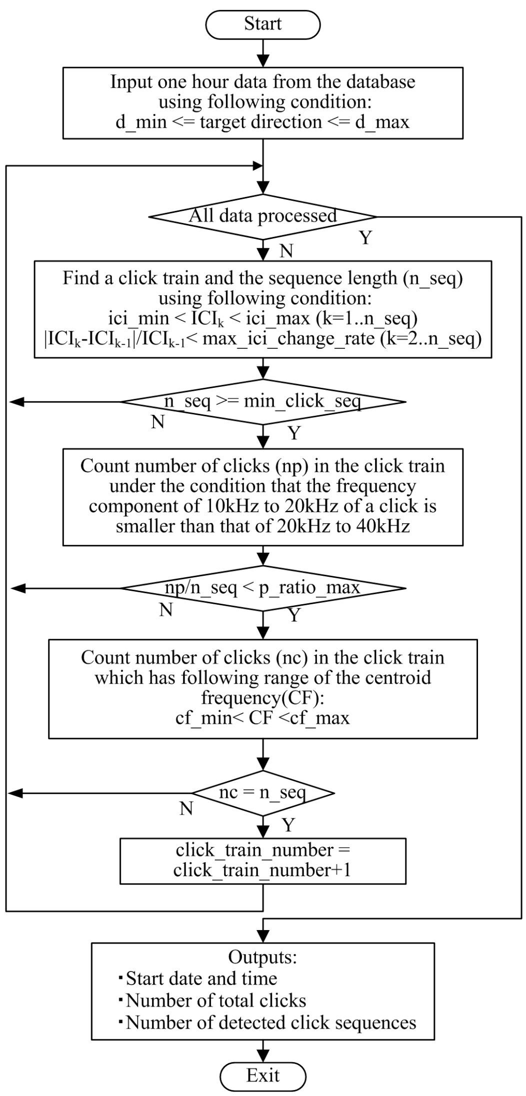


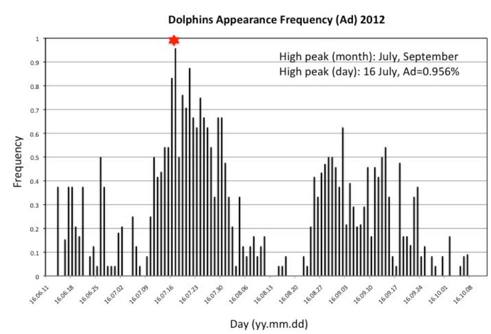
Figure 8. The flow chart of the algorithm of the proposed method

III. RESULTS

A. *Evaluation of the proposed method*

To evaluate the reliability of the method proposed in Section II, applying the method with default values of parameters, data recorded during the phases one and two was analyzed, and compared with the manual analysis results (c.f. Table II) [6]. Here, it was assumed that the manual analysis results were quite reliable, even though occurrence of miss-counting due to human error could not be entirely avoided since the method required lot of time for analysis. The number of the dolphin's appearance hours that were detected from both manual analysis and proposed method were as shown in Table III. The daily trends of the dolphin's appearance frequency (Ad) in the phases one and two data counted by both methods are shown in Fig. 9. Therein, the average difference between Ad manually counted and that counted by the proposed method was ± 0.056 in the phase one, and ± 0.067 in the phase two, respectively. Then, monthly trends of the dolphin's appearance frequency (Ad) counted by both manual and proposed methods were as shown in Table IV. The difference between Ad manually counted and that counted by the proposed method was within ±0.080. This means that the proposed method could capture the overall trends of the dolphin's appearance frequency in a long-term span. With the comparison of the results between the proposed method and the manual analysis, performance of the proposed method was demonstrated well. Instead of the manual analysis, then, the method was applied for statistical analysis of a large amount of data sets recorded during the long-term monitoring.

(a)



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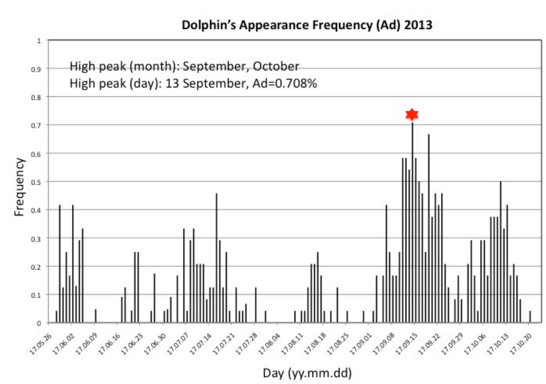

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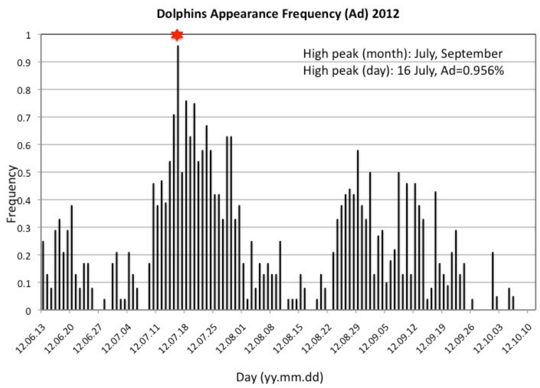

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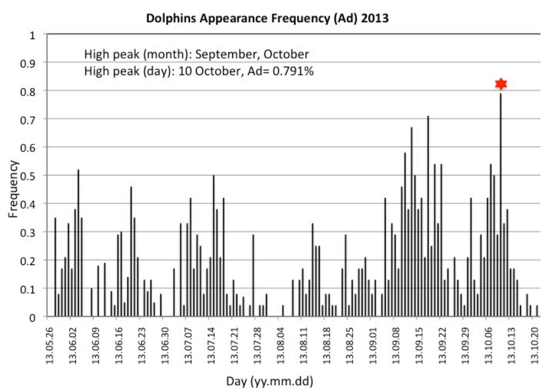

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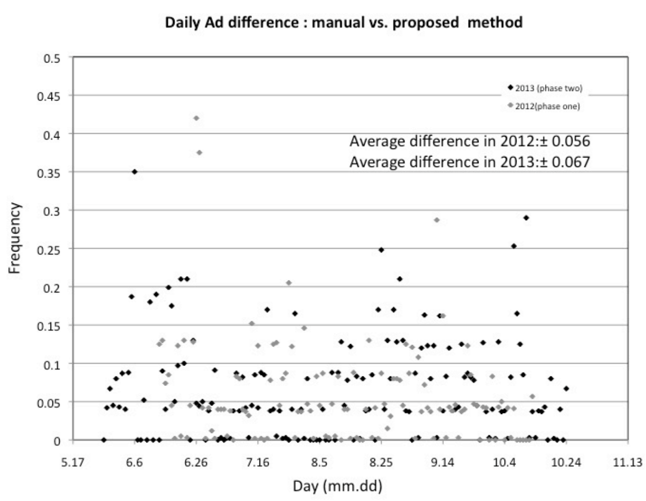

Figure 9. The daily trends of the dolphin's appearance frequency (Ad) in phases one and two (a) Ad in the phase one (2012) counted by the proposed method, (b) Ad in the phase two (2013) counted by the proposed, (c) Ad in the phase one (2012) counted by the maunal analysis, (d) Ad in the phase one (2013) counted by the maunal analysis, (e) difference (ratio) between the manual analysis and the proposed method in 2012 and 2013 data.

TABLE III. COUNTED BY BY THE PROPOSED METHOD AND MANUAL ANALYSIS

	Dolphin appearance hours (h) With condition 13/ No condition Propoosed method	Dolphin appearance hours (h) Manual analyis
2012	722/836	638
2013	522/619	643
2014	2132/2435	-
2015	739/771	-
Total	4115/4661	-

TABLE IV. COMPARISON OF MANUAL ANALYSIS RESUTLS (AD) AND PROPOSED METHOD RESULTS (AD)

	Ad Manual analysis		Ad Proposed method	
Month	**2012**	**2013**	**2012**	**2013**
May	-	0.148	-	0.186
June	0.155	0.160	0.194	0.08
July	0.415	0.164	0.463	0.126
August	0.177	0.102	0.173	0.044
September	0.196	0.285	0.245	0.303
October	0.036	0.237	0.036	0.202
Total	0.228	0.185	0.257	0.149

B. *Diel/Daily/Monthly/Seasonal dolphin's migration anlaysis*

Applying the proposed method with default values of parameters, then, data recorded during phases one to four was initially analyzed to estimate the diel/daily/monthly/seasonal trends of the dolphin migration from the lake to and from the river. Fig. 10 showed the monthly trends of the dolphin's appearance frequency (Ad) in 2012 to 2015 (from phase one to phase four). The trends of Ad significantly changed both monthly and seasonally. Fig. 11 showed the daily trends of the dolphin's appearance frequency (Ad) in 2014 (the phase three). In the phase three, the long-term monitoring through the entire year has been realized for the first time. The Ad high peaks were seen in April and May in 2014. The dolphins migrated across the observatory almost every day on 10, 11 and 27 April 2014, however, very few dolphins were observed from June to October 2014 (c.f. Fig. 11). The diel trends of the dolphins' appearance frequency (Ad) from 2012 to 2015 are shown in Fig. 12, where the 24 hours of a day was divided into four parts from 00:00 to 06:00, 06:00 to 12:00, 12:00 to 18:00 and 18:00 to 24:00. The dolphins' appearance frequency (Ad) from 12:00 to 18:00 was lower than that of other parts of the day in 2012 and 2013, however, no significant differences were seen in the figures for 2014 and 2015 (c.f. Fig. 12).

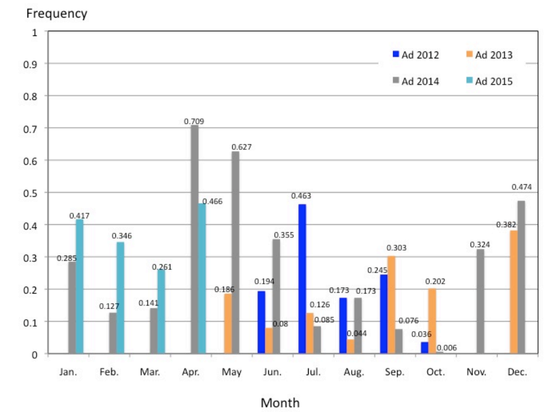

Figure 10. The monthly trends of the dolphin's appearance frequency (Ad) in 2012 to 2015 (from the phase one to phase four).

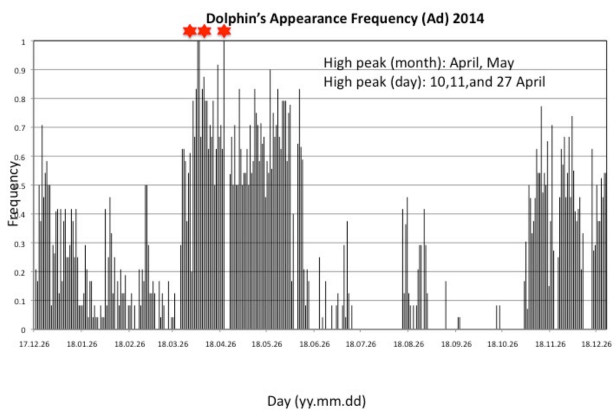

Figure 11. Daily trends of the dolphin's appearance frequency (Ad) in 2014 (the phase three)

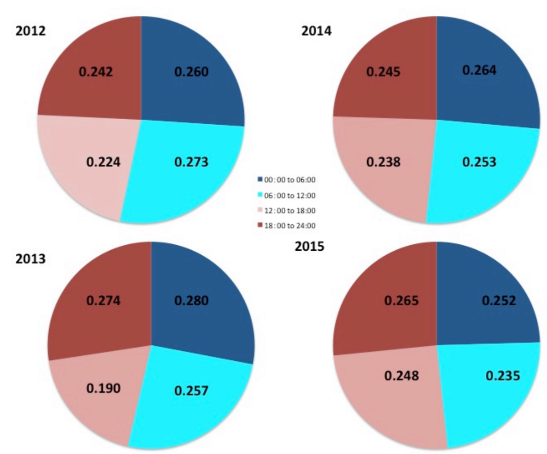

Figure 12. The diel trends of the dolphins' appearance frequency (Ad) from 2012 to 2015 (from the phase one to phase four).

IV. SUMMARY

For statistical data analysis using a large amount of data (both Irrawaddy dolphin clicks and boat noise pulses) acquired by the long duration acoustic monitoring and uploaded to the database, applying the click train based ICI change rate and CF/ frequency component analysis, a new integrated automatic discrimination method of the dolphin clicks from various types of boat noises was developed. For evaluation of the proposed method, the analysis results of the phase one and phase two data were compared with the manual analysis results. Similar trends were seen in both analysis results on the daily/monthly dolphin's appearance frequency (Ad), and differences of the Ad values were within acceptable range. It can be said that the proposed method could capture the overall trends of the dolphin's appearance frequency in a long-term span. The effectiveness of the proposed method was demonstrated well. Instead of the manual analysis that requires a lot of time for analysis, then, analysis using the proposed method was made to estimate the diel/daily/montly/seasonal trends of the dolphin appearance frequency (Ad) of the data recorded from 2012 to 2015. Details of their migration behavior changes will be considered separately.

In the follow-up step, applying similar parameters used for the click train based ICI change rate and CF/frequency component analysis method, the algorithm that could automatically discriminate not just the dolphin clicks but the boat noise pulses will be developed for evaluation of increasing boat noise effect.

To realize a more accurate automatic discrimination of the dolphin clicks from a variety of boat noise pulses, however, a simple improvement of the proposed method, such as re-consideration of the condition of CF characteristic may not be adequate, but a new concept for the analysis should be introduced in future.

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