Automatic discrimination and detection of small calf Ganges river dolphin (*Platanista gangetica*) from other age groups based on bio-sonar inter-click interval characteristics

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***Abstract*—Targeting 15-20 Ganges river dolphins (adults, young adults and calves) in a 10 km stretch from Karnavas to Narora in the Ganges river system, for detailed understanding of their echolocation strategies and underwater behavior over a long-term span, the annual long-term in-situ monitoring using a high frequency 6-hydrophone array system (Array #1) has been conducted at the stationary observatory for 5 years since November 2008. From phase 5 monitoring, one more 6-hydrophone array system (Array #2) has been deployed approximately 100 meters upstream from the original array system (Array #1) to increase the coverage and the overall positioning accuracy. Recorded data from both array systems was automatically uploaded to the database every hour for further analysis. From the visual observations that were periodically made by WWF-India, followed by the phase 4 monitoring, the appearances of small calves (body size:0.6 - 0.8m) was visually confirmed. Considering ICI characteristics differences between small calf and other age groups from our previous studies (Sugimatsu et al.) [1], "small calf" group was acoustically defined as "click train" whose mean value of ICI is approximately from 6msec to 12msec and ICI spread (SD) is less than±3msec. Taking advantage of revealed unique ICI characteristics of "small calf", the method that can automatically discriminate and detect the click train of "small calf" from data uploaded to the database was developed and demonstrated using the data set recorded from the previous 5 monitoring phases.**

Keywords-Ganges river dolphin, Passive Acoustic Monitoring, Bio-Sonar, Inter-Click Interval

I. INTRODUCTION

The Ganges river dolphin (*Platanista gangetica*) belongs to small toothed whale (dolphin) family and inhabits mainly the Ganges river system in India. The dolphin is facing threats due to ongoing human activities. Similar to other dolphin species, the Ganges river dolphin uses bio-sonar clicks and the returning echoes to understand its surrounding environment and capture prey [2] [3]. In order to develop a viable strategy for their conservation, an understanding of their ecology, especially of their acoustic characteristics and underwater behavior in the wild environment is essential. However, they inhabit mostly turbid water and stay underwater except for respiration that makes visual observations difficult.

Passive acoustic monitoring (PAM) using an array of hydrophones that can record the high frequency echolocation clicks of the dolphins has been used as one of major observation system for the field studies in the wild environment [4], [5]. To understand the Ganges river dolphin's acoustic characteristics and underwater behavior in the wild environment, the authors have been developing various types of passive acoustic monitoring systems and conducted field experiments using the systems [6]. Based on the results [7], [8], targeting 15-20 Ganges river dolphins (adults, young adults and calves) in a 10 km stretch from Karnavas to Narora in the Ganges river system, for detailed understanding of their echolocation strategies and underwater behavior over a long-term span, the annual long-term in-situ monitoring using a high frequency 6-hydrophone array system (Array #1) (c.f. Fig. 1), has been started at the stationary observatory since November 2008 [9]. It has been already conducted for 5 consecutive seasons, i.e. 5 monitoring phases since then.

The array system can estimate each dolphin's real-time 3-D location by calculating relative time delay of clicks recorded at each hydrophone, based on the dolphin's high frequency echolocation clicks received on each hydrophone (-3dB bandwidth between 10kHz to 200kHz). The detection range of the array system is approximately 200 meters. However, the position accuracy deteriorates considerably when the distance to the target exceeds 50 meters due to the baseline of the array being 0.8 meters. The estimated transmit beam width of clicks of the Ganges river dolphin is approximately 12 degrees, i.e. narrow [7]. This means that the clicks are detected only when the dolphins are facing towards the array direction. Therefore, from phase 5 monitoring that was conducted from 26 November 2012 to 31 May 2013, one more 6-hydrophone array system (Array #2) has been deployed approximately 100

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meters upstream from the original array system (Array #1) to increase the coverage and the overall positioning accuracy. Fig. 2 shows the arrangements of the two array systems.

Recorded data from both array systems was automatically uploaded to the database every hour for further analysis. From the visual observations that were periodically made by WWF-India, followed by the phase 4 monitoring, appearances of small calves having body length between 0.6 meters to 0.8 meters near the both arrays (Array #1 and Array #2) was visually confirmed from mid-December 2012 to mid-January 2013. In our previous studies, based on the body length analysis, the Ganges river dolphin was classified into three groups, i.e. group A (adult and young adult), group B (calf: up to one year old) and group C (calf: less than 6 month old) (Sugimatsu et al.,) [1]. From this, above small calves with body length between 0.6 meters to 0.8 meters were classified into group C for further analysis. Considering ICI characteristics differences between small calf (group C) and other age groups (group A and group B), "small calf" (group C) was acoustically defined as "click train" whose mean value of ICI is approximately from 6msec to 12msec and ICI spread is less than ±3msec. Taking advantage of ICI characteristics differences of "small calf" (group C), the method that can automatically discriminate and detect "click train" of "small calf" from data uploaded to the database has been proposed in this paper.

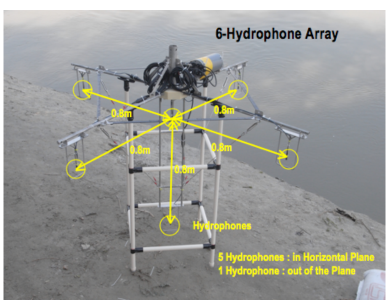


Figure 1. 6-hydrophone cross array system architecture (Array #1)

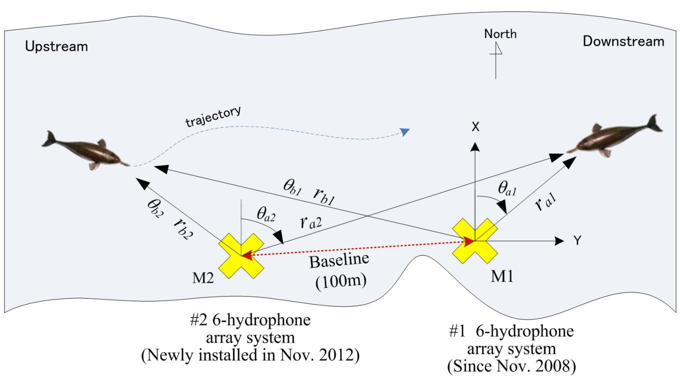


Figure 2. Arrangement of two array systems since the phase 5 monitoring

II. Materials and Methods

A. *Passive Acoustic Monitoring system*

A high frequency 6-hydrophone array system developed in January 2008 (Array #1) (cf. Fig. 1) has been used for the entire period of the five monitoring phases. From the phase 5 monitoring, in addition, one more 6-hydrophone array system (Array #2) was installed approximately 100 meters upstream from the existing array system (Array #1), as shown in section I (c.f. Fig. 2). Configuration and specification of two sets of array systems are almost similar as shown in Fig. 3 and TABLE 1. Calibration results of the arrays for acoustic measurements are reported in the papers (Sugimatsu et al., 2009 and Kojima et al., 2013) [10], [11].

The dolphin's clicks received on each hydrophone are amplified over a -3dB bandwidth of 10kHz – 200kHz, and digitized at a sampling rate of 500kHz with 16 bits resolution through an A/D converter. The system calculates each dolphin's real-time 3-D location and transmits the 3-D data to the host server through a network using the CDMA modem (Array #1) / the mobile router (Array #2), as shown in Fig. 4 and Fig. 5. A laptop PC is connected to a wireless LAN system to access and monitor the signal-processing unit and to display the 2D trajectory of the dolphins on a GUI (graphical user interface). Simultaneously, PCs with an appropriate viewer program can connect to the host server anywhere in the world via the internet and display the real-time 2D location data of the dolphins. The click data, the dolphin's 3-D location and sensor data are also stored in a hard-disk for further analysis. For reducing the amount of data volume during the long-term monitoring, the system has four options of recording mode, i.e. 1) Full recording mode (output of hydrophones, dolphin's 3-D location and sensor data are constantly recorded), 2) One channel recording mode (output of hydrophone No. 1, dolphin's 3-D location and sensor data are constantly recorded), 3) Event mode (full recording only when clicks are detected), 4) CSV mode (dolphin's 3-D location and sensor data are constantly recorded), suitable for every condition.

A comprehensive database has been produced for data acquisition from the long-term in-situ monitoring and further analysis. Dolphin's click data transmitted from the observation site to the host server by internet is automatically uploaded to the database every one hour. Basic information such as dolphin's horizontal trajectories around the array area (10 -200 meters), their click density, XY position in time variation and ICI (Inter-click Interval) histogram are displayed in 24/6/1h time scale on GUI. De-noise condition for click uploaded to the database during ongoing monitoring is; DF (click's dominant frequency) > Spec. 20kHz. After the termination of the monitoring, then, de-noise using off-line data through entire monitoring period is performed for reconstruction of the database. De-noise conditions for off-line analysis are as shown in TABLE II.

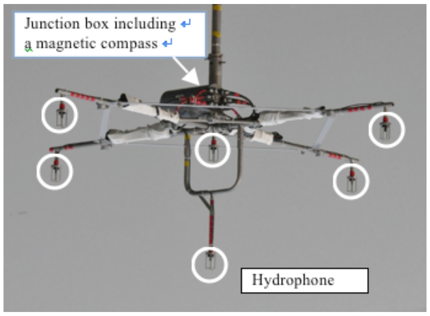


Figure 3. Structure of both array system (Array#1 and Array #2)

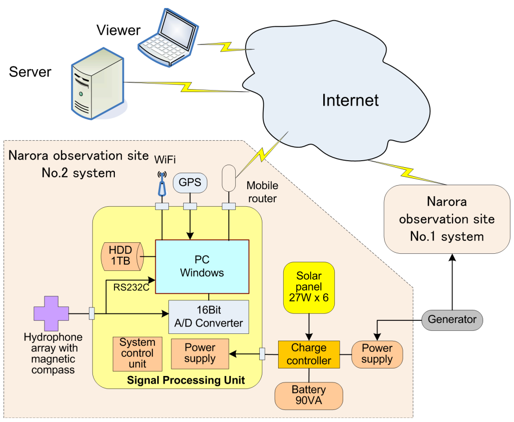


Figure 4. System architecutre of passive acoustic monitoring system

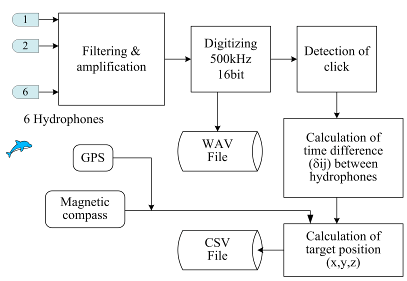


Figure 5. Functional block diagram of the system

TABLE I. SPECIFICATION OF TWO 6-HYDROPHONE ARRAY (ARRAY #1 AND ARRAY#2)

Items	Specification
Array of Hydrophone	6-hydrophone cross array
Length of Baseline	0.8m
Number of Hydrophone	6 (horizontal: 5, vertical: 1)
Frequency Range	10kHz -200kHz
A/D Converter	16bit 500kHz simultaneous sampling
Processor	#1 1.4GHz Pentium III #2 1.3GHz Atom
OS	#1 Windows XP #2 Windows Embedded 2009
Communication	#1 CDMA data card, Wi-Fi #2 Mobile router
Storage	2.5'USB HDD (Max. 1TB)
Power	#1 DC 24V 1.3A max. #2 DC 12V 1.5A, 27W x 6 solar panels
Peripherals	GPS, Magnet compass, CT

TABLE II. DE-NOISE CONDITIONS

Parameter	De-noise Conditions
ASL (Apparent Source Level) of a click received on hydrophones H1 to H6	H1pp>144.2dB/μPa H2 to H6pp>138.2 dB/μPa
Frequency of a click	Dominant Frequency > Spec. 20kHz
Dolpin's 3-D position X: Longitudinal position along the river	-200<=X<=200m
Y: Transversal position across the river	-100<=Y<=200m
Z: Depth	-5<= Z <=5m
Range:R	R>1m

B. *Recordings during the 5 Phase Monitoring*

15-20 Ganges river dolphins (adults, young adults and calves)) inhabit the 10 km stretch from Karnavas (upstream) to Narora (downstream) in Ganges river system in India were subjected to this study. They migrate in the district from up/down stream to down/up stream almost everyday. Targeting these dolphin groups, the passive acoustic monitoring using the array of hydrophones has been conducted at the same observation site for five monitoring phases since November 2008. The monitoring period of each phase is as shown in TABLE III. Recorded data of each monitoring phase was uploaded to the database for further analysis. To increase the coverage and the overall positioning accuracy, especially for understanding of the trend of small calf dolphin's appearance frequency in wider areas, from the latest phase 5 monitoring, one more array system (Array #2) was deployed approximately 100 meters upstream from the original array system (Array #1) (c.f. Fig. 6). The distance between the systems was measured by the differential GPS is shown in TABLE IV. In addition, recording mode of two sets of array systems was set to one channel recording mode during the entire phase 5 monitoring for detailed understanding of acoustic characteristics of small calf's clicks.

Although visual observations made by WWF-India were interrupted for several days due to misty weather, followed by the phase 4 monitoring, the appearances of small calves having body length between 0.6 meters to 0.8 meters near the both arrays (Array #1 and Array #2) was visually confirmed from mid-December 2012 to mid-January 2013. In our previous studies, based on the body length analysis, the Ganges river dolphin was classified into three groups, i.e. group A (adult and young adult), group B (calf: up to one year old) and group C (calf: less than 6 month old) [9]. From this, above small calves with body length between 0.6 meters to 0.8 meters were classified into group C for further analysis.

Figure 6. Deployment of the two sets of array systems

TABLE III. PERIOD OF FIVE MONITORING PHASES

Monitoring phases	Period
Phase 1	2008.11.13 – 2009.4.23
Phase 2	2009.11.23 – 2010.5.31
Phase 3	2010.11.28 – 2011.5.22
Phase 4	2011.11.11 – 2012.5.31
Phase 5	2012.11.11 – 2013.5.31

TABLE IV. LOCATION OF BOTH 6-HYDROPHONE ARRAY (ARRAY #1 AND ARRAY#2)

Array	Latitude	Longitude	Distance (m)	Azimuth (deg)
Array #1	N28°16 '11.1"	E78°19'39.2"	origin	origin
Array #2	N28°16'10.3"	E78°19'35.6"	100.8	256.5

C. Acoustic Definition of "Small Calf" (group C)

From our previous analysis of acoustic data of small calf (group C) and other age groups (group A and group B) corresponding to visual observation records, ICI characteristics differences between small calf and other age groups were revealed (c.f. Fig. 7) [9] [12]. Example data recorded from small calf during the phase 5 monitoring shows also similar ICI characteristics as shown in Fig. 8. Here, ICI characteristics of small calf and other age groups are listed as follows;

Small calf (group C):

1. ICI varies approximately from 6msec to 12msec
2. ICI is almost constant through a click train
3. No significant sequential changes of three echolocation phases (search, approach and terminal phases)

Other age group (group A and group B)

1. ICI varies approximately from 10msec to 100msec
2. Sequential changes of above three echolocation phases
3. ICI reduces rapidly near to approximately 10msec during the terminal phase

From above ICI characteristics of small calf, it can be estimated that the mean value of ICI of a click train of small calf is approximately from 6msec to 12msec and ICI spread (SD) is narrow (c.f. Fig. 7). On the other hand, the mean value of ICI of a click train of other age groups is at a higher point and ICI spread (SD) is wider. Consequently, here, it can be acoustically defined that "small calf" (group C) as "click train" which mean value of ICI is approximately from 6msec to 12msec and ICI spread (SD) is less than ±3msec.

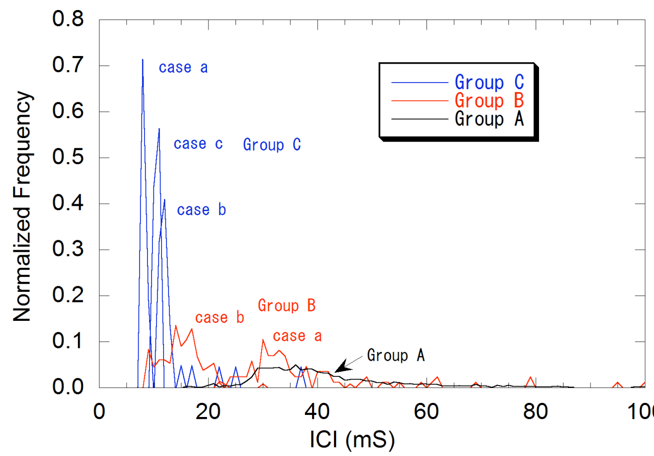
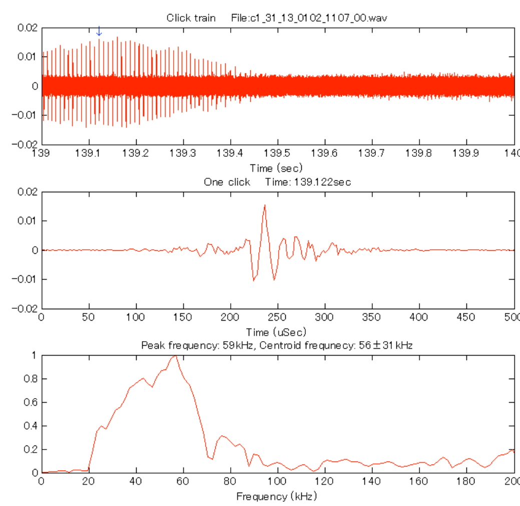


Figure 7. Examples of normalized ICI histogram of click trains from group A, group B and group C dolphn in phase 4 (file number: 2012.01.12.09.45.32, 2012.01.12.13.55.34 , 2012.01.17.12.47.57 and 2012.03.06.01).

(a)



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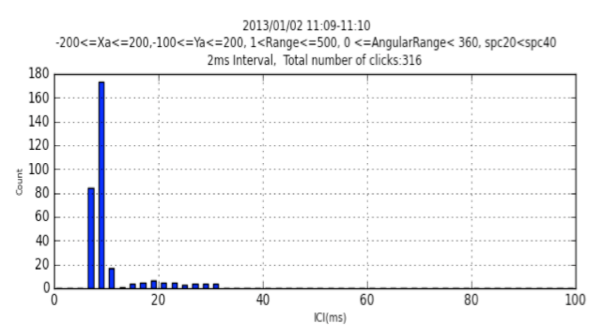


Figure 8. An example click train for a "small calf " (group C) recorded by Array #2 during the phase 5 monitoring (file number: #2-2013.01.02.11.11.07.00) (a) an example click train and an isolated click and its spectrum recorded for a small calf (group C) that was found in 1 minute data 11.09 to 11.10. (b) ICI histogram of 1 minute data from 11.09 to 11.10. Other age groups' clicks are also seen in the graph (ICI distribution is different from that of small calf's).

D. *Proposed Automatic Discrimination and Detection Method of Small Calf from Other Age Groups*

Taking advantage of ICI characteristics differences of "small calf " (group C), the method that can automatically discriminate and detect the click train of "small calf" from data uploaded to the database has been newly developed. Fig. 9 shows flow chart of the algorithm. Data of appointed time (n) is analyzed for selecting the click train of "small calf" that fulfills the values of selected parameters. Calculation results with basic information such as date, time, ICI center value and its SD, number of detected click train (m) and etc in the appointed time are recorded in a csv. file. Filtering conditions of data extraction from database are shown in TABLE V. Parameters used for the selection of the click train of "small calf" and default values are listed as follows;

Parameters:

1. time interval (m): n: 1
2. start time (yyyy/mm/dd/HH/mm/ss): s:
3 termination time (yyyy/mm/dd/HH/mm/ss): e:
4. ICI distribution min. (ms): a1: 0
5. ICI distribution max. (ms): a2: 50
6. ICI window min. (ms): b1: 0
7. ICI window max. (ms): b2: 20
8. ICI distribution small calf min. (ms): c1: 6
9. ICI distribution small calf max. (ms): c2: 12
10. ICI mean value small calf min. (ms): d1: 6
11. ICI mean value small calf max. (ms): d2: 12
12. ICI spread (SD) small calf max. (ms): d3: ±5
13. number of clicks of a click sequence min. : k: 5

Considering the ICI variation characteristics of "small calf", the mean value of ICI was selected as main parameter. If the click trains of other age groups overlap each other, however, ICI of the click sequences becomes smaller than that of original click train. To avoid selecting such overlapped click sequences as a click train of "small calf" and miss-recording of a click of small calf, ICI spread (SD) was also added as a parameter and its upper limit was set to ±5msec (default value). To decide the applicable value of a number of clicks of a click sequence (k), isolated click trains that were sometimes recorded from "small calf " during the phase 5 monitoring (c.f. Fig. 10) were considered. Herein, some click trains that consist of a small number of clicks were recorded. Along with the algorithm development, an additional function that can display ICI histogram of appointed time interval (n), appointed ICI and frequency of a number of clicks of a click sequence (k) was added to the existing database to demonstrate the calculation results in GUI.

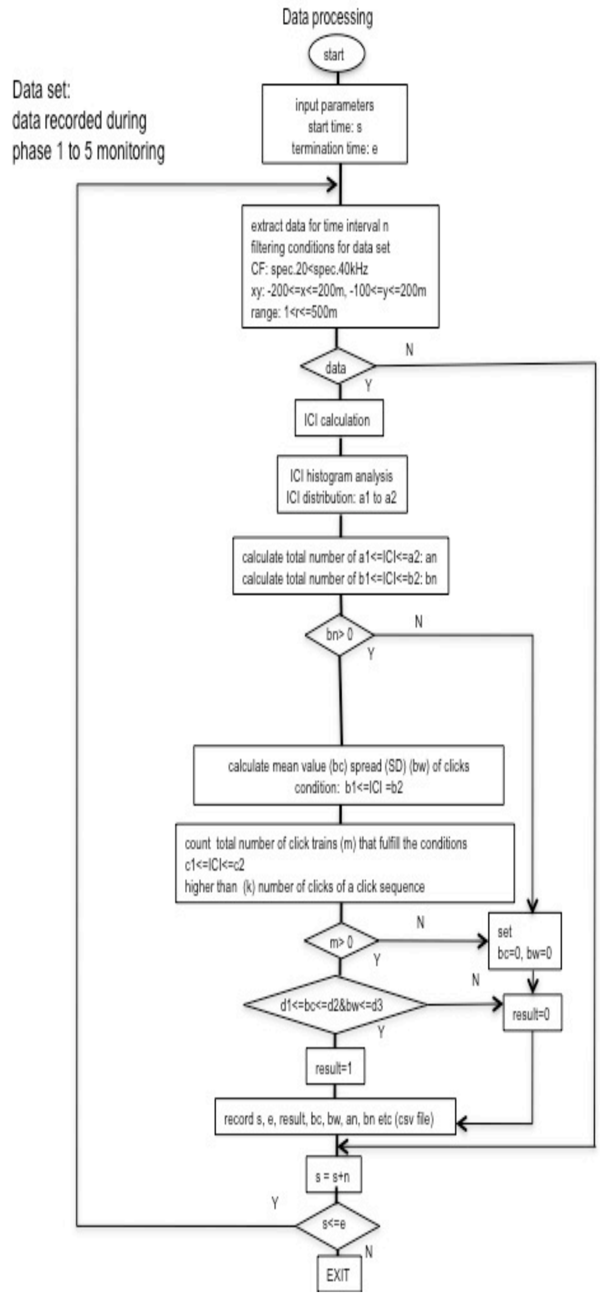


Figure 9. Flow chart of the developed alogrithm

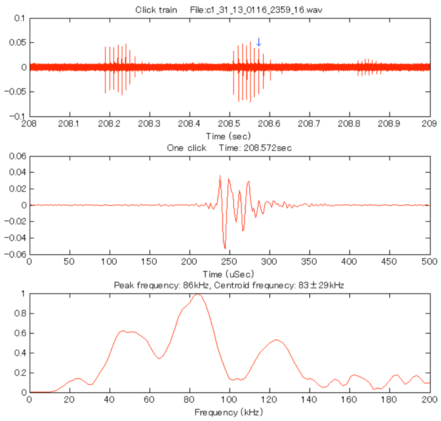


Figure 10. Example clicks trains for a “small calf “ (group C) recorded by Array #2 during the phase 5 monitoring (file number: #2-2013.01.16.11.23.59.16)

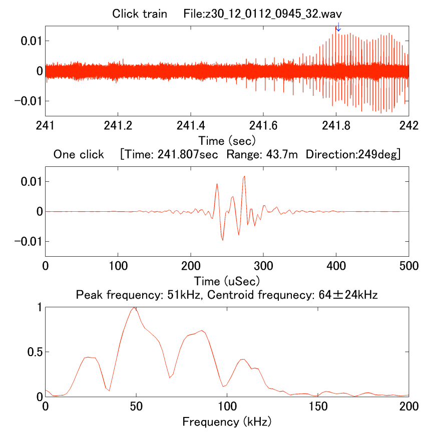
TABLE V. CONDITIONS FOR DATA EXTRACTION FROM DATABASE

Filter	Conditions
Frequency of a click: Centroid Frequency (CF)	CF: Spec.20<Spec.40kHz
Dolpin’s 3-D position X: Longitudinal position along the river	-200<=X<=200m
Y: Transversal position across the river	-100<=Y<=200m
Z: Depth	-5<= Z <=5m
Range:R	1<R<=500m

III. RESULTS

For understanding the appearance frequency of small calf Ganges river dolphin’s and its behavioral pattern around the observation areas in long-term span, the method which can automatically discriminate and detect the click train of “small calf” (group C) from data uploaded to the database has been proposed as shown in the Section II D. To evaluate the reliability of the proposed method, applying default values of parameters, data recorded during January 2012 was initially analyzed. A number of appointed times when more than one click train of “small calf” was selected was 207 through the month. Click trains of “small calf” were discriminated and detected from the data of the periods when the appearances of small calves were confirmed by both acoustic and visual observation records (2012.1.12.9.49, 2012.1.12.13.59, 2012.1.17.12.49 and 2012.1.17.12.51). Fig.11 shows a click train of a “small calf” discriminated and detected from other click sequences recorded during the appointed time (09:49 to 09:50 January 2012) and ICI histogram during the period. Subsequently, data recorded by both arrays (Array #1 and Array #2) during January 2013 was also analyzed for the evaluation. A number of appointed times when more than one click train of “small calf” was selected was 17 (Array #1) and 44 (Array #2) through the month. Acoustic data recorded by both arrays during the periods were in accordance with calculation results. Fig. 12 shows some example click trains discriminated as “small calf” and detected from other click sequences recorded by Array #2 during the appointed time and ICI histogram during the period. Even some ICI peaks were seen from 0-20 msec in the histogram (c.f. Fig. 12(b)), totally two click trains of “small calf” were discriminated and detected from other dolphin groups’ click sequences.

(a)



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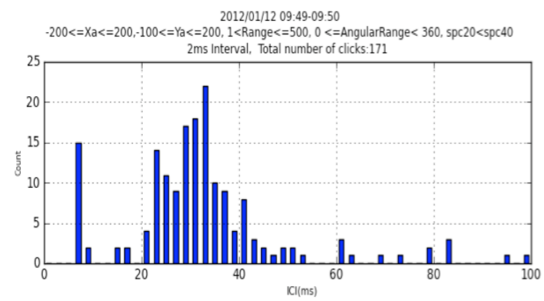
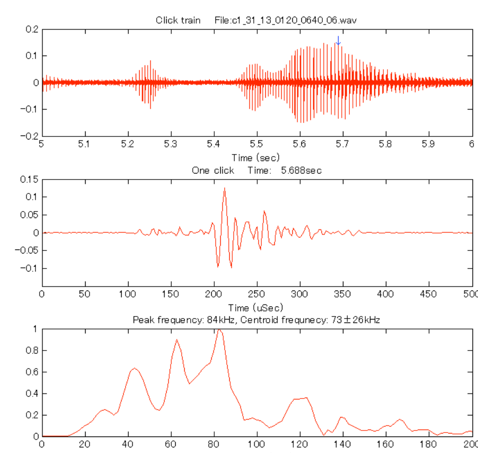


Figure 11. An example click train for “small calf “ and ICI histogram in the appointed time (09:49 to 09:50 January 2012) (a) a click train for a “small calf “. (b) ICI histogram during the priod.

(a)



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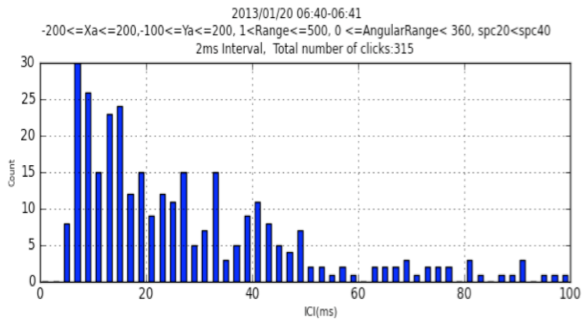

Figure 12. some example click trains for “small calf “and ICI histogram in the appointed time (06:40 to 06:41 20 Januay 2013 recorded by Array #2) (a) a click train for “small calf. (b) ICI histogram in the appointed time. Even some ICI peaks were seen here, two click trains of “small calf” were discriminated and detected from other dolphin groups' click sequences.

IV. CONCLUSIONS

Based on the ICI characteristics differences between "small calf" (group C) and other age groups (group A and group B), “small calf” (group C) was acoustically defined as “click train” whose mean value of ICI is approximately from 6msec to 12msec and ICI spread (SD) is less than ±3msec. Using revealed unique ICI characteristics of “small calf”, the method that can automatically discriminate and detect the click train of “small calf” from other click sequences of the selected data was proposed. Using the sample data set recorded from the long-term in-situ monitoring, performance of the method was demonstrated as shown in the Section III (c.f Fig. 11 and Fig. 12).

As a follow-up step, to evaluate the higher reliability of the proposed method, comparison between the calculation results and corresponding acoustic data recorded by both arrays (Array #1 and Array #2) throughout the phase 5 monitoring will be made. After improvement of the algorithm with re-consideration of adapted parameters and its available values based on the analysis results, the method will be applied to the data recorded through the entire 5 monitoring phases, to help the understanding of the trend of small calf dolphin's appearance frequency and its behavioral pattern around the observation area in long term-span.

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