Benthic Fish Behavior Characterization with a Mechanically Scanned Imaging Sonar

Wen-Miin Tian
Department of Marine Environment and Engineering
National Sun Yet-sen University
Kaohsiung City, Taiwan
tiwemi@mail.nsysu.edu.tw

***Abstract*—A point stationary, acoustic-based surveying system was proposed to fulfill the necessities of benthic fish behavior assessment. The surveying system can be split into two major and inter-dependent techniques, i.e., acoustic image acquisition and image processing. The first part comprises a high-frequency, mechanically scanned imaging sonar (MSIS) with bottom-fixed, side-looking working configuration. Major modules of the proposed image processing procedure include: stationary objects subtraction, region and textural feature extraction, unsupervised classification, fish target identification and quantification. For the specific case study conducted in a deep water fishpond, it is evident that both individual and school fish could be discriminated by image frames collected at a randomly selected point with scanning range setting at 5 m and frame rate at 75 second. Based on spatial and temporal analyses on position and area of the discriminated fish targets, it was concluded that fish movement pattern in the scanned area followed two distinctive corridors with significant different passage rate, i.e., a discrete, periodic and high passage rate mode in Corridor#1 and a continuous, steady and low passage rate mode in Corridor#2. Environmental features, such as bank slope, substrate mound and float raft represented specific meeting points for dynamic aggregations and schooling. Fish tended to converge into prominent schools subsequent to interactions with these features. The proposed system represented a practical and cost effective tool in acquiring image frames with sufficient spatial and temporal resolution for the characterization of fish behavior.**

Keywords-image sonar; mobile target; image processing; unsupervised classification; fish behavior.

I. INTRODUCTION

Artificial benthic habitats are known to be effective in promoting coastal fishery resources and coastal fisheries management. A large number of artificial reef programs have been conducted world wide, basically in Japan, France, the United States of America and Spain among others [1][2]. In Taiwan, a long-term, government sponsored project for the construction and deployment of artificial reefs to enhance commercial fisheries was initiated in 1973. For the last forty years, over 220,000 units of various types of artificial reefs were deployed in 88 promulgated sites [3]. For the purpose to promote an efficient administrative and management system, these artificial reef sites were systematically surveyed especially by side-scan sonar [4]. Information regarding geographic position and engineering characteristics of these artificial reefs as well as substrate composition were collected, evaluated and documented. However, due to a shortage of professionals devoted to conduct in-situ biological assessment investigation and the limitations of some traditional sampling techniques employed, the biological effectiveness of the most of these artificial reef sites was assessed in a very primitive way.

From a physics point of view, benthic fish which aggregated around artificial reefs is a type of underwater mobile object which distributed on or near to the artificial reefs and sea bottom. The dimensions of a typical reef fish could be varied from as small as several centimeters (e.g., juvenile fish) to over 50 cm. The swimming speed and behavior of the fish added complexity to an assessment system. Nondestructive underwater surveying techniques which can offer adequate information for the effective detection and evaluation of this type of mobile object to fine spatial and temporal scales should therefore include the following fundamental requirements, i.e., effective in dark and turbid water environment, capable of cover sufficient water volume and feasible for extended working time (24 hours or even over a week). In addition, the quality and resolution of the information collected should comply with the criteria to the detection, classification or even identification of each object individually.

Underwater acoustic systems are standard tools for monitoring fish and other objects in marine and freshwater environments [4]-[8]. Advances in acoustic technology and analysis software have made this survey method more powerful in recent years. Based on deployment configurations, these systems can be classified into two categories of operation modes, i.e., mobile survey mode (e.g., echo sounder and side-scan sonar) and point stationary survey mode (e.g., split-beam sonar, sector scanning sonar, multi-beam sonar and 3D-sonar). Among them, systems operated in mobile survey mode with a vertically oriented, hull-mounted transducer are a standard tool for assessment of mid-water fish stocks. A significant benefit of this survey mode is that large areas can be sampled continuously in a

 ISBN: 978-1-61208-375-9

short amount of time [5]. Systems operated in point stationary survey mode with fixed-location and side-looking sonar techniques are capable of detection, quantification and even identification of demersal and benthic fish. They are mostly used for anadromous fish abundance estimation, fish behavior observation around fixed facilities and may be helpful in validation of fish species [7][8].

To fulfill the necessities of underwater mobile object detection and benthic fishery abundance assessment in a cost effective way, a comprehensive research project sponsored by National Science Council and National Chung-Shan Institute of Science and Technology was conducted. Based on theoretical evaluations, a point stationary, acoustic-based surveying system was proposed and implemented. The system can be split into two major and inter-dependent components, i.e., image acquisition and image processing. The first part comprises a high-frequency, mechanically scanned imaging sonar (MSIS) with bottom-fixed, side-looking working configuration. The second part incorporates an unsupervised Bayesian classification procedure for fish target detection and quantification. The objective of this paper was dedicated in evaluating the practicality and characteristics of the proposed surveying system.

Performance of the proposed sonar equipment in detecting mobile objects is discussed in Section 2. Image processing procedures and techniques are described in Section 3. A comprehensive evaluation of the entire surveying system for the purpose of fish target detection, relative abundance quantification and behavior investigation is illustrated in Section 4. Finally, results and conclusion remarks are shown in Section 5.

II. Equipment and Acoustic Principles

MSISs perform scans in a 3D volume by rotating a sonar beam through a series of small angle steps. The side-looking acoustic pulse is projected perpendicular to the sonar head. For each emitted beam, distance vs. echo-amplitude data is returned. Thus, accumulating this information along a complete 360^o sector, a composite acoustic image of the surroundings can be obtained [9]. Commonly, the waiting time between each beam is directly proportional to the selected range setting and a total of 1,200 pings are needed to complete a 360^o sector with stepping speed of 0.3^o. Therefore, these devices have a slow scanning rate of at least several seconds per image frame.

The quality or naturalness of the acoustic images, i.e., identifiability of image content, can be degraded by distortion due to an unstable transducer. MSISs with bottom-fixed and completely stationary configuration for image acquisition provide a stable mount and there will be no effects of yaw or roll-induced movement when the sonar is suspended from a cable [10]. This working configuration is, therefore, ideal for operations to obtain the highest quality or undistorted images.

The basic principles behind the detection of an object in the water with an acoustic system are described by the "sonar equation" [11]:

$$V = SL + G - 40\log R - 2\alpha R + TS + 2B(\theta, \phi) \qquad (1)$$

where,

V	= the received intensity of the echo
SL	= the transmitted source level
G	= the receiving gain of the system
40logR	= the two-way spreading loss, R is the range
α	= the sound attenuation coefficient
TS	= the acoustic target strength
$B(\theta,\phi)$	= the transducer directivity pattern function

If the value of V is sufficiently greater than background noise, the object will be detected. For any given noise level, the potential to detect a target is improved with greater source level, less propagation loss, greater target size, and proximity of the target to the center of the beam. As a result, the received echo intensity of an individual target is primarily dependent on the sonar equipment (e.g., frequency and electronic characteristics), physical properties of seawater as well as the physical and behavior properties of the target. The importance of these factors is discussed in the following sections.

A. Sonar equipment

The primary component of the acoustic equipment in this investigation is a digital, multi-frequency imaging sonar (model 881A, Imagenex), capable of operating at frequencies of 1 MHz, 675 kHz and 310 kHz with fan shaped beams of 0.9^ox10^o, 1.8^ox20^o and 4^ox40^o, respectively. The stepping speeds of the sonar are from 0.3^o/step to 2.4^o/step with range scales from 1 m to 200 m. Because the sonar is limited to 512 by 512 pixels for displaying each frame, the size of the frame determines the display resolution and images with smaller range length are better resolved. The mid-range area insonified by a single ping of the sonar at range setting of 5 m, frequency of 1 MHz and fan shaped beam of 0.9^ox10^o is 3.9 cm (width) by 44 cm (height). The area insonified will increase dramatically with increased range length setting due to the inherent adjustment of frequency and beam pattern settings. The frame update rate of the sonar is controlled by the combination of range and stepping speed settings. At range scale of 5 m and stepping speed of 0.3^o/step, the minimum theoretical scanning time for each frame needs 42 seconds. At the same range scale but faster stepping speed (e.g., 0.9^o/step), the time could be reduced to 14 seconds.

B. Environmental and target properties

Physical properties of seawater, physical and behavior properties of the target, as well as the influence of noise to the detection of mobile object were discussed in this section.

As the sound wave passes through the water column, transmission loss due to absorption and spreading occurs, which reduces the energy strike on the target. In general, sound absorption is greater with higher sound frequencies and more saline water [11].

The two key measurement issues in the acoustic quantification of fish are target strength and fish behavior [5]. Target strength of a single fish is dependent upon its species, length, shape, body structure, orientation relative to the transducer, condition of maturity and sonar frequency. Fish

 ISBN: 978-1-61208-375-9

behavior, or how the fish is moving and orienting itself, includes swimming speed and direction of individual fish.

The ultimate limit to the detection of a specific target is noise. Noise is the background against which sonars must detect signals from targets. For the active sonar, noise is augmented by reverberations from unwanted sources and the signal is an echo from the target. Major sources on noise include: thermal noise, noise from the sea, vessel noise and biological noise. Reverberation may be classified into surface, volume and seabed reverberation. Among them, volume reverberation plays an important role in fish detection and arises from small organisms, bubbles, suspended sediment particles, turbulence and other inhomogeneities in the volume of water being insonified.

C. *Survey design*

Imaging sonar systems have two main functions to perform: the detection of objects and the identification of such objects [5]. An effective and optimized imaging sonar survey in the quantification of fish target should incorporate the considerations of the following two aspects, i.e., the detectability of the fish (i.e., target strength and fish behavior) and the resolution of the sonar image. Theoretically, it is capable of detecting any target that produces an echo above the background noise level. From a practical point of view, to achieve the task of object detection by the application of an active imaging sonar system, the minimum requirement is that the object must receive five consecutive sonar insonifications. On the other hand, for the purpose of identification a specific object, a conservative plan should include one which chooses scanning speeds and ranges that will allow for at least 12 consecutive insonifications in a scanning distance equal to the object's dimension [11][12]. It is evident that with range setting of 5 m and stepping speed of 0.3^{o}/step, the smallest detectable objects at mid-range of the image frame should have a scanning length of 6.5 cm. In addition, for an object with scanning length of over 15.6 cm, outline and shape of this object might be delineated or defined which would improve its characteristics recognition or even identification.

For bottom-fixed, side-looking MSISs, the system parameters affecting the number of insonifications an object receives are: sonar range scale (which sets pulse repetition rate), stepping speed and horizontal beam directivity (i.e., horizontal aperture). Among these parameters where the operator has control over are range scale and stepping speed. Adjustment of system parameters illustrates how acoustic surveys can be fine tuned to match the purpose of a specific investigation.

III. PROCEDURE FOR IMAGE PROCESSING

Acoustic data are generally voluminous. Processing such data can be overwhelming without the aid of image processing software. In fact, the successfulness of image processing is highly dependent on quality, resolution and signal-to-noise ratio (SNR) of the image acquired, i.e., the existence of acoustic diversity is a pre-requisite for the detection of fish target [11]. The overall goal of the imaging processing software was to aid the operators in detection and evaluation of fish target in the MSIS imagery collected in the field. Major modules of the proposed image processing procedure included: stationary objects subtraction, region extraction, textural feature extraction for fixed-sized regions, unsupervised classification based on texture features, hierarchical cluster analysis and principle feature threshold evaluation for fish target detection, and target quantification and visualization of the results (see Figure 1).

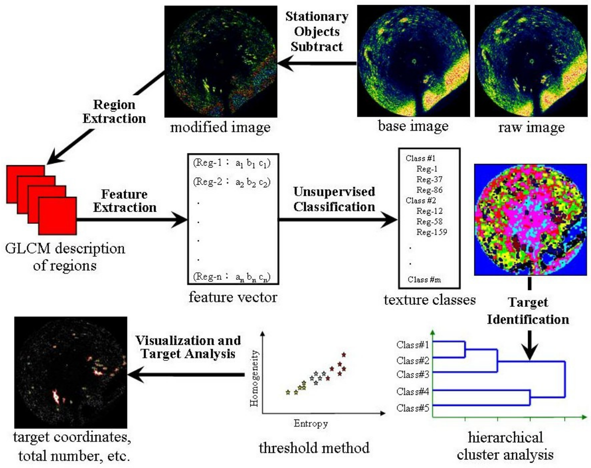


Figure 1. Image processing procedure for fish target detection and quantification.

A. *Stationary objects subtraction*

The existence of various stationary objects (e.g., seabed and anthropogenic structures) in acoustic image frames collected by bottom-fixed and side-looking sonar techniques is an unexceptional reality. In fact, seabed echoes have levels that are 20 to 40 dB higher than fish and their existence in the image frames tends to obscure the detection and evaluation of fish target [6]. However, due to their stationary status in the image frames, these objects could be removed straightforward from the image frame by using a pixel-based image superposition and subtraction algorithm [13]. The result was a modified image frame showing the changes in the image area due to fish movement.

B. *Textural feature extraction for fixed-sized regions*

Image texture is an attribute of groups of adjacent pixels, therefore, it is useful to group pixels into regions and to extract features that describe the texture of the region. A square sliding region was used for region extraction in this investigation [14]. Region size and sliding distance are, therefore, the two major parameters for the algorithm.

Measurements of texture in images can be one dimensional (e.g., run-length and fixed-size pixel neighborhoods) or two dimensional (e.g., grey level co-occurrence matrices, fractal dimension and wavelet transform) [14]. In this investigation, three textural features (mean, entropy and homogeneity) were proposed and incorporated into the classification system [15][16]. Among them the mean pixel intensity is one dimensional feature and the other two are two dimensional features. For a specific region, the mean is the average of the intensity value of the unquantized pixel values for this region. The entropy and homogeneity are computed based on the grey level co-occurrence matrix (GLCM) for this region [15].

C. *Feature classification*

The goal of classification is to assign the regions of an image to an 'appropriate' class in such a way that some error measure is minimized. An unsupervised Bayesian classification system, i.e., AutoClass, was used to cluster regions from acoustic images [16]. Three texture features with equivalent weight were used in this process.

D. *Target identification*

Like any unsupervised classification routine, it cannot give these classified classes descriptive names or assign target to a specific class. To fulfill the necessity of target class identification among classified classes, two independent approaches were proposed in this investigation, i.e., a hierarchical cluster analysis and principal feature threshold evaluation. The hierarchical cluster analysis of the classified classes was based on the posterior probabilities and the algorithm of between-groups linkage with Euclidean distances. The results of the analysis are illustrated in a dendrogram and the similarity among classes can be evaluated based on the sure group clicking value. Target cluster detection through principal feature threshold method was conducted by visual inspection of scatter plots of cluster averaged textural features. Under this circumstance, a single textural feature threshold or a combination of multiple thresholds among textural features might suffice for the discrimination of the fish target class among classified classes.

E. *Target quantification and visualization of the results*

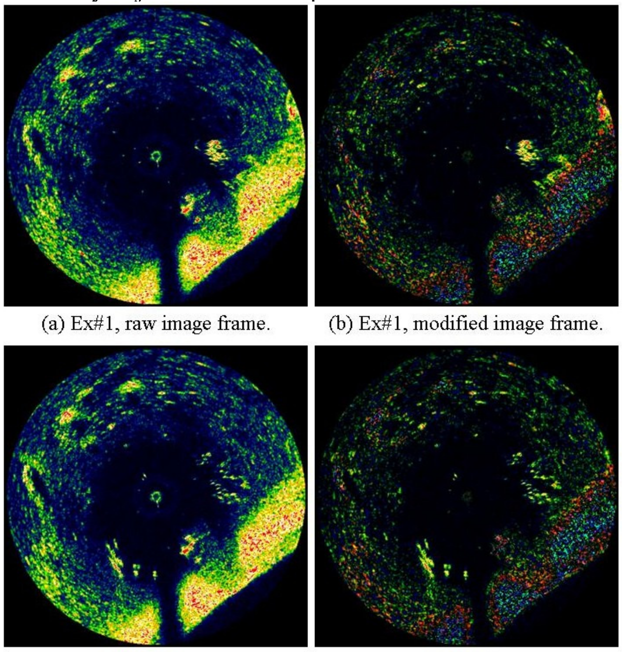
Region growing technique was employed to isolate contiguous target blocks to a single detected target. Visualization of the results was accomplished by mapping the representative pixels of the specific region classified as fish target cluster and those of non-fish target clusters into a distinctive binary plot. Physical properties of each fish target were therefore quantized which includes center coordinates, perimeter, area and shape factor as well as averaged value of textural features (i.e., mean, entropy and homogeneity).

IV. CASE STUDY AND RESULTS

A comprehensive evaluation of the entire surveying system with consecutive image acquisition and image processing for the purpose of fish target detection, relative abundance quantification and behavior investigation was performed in a deep water aquaculture pond in 2010. The pond covers an area with dimensions of 70 by 90 m (6,300 m^2) and an averaged depth of 3 m was reported. Due to the existence of suspended particulate matters, water clarity of this pond is quite poor which makes video observations completely obscured. Approximately 20,000 milk fish (*Chanos chanos*), each about 40 cm in length, were cultured in the pond. The MSIS was deployed at a randomly selected point near to the southern dike and 4 m off the pond bank where a small plastic pipe raft was deployed previously for the purpose of a surface working platform. Acoustic image frames collected with range setting at 5 m, stepping speed at 0.3^o/step and gain setting at 20 dB were selected for detailed analyses. Under these specific settings, each frame provided a viewing area of 78.5 m^2 (1.2% to the pond area) with spatial resolution of 2 x 2 cm per pixel, temporal resolution or scanning rate of 75 seconds per frame and maximum scanning speed of 42 cm/sec. A total of 46 consecutive image frames was acquired in this case study which lasted for an hour at around noon time (i.e., 12:54 to 13:54 local time).

A. *Image processing program verification and calibration*

Image processing computer program developed for fish target detection and relative abundance estimation was verified and optimal system parameters were determined with the modified image frames (i.e., stationary objects subtracted) of two typical examples (i.e., EX#1 and EX#2 in Figure 2). In this case, the entire image frames were used to generate the synthetic background frame for the purpose of stationary objects subtraction process.



(a) Ex#1, raw image frame. (b) Ex#1, modified image frame.

(c) Ex#2, raw image frame. (d) Ex#2, modified image frame.

Figure 2. Two typical examples illustrated bottom features (raw image frame) and the readily discriminated fish targets (modified image frame).

Feature extraction is a dominant issue in target detection from images. Values for a number of different parameters related to feature extraction and classification need to be determined, which include: region size, region sliding distance, number of grey levels and number of clustered classes. An evaluation process based on producer's and consumer's accuracy was adopted in this investigation [14].

Optimal region size and region sliding distance for this specific type of image frames were evaluated and determined empirically. Initial investigation illustrated that a region sliding distance of 4 pixels and 16 grey levels are acceptable selections in this case. Based on these sliding distance and grey levels, ten sets of square region sizes from 6x6 to 24x24 were systematically evaluated. For these experiments, AutoClass was set to execute for 4 attempts as suggested by the computer program, all regions were used for classification, and AutoClass was allowed to determine the optimum number of classes. In most cases, AutoClass would cluster the features into 9 classes. Performance evaluation was conducted by comparing manually depicted target pixels and computer classified target pixels of the two examples where manual detections were assumed without error. Results of the evaluation indicated that the 8x8 region size, with maximum value of producer's accuracy (85% and 78%, with respect to EX#1 and EX#2), was the optimal region size for the detection of fish target in this case. The relatively low producer's accuracy in EX#2 was correlated with a relatively high amount of fish target off the acoustic beam axis which was omitted by the manual detections and therefore caused the difference between manually depicted target pixels and computer classified target pixels.

Binary visualization and characteristic properties quantification of the detected fish targets of EX#1 were illustrated in Table 1. Basic fish target information extracted in this case included positional parameters (Cartesian and Polar Coordination), morphological descriptors (e.g., area, perimeter, shape factor and/or length) and energetic characteristics (e.g., acoustic energy reflected and indices of internal variation). In addition, information regarding size of detected fish target (in 'block' of 4x4 pixels), abundance variations and cumulative area of fish target by frame, which are associated with fish abundance and behavior patterns in the insonified volume, were estimated and enumerated for further investigation.

As criteria for fish target class identification is concerned, both hierarchical cluster analysis and principal feature threshold criterion were systematically tested and evaluated. It is evident that both procedures are effective in discriminating fish target class among classified classes. However, for principal feature threshold method, a combination of two thresholds among textural features (i.e., mean and homogeneity) is more efficient than a single textural feature threshold. An automatic image processing computer procedure with limited human intervention is therefore developed and verified.

TABLE 1. BASIC FISH TARGET INFORMATION EXTRACTED IN EX#1 INCLUDED POSITIONAL, MORPHOLOGICAL AND ENERGETIC PARAMETERS.

Target number	Center of Target (x , y)	Target Area	Target Perimeter	Shape Factor	Average Entropy	Average Homogeneity	Average Mean	Polar Coordination (Distance , Bearing)
#1	(−170.8 , −111.8)	48	32	1.5	1.497	0.375	63.7	(204.2, −123.2)
#2	(−121.5 , −166.5)	16	12	1.3	1.521	0.374	52.9	(206.1, −143.9)
#3	(−74.8 , 114.8)	48	32	1.5	1.515	0.390	63.2	(137.1, −33.1)
#4	(99.8 , 5.7)	832	156	5.3	1.555	0.473	97.3	(100.0, 86.8)
#5	(118.5 , −46.5)	16	12	1.3	1.487	0.420	55.8	(127.3, 111.4)
#6	(141.2 , −38.1)	144	60	2.4	1.555	0.465	64.5	(146.2, 105.1)
#7	(157.8 , −7.2)	96	40	2.4	1.554	0.465	60.9	(158.0, 92.6)
#8	(160.5 , −32.5)	64	32	2.0	1.560	0.419	61.6	(163.8, 101.4)
#9	(168.9 , −17.7)	80	40	2.0	1.557	0.444	63.7	(169.8, 96.0)
#10	(222.5 , 99.5)	32	24	1.3	1.564	0.443	73.7	(243.7, 65.9)
#11	(227.7 , 68.7)	384	80	4.8	1.492	0.371	93.2	(237.8, 73.2)

B. Results and discussion

Both surficial and bottom stationary environmental and anthropogenic features within the scanned volume of this randomly selected test point were imaged and recognized. At the water surface, a meter-sized floating object (i.e., the plastic pipe raft) is located at a location closed to the bank slope. On the bottom, among a relatively flat, muddy and stiff substrate, two types of explicit features are identified which include a continuous and moderately steeped bank slope at the pond bank area and several prominent mud mounds at the off bank area (see Figure 2). These features offered strong reflecting surfaces and therefore stronger echo intensities were generated at these areas in the image frames.

Quantitative information of fish targets discriminated from the consecutive 46 image frames was generated and exported to text formats for evaluating the characteristics of the proposed surveying system especially in the quantification of fish behavior related issues. A total of 2,928 individual and school fish targets were tabulated and based on the basic target area counting unit adopted in this investigation (i.e., "block" of 4x4 pixel), target area size or type of target varied from 1 block (#b-1) to as large as 171 blocks (#b-171). Among them, #b-1 and #b-2 are strictly linked to individual fish, whereas #b-5 can be considered as a minimum threshold for a fish school or closely spaced individuals. By the relationship of abundance of detection at each type of target in a semi-logarithmic plot (see Figure 3), two distinct categories, which are strictly related to fish behavior, were observed. The first category (i.e., Cat#1: Individual-School Mixture) followed an approximately linearly and continuously declined trend from #b-1 to #b-16 where number of target abundance varied by nearly two logarithmic cycles from 1,160 to 13. The second category (Cat#2: Prominent Schools) exhibited a level off trend from #b-17 up to #b-171. Based on a mutual consideration of target area size (type of target), number of abundance and continuity of distribution, the contents of the second category were further classified into two sub-categories by #B-40, i.e., Cat-2(A): Large School Set (#B-17 to #B-39) and Cat-2(B): Giant School Set (#B-40 and above).

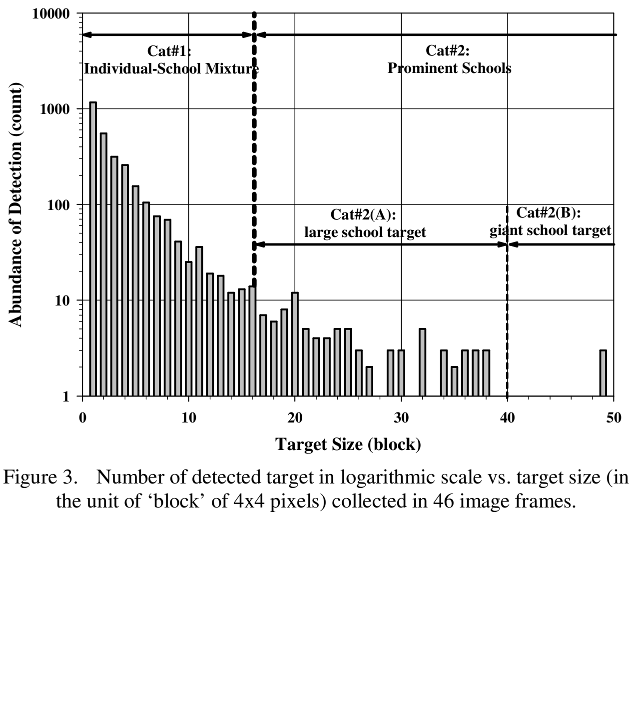


Figure 3. Number of detected target in logarithmic scale vs. target size (in the unit of 'block' of 4x4 pixels) collected in 46 image frames.

Quantitative evaluation of fish behavior from a spatial point of view was conducted by two measures, i.e., target area distribution by polar angle sectors (see Figure 4) and the relationship between fish target and environmental features (see Figure 5). Fish targets and environmental features, when presented and analyzed together, can provide valuable information about population dynamics and aggregation location with respect to these environmental features and surrounding environment. Two fish movement corridors in parallel with the pond bank were concluded (i.e., Corridor#1 and Corridor#2), which guided the mass movement and direction of travel of both individual and school fish (see Figure 5). Among them, Corridor#1, which is bordered by the pond bank, extends off bank to a distance of 5m in wideness and includes the floating raft within its coverage. A proportion of 73% detected targets by area were located in Corridor#1 and only 27% were located in Corridor#2. Nearly all of the targets which fit in Cat#2 (i.e., Prominent Schools Category) were located in Corridor#1 at specific locations such as bank slope area, substrate mound area and the area around the floating raft. In addition, all of the targets in Cat-2(B) (i.e., Giant School Set) were located at only two restricted areas in the vicinity of the floating raft. Alternatively, in Corridor#2, only six targets which fit in Cat-2(A) (i.e., Large School Set in the Prominent Schools Category) were located specifically on the substrate mound.

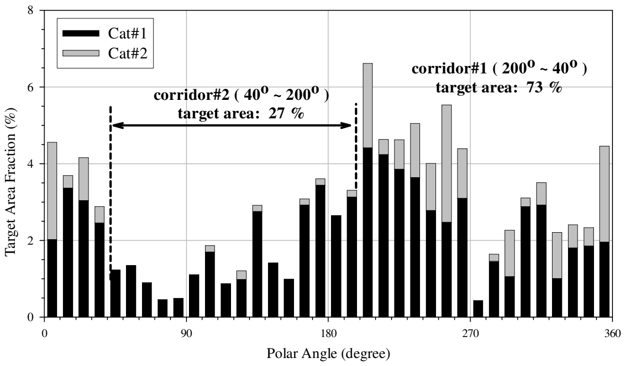


Figure 4. Target area distribution by polar angle sectors. Two fish movement corridors were concluded (i.e., Corridor#1 and Corridor#2).

Time-dependent variations of target area in each frame were evaluated by means of total integrated area and area by the Prominent Schools Category (see Figure 6). Values of the total integrated area varied significantly by a factor of 11 times from a maximum value of 10,224 pixels to a minimum of 896 pixels with average and standard deviation of 3893±2081 pixels. Periodic fluctuations in target areas through time were observed evidently, which included five key epochs with total integrated area over 6,000 pixels. Combined with time-dependent variations of target area through fish movement corridors illustrated that major fish movement patterns in the scanned area followed a continuous, steady and low passage rate mode (Corridor#2) (see Figure 7) superimposed a discrete, periodic and high passage rate mode (Corridor#1). A total of eight discrete and high passage rate events were discriminated and an averaged period of about seven minutes in time was concluded for each discrete and high passage rate event. During each event, the fish converged into large and giant schools subsequent to interactions with environmental features such as bank slope, substrate mound and the float raft.

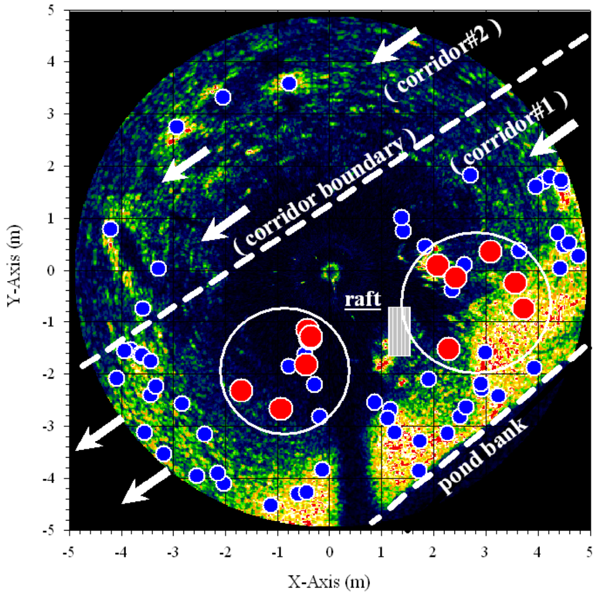


Figure 5. Relationship between fish target and environmental features. Two fish movement corridors were recognized. Arrows outline a general travel direction of the fish target. Blue and red circle represent large and giant school fish respectively.

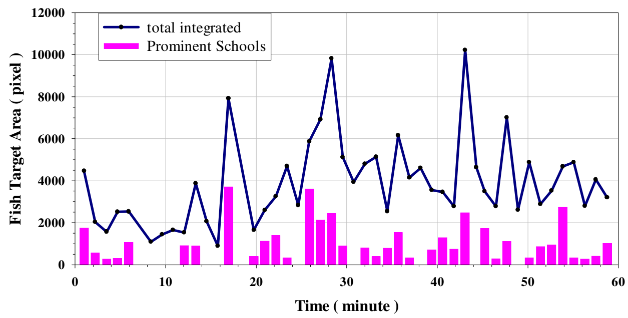


Figure 6. Time-dependent variations of fish target area.

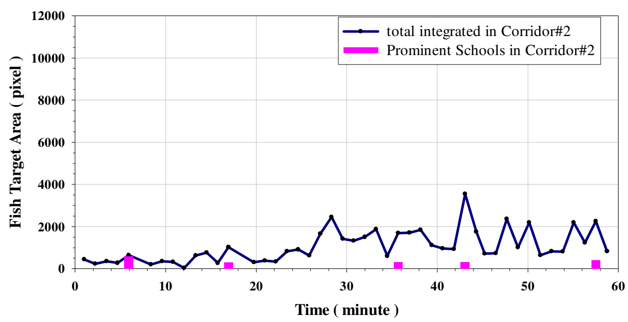


Figure 7. Time-dependent variations of target area in Corridor#2 followed a continuous, steady and low passage rate mode.

 ISBN: 978-1-61208-375-9

Based on spatial and temporal analyses on position and area of discriminated fish targets, it was concluded that fish movement behavior in the scanned area followed two distinct patterns in two separate corridors with significant different passage rate, i.e., a discrete, periodic and high passage rate (73%) mode in Corridor#1 and a continuous, steady and low passage rate (27%) mode in Corridor#2. Environmental features, such as bank slope, substrate mound and the float raft represented specific meeting points for dynamic aggregations and schooling. Fish tended to converge into large and even giant schools subsequent to interactions with these features. The fish converging effects of these environmental features varied in proportion with fish passage rate. In addition, behavior characteristics suggested by the first category (i.e., Cat#1: Individual-School Mixture), defined in the abundance and target size relationship, could be correlated with schooling and erratic behavior as well as swift swimming activity and chasing, occasional leaping and water-slapping activities of milk fish [17]. Behavior characteristics represented by the second category (Cat#2: Prominent Schools) were correlated with the existence of principal environmental features which acted as meeting points for swimming fish to converge into prominent schools.

V. CONCLUSIONS

A point stationary, acoustic-based surveying system, which incorporated acoustic image acquisition and image processing techniques, was developed and evaluated for its applicability in fulfilling the necessities of time-dependent benthic fish behavior investigation.

For the specific case study conducted in a deep water fishpond, it is evident that both individual and school fish could be discriminated by image frames collected at a randomly selected point with range setting at 5 m and frame rate at 75 second. Based on this investigation, fish movement behavior in the scanned area followed two distinct patterns, i.e., a discrete, periodic and high passage rate mode in Corridor#1 and a continuous, steady and low passage rate mode in Corridor#2. Environmental features, such as bank slope, substrate mound and float raft represented specific meeting points for dynamic aggregations and schooling. Fish tended to converge into large and even giant schools subsequent to interactions with these features.

The proposed system, which is an effective sampling tool due to its large sampling volume and the target-identification power, represented a practical and cost effective tool for the characterization of fish behavior. Other related issues such as the determination of fish swimming speed and length by the proposed system will be discussed in additional publications.

ACKNOWLEDGMENT

This work was supported by National Science Council (101-2221-E-110-014) and National Chung-Shan Institute of Science and Technology (CSIST-0884-V104).

REFERENCES

[1] S. F. Vik, Japanese Artificial Reef Technology, Maryland, USA: Aquabio, Inc. 1982.

[2] W. Jr. Seaman and L. M. Sprague, “Artificial habitat practices in aquatic system,” in Artificial habitats for marine and freshwater fisheries, W. Jr. Seaman and L. M. Sprague, Eds. New York, USA: Academic, 1991, pp. 1-16.

[3] Fishery Administration Taiwan, *Coastal Fishery Resources*, Available from: fttp://www.fa.gov.tw [retrieved: July 2014].

[4] W. M. Tian, “Side-scan sonar techniques for the characterization of physical properties of artificial benthic habitats,” Brazilian Journal of Oceanography, vol. 59 (special issue CARAH), April 2011, pp. 77-90, doi: 10.1590/S1679-87592011000500010.

[5] D. N. MacLennan and E. J. Simmonds, Fisheries Acoustics, London, England: Chapman & Hall, 1992.

[6] W. M. Tian, “Integrated method for the detection and location of underwater pipelines”, Applied Acoustics, vol. 69, April 2008, pp. 387-398, doi:10.1016/j.apacoust.2007.05.001.

[7] R. A. Moursund, T. J. Carlson, and R. D. Peters, “A fisheries application of a dual-frequency identification sonar acoustic camera,” ICES Journal of Marine Science, vol. 60, March 2003, pp. 678–683, doi:10.1016/S1054–3139(03)00036-5.

[8] J. A. Holmes, G. M. W. Cronkite, H. J. Enzenhofer, and T. J. Mulligan, “Accuracy and precision of fish-count data from a ‘dual frequency identification sonar’ (DIDSON) imaging system,” ICES Journal of Marine Science, vol. 63, April 2006, pp. 543–555, doi:10.1016/j.icesjms.2005.08.015.

[9] Imagenex Technology Corp, Imagenex model 881A Digital Multi-Frequency Imaging Sonar, Port Coquitlam, Canada: Imagenex Technology Corp, 2007.

[10] Konsberg Mesotech, Use of Scanning and Side-scan Sonar for Body Recovery, Port Coquitlam, Canada: Konsgerg Mesotech, 2002.

[11] X. Lurton, An Introduction to Underwater Acoustics: Principles and Applications, Chichester, UK: Praxis Publishing, 2002.

[12] J. P. Fish and H. A. Carr, Sound Underwater Images—A guide to the generation and interpretation of side scan sonar data, Orleans, MA: Lower Cape Publishing, 1990.

[13] N. O. Handegard and K. Williams, “Automated tracking of fish in trawls using the DIDSON (Dual frequency IDentification SONar),” ICES Journal of Marine Science, vol. 65, March 2008, pp. 636–644, doi:10.1093/icesjms/fsn029.

[14] J. B. Campbell, Introduction to Remote Sensing, 3rd ed., NewYork, USA: The Guilford Press, 2002.

[15] Ph. Blondel, “Automatic Mine Detection by Textural Analysis of COTS Sidescan Sonar Imagery,” International Journal of Remote Sensing, vol. 21, Dec. 2000, pp. 3115-3128, doi:10.1080/01431160050144983.

[16] S. Bridges, J. Hodges, B. Wooley, D. Karpovich, and G. B. Smith, “Knowledge Discovery in an Oceanographic Database,” Applied Intelligence, vol. 11, Sep. 1999, pp. 135-148, doi: 10.1023/A:1008395129406.

[17] I. C. Liau and E. M. Leano, Milkfish Aquaculture in Asia, Keelung, Taiwan: National Taiwan Ocean University, 2010.