Final Report

A Manatee Avoidance System

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A Manatee Avoidance System

1. Executive Summary

The research team from the University of Massachusetts Lowell/University of Florida has completed its research effort to develop an acoustically based manatee avoidance system. Several important findings and accomplishments were made, which include the following:

(1) A survey of the underwater background noise levels found in the manatee habitat and waterways of Florida was completed. A set of recordings of boat traffic and watercraft noise was obtained.

(2) The most appropriate acoustic spreading (transmission loss) model based on the empirical tests conducted was identified.

(3) The distance in which manatees can be effectively detected by means of their vocalizations was effectively quantified.

(4) A simulation was created that combines measured source levels of manatee vocalizations with the modeled acoustic properties of manatee habitats to illustrate the effective ranges in which manatees are detectable. The simulation indicates that background noise significantly affects the detectable range and that the detection range can be increased considerably if the background noise is suppressed.

(5) Having a system with a large detection range is critical for practical implementation. By improving the signal-to-noise ratio (SNR) of the manatee vocalization signal, it is possible to extend the detectable range of manatee vocalizations while also reducing the false alarm rate and the number of missed calls.

(6) Several advanced digital signal processing techniques were implemented in order to reduce the background noise: (a) a bandpass filter; (b) a finite impulse response (FIR) structure of an adaptive line enhancer (ALE); (c) a constrained infinite impulse response (IIR) ALE, called feedback ALE (FALE); and (d) wavelet based noise reduction approaches. Significant reductions in background noise can be achieved using the techniques investigated.

(7) At present, it is the investigators' conclusion that an acoustic based manatee avoidance technology is not practically realizable, *unless background noise cancellation technology is also implemented in parallel with the detection system.* By using a background noise reduction system it will be possible to significantly extend the detection range of an acoustically based manatee avoidance technology.

The results of the research were published in five separate peer-reviewed journal publications and presented in nine different conference presentations.

2. Introduction

2.1 Background

Controversy currently exists between users of waterways (recreational and commercial boaters, marinas, and waterfront developers: Standing Watch, Citizens of Florida Waterways, Marine Industries Association of Florida) and proponents that wish to protect manatee habitat (The Ocean Conservancy, Save the Manatee Club). In the last twenty years, a major focus of wildlife conservation in the state of Florida has been the identification and preservation of the West Indian Manatee (Trichechus manatus latirostris). Manatees are often injured or killed by collisions with watercraft traffic on Florida's many rivers and waterways. The collisions are so frequent that manatees are routinely identified by the scars they receive from boat strikes. The risk of a collision increases greatly in the winter when water temperatures drop below 20^{o}C and manatees migrate to warmer inland waters such as Crystal River, Blue Springs, St. Johns River, and industrial plant discharges. These warm water habitats can be dangerous places for manatees as many of them are also popular locations for boating and water recreation (see Figure 2.1a). However, the existing regulations designed to protect the manatee also have a tremendous impact on Florida's economy. In the future the results of this research has the potential to significantly reduce the economic impact that round-the-clock idle speed zones have on boating associated businesses and recreational boating activities in some of Florida's most heavily used waterways. The research may ultimately help to sustain economic viability and foster development in Florida's coastal communities while maintaining the integrity of the manatee habitat.

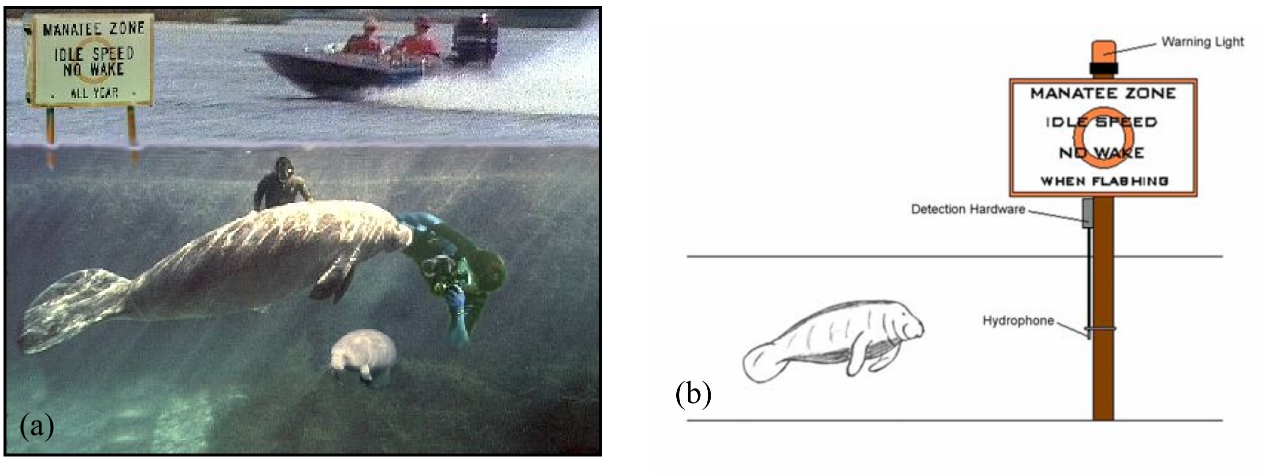

Figure 2.1 a) Traditional manatee warning sign; b) Conceptual manatee warning sign.

In response to the growing evidence of the negative effects of boating on the manatee population, the state legislature passed the Florida Manatee Sanctuary Act in 1978, which allows for the creation and enforcement of boating restrictions in manatee habitats. This act has been used to create many "idle-speed" and "no-wake" zones throughout Florida's many waterways. These zones have created conflict throughout the years between environmentalists, who believe that more zones should be added in order to protect more habitats, and boaters, who want fewer restrictions on the waterways they use for both commercial and recreational purposes. Despite all the protective efforts in the last twenty years, the number of manatee deaths per year continues to rise at a troubling rate. The number of deaths is so great that the Endangered Species Act of 1973 classifies the manatee as a species "in danger of extinction without human protection." In surveys conducted throughout Florida in February 2006, the manatee population was estimated at 3,113 (FWC, 2006a). Since scientists began documenting manatee deaths in 1974, the number of manatee deaths per year has exceeded 10% of the estimated total population. The number of manatee deaths caused by collisions with watercraft per year from 1976 to 2006 has steadily increased over the last thirty years and is shown in Figure 2.2. It can be seen that 24% of all manatee deaths are caused by collisions with watercraft (FWC, 2006b). These numbers demonstrate the need for a different approach to protecting manatees and their habitats.

There are currently more than one quarter of a million acres of manatee protection zones that have been established by the state of Florida (Farren, 2003). The existing regulations designed to protect the manatee also have a tremendous impact on Florida's economy. The manatee protection zones affect marinas, the construction of new boat ramps, boat sales and use, as well as residential development and property values. Although the research being proposed can certainly not remedy all of the issues of contention, it has the potential to alleviate some of the problems associated with manatee idle speed zones.

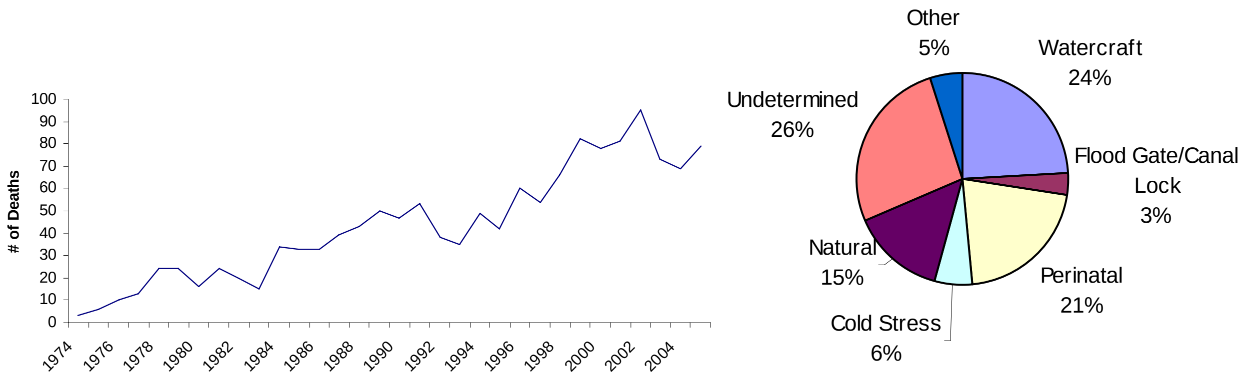

Figure 2.2 Number of watercraft related manatee mortalities and distribution of manatee mortalities according to cause of death between 1974-2005 (FWC, 2006b)

Our ***long range goal*** is to develop an efficient, cost-effective method for signaling to boaters that manatees are present in the immediate vicinity of heavily-used waterways, thus the boaters should slow to idle speed and maintain a sharp lookout until clear of the affected area. Because final implementation of this system is likely to cost between $5,000 and $10,000 per mile of protected waterway, depending on water depth, boat traffic, and channel complexity, it is intended for deployment primarily in those waterways where existing round-the-clock idle speed zones have caused significant economic impact on boating associated businesses and/or major constraints on recreational boating activities (see Figure 2.1b).

Our ***hypothesis*** is that the presence of manatees can be detected and localized to within 100 meters or less in any given area. This is accomplished by analyzing the underwater sound spectrum in the target area by using an inexpensive array of hydrophones. Once the presence of one or more manatees is detected within 100 meters of a navigable channel, their presence, and thus the need for boaters to slow to idle speed, could be signaled via a variety of methods. The visual notification of manatee presence would remain active for a period of time to ensure that the idle speed zone was in force while manatees are in the vicinity. Additionally, the detection system can be used to capture the manatee location data in order to track manatee movement routes and favored lounging areas within the protected area.

2.2 Description of the Technology

An example of one way in which acoustic signals are identified is by performing a spectrum analysis. Underwater sound measurements of the time domain signals are sampled by using a hydrophone. Analysis of the multiple, overlapping sound signals in the time domain is extremely difficult. However when the signals are transformed to the frequency domain, distinct characteristics can be revealed. Spectrum analysis is based on a mathematical algorithm

(Discrete Fourier Transform) that converts the signals from the time to frequency domain. This allows several distinct acoustic signals or measurements that contain a significant amount of background noise to be differentiated and clearly identified. When making underwater sound measurements of manatees, the total acoustic signal will be comprised of background noise (fish, shrimp, marine mammals, and wave motion), boat noise (engine and propeller), and sounds produced by the manatee (chewing, digestion, flatulence, and squeaks). ***Our results indicate that the sounds a manatee makes can be discriminated from both boat and background noise***.

After performing a spectrum analysis on the various sound signals, it is clearly evident that the sound that a manatee makes is discernable from background noise and boat noise (see Figure 2.3). The manatee sound autospectrum indicates that a manatee squeak consists of a fundamental frequency and several higher harmonics. The relative amplitude of these harmonics, their duration, and their frequencies can be used to distinguish the squeak of a manatee from other background noise. It is imperative that the intensity of the vocalizations be high enough such that the amplitude of the peaks generated by manatees is higher than the background and boat noise.

If a manatee approaches the target area or hydrophone location, the manatee's location will be detected acoustically and a signal will be triggered, indicating to boaters that a manatee is nearby. The manatee indicator light would be triggered by a vocalization and would stay active for a period of time (ranging from 30 minutes to several hours), sufficient to verify that no manatees are present in the area prior to turning off the indicator. As a result, the boater will reduce speed and avoid a collision. If no manatees are detected, the boater can be permitted to resume at normal operating speeds.

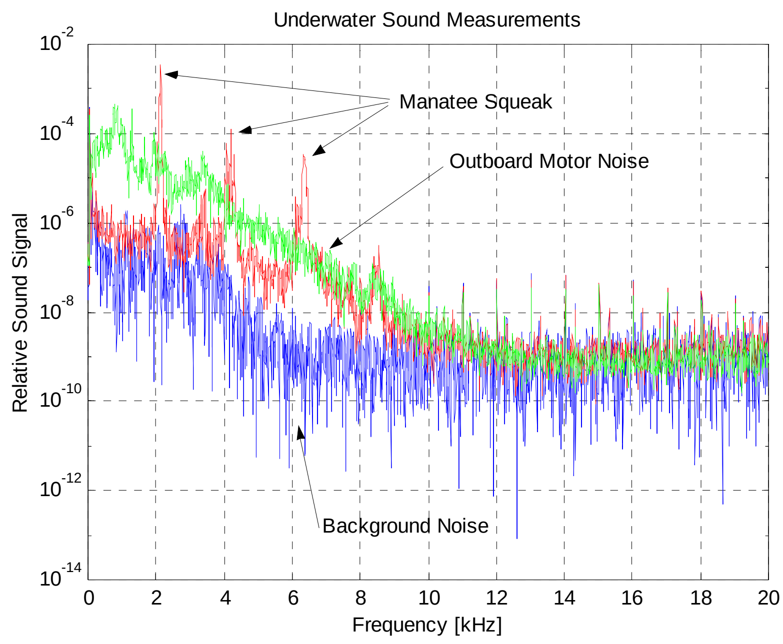

Figure 2.3 Underwater hydrophone sound autospectrum. (Note the pronounced peaks emerging just beyond the 2, 4, 6, and 8 kHz frequencies.)

2.3 Review of Related Literature

Schevill and Watkins were among the first researchers to describe the calls of the West Indian manatee and to add the manatee to the list of aquatic mammals known to produce sounds. They described the manatee's calls as being squeaky and rather ragged. They found these calls to last between 0.15 and 0.5 seconds and to be 10-12 dB above the background noise. They also found the fundamental tones of the manatee's calls to be between 2.5 and 5 kHz but sometimes as low as 600 Hz (Schevill and Watkins, 1965). Hartman continued this research in 1969 and became the first biologist to study the West Indian manatee in their underwater habitat. Hartman found the vocabulary of manatees to be highly variable and to include chirp-squeaks, squeals, and screams (Hartman, 1969).

In 1982, Cathy Steel created a detailed characterization of captive manatee sounds and separated them into nine different categories. Steel determined the patterns that are associated with vocalizations. She found that vocalizations occur under many different circumstances, including manatees approaching one another, submergence from breathing, and especially during play. Both individual manatees as well as several manatees interacting with one another were found to make sounds. A close bond was seen between infants and their mothers with the pairs communicating on a frequent basis. Steel also noted a rise in amplitude in calls when the manatees were under conditions of distress, alarm, or annoyance (Steel, 1982).

Perhaps the most extensive catalog of manatee recordings was created by Thomas O'Shea between 1981 and 1984 while working for the United States Geological Survey (O'Shea, 1981-1984). These recordings were used to quantify the performance of the preliminary detection algorithms discussed in this proposal.

Other researchers studied the rate at which manatee calls are made. Apart from when they are feeding, manatees vocalize approximately 1 to 5 times within a five minute period (Bengston and Fitzgerald, 1985). Within a protected channel, they are not likely to be feeding. Therefore, as long as a manatee warning device remains active for a few minutes, this rate of vocalization should be adequate for detecting and locating manatees. The investigator's own field studies confirm the vocalization rates measured by the previous researchers (Phillips, Niezrecki, and Beusse, 2003).

In 1991, Ellen Marie Richard-Clark discovered a difference between the breeding populations of manatees on the east and west coasts of Florida. She found that manatees on the east coast produce slightly higher frequency calls than those on the west coast. This implies that there is a possible barrier between the east and west coast breeding populations (Richard-Clark, 1991). Clearly any detection algorithm will need to take these differences into account.

Another important area of research with manatees has been in determining their hearing potential and the creation of audiograms. Gerstein and others looked at the hearing potential of manatees and created one of the first manatee audiograms. They found the maximum hearing sensitivity of manatees to be around 50 dB (re 1μPa) at approximately 16 kHz (Gerstein *et al.*, 1999). This research led Gerstein to create an acoustic device to alert manatees of approaching boats. The device would be placed on the front of boats and would create a highly directional, low-intensity signal to alert manatees to the boat's presence (Gerstein, 2002). However, critics claim that a manatee has to be struck by a boat before the animal can associate the sounds with the oncoming danger and the animals will habituate to the sounds.

Nowacek and others compared the vocalization rates in Florida and Belize and found that the manatees vocalized at a rate of 1.29 and 0.09 to 0.75 vocalizations per animal per minute, respectively (Nowacek et. al., 2003). The high rate of vocalization at Crystal River is based on visual estimates of the number of manatees (~50) in the area. However the visual estimate of the number of manatees is not an accurate assessment of the number of manatees in the river. Additionally, the behavior of the manatees during the measurement was not reported in their work and can affect the vocalization rate. Nowacek also estimated the mean received sound pressure levels of the peak frequency (in Crystal River) to be approximately 100 dB (re 1 μPa). The received values are recorded with the hydrophone at approximately 20m from a group of 50 manatees. Additionally, the source levels from the hydrophones tagged on the Belize manatees were estimated to be between 106 and 115 dB.

3. Summary of Significant Results

The following work was accomplished as part of this research contract. The descriptions below represent a synopsis of the significant findings. More detail can be found in the references described in Section 3.6.

3.1 A Survey of Underwater Sound

The feasibility and practical implementation of an acoustic based manatee detection system is strongly dependent on its cost and the number of hydrophones required to monitor a channel or waterway. The required hydrophone spacing will depend on three important factors: (1) the intensity of the manatee sound signals, (2) the background noise levels, and (3) the decay of the signal's strength with distance. Without knowing all of this information it is difficult to quantify a detection system's useful range. The researchers have determined each of the three quantities mentioned:

(1) Typical manatee vocalizations have source level of 112-118 dB (ref. 1 μPa at 1 m).
(2) A survey of the underwater background noise levels found in the manatee habitat and waterways of Florida was completed. Natural background noise is largely attributed to snapping shrimp and ranged from 70 to ~105 dB (ref. 1 μPa) depending on salinity. Typical boat noise (operating at full throttle) has an overall source level of ~140 dB (at 1m) and a noise floor of 120 dB above 2k Hz.
(3) Based on the tests performed, the acoustic spreading within the shallow waters of Florida can be best modeled by a mixed spreading model.

3.2 Manatee Detection Ranges

The maximum distance in which a manatee is detectable (R_M) is dependent on the source level of the manatee vocalization (SL_M), the ambient background noise level (BL), the source level of the boat (SL_B), the distance of the boat from the hydrophone (R_B), the type of acoustic spreading model chosen (mixed-spreading), and the system detection threshold (DT). The detection range is governed by the following equation in which the maximum distance a manatee is detectable and is given by,

$$R_M = 10\wedge\left(\frac{SL_M - \max\left(BL, SL_B - 15\cdot\log\left(R_B\right)\right) - DT}{15}\right) \quad (1)$$

The manatee detection range is largely dependent on the background noise levels. A computer simulation of the acoustic environment and associated source levels has been created to demonstrate the detection range. In low background noise levels (70 dB) manatees can likely be detected ~400 m away. However if the background noise level increases to 100 dB, the detection range drops to ~4 m. This result is shown in Figure 3.1 in which the noise from the boat has been excluded.

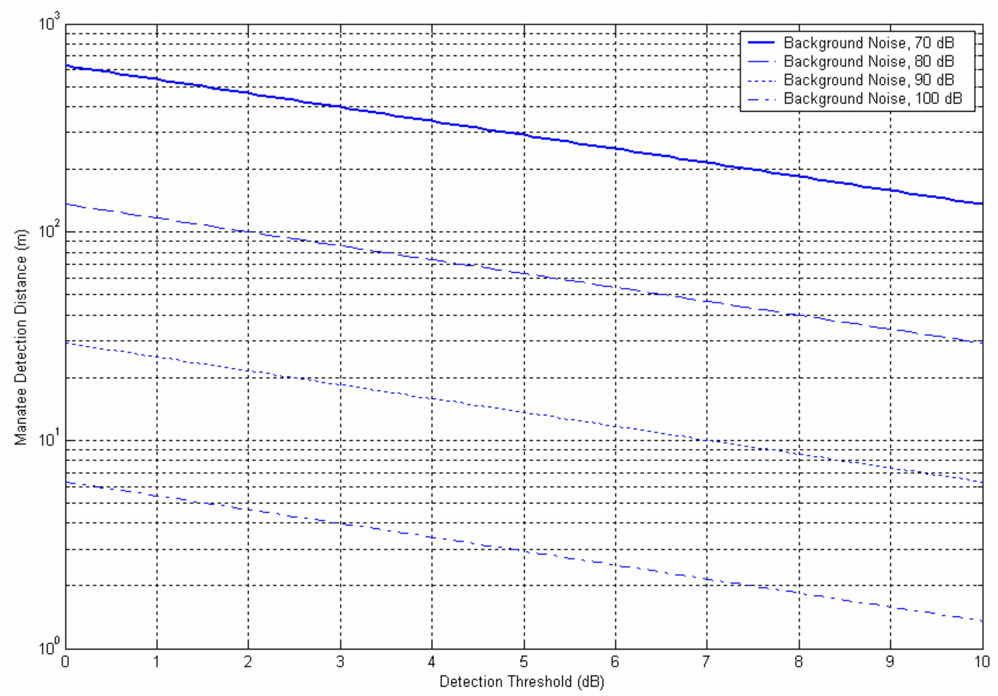

Figure 3.1. Maximum manatee detection ranges at various background levels assuming a manatee source level of 112 dB @ 1 m, ref 1 µPa (with no boat noise present).

Using a manatee vocalization source level of 112 dB, estimated mean ambient background noise levels, and including a boat generating a 120 dB noise floor (above 2 kHz) the maximum theoretical detection range can be calculated. Cases with ambient background noise levels at 83 and 90 dB, and boat distances from 0 to 300 m are presented in Figures 3.2 and 3.3, respectively. Each of the three graphs in Figures 3.2 and 3.3, contain the same information presented in a slightly different manner. For example if the reader peruses the lower right hand graph of Figure 3.2, for a detection threshold of 3 dB, it is evident that the detection range is ~55m when the boat is located 300 m away from the hydrophone. If the boat moves closer and is located 100 m from the hydrophone, the manatee detection range drops to ~18.5 m. If the boat moves even closer and is located less than 5 m from the hydrophone, the boat noise levels have exceeded the detection threshold (3 dB) required to detect the manatee.

As the ambient background noise levels increase from 70 dB, the results presented in Figure 3.2 will not change until ~83 dB for a boat operating within 300 m of the hydrophone and a manatee source level of 112 dB. With ambient background noise levels less than 83 dB, the limiting factor in the manatee detection distance is the boat noise, for a boat cruising within 300 m of the manatee. If the ambient background noise levels are increased to 90 dB (see Figure 3.3), the detection range is governed by the background noise until the boat is located closer than ~100 m from the hydrophone. Within the range <100 m, the boat noise limits the detection range, while if the boat is further than 100 m, the detection range is limited by the background noise. If the ambient background levels are increased to 100 dB, the background noise limits the detection range until the boat is within ~25 m. Beyond this range the manatee detection distance is limited by the boat noise. For a manatee source level of 112 dB, in all of the cases the hydrophone is saturated by engine and propeller noise when the boat is closer than 5 to 10 m, depending on the detection threshold.

If the manatee source level is increased from 112 to 118 dB for an ambient background noise of 90 dB, the detection range graphs will have a similar appearance to the ones shown in Figure 3.3, however the values will be higher. For example, the maximum detection range increases from 18.48 m to 46.42 m for a 90 dB ambient background noise environment (DT = 3 dB). This clearly indicates that the detection range estimation is sensitive to variability in the manatee vocalization source levels.

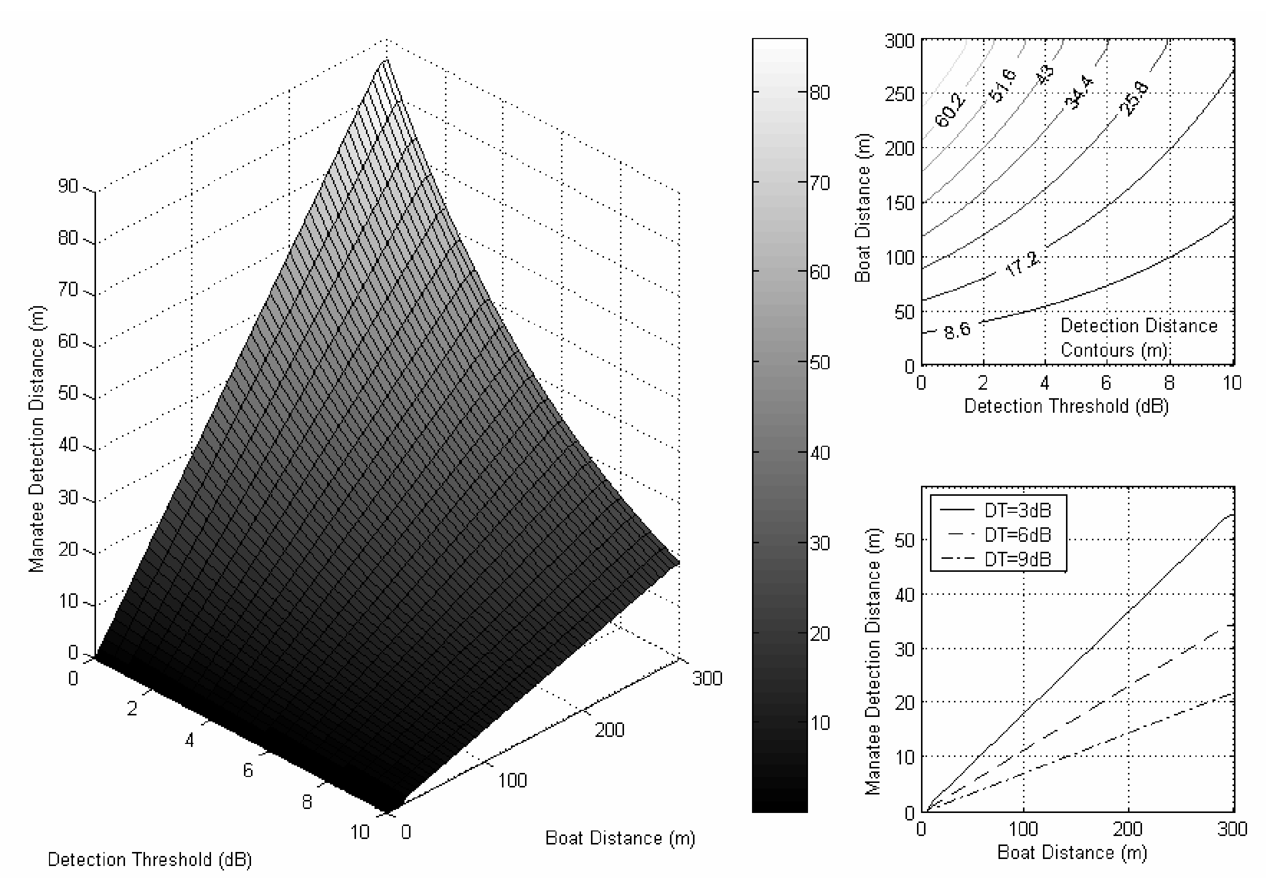

Figure 3.2. Maximum manatee detection ranges at BL = 83 dB, SL_M = 112 dB, & SL_B = 120 dB.

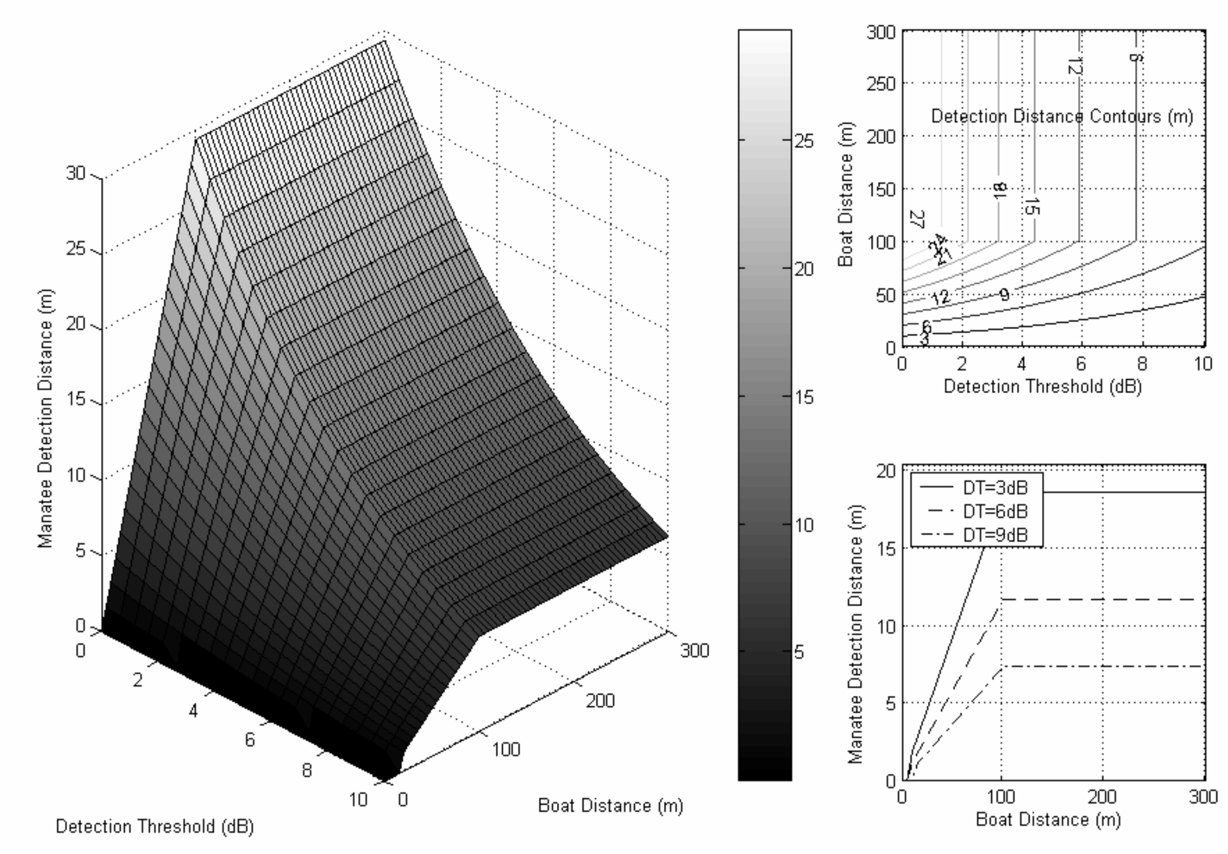

Figure 3.3. Maximum manatee detection ranges at BL = 90 dB, SL_M = 112 dB, & SL_B = 120 dB.

Boat noise and location has a strong influence on the detection range. **Without removing the boat and background noise, acoustic based manatee detection is not realizable.** Therefore, the researchers have placed a great deal of prior effort and made significant advances to remove the boat and background noise in order to improve the manatee signal-to-noise ratio (SNR).

3.3 Background Noise Reduction

The research has shown that background noise limits the manatee vocalization detection range of acoustic based detection systems. Primary examples include boat and snapping shrimp noise. Secondary noise sources are generated by wind, rain, water movement, and other biological species. Having a system with a large detection range is critical for practical implementation. By improving the signal-to-noise ratio (SNR) of the manatee vocalization signal, it is possible to extend the detectable range of manatee vocalizations while also reducing the false alarm rate and the number of missed calls. Several advanced digital signal processing techniques were implemented in order to reduce the background noise: (1) a bandpass filter; (2) a finite impulse response (FIR) structure of an adaptive line enhancer (ALE); and (3) a constrained infinite impulse response (IIR) ALE, called feedback ALE (FALE).

The performance of each of these techniques (bandpass filter, FIR-ALE and FALE) was compared on a series of time domain measurements. The measurements consisted of pure manatee calls, natural noise, boat noise, snapping shrimp noise, and the superposition of these four signals as shown in Figure 3.4(a-e), respectively. The superposed signal shown in Figure 3.4e, contains the indiscernible manatee calls along with high level background noise. A hydrophone measurement will generally contain some percentage of all of these types of noise. The superposed signal after the bandpass filter, FIR-ALE, or FALE is applied, are shown in Figure 3.5(a-c), respectively. After processing the measured signal with the various filters, it is clearly evident that the original manatee vocalizations are easily discernable by using either of the two adaptive filters (FIR-ALE, or FALE). For a manatee vocalization that initially has a SNR of -5 dB, the average SNR after processing with FALE is approximately 25 dB (a 30 dB improvement). Background noise can be significantly reduced, therefore making manatee vocalizations easier to detect and extending the range of detection.

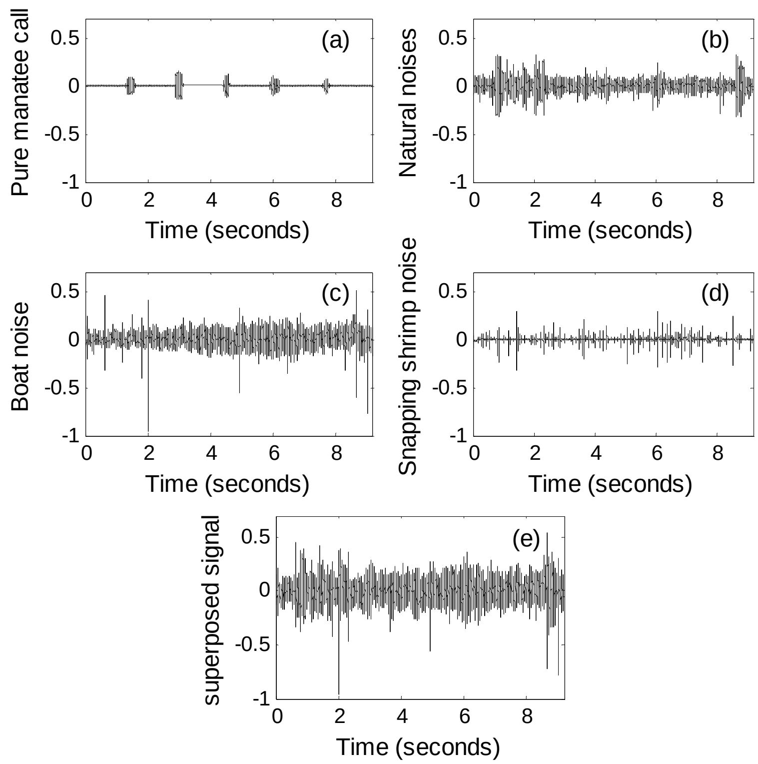

Figure 3.4. (a) Pure manatee call; (b) natural noise; (c) boat dominated noise; (d) snapping shrimp noise; (e) superposition of manatee calls, natural noise, boat dominated noise, and snapping shrimp noise.

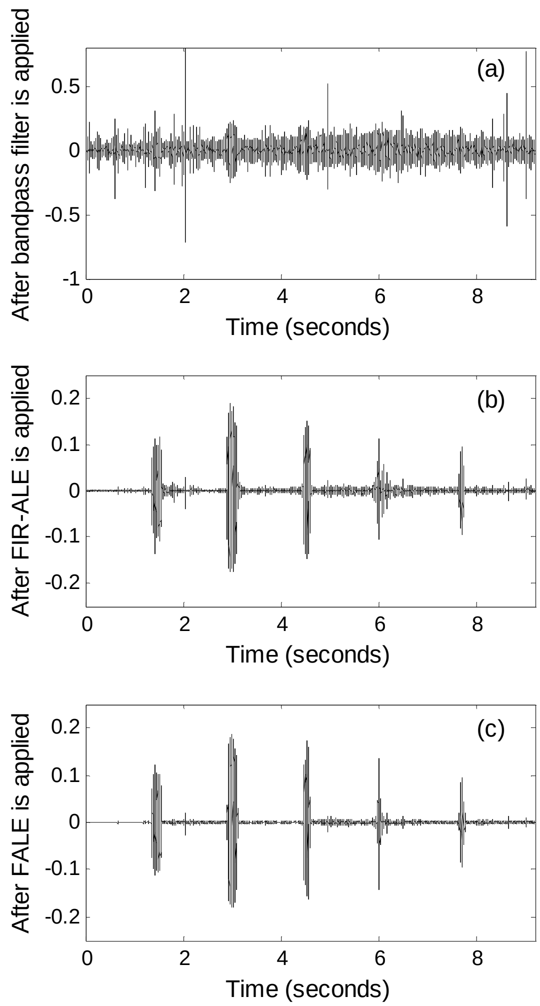

Figure 3.5. (a) Superposed signal after the bandpass filter is applied; (b) superposed signal after FIR-ALE is applied; (c) superposed signal after FALE is applied.

3.4 Simulation of Detection Range Improvement

One aspect of the feasibility of an acoustically based manatee detection system relies upon the distance in which a manatee vocalization is detectable. A simulation was created that combines measured source levels of manatee vocalizations with the modeled acoustic properties of manatee habitats to illustrate the effective ranges in which manatees are detectable. The simulation indicates that background noise significantly affects the detectable range and that the detection range can be increased considerably if the background noise is suppressed. These results are demonstrated in Figure 3.6 (a-e) in which the source level of the manatee vocalization (SL_M) is set to 115 dB, the ambient background noise level (BL) is set to 90 dB, the source level of the boat (SL_B) is set to 120 dB, the distance of the boat from the hydrophone (R_B) is set to 50 m, a mixed-spreading model is assumed, and the system detection threshold (DT) is set to 3 dB. The detectable region is shown in blue/white and the non-detectable region is shown in black. As the level of noise reduction is increased, the detection range increases significantly.

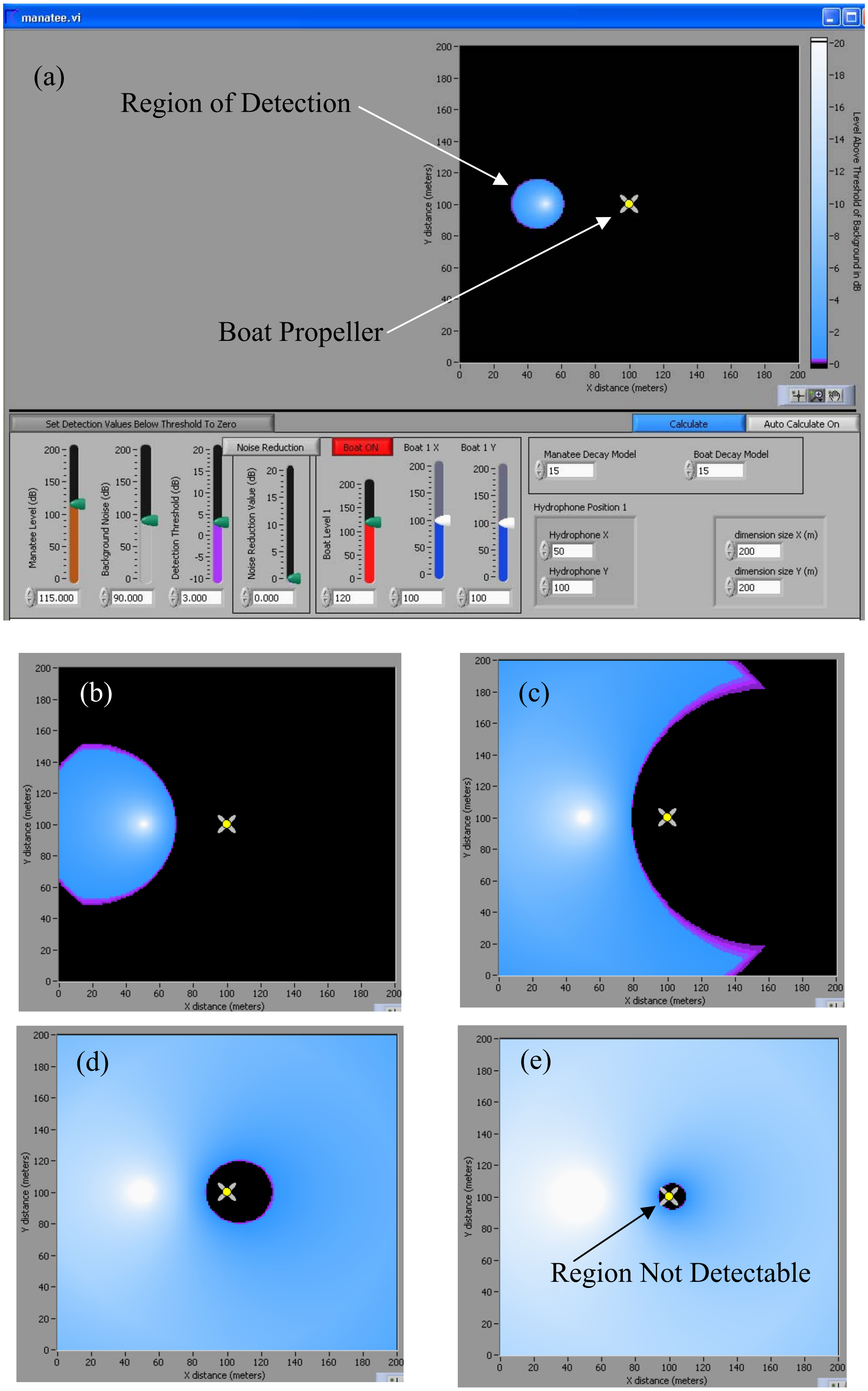

Figure 3.6 a) Detection range simulation with $SL_M = 115$ dB, $SL_B = 120$ dB, $BL = 90$ dB, $R_B =$ 50 m, mixed-spreading, DT = 3dB, and no noise reduction; b) Noise reduction = 5 dB; c) Noise reduction = 10 dB; d) Noise reduction = 15 dB; e) Noise reduction = 20 dB.

3.5 Manatee Position Localization

An automated system that can identify the source location of a manatee vocalization in real time by using time difference of arrival of several hydrophone signals has been developed by the researchers. The details of the system are described in the reference provided in the next section.

3.6 Summary of Work and Conclusions

At present, it is the investigators' conclusion that an acoustic based manatee avoidance technology is not practically realizable, **unless background noise cancellation technology is also implemented in parallel with the detection system.** By using a background noise reduction system it will be possible to extend the detection range of an acoustically based manatee avoidance technology. More details of the investigators' research, described in the preceding sections, can be found in the following peer reviewed references that were published as a result of this research contract:

Journal Publications Resulting from this Contract:

1. *Gur, B.* and Niezrecki, C., "Autocorrelation based de-noising of manatee vocalizations using the undecimated discrete wavelet transform," *Journal of the Acoustical Society of America*, accepted January, 2007.

2. Buaka, P., and Niezrecki, C., "Manatee position estimation by passive acoustic localization," *Journal of the Acoustical Society of America*, Volume 121, Issue 4, pp. 2049-2059, April 2007.

3. *Yan, Z.*, Niezrecki, C., Cattafesta, L., and Beusse, D. O., "Background Noise Cancellation of Manatee Vocalizations Using an Adaptive Line Enhancer," *Journal of the Acoustical Society of America*, Volume 120, Issue 1, pp. 145-152, July 2006.

4. *Phillips, R.*, Niezrecki, C., and Beusse, D. O., "Theoretical Detection Ranges for Acoustic Based Manatee Avoidance Technology," *Journal of the Acoustical Society of America*, Volume 120, Issue 1, pp. 153-163, July, 2006.

5. Yan, Z., Niezrecki, C., and Beusse, D. O., "Background Noise Cancellation for Improved Acoustic Detection of Manatee Vocalizations," *Journal of the Acoustical Society of America*, Vol. 117, No. 6, pp. 3566-3573, June 2005.

Dissertations Resulting from this Contract:

1. Yan, Zheng, "Background Noise Cancellation for Acoustic Detection of Manatee Vocalizations," Ph.D. Dissertation, University of Florida, Gainesville, FL, 2006.

Conference Presentations Resulting from this Contract:

1. *Gur, B.* and Niezrecki, C., "Wavelet-based denoising of manatee vocalizations," 151st Meeting of the Acoustical Society of America, Providence, RI, June 5-9, 2006, *Journal of the Acoustical Society of America*, Vol. 117, No. 5, Pt. 2 of 2, May 2006, pp. 3404.

2. Muanke, P. B. and Niezrecki, C., "Locating manatee position with an acoustic array," 151st Meeting of the Acoustical Society of America, Providence, RI, June 5-9, 2006, *Journal of the Acoustical Society of America*, Vol. 117, No. 5, Pt. 2 of 2, May 2006, pp. 3405.

3. *Yan, Z.*, Niezrecki, C., Cattafesta III, L. N. and Beusse, D. O., "Background noise reduction of manatee vocalizations," 151st Meeting of the Acoustical Society of America, Providence, RI, June 5-9, 2006, *Journal of the Acoustical Society of America*, Vol. 117, No. 5, Pt. 2 of 2, May 2006, pp. 3405.

4. Niezrecki, C., *Gur, B.*, *Cramer, J.*, and Beusse, D. O., "Simulation of ranges for acoustic-based manatee

detection," 151st Meeting of the Acoustical Society of America, Providence, RI, June 5-9, 2006, *Journal of the Acoustical Society of America*, Vol. 117, No. 5, Pt. 2 of 2, May 2006, pp. 3405.

5. Niezrecki, C. "Acoustic Based Manatee Avoidance Technology," Florida Marine Mammal Health Conference, April 9, 2005 (*invited*).

6. *Phillips, R.*, Niezrecki, C., and Beusse, D. O., "Acoustic Spreading and boat noise within shallow Florida waterways," 149th Meeting of the Acoustical Society of America, Vancouver, CA, May 16-20, 2005, *Journal of the Acoustical Society of America*, Vol. 117, No. 4, Pt. 2 of 2, April 2005, pp. 2577.

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