Shallow water assessment of an interferometric phase differencing sonar

Steve Wright, Lisa N Brisson* (EdgeTech)

Abstract

In the last few decades substantial efforts have been made to improve and facilitate the way hydrographic data is obtained. One technology is the EdgeTech 4600, an interferometric phase differencing sonar (IPDS). This system's performance in shallow water was evaluated using three parameters: data density, standard deviation within cells, and feature size detection. The test site used in the study was a small channel in Port Everglades, Florida, USA, named the Dania Cut-Off Canal. The 540 kHz model of the EdgeTech 4600 system was chosen for the survey carried out on March 30th, 2011. The unit was deployed over the side of the research vessel, the *Ocean Researcher II*. Calibration data was obtained in the morning and the survey of the Dania Cut-Off Canal was performed in the afternoon. Hypack® was used to acquire, illustrate, and analyze the data utilizing its *Survey and Hysweep Survey*, *MBMax*, and *Side Scan Targeting & Mosaicing* programs. This paper presents the results for 1 m and 0.5 m cell sizes.

Introduction

The standard and most commercially available piece of equipment used in shallow water surveys today is a beam-forming system, or more commonly known as a multibeam echosounder. Shallow water surveys with this type of system pose potential dangers near shore and require a relatively lengthy survey time due to their angular limitations on swath width. A dual headed system may be used to extend the swath but then the costs may outweigh the benefits.

Over the last few decades substantial efforts have been made to improve and facilitate the way hydrographic data is acquired. One such technology is an interferometric phase differencing sonar (IPDS). These types of systems have larger swath widths compared to the multibeam systems, decreasing the amount of time and effort it takes to complete a shallow water hydrographic survey. One such system is the EdgeTech 4600 Swath Bathymetry and Side Scan Sonar System (Fig.1).

This IPDS produces real-time high resolution 3D maps of the seafloor and provides co-registered simultaneous side scan and bathymetric data. The IPDS has two 30 inch long arrays, one port and one starboard. Each array is constructed using 9 independent longitudinal PZT elements. One of these is strictly used for the transmit function, and the remaining eight elements make up the receiver. These eight elements make up a half wavelength spaced array of sensors which are connected to eight independent receive channels per side and are used for the phase measurement and differencing calculations. Selected sub elements of each array are used to form the side scan display data.

The IPDS is available in two frequencies, 230 kHz and 540 kHz. For the purpose of this paper, the 540 kHz model was used and its performance was evaluated in shallow water. The area used in this assessment is a section of the Dania Cut-Off Canal in Port Everglades, Florida, USA.

Fig. 1 *– EdgeTech's 4600 Swath Bathymetry and Side Scan Sonar System*

Test Site

The Dania Cut-Off Canal is a canal in South Florida that originates in the Florida Everglades, flows east into the Intra Coastal Waterway (ICW) and eventually to the Atlantic Ocean (Fig. 2). The canal is known for its numerous boat yards and harbors. It is an area of interest to survey with an interferometric bathymetry system because of its shallow shoals and interesting bottom features. Currently, the waterway averages a depth of about 4 meters and spans a distance of roughly 40 meters across. The large swath of the IPDS allows for the entire length of the canal to be safely navigated, mapping the seafloor from bank to bank with just one pass.

Fig. 2 *– Dania Cut-Off Canal, Port Everglades, Florida, USA; test section highlighted in red; North facing up.*

Data Collection and Processing

The Dania Cut-Off Canal was surveyed on March 30th, 2011 using the 540 kHz model of the EdgeTech 4600 to acquire the bathymetry and side scan data at an average speed of 4 knots. The IPDS was deployed over the starboard side of the Research Vessel, the *Ocean Researcher II*, using a vertical pole (Fig. 3). The pole was held tightly in place by a cross beam laid across the ship.

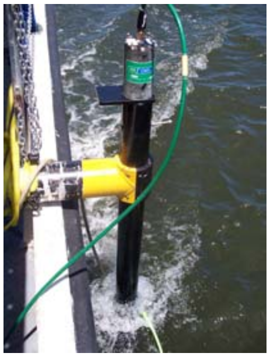

***Fig. 3** – Side mount deployed on the Ocean Researcher II*

A TSS DMS-05 Motion Reference Unit was rigidly secured to the top of the vertical pole to measure roll, pitch, and heave. A Hemisphere Crescent VS100 Dual Headed GPS system was used to gage heading, position, and speed. In addition, the measured offsets for each device were recorded and are presented below in Table 1.

***Table 1** – Device Offsets for March 30th Survey*

Device	Starboard	Forward	Vertical
IPDS Port Array	1.96m	0.00m	1.14m
IPDS Stbd Array	2.16m	0.00m	1.14m
DMS-05 MRU	2.06m	0.00m	-1.40m
GPS Antennas	-1.25m	1.50m	-2.35m

The reference point (x=0, y=0, z=0) for these measurements is the center of rotation of the vessel. The convention for the measured values are positive to starboard (x), positive forward (y), and positive downward (z).

In addition, Hypack® 2010 was used to acquire the raw data using the *Survey and Hysweep Survey* plugin. One pass each way was collected using a total of 360 beams divided into 0.2 m bins. These interferometric parameters were used to achieve a total swath of 72 meters. The only filter used during data collection was the “Filter by Display Limits.” This filter was set to obtain 35 meters per side to yield a total swath of 70 meters. The vertical limits were set to - 4 meters to 15 meters due to its 200 degree field of view.

Furthermore, calibration data was obtained in the ICW earlier that day. Hypack®'s *MBMax* program was then used to clean and process the calibration data. The resulting latency, roll, pitch, and yaw offsets were applied before the survey began. These calculated offsets are listed in Table 2.

***Table 2** – Calibration Offsets for March 30th Survey*

Parameter	Value
GPS Latency	0.0s
Pitch	1.0˚
Port Roll	0.5˚
Starboard Roll	0.1˚
Yaw	2.5˚

Sound velocity measurements, acquired using the Valeport SVP sensor at the head, were also applied to correct the raw data and navigation records were checked.

Data Analysis

Hypack®'s *MBMAx* program was used to analyze the data. The performance parameters used in this assessment are data density, standard deviation of soundings within one cell, and feature size detection. Swath coverage was limited by the width of the channel and so it was not used as a performance gage.

Data Density

The data density of the bathymetry data can be computed as,

$$\rho_{Data} = N_X \times N_Y \,, \tag{1}$$

where, ρ_{Data} is the data density of the bathymetry data in soundings per cell, N_X is the number of soundings across track per cell, and N_Y is the number of soundings along track per cell. To obtain how many raw data points are along the entire swath, the maximum swath is divided by the sample spacing of the raw bathymetry data, or

$$N_{Swath} = \frac{Swath}{X} \,. \tag{2}$$

For raw bathymetry data, the across track sample spacing is strictly dependent upon the pulse sample rate of the interferometric sonar (if slant range effects are ignored),

$$X = \frac{c}{(SR_{Pulse} \times 2)} \,, \tag{3}$$

where, X is the across track sample spacing for the raw bathymetry data in meters, c is the speed of sound in saltwater in meters per second, and SR_{Pulse} is the pulse sample rate in Hz. Furthermore, the number of raw data points along the entire swath is divided by the number of beams and then binned according to the values specified in Hypack®'s *Survey and Hysweep Survey* program, or

$$N_{Bin} = \frac{N_{Swath}}{N_{Beams}} \,, \tag{4}$$

where, N_{Bin} is the number of raw data points placed within a bin of size Δ_B, N_{Swath} is the number of raw data points across the total swath, and N_{Beams} is the total number of beams. In addition to being binned, these points are averaged to achieve a single value, known as a sounding,

$$S = \frac{1}{N_{Bin}}\left(d_1 + \ldots + d_{N_{Bin}}\right), \quad (5)$$

where, S is one sounding per bin of size Δ_B, and d_1 through $d_{N_{Bin}}$ are the individual depth values within a bin. To find the number of soundings across track, the specified cell size is divided by the bin size,

$$N_X = \frac{Cell\ Size}{\Delta_B}. \quad (6)$$

Now, to acquire the number of points along track, the specified cell size is divided by the along track sample spacing, or

$$N_Y = \frac{Cell\ Size}{Y}. \quad (7)$$

The along track sample spacing is strictly a function of the vessel's traveling speed and the interferometric sonar's ping rate, or

$$Y = V/PR, \quad (8)$$

where, Y is the along track sample spacing of the bathymetry data in meters, V is the traveling speed of the sonar in meters per second, and PR is the ping rate of the sonar system in Hz. Since the interferometric sonar is mounted to the survey vessel, V is equal to the velocity of the survey vessel.

Standard Deviation

The standard deviation of soundings within a cell shows how much variation there is from the mean value and can be calculated by,

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(s_i - \mu\right)^2}, \quad (9)$$

where, σ is the standard deviation within the cells, N is the number of soundings within a cell, s is one sounding within a cell, and μ is the average of all soundings within a cell. A low standard deviation indicates that the data soundings tend to be very close to the average value and increases the confidence in the seafloor solutions.

Feature Size Detection

The minimum feature size detected is strictly determined by user observation. If a feature is detected in the bathymetry data, then the side scan record is used to confirm and measure the existence of that feature.

Results

The data density, standard deviation within the cells, and feature size detection of the Dania Cut-Off Canal bathymetry data were visualized in Hypack®'s *MBMax* program. The data were processed using two different cell sizes: 1 m and 0.5 m. To illustrate the concepts discussed in the *Data Analysis* section of this paper, an example is utilized.

Example 1: Cell Size = 1 meter

The parameters used in the computations are tabulated in Table 3.

***Table 3** - Known Parameters for 1 m Cell Size*

Maximum Swath	70 m
Speed of Sound	1500 m/s
Pulse Rate	60 kHz
Number of Beams	360
Bin Size	0.2 m
Travel Speed	2.06 m/s
Ping Rate	10.7 Hz

Equations 2 and 3 were used to yield a total number of 5600 raw data points along the entire swath for one ping (Fig. 4).

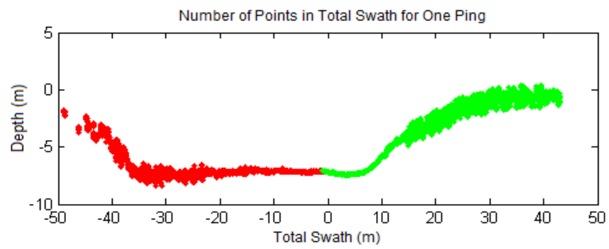

***Fig. 4** – Raw interferometric bathymetry data along the entire swath for one ping. Red corresponds to the port side data and green represents the starboard side data across track.*

Those 5600 points were divided by 360 beams (Eq 4.) to achieve about 16 raw points per bin. Those 16 points were then averaged to achieve one sounding per 0.2 m bin (Eq 5, Fig. 5, Fig. 6).

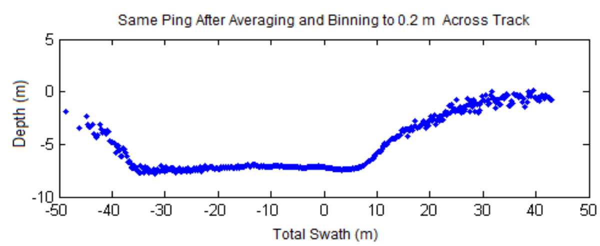

***Fig. 5** – Same ping after dividing by the number of beams and binning raw points to 0.2 m across track.*

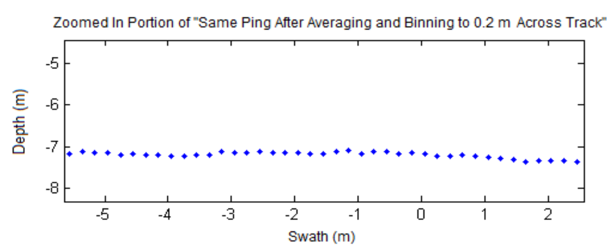

***Fig. 6** – Same ping after averaging binned raw values. Notice 5 soundings per 1 m across track.*

The total number of soundings across track achieved is about 5 soundings (using equation 6 with 0.2 m bins within a 1 m cell size). For along track, equations 7 and 8 are utilized to obtain an approximate total of 5 soundings. Therefore, the resulting data density for a 1 meter cell size is approximately equal to 25 soundings per cell (Eq. 1). This result is illustrated in Fig. 7 (the artifacts seen in Fig. 7 are caused by yaw variations in the vessel's track).

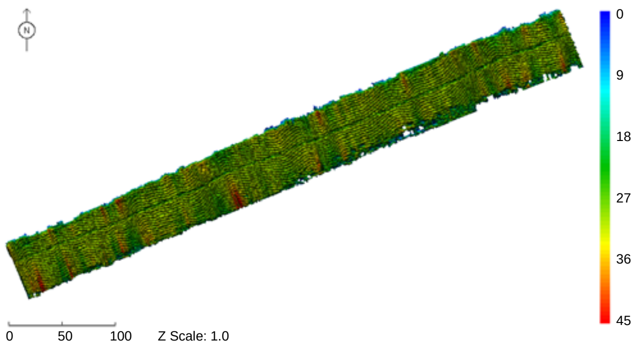

Fig. 7 *– Dania Cut-Off Canal; number of soundings per 1 m cell = approximately 25 soundings (ignoring yaw variations in the vessel's track).*

Also, the standard deviation within the cells was then computed using equation 9. The outcome was approximately equal to 0.1 m (Fig. 8) in the bottom of the channel (flat section). Some areas in Fig. 8 are expected to have a larger standard deviation than 0.1 m because of the natural relief along the banks of the Dania Cut-Off Canal.

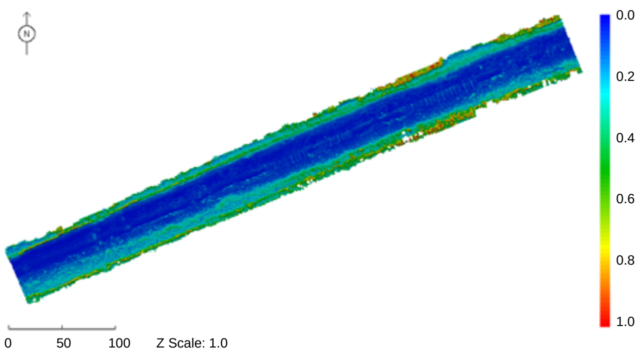

Fig. 8 *– Dania Cut-Off Canal; standard deviation within the cells = approximately 0.1 m for a 1 m cell size (in the flat section of the channel). Units are in meters.*

Furthermore, Hypack®'s *Side Scan Targeting & Mosaicing* program was used to find small features within the bathymetry data of the Dania Cut-Off Canal. One of the smallest features recognized was roughly equal to 1.5 m long x 1.2 m wide x 0.5 m high, using a 1 m cell size to generate the average depth of the test site. This feature is confirmed by analyzing the side scan images of the IPDS (Fig. 9 and Fig. 10).

The same calculations carried out in Example 1 were reproduced for a 0.5 m cell size using the same parameters listed in Table 3. Its results are depicted in Fig. 11 through Fig. 14.

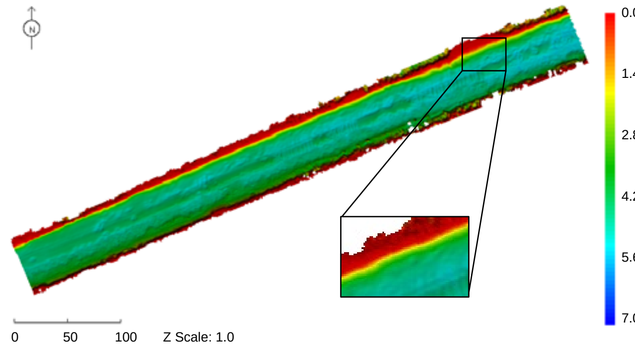

Fig. 9 *– Dania Cut-Off Canal; average depth in meters for a 1 m cell size. One small feature detected is a boulder, approximately equal to 1.5 m (L) x 1.2 m (W) x 0.5 m (H) and highlighted within the black box.*

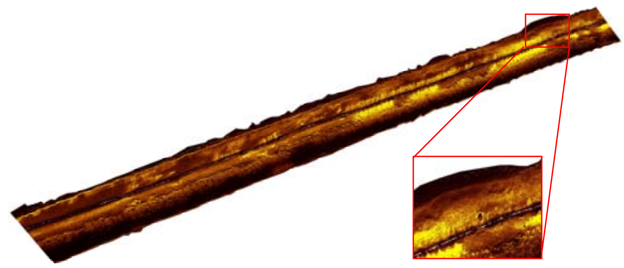

Fig. 10 *– Dania Cut-Off Canal; side-scan mosaic for a 1 m cell size. The boulder recognized in Fig. 9 is highlighted in the red box.*

<u>Cell Size = 0.5 m</u>

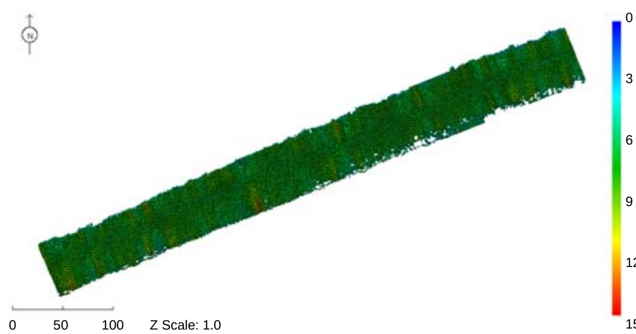

Fig. 11 *– Dania Cut-Off Canal; number of sounders per 0.5 m cell = approximately 6-7 soundings (ignoring yaw variations in the vessel's track).*

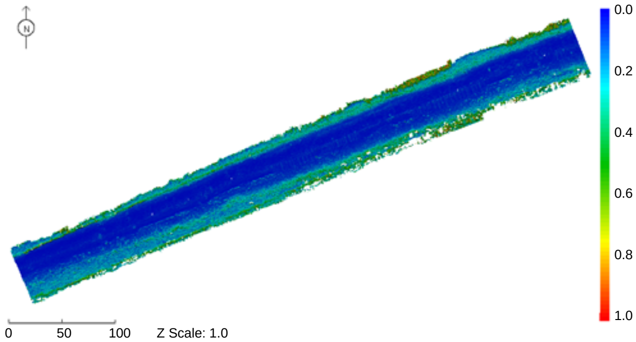

***Fig. 12** – Dania Cut-Off Canal; standard deviation within the cells = approximately 0.1 m for a 0.5 m cell size (in the flat section of the channel). Units are in meters.*

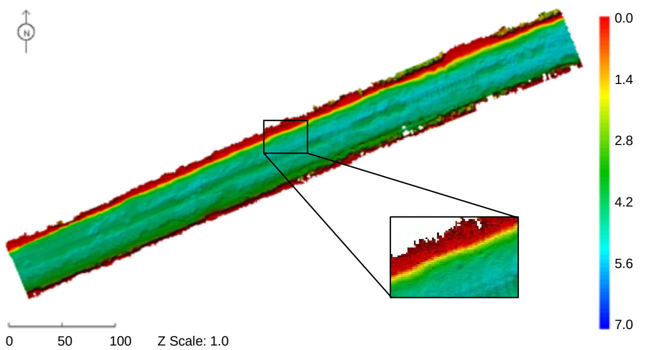

***Fig. 13** – Dania Cut-Off Canal; average depth in meters for a 0.5 m cell size. One small feature identified is a rock, approximately equal to 0.8 m (L) x 0.3 m (W) x 0.2 m (H) and highlighted within the black box.*

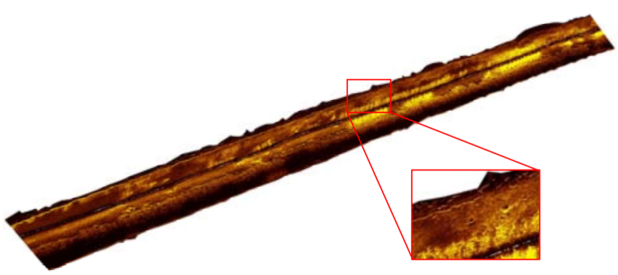

***Fig. 14** – Dania Cut-Off Canal; side-scan mosaic for a 0.5 m cell size. Small rock distinguished in Fig. 9 is highlighted in the red box.*

Conclusions

The data density, standard deviation within the cells, and feature size detection of the IPDS was evaluated using a 1 m and 0.5 m cell size. The results are summarized in Table 4.

***Table 4** – Result Summary; units are in soundings, meters, and meters, respectively. Feature size is listed as L x W x H.*

Cell Size	Data Density	Standard Deviation	Feature Size
1 m	25	0.1	1.5 x 1.2 x 0.5
50 cm	6-7	0.1	0.8 x 0.3 x 0.2

It was found that the IPDS could produce a data density as much as 25 soundings, a standard deviation as low as 0.1 m, and detect a feature as small as 0.8 m (L) x 0.3 m (W) x 0.2 m (H) for a 0.5 m cell size. As the cell size decreased, the number of soundings decreased proportionately according to equation 7. The average standard deviation within the cells did not change, but the standard deviation along the bank of the canal decreased. This result is anticipated because as the cell size decreases, the more focused the features become in the bathymetry data. The smaller cell sizes make it easier for the contours of the channel to be followed. Also, smaller features were recognized as the cell size was reduced. This is to be expected because of the same reasons stated above for the standard deviation results. Lastly, it is worth noting here, that the Nadir region showed no gaps and has a sounding density and standard deviation as good as the surrounding data – much like the traditional multibeam.

References

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