DSP Analysis of Digital Vector Slope Gauge Data
Produced by Ocean Wave Simulation

EECS 803 - Introduction to Research
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Overview

- Ocean Wave Behavior
- The Vector Slope Gauge (VSG)
  - VSG History
  - VSG Function
- Ocean Wave Data Simulation
- Off-line Processing
- Future Work
Overview

• **Ocean Wave Behavior**

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Ocean Wave Behavior

- Spectrum
- Wavelength, period, and velocity
- Deep water vs. shallow water waves
- Sea = linear sum of waves
- Orbital velocity
Ocean Wave Spectrum

Fig. 6—The Ocean Wave Spectrum

(From Kampion, 1997)
Wave Velocity vs. Wavelength and Period

(From Kampion, 1997)

**Fig. 5—Speed, Length and Period**

*After Nathaniel Bowditch.*
Simple Wavefront Description

Height of ocean wave at time $t$ and position $(x,y)$:

$$h(x, y, t) = A \cos(\Omega t + \kappa x \cos \alpha + \kappa y \sin \alpha + \phi)$$

where $\Omega = \frac{2\pi}{T} = \text{angular frequency (rad/sec)}$

$$\kappa = \frac{2\pi}{L} = \text{wave number (rad/m)}$$

$L = \text{wavelength (m)}$

$T = \text{wave period (sec)}$

$\alpha = \text{wave approach direction}$

$\phi = \text{phase}$
Superposition of Waves

- Complex Sea = Superposition of many wavefronts
- Individual wavefronts are approximately sinusoidal in deep ocean
- Wavefronts change shape near shore as water depth decreases
- Single wavefront is rare in nature
- Wavefronts are initiated by winds over the ocean at other locations

(From Bascom, 1964)
Orbital Velocity

(From Bascom, 1964)

(From Kampion, 1997)
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VSG History

• Version 1 – Analog VSG
  – Tested in the North Sea in 1990

• Version 2 – Improvement of Version 1
  – Tested at Duck Pier in 1995

• Version 3 – Digital VSG
  – No ocean surface data available
VSG Function

- y axis is radar look direction
- $\Theta$ is incidence angle
- H is height above mean ocean surface
Typical VSG Beam Pattern on Ocean Surface

Beam 1

Beam 2

Beam 3

~ 1 meter
Frequency Format of VSG Radar Signal

- Cycle
- Sweep
- Up-sweep
- Down-sweep
- Bandwidth
- Beam 1
- Beam 2
- Beam 3
Instantaneous IF Output and Return for Range Measurement

Radar Signals

Transmitted Signal

Returned Signal

Intermediate Frequency Signal (Difference Frequency)

(Adapted from Ulaby, Moore, and Fung, Fig. 7.25, p. 513)
Instantaneous IF Output and Return for Range and Doppler Measurement

Radar Signals

Transmitted Signal

Returned Signal

Intermediate Frequency Signal (Difference Frequency)

(Adapted from Ulaby, Moore, and Fung, Fig. 7.25, p. 513)
Instantaneous Frequencies for Point Target

Magnified View of a Portion of the Signal

Transmitted Signal

Returned Signal

$\Delta F$

$\Delta T$

(Adapted from Ulaby, Moore, and Fung, Fig. 7.25, p. 513)
VSG Parameters

- **Range**
- **Sweep repetition frequency**
- **Single (Up or Down) sweep time**
- **Sweep rate**
- **Minimum DSP sample rate**

\[
R = \frac{h_{VSG}}{\cos \theta} = \frac{10}{\cos(45)} = 14.14 \text{ m}
\]

\[
f_B = \frac{c \cdot f_{IF}}{4B \cdot R} = \frac{(3 \cdot 10^8) \cdot 450 \cdot 10^3}{4(600 \cdot 10^6) \cdot 14.14} \approx 4000 \text{ Hz}
\]

\[
T_{sweep} = \frac{1}{2f_B} \approx 126 \mu \text{s}
\]

\[
\Delta f = \frac{B}{T_{sweep}} = \frac{600}{126} = 4.76 \text{ MHz/\mu sec}
\]

\[
f_{smin} = 2 \cdot f_{IF} \cdot 1.1 = 1.0 \text{ MHz}
\]
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Ocean Wave Data Simulation
for Digital VSG

- Characterize simple ocean surfaces
  - Flat surface (calm sea)
  - Single wavefront
  - Multiple wave fronts
- Add Doppler shift to surfaces
- Convert ranges + Doppler to frequencies
- Digital sampling of frequencies
- Scale and shift
- Convert to 12-bit unsigned integers
- Create data files in digital VSG format
Ocean Wave Data Simulation
WaveSim7.m

- VSG Parameters
- Wavesim7.m
- Ocean Wave Parameters

- RangeEst.m
- slrangemod.m
- slopepoimod.m
- Save2Slopes.m
- slopeab2.m
- SlopeOut.txt

- Range
- IF
- SampGen.m
- Sampled IF
- VSGOutput.m
- VSGOut.bin

- NsPerSweep.m
Digital VSG Data Format

- **MSB** (Most Significant Bit) to **LSB** (Least Significant Bit)

- **Beam #**
  - 00 = Beam 1
  - 01 = Beam 2
  - 10 = Beam 3
  - 11 = not used

- **Up/Down**
  - 0 = Up
  - 1 = Down

- **Data**
  - 12 bit unsigned integer

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Off-line Processing

Current Vector Slope Gauge Concept

- VSG
- Raw VSG Data
- Data Storage Hard Disk
- Delay
- Data Preparation
- Data Processing and Calculations
- Printer Output of Results
Adapted from DSP Algorithm for Ocean Radar Project, Gary W. Hamilton II
DSP of Stored Ocean Wave Data

DSP2.m

- VSG Parameters

VSGOut.bin

- GetTimeSeries2.m

- Shift and Scale

DSP2.m

- FindPSD.m

- FindEffFreq.m

- evanslope.m

  - Slopes Sx, Sy

Upsweep

- Sum Average Frequency

Downsweep

- Difference Average Frequency

- Range

- Doppler
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Future Work

- Collect ocean data on digital VSG
- Comparison to Duck Pier results
- Orbital velocity measurement
- Real-time DSP
- Adaptation to shipboard environment
Real-Time Vector Slope Gauge Concept

- VSG
- Raw VSG Data
- DSP Board
- DSP Program
- On-Screen Results