Comparison of Spectral Estimation Methods for Current Estimation by an HF Surface Wave Radar

HU, Senkang

School of Information and Electronics
Beijing Institute of Technology
Beijing, China, 100081

1120183150@bit.edu.cn

May, 2021

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

- Conventional spectrum estimation method, such as the periodogram method
- Modern techniques, such as the autoregressive method and multiple signal classification methods

1. Introduction

- For calculate the radial current velocity, it is important to estimate its associate Doppler shift from the frequency spectrum.
- In addition to the conventional centroid method, a more robust Bragg frequency identification method, termed the symmetric-peak-sum, is proposed and examined in conjunction with each of the spectral estimation techniques.

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

1. Introduction

- For calculate the radial current velocity, it is important to estimate its associate Doppler shift from the frequency spectrum.
- In addition to the conventional centroid method, a more robust Bragg frequency identification method, termed the symmetric-peak-sum, is proposed and examined in conjunction with each of the spectral estimation techniques.

1. Introduction

- It has been found that a weighted sum of the radar-derived current estimates using these two methods generally provides a lower rms difference from the buoy measurements.
- The weighting ratio is optimized using a genetic algorithm
- Field data indicate that a combination of these spectral estimation methods is capable of providing improvements in retrives current velocities for various current conditions.

1. Introduction

- High frequency surface wave radar (HFSWR) systems are a cost-effective tool for remote sea-state sensing and are well known for current mapping.
- High frequency surface wave radar takes advantage of the short wave (3∼30MHz) diffracted propagation and low attenuation on the conductive ocean surface, and uses the vertically polarized antenna to radiate the radio waves. It can detect the moving targets such as ships, aircraft, icebergs and missiles that appear below the line of sight on the sea level beyond the horizon, and the action range can reach more than 300km.

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

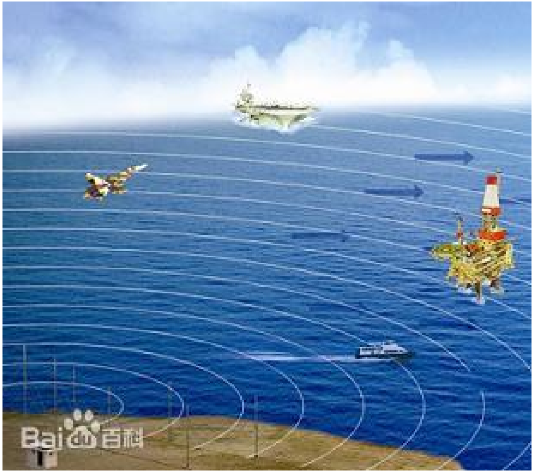


Figure 1-1: Schematic diagram of application of high frequency surface wave radar (HFSWR)

Figure 1-2: The medium range high frequency surface wave radar system developed by Wuhan University

- At the same time, using the first-order scattering and second-order scattering mechanism of the sea surface to the high frequency electromagnetic wave, the high frequency ground wave radar can extract sea state information such as wind field, wave field and current field from the radar echo, so as to realize the real-time monitoring of the Marine environment in a large range, with high precision and all weather.
- It is widely used in military field and Marine environment detection field

1. Introduction

High frequency surface wave radar (HFSWR)

- High frequency surface wave radar (HFSWR) systems are a cost-effective tool for remote sea-state sensing and are well known for current mapping.
- The power spectrum of the received signal, which for these coherent radars is a Doppler spectrum, typicallly consist of two large peaks which arise from Bragg resonant scattering of the signal from ocean gravity waves of halfs the radio wavelength.
- This so-called Bragg peaks occur at positive and negetive Doppler for waves moving towards or away from the radar.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

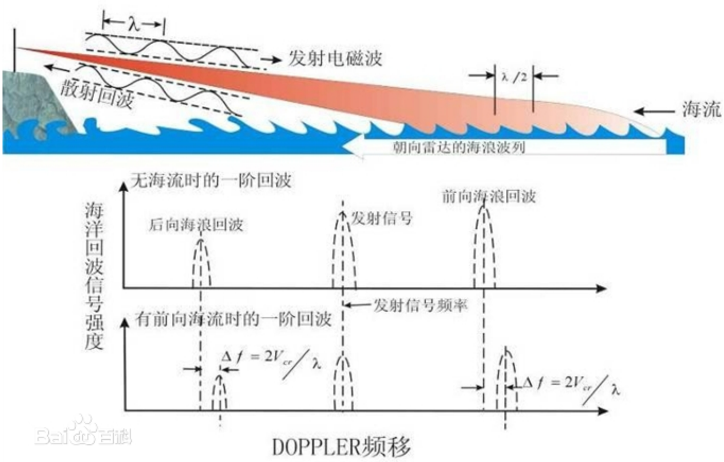


Figure 1-3: Shore-based ground wave radar detection principle diagram

- The associated Bragg frequency shift in the backscatter signal is used to determine surface currents.
- For still water and an operating frequency of f, due to the speed of the Bragg waves, the Bragg peaks appear at Doppler frequencies given by

$$f_b = \pm\sqrt{\frac{gf}{\pi c}} \tag{1-1}$$

where c and g are the speed of the light and the acceleration due to gravity.

- When a uniform surface current exists, both peaks will be shifted in the same direction by an amount of

$$\Delta f_c = \frac{2 v_c f}{c} \tag{1-2}$$

where v_c is the radial component of the surface surrent along the radar look direction.

- The most important radar parameter for current mapping is the resolution of the Doppler spectrum estimation (SE) and the resulting accurate identification of the Bragg frequency

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

- When a uniform surface current exists, both peaks will be shifted in the same direction by an amount of

$$\Delta f_c = \frac{2v_c f}{c} \tag{1-2}$$

where v_c is the radial component of the surface surrent along the radar look direction.

- The most important radar parameter for current mapping is the resolution of the Doppler spectrum estimation (SE) and the resulting accurate identification of the Bragg frequency

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

1. Introduction

But there are two main difficulties in estimating Δf_c :

1. There are various SE methods from which to choose
2. Difficulty asises in estimating the Bragg shift directly based on the identification of the maximum amplitude.

Broadening of the Bragg peaks, which may arise from current fluctuations or contamination by ionospheric clutter, can be very significant under certain sea states. Even in ideal conditions, an inherent randomness associated with the spectral amplitudes is observed, and this also translates into a fluctuation in the Bragg peak locations.

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

1. Introduction

But there are two main difficulties in estimating Δf_c :

1. There are various SE methods from which to choose
2. Difficulty asises in estimating the Bragg shift directly based on the identification of the maximum amplitude.

Broadening of the Bragg peaks, which may arise from current fluctuations or contamination by ionospheric clutter, can be very significant under certain sea states. Even in ideal conditions, an inherent randomness associated with the spectral amplitudes is observed, and this also translates into a fluctuation in the Bragg peak locations.

Outline

1 Introduction

2 Spectrum Estimation Methods
- Welch Method
- Autoregressive (AR) Method
- MUSIC

3 Bragg Peak Frequency Identification
- Centroid Method
- Symmetric-peak-sum (SPS)
- Optimal Weighting

4 Ground-Truth Data Validation

5 Conclusion

6 Reference

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

The standerd periodogram method:

The periodogram of an L-point sequence, $x(0), x(1), \cdots, x(L-1)$, is defined as

$$S\left(f_k\right) = \frac{1}{L}\left|\sum_{n=0}^{L-1} x(n) e^{-j2\pi n f_k T}\right| \tag{2-3}$$

Where T is the sampling rate.

2.1. Welch Method

In order to reduce the noise caused by imperfect and finite data, so the Welch Method is introduced in exchange for reducing the frequency resolution.

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

2.1. Welch Method

In order to reduce the noise caused by imperfect and finite data, so the Welch Method is introduced in exchange for reducing the frequency resolution.

Procedure

1. *The sequence $x(n)$ is divided into K segments of length M, overlappd by P percent.*
2. *Each segment is multiplied by a window function prior to computing the periodogram.*
3. *Then, the power spectral estimate is obtained by averaging the periodograms for the K segments.*

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Procedure

1. *The sequence $x(n)$ is divided into K segments of length M, overlappd by P percent.*
2. *Each segment is multiplied by a window function prior to computing the periodogram.*
3. *Then, the power spectral estimate is obtained by averaging the periodograms for the K segments.*

Procedure

1. *The sequence* $x(n)$ *is divided into* K *segments of length* M*, overlappd by* P *percent.*
2. *Each segment is multiplied by a window function prior to computing the periodogram.*
3. *Then, the power spectral estimate is obtained by averaging the periodograms for the* K *segments.*

The advantage of the Welech method over the standerd periodofram method is that the variance can be reduced by overlapping and averaging.

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

Example

When K segments are averaged, the variance of the average, σ^2_{ave}, is related to the individual variance of the segments, σ^2_{ind}, for a special case of 75% overlap as:

$$\frac{\sigma^2_{ave}}{\sigma^2_{ind}} = \frac{1}{K}\left\{1 + 2\operatorname{cor}^2(0.75) + 2\operatorname{cor}^2(0.5)\right\} \tag{2-4}$$

Where $\operatorname{cor}(P)$ is the correlation existing between successive window transforms having a overlap of P percent[1].

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Example

- It is clear that the variance in the Welch Method as compared to the periodogram method is reduced by a factor K.
- The Welch method has been commonly used in HF radar spectral estimation, but the frequency resolution of the required FFT limits the precise of the current estimate.

Outline

1 Introduction

2 Spectrum Estimation Methods
- Welch Method
- Autoregressive (AR) Method
- MUSIC

3 Bragg Peak Frequency Identification
- Centroid Method
- Symmetric-peak-sum (SPS)
- Optimal Weighting

4 Ground-Truth Data Validation

5 Conclusion

6 Reference

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

2.2. Autoregressive (AR) Method

Brief introduction of AR method

- In statistics, econometrics and signal processing, an autoregressive (AR) model is a representation of a type of random process; as such, it is used to describe certain time-varying processes in nature, economics, etc.
- The autoregressive model specifies that the output variable depends linearly on its own previous values and on a stochastic term (an imperfectly predictable term);

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

- thus the model is in the form of a stochastic difference equation (or recurrence relation which should not be confused with differential equation).
- Together with the moving-average (MA) model, it is a special case and key component of the more general autoregressive–moving-average (ARMA) and autoregressive integrated moving average (ARIMA) models of time series, which have a more complicated stochastic structure;

2.2. Autoregressive (AR) Method

Brief introduction of AR method

- it is also a special case of the vector autoregressive model (VAR), which consists of a system of more than one interlocking stochastic difference equation in more than one evolving random variable.
- Contrary to the moving-average (MA) model, the autoregressive model is not always stationary as it may contain a unit root.

2.2. Autoregressive (AR) Method

As one of the two main categories of high-resolation SE mathod, AR is a model-based method, the parameters of which are estimated from a given data sequence $X_t, 0 \leq t \leq N-1$. The data can be modeled as output of casual, all-pole, discrete filter whose input is white noise, given by

$$X_t = c + \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t \tag{2-5}$$

where $\varphi_1, \ldots, \varphi_p$ are the parameters of the model, c is a constant, and ε_t is white noise.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

2.2. Autoregressive (AR) Method

As one of the two main categories of high-resolation SE mathod, AR is a model-based method, the parameters of which are estimated from a given data sequence $X_t, 0 \leq t \leq N-1$. The data can be modeled as output of casual, all-pole, discrete filter whose input is white noise, given by

$$X_t = c + \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t \tag{2-5}$$

where $\varphi_1, \ldots, \varphi_p$ are the parameters of the model, c is a constant, and ε_t is white noise.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

This can be equivalently written using the backshift operator B as

$$X_t = c + \sum_{i=1}^{p} \varphi_i B^i X_t + \varepsilon_t \tag{2-6}$$

so that, moving the summation term to the left side and using polynomial notation, we have

$$\phi[B] X_t = c + \varepsilon_t \tag{2-7}$$

An autoregressive model can thus be viewed as the output of an all-pole infinite impulse response filter whose input is white noise.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

This can be equivalently written using the backshift operator B as

$$X_t = c + \sum_{i=1}^{p} \varphi_i B^i X_t + \varepsilon_t \tag{2-6}$$

so that, moving the summation term to the left side and using polynomial notation, we have

$$\phi[B] X_t = c + \varepsilon_t \tag{2-7}$$

An autoregressive model can thus be viewed as the output of an all-pole infinite impulse response filter whose input is white noise.

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Some parameter constraints are necessary for the model to remain wide-sense stationary.

Example

Process in the $AR(1)$ model with $|\varphi_1| \geq 1$ are not stationary. More generally, for an $AR(p)$ model to be wide-sense stationary, the roots of the polynomial $\Phi(z) := 1 - \sum_{i=1}^{p} \varphi_i z^{p-i}$ must lie outside the unit circle.

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Some parameter constraints are necessary for the model to remain wide-sense stationary.

Example

Process in the $AR(1)$ model with $|\varphi_1| \geq 1$ are not stationary. More generally, for an $AR(p)$ model to be wide-sense stationary, the roots of the polynomial $\Phi(z) := 1 - \sum_{i=1}^{p} \varphi_i z^{p-i}$ must lie outside the unit circle.

2.2. AR Method

The power spectral density (PSD) estimate is then computed from φ_i and σ^2[2], as given by

$$P_{AR}(f) = \frac{T\sigma^2}{\left|1 + \sum_{k=1}^{p} \varphi_i e^{-j2\pi k f T}\right|^2} \tag{2-8}$$

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Outline

1 Introduction

2 Spectrum Estimation Methods
- Welch Method
- Autoregressive (AR) Method
- MUSIC

3 Bragg Peak Frequency Identification
- Centroid Method
- Symmetric-peak-sum (SPS)
- Optimal Weighting

4 Ground-Truth Data Validation

5 Conclusion

6 Reference

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

2.3. MUSIC

Another main category of the high-resolution SE methods is the subspace method, of which MUSIC is a commonly-used example. It generates frequency component estimates for signal based on an Eigen-analysis of the autocorrelation matrix.The MUSIC frequency estimater, which is based on noise subspace eigenvectors U_N and a vector $a(\theta)$ of complex sinusoidal components, is given by

$$P_{MUSIC} = \frac{1}{a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta)} \tag{2-9}$$

where H represents tht conjugate transpose.

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

2.3. MUSIC

The DOA mathematical model of the narrow band far field signal is

$$X(t) = A(\theta)s(t) + N(t) \tag{2-10}$$

The covariance matrix of the array matrix is

$$R = E\left[XX^H\right] = AE\left[SS^H\right]A^H + \sigma^2 I = AR_S A^H + \sigma^2 I \tag{2-11}$$

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

Since the signal and noise are independent of each other, the data covariance matrix can be decomposed into signal and noise, AR_SA^H is the part of signal. We do the eigendecomposition of R,

$$R = U_S V_S U_S^H + U_N V_N U_N^H \tag{2-12}$$

The first term of the formula U_S is the signal subspace spanned by large eigenvalues corresponding to eigenvectors, and the second term U_N is the noise subspace spanned by small eigenvalues corresponding to eigenvectors.

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

2.3. MUSIC

Since the signal and noise are independent under ideal conditions, the signal subspace and noise subspace are orthogonal to each other, and the guide vector in the signal subspace is orthogonal to the noise subspace

$$a^H(\theta)U_N = 0 \tag{2-13}$$

Based on this property, classical MUSIC algorithm can be obtained. Considering that the actual received data matrix is of finite length, the maximum likelihood estimate of the data covariance matrix is

$$\hat{R} = \frac{1}{L}\sum_{i=1}^{L} XX^H \tag{2-14}$$

2.3. MUSIC

Since the signal and noise are independent under ideal conditions, the signal subspace and noise subspace are orthogonal to each other, and the guide vector in the signal subspace is orthogonal to the noise subspace

$$a^H(\theta)U_N = 0 \tag{2-13}$$

Based on this property, classical MUSIC algorithm can be obtained. Considering that the actual received data matrix is of finite length, the maximum likelihood estimate of the data covariance matrix is

$$\hat{R} = \frac{1}{L}\sum_{i=1}^{L} XX^H \tag{2-14}$$

2.3. MUSIC

The eigenvector matrix $\hat{U}_N$ of noise subspace can be calculated by eigendecomposition of $\hat{R}$. Due to the existence of noise, A and UN are not completely orthogonal, so DOA is realized by the minimum optimization search,

$$\theta_{MUSIC} = \operatorname{argmin} a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta) \tag{2-15}$$

Therefore, the spectrum estimation formula of MUSIC algorithm is

$$P_{MUSIC} = \frac{1}{a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta)} \tag{2-16}$$

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

2.3. MUSIC

The eigenvector matrix $\hat{U}_N$ of noise subspace can be calculated by eigendecomposition of $\hat{R}$. Due to the existence of noise, A and UN are not completely orthogonal, so DOA is realized by the minimum optimization search,

$$\theta_{MUSIC} = \operatorname{argmin} a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta) \tag{2-15}$$

Therefore, the spectrum estimation formula of MUSIC algorithm is

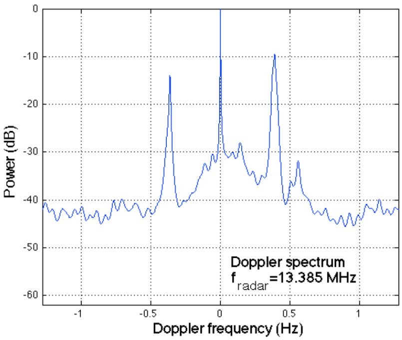
$$P_{MUSIC} = \frac{1}{a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta)} \tag{2-16}$$

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

2.3. MUSIC

An example of the MUSIC estimated spectrum using the same field data as in Fig.2-4 is show in Fig.2-5.

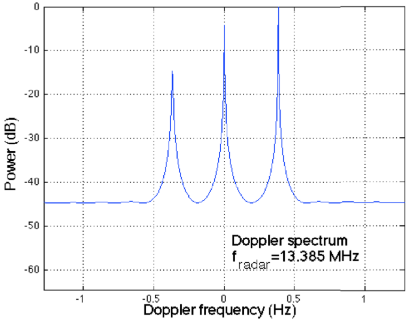
Figure 2-4: Power spectral density estimation by AR



2.3. MUSIC

An example of the MUSIC estimated spectrum using the same field data as in Fig.2-4 is show in Fig.2-5.

Figure 2-5: Power spectrum density estimation by MUSIC



2.3. MUSIC

- It is clearly seen that, compared with the AR method, the MUSIC algorithm is able to provide frequency estimates with higher resolulation.
- The MUSIC method is sentive to the conditioning of the autocorrelation matrix.
- Under low SNR conditions, if signal subspace is small, the autocorrelation matrix may be ill-conditioned and the MUSIC algorithm may fenerate false spectral peaks.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

3. Bragg Peak Frequency Identification

Brief Introduction

- In HF radar data, the Bragg Doplpler exhibits time-varying and width-broadening features.
- The amplitude of the Rayleigh random process, is due to the random phases of the waves on the scattering surface. The Bragg peak is also spread in frequency.
- No matter which waveforms are used (pulses or FM modulated waveforms), the transmitted signal is spread over a bandwidth and will cause a certain degree of Bragg broadening determained by the pulse width or sweep bandwidth.

3. Bragg Peak Frequency Identification

Brief Introduction

- Also, an increase of the half-power beamwidth of the receiving antenna from 0.5 to 4 degree will broaden the Bragg frequency by 30%.
- Considering the time-varying and width-broadening features discussed above, two Bragg Doppler shift identification methods are proposed.

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

3.1. Centroid Method

The commonly used 'centroid' method is considered here to estimate the mean or center frequency of the Bragg peak having narrow but finite width.

Procedure

1. *In this method, a small Doppler region determined by the largest expected current speed in the radar experiment area and centered on the Bragg peak having the higher signal-to-noise ratio (SNR), is isolated first.*
2. *The centroid frequency for this region of the Doppler spectrum is calculated by weighting the frequency components with the SNR values in the region. The SNR values at each frequency used in the weighting should be above 10 dB.*

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

3.1. Centroid Method

The commonly used 'centroid' method is considered here to estimate the mean or center frequency of the Bragg peak having narrow but finite width.

Procedure

1. *In this method, a small Doppler region determined by the largest expected current speed in the radar experiment area and centered on the Bragg peak having the higher signal-to-noise ratio (SNR), is isolated first.*
2. *The centroid frequency for this region of the Doppler spectrum is calculated by weighting the frequency components with the SNR values in the region. The SNR values at each frequency used in the weighting should be above 10 dB.*

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

Outline

1 Introduction
2 Spectrum Estimation Methods
- Welch Method
- Autoregressive (AR) Method
- MUSIC

3 Bragg Peak Frequency Identification
- Centroid Method
- Symmetric-peak-sum (SPS)
- Optimal Weighting

4 Ground-Truth Data Validation
5 Conclusion
6 Reference

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

3.2. Symmetric-peak-sum (SPS)

The presence of swell or target peaks will affect the SNR values at those frequencies and may thus negatively influence the centroid calculation. To reduce the impact of swell and targets, the SPS method is proposed.

Procedure

1. *Two spectral regions centered on $+f_b$ and $-f_b$ are first identified.*
2. *Then, these regions are superposed completely and averaged.*
3. *A maximum in the averaged signal is considered to be the power at the Bragg frequency.*

3.2. Symmetric-peak-sum (SPS)

The presence of swell or target peaks will affect the SNR values at those frequencies and may thus negatively influence the centroid calculation. To reduce the impact of swell and targets, the SPS method is proposed.

Procedure

1. *Two spectral regions centered on $+f_b$ and $-f_b$ are first identified.*
2. *Then, these regions are superposed completely and averaged.*
3. *A maximum in the averaged signal is considered to be the power at the Bragg frequency.*

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

3.3. Optimal Weighting

It is found that a weighted sum of the current estimates using the centroid method (v_{c1}) and the SPS method (v_{c2}) generally provides lower root mean square (RMS) differences from the buoy measurments than using each of these alone. The weighting process is given by

$$v_c(t) = (1 - r) * v_{c1}(t) + r * v_{c2}(t) \qquad \text{(3-17)}$$

where r is the weighting ratio.

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

3.3. Optimal Weighting

An optimization problem of the weighting ratio is first attempted using the Nelder-Mead method, which is a gradient search method known for

- being vulnerable to being trapped on local extrema
- possible low convergence near the extrema

In this case, another approach, termed the genetic algorithm (GA), is considered.

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

3.3. Optimal Weighting

An optimization problem of the weighting ratio is first attempted using the Nelder-Mead method, which is a gradient search method known for

- being vulnerable to being trapped on local extrema
- possible low convergence near the extrema

In this case, another approach, termed the genetic algorithm (GA), is considered.

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

3.3. Optimal Weighting

An optimization problem of the weighting ratio is first attempted using the Nelder-Mead method, which is a gradient search method known for

- being vulnerable to being trapped on local extrema
- possible low convergence near the extrema

In this case, another approach, termed the genetic algorithm (GA), is considered.

In the GA algorithm , a population of candidate solutions to an optimization problem is evolved toword a better solution. The definition of the problem is made in terms of the

1. parameters space (R)
2. the objective space (Y)
3. an objective function (μ)

Initially, candidate solutions are randomly selected.

3.3. Optimal Weighting

- During each iteration in the evolution, they are altered or mutated. According to its fitness to the problem, some are retained for the next iteration while others are discarded.
- Fitness here refers to the value of the objective function in the optimization problem.
- The algorithm terminates when either a maximum number of iterations has been produced, or a satisfactory fitness level has been reached.
- Seeking the optimal ratio of the current estimates using the two Bragg identification methods is fomulated into a single parameter and single objective problem.

北京理工大學 BEIJING INSTITUTE OF TECHNOLOGY

3.3. Optimal Weighting

To find the weighting ratio r belonging to the peremater space $r \in R$, y is minimized in the objective space Y through the objective function mapping μ: $R \to Y$ as

$$\{r_{opt}\} = \min_{r \in R}(\mu(r)) \tag{3-18}$$

The rms difference between the buoy and the weighted radar current measurements is calculated in the objective function and is considered the figure of merit. The lower the difference, the better fit will be. For the Welch, AR, and the MUSIC method, the opotimal ratio r is found to be 85%, 75%, and 100%, respectively.

Outline

1 Introduction

2 Spectrum Estimation Methods
- Welch Method
- Autoregressive (AR) Method
- MUSIC

3 Bragg Peak Frequency Identification
- Centroid Method
- Symmetric-peak-sum (SPS)
- Optimal Weighting

4 Ground-Truth Data Validation

5 Conclusion

6 Reference

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

4. Ground-Truth Data Validation

The methods discussed above were evaluated using HF radar data collected from Nov. 29th, 2012 to Aug. 21st, 2013 at Placentia Bay, Newfoundland in conjunction with with the deployment of two oceanographic buoys

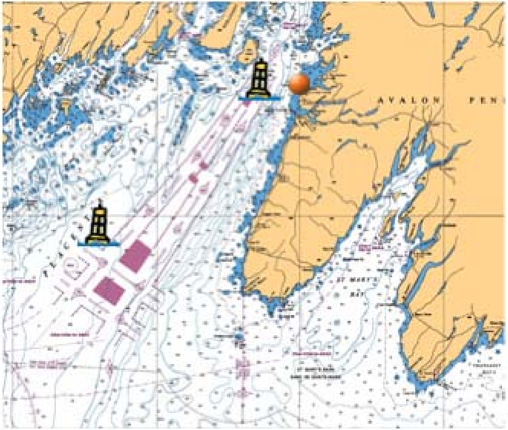


Figure 4-6: The locations of two buoys (the two towers) and a single radar site (orange button). The bottom left buoy is at at the mouth of Placentia Bay, and the top right buoy is at the Pilot Boarding Station at the south end of Red Island.

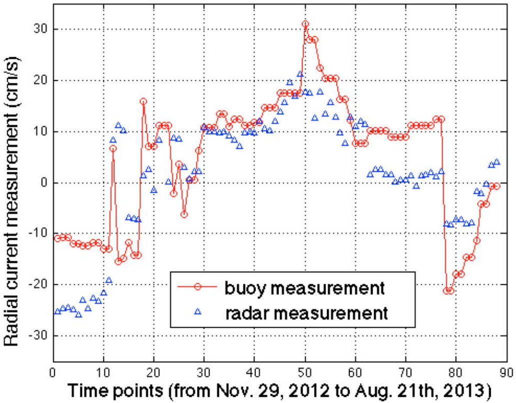


Figure 4-7: MUSIC, p=3, centroid, cor=0.77, rms=8.84 cm/s

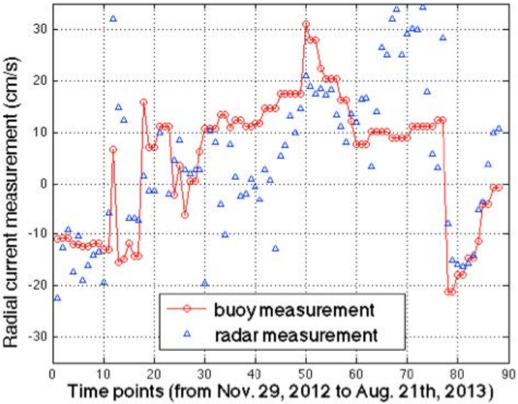


Figure 4-8: AR, p=14, centroid, cor=0.61, rms=12.17 cm/s

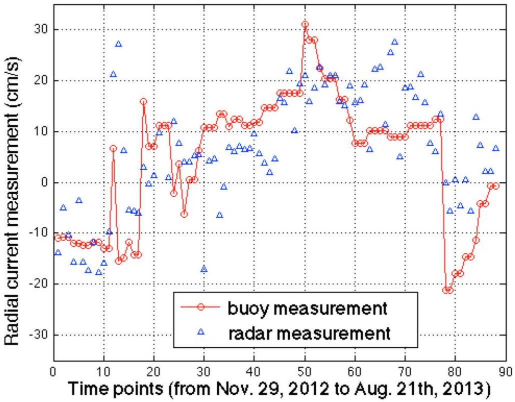


Figure 4-9: WELCH, centroid, cor=0.63, rms=10.69 cm/s

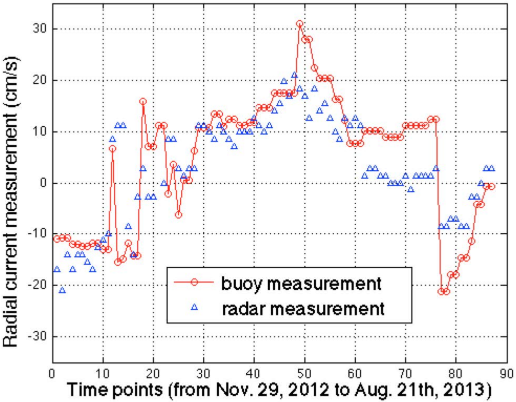


Figure 4-10: MUSIC, p=3, SPS, cor=0.79, rms=8.03 cm/s

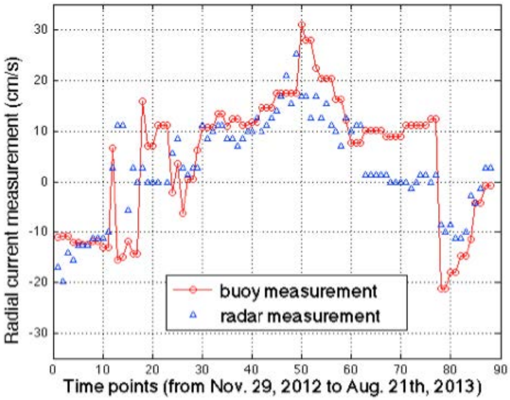


Figure 4-11: AR, p=14, SPS, cor=0.77, rms=8.27 cm/s

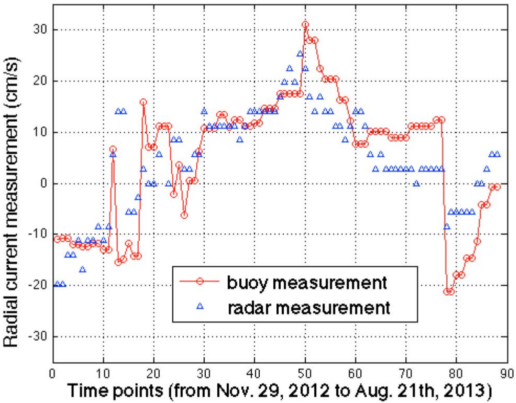


Figure 4-12: WELCH, SPS, cor=0.77, rms=8.16 cm/s

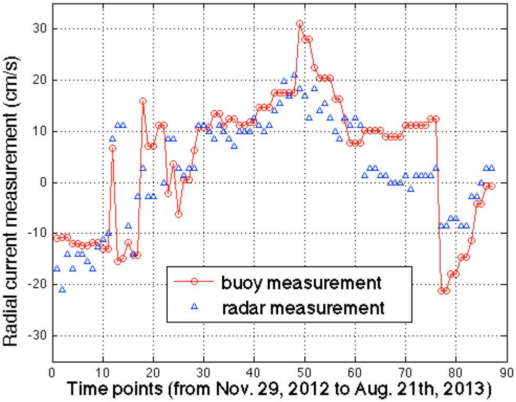


Figure 4-13: MUSIC, p=3, GA/SPS, cor=0.79, rms=8.03 cm/s

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

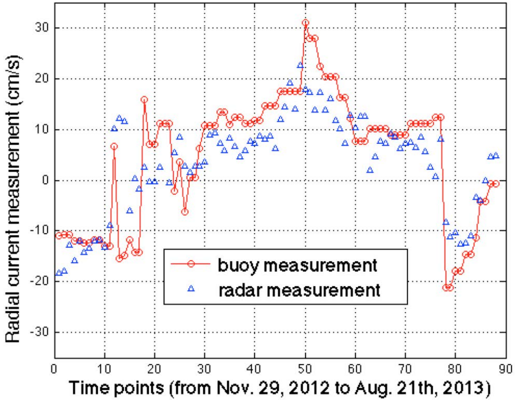


Figure 4-14: AR, p=14, GA, cor=0.81, rms=7.58 cm/s

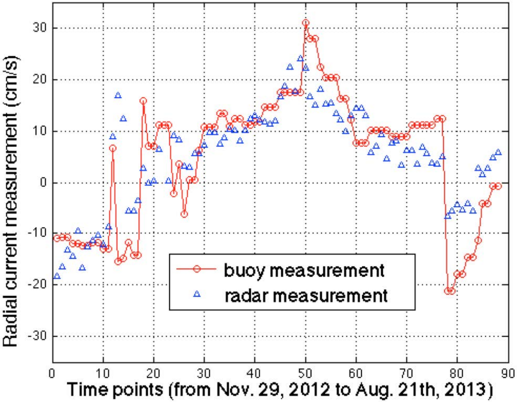


Figure 4-15: WELCH, GA, cor=0.79, rms=7.92 cm/s

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

Method	cor	rms	Method	cor	rms	Method	cor	rms
MUSIC, centroid	0.77	8.84	AR, centroid	0.61	12.17	Welch, centroid	0.63	10.69
MUSIC, SPS	0.79	8.03	AR, SPS	0.77	8.27	Welch, SPS	0.77	8.16
MUSIC, GA/SPS	0.79	8.03	AR, GA	0.81	7.58	Welch, GA	0.79	7.92

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

Outline

1. Introduction
2. Spectrum Estimation Methods
   - Welch Method
   - Autoregressive (AR) Method
   - MUSIC
3. Bragg Peak Frequency Identification
   - Centroid Method
   - Symmetric-peak-sum (SPS)
   - Optimal Weighting
4. Ground-Truth Data Validation
5. Conclusion
6. Reference

北京理工大学 BEIJING INSTITUTE OF TECHNOLOGY

5. Conclusion

- In this paper, the conventional periodogram method (i.e. Welch) and high-resolation spectral estimation methods (i.e. AR and MUSIC) were investigated in conjunction with two Bragg identification methods (i.e. the centroid and the SPS methods).
- The SPS method exhibited significant imporvement over the centroid method for all three SE techniques.

5. Conclusion

- A weigthed sum of the radar currents estimated by the SPS and the centroid methods is found to reduce the rms difference from the buoy currents.
- A genetic algorithm has been successfully implemented to find the global solution for the optimal weighting ratio.
- This ratio is found to be 85%, 75%and 100% for Welch, AR, and MUSIC methods.

Reference

- M. TRETHEWEY, "Window and overlap processing effects on power estimates from spectra," *Mechanical Systems and Signal Processing*, vol. 14, no. 2, pp. 267–278, 2000. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0888327099912748
- J. F. Tunnicliffe, "Holocene sedimentary history of chilliwack valley, northern cascade mountains," Ph.D. dissertation, University of British Columbia, 2008. [Online]. Available: https://open.library.ubc.ca/collections/ubctheses/24/items/1.0066305

北京理工大學
BEIJING INSTITUTE OF TECHNOLOGY

Thanks Listening
& Best Regards !