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The Application of a Multicorrelator Receiver in Bistatic Radar

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ABSTRACT

A height measurement using a GPS signal reflected off the ocean's surface can be used to assist in disaster early warning systems. This paper investigates the use of a multicorrelator receiver and piecewise linear regression to measure the height of sea level in a bistatic configuration using GPS as the readiator. The standard deviation of the error using this method is 1.6m, a significant improvement compared with that of standard correlation techniques.

A NordNav (NN) Quad Front-End R30 was used as the receiver. It is capable of measuring the altitude quantity, and had cross correlation capabilities that can measure the delay between the LOS and multipath signal components.

A Spirent simulator was used to fabricate the GPS signal. The signal was defined to include a LOS component and a single multipath component. This output was plugged directly into NN's antenna input for detection.

Delay measurements using NN were restricted by the correlation resolution. The minimum separation of the points in its correlation plot was 0.1875us, which equated to a distance of 56.2m. Hence, the resultant delay measurement had an error bound of +/-56.2m. Signal processing techniques were used to determine a more accurate delay quantity.

MATLAB was used to employ linear regression estimation on the correlation outputs, which could potentially position the correlation maxima more accurately. This technique improved the delay measurement error bound to +/-6.46m.

KEYWORDS: Multicorrelator, Bistatic, Oceanographic Altimetry, Regression

1. INTRODUCTION

The Global Positioning System (GPS) has completely changed the way navigation and positioning is achieved. This revolution is still in its infancy, and newer fields of application for the GPS signal are still being found. This paper focuses on GPS oceanographic altimetry, where receivers detect GPS signals reflected from the oceans surface in a bistatic configuration. This paper will show how this provides a means of performing altimetric measurements.

In this application, measurements are made on the reflection of a signal transmitted by only ONE satellite {put references in here}. The advantage of making oceanographic altimetry measurements with only one GPS satellite is twofold. The receiver technology is inexpensive and complexity is reduced {but is complexity reduced? The correlator becomes more complex}.

By tracking the height of a static receiver (or one with highly accurately known position) above an oceans surface, changes in sea level can be detected. When this occurs suddnely, it can be an indicator of the onset of a natural disaster, like a tsunami. The application of this research in disaster early warning systems is what motivates the research.

The Jet Propulsion Laboratory [1] addresses several criteria for GPS altimetry to be viable. These include the signal strength, delay characteristics, the receiver capability of discriminating and tracking these signals from the direct signal, and the information content of these signals. Their investigations show GPS signals reflected off the ocean surface contain strong altimetric information, and the technology in existence to exploit it is viable and promising. Consequently, they've developed a spaced based altimeter [2]. It senses numerous GPS signals scattered off the ocean surface using instruments operating in bistatic geometry. {what's the application? Height resolution?}

Similarly, Gleason [3] performs a space borne experiment to assess the conditions under which reflected signals could be reliably detected.

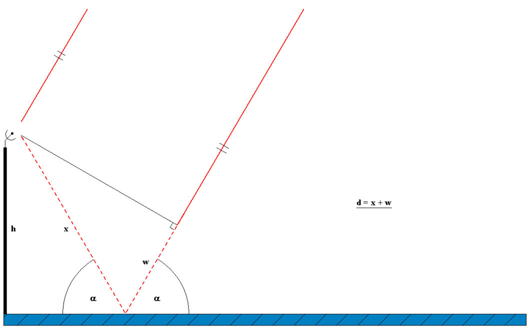
Garzon et al [4] use GPS reflection techniques to obtain sea state information. They implement a set of software routines that arrange and process data collected by a bistatic receiver, and infer sea level from the results.

The Department of Geodesy and Remote Sensing (Germany) [5], [6] undertook a GPS reflectometry experiment with a 12 channel ground-based GPS receiver. The receiver measured the correlation function of the direct and the reflected signal of one GPS satellite simultaneously. Rather than measuring a relative delay from the correlation data to produce the height measurement, they use variations in the amplitude of the in-phase and quad-phase components of the correlation sums to determine an altimetric height within a precision of 2cm.

2. PROBLEM STATEMENT

This paper aims to determine the height of a bistatic GPS receiver relative to the surface of a calm ocean, with accuracy. A typical scenario where an oceanographic altimetry measurement is made is presented in Figure 1.

(a)



(b)

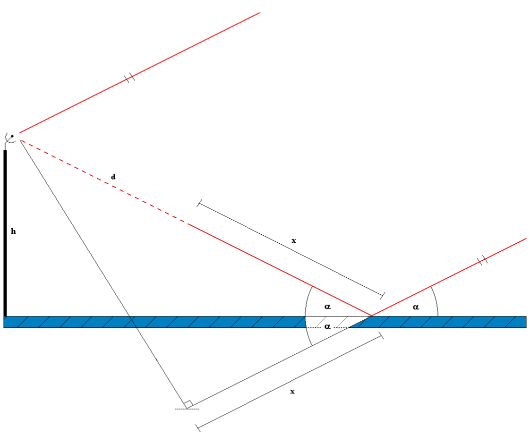


Figure 1: **(a)** Altimetric measurement scenario with satellite at low altitude **(b)** Altimetric measurement scenario with satellite at high altitude {why are there two cases?}

In Figure 1,

d = Extra distance (m) the multipath GPS signal component must travel before it's detected by our receiver (relative to the distance travelled by the LOS component)

h = height of the receiver

x = distance the reflected signal would have to travel after the reflection event to equal the distance LOS has travelled

a = satellite angle of elevation (altitude)

Figure 1 shows the satellite signal that descends on the receiver. The receiver detects the signal directly (the LOS component), and a delayed version of this signal due to a reflection off the oceans surface (the multipath component).

Note how only one satellite is required to find the desired height measurement, rather than four traditionally used in GPS positioning. {yes but you need to know where you are, so that requires at least 4 sats}

To solve the geometry, some assumptions that assist the analysis are made. These are:

- The incident LOS and multipath signal components are considered to be parallel with respect to each other. This assumption is valid given the broadcast satellite is a significant distance ($O(10^7 m)$) away from the receiver.

- The ocean surface is considered flat, not rough. This in turn allows the effects of signal scattering to be neglected. {so what happens when it's not? Specular vs dispersive refelction?}

The geometric solution to the scenario in Figure 1 is below. It is much easier to see how it is derived when the satellite has a large elevation angle, as depicted in Figure 1(a) {just show that case then}. From this it is determined:

d = x+w ……………… …(*) {give these equations numbers}

The right-angled triangle produces:

w = x*cos(180-2a) ……… …(**)

Then substituting (*) into (**):

d = x + x*cos(180-2a)

x= d/(1− cos2a) ……… …(***)

Once again, from the right-angled triangle:

h = x*sin a …………… …(****)

Then substituting (***) into (****):

$$h = \frac{d \sin a}{1 - \cos 2a}$$

Thus a function of the receiver's height relative to the waters surface is derived. The function only requires the input of a delay measurement (d), and the altitude (a) of a broadcasting GPS satellite.

The receiver can readily detect the altitude quantity from satellite ephemeris and the receiver's known position, but a method must be devised to measure the delay quantity. Cross correlation is proposed as the solution to finding this value. The remainder of this paper is dedicated to measuring the delay as accurately as possible using cross correlation.

3 MULTICORRELATOR RECEIVER APPROACH TO MEASURING HEIGHT

3.1 Signal Acquisition

A real incident GPS signal will contain distinct LOS and multipath components; both are required to measure relative delay. The Spirent test signals are designed with these characteristics. Producing several GPS reflections is straightforward in a Spirent "scenario".

The test scenario has the geographic location of the receiver on Earth chosen at random, with the only constraint being that it is in range of at leat one GPS satellite. The receiver is set to be stationary.

The strength of the LOS signal is set to 12 dB and a single multipath signal is set to 6dB {what does this mean? Db wrt what? Signals should be in dBm?}. These levels may seem somewhat unrealistic, but they make the correlation maxima more distinct, hence their relative separation easier to distinguish {and the whole exercise less realistic?}.

A pseudorange option for the multipath signal is set at 320m. This represents the horizontal distance between the reflection point of the multipath signal and the location of our receiver (i.e. the delay quantity) {the delay quantity is not the horizontal distance?. In a real situation this distance is the unknown to be estimated.

NordNav (NN) is the receiver of choice because it readily allows the use of several correlators. Its purpose is to detect and log the signal broadcast by the Spirent simulator in real time, calculate the satellite altitude, and create the correlation plot desired for delay calculation. Figure 2 shows the correlation plot produced by NN after detecting the Spirent signal with multipath component delayed by 320m. There is a minimum correlation spacing allowed by NN. This is a function of sampling frequency (Fs), which is hardware set to 16.3676MHz. The user cannot adjust this so resolution cannot be improved by increasing Fs.

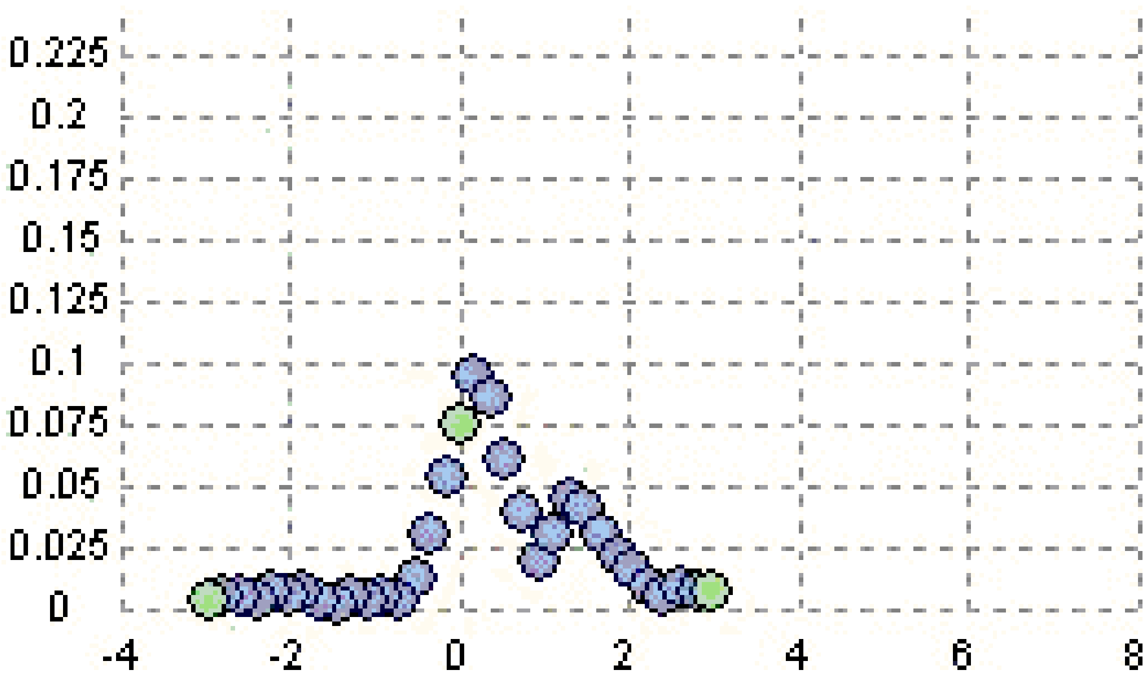


Figure 2: Screenshot of the NN correlation plot for signal with delay 320m

The sampling frequency constraint means the minimum separation distance of the multicorrelators is only 0.1875us, which corresponds to a distance of 56.2m. This has severe implications for the delay measurements. Only delays that are multiples of 56.2m can be calculated accurately. Hence, the resultant delay calculations will have an error range of +/- 56.2m.

Signal processing techniques are employed in MATLAB to increase the resolution of the correlation plot, and thus obtain more accurate positions of the correlation maxima from which the delay measurement is obtained.

3.2 Correlation Peak Estimation

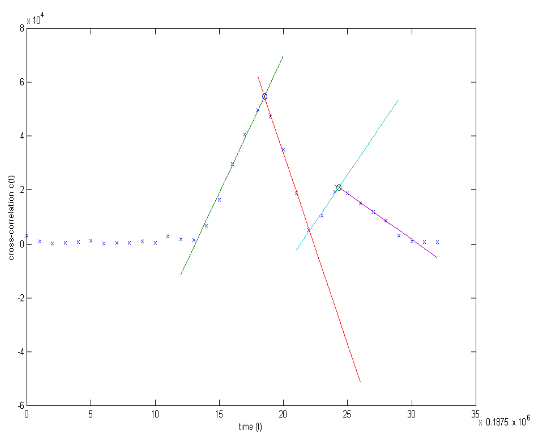
Linear regression estimation is applied to the correlations plots to enhance the accuracy of delay measurements. It is known that the multicorrelator separation in NN represents a distance of 56.2m. When the pseudorange in Spirent is set to multiples of 56.2m, the resultant correlation plot remains almost stationary at different instances in time (different "snapshots" of the correlation plot). The correlation peaks are distinct and also remain stationary.

However, when the pseudorange is not set to a multiple of 56.2m, an interesting phenomenon is observed. The resultant correlation plot does not show a distinct point as being the peak. Rather, in consecutive snapshots two neighbouring points will oscillate, with one or the other representing the peak. This phenomenon occurs in the correlation plot of the GPS signal with delay of 320m (not a multiple of 56.2m). The oscillation occurs because the correlation peak should lie somewhere between the two points, and NN attempts to compensate for its lack of resolution. By fitting a regression line to the side of each correlation triangle, their point of intersection will lay somewhere in between the oscillating points. The point of intersection will represent where the correlation peak should be.

EXPERIMENTAL RESULTS

Figure 3(a) shows the points of intersection for a single snapshot of the correlation plot with 320m delay. Accuracy is further improved by taking the averaged points of intersection from 20 snapshots (refer Figure 3(b)).

(a)



(b)

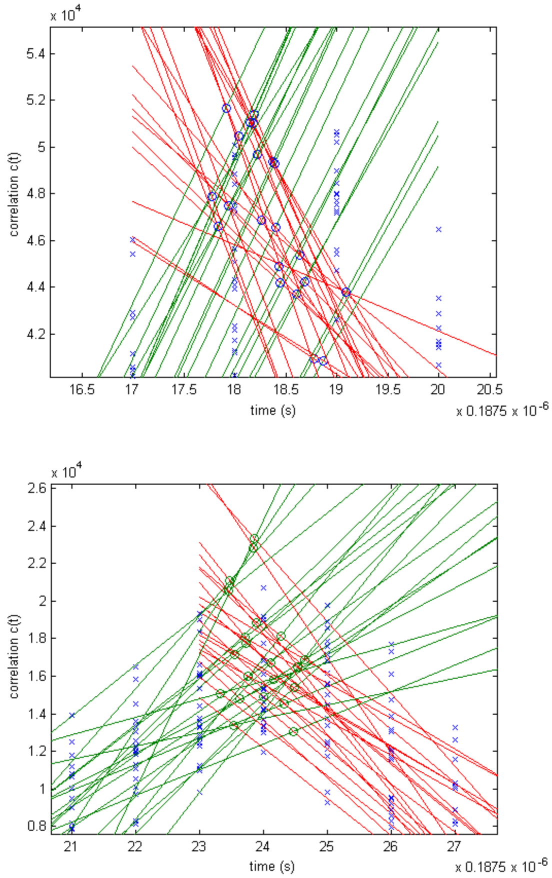


Figure 3: (a) Correlation plot with regression estimation **(b)** Regression estimations for multiple snapshts (zoomed on peaks) {should have ba and c – explain each figure separately}

It is important to avoid taking the average of too many snapshots as the satellite altitude will vary with time {refer to work on the change of multipath effects with time – e.g. Jan Weiss's work}. The distance between the averaged values now represents a more accurate delay measurement. For the GPS signal with 320m delay, 321.40m was calculated using this method.

The linear regression method is repeated a further 19 times on 19 different signals. The pseudorange of each signal is incremented by an additional 10m, so in total 20 signals are produced with pseudoranges in the range of 320m-520m. The delay is calculated for each.

Figure 4 shows a graph with actual delay versus regression estimated delay. Figure 5 is a table of the plotted values. A one-to-one line has been included in the graph to represent what the plot should look like if the regression technique measured the delay perfectly. The results do not deviate much from this line, the largest deviation being 6.45m. Hence, it has been proven that linear regression estimation is a satisfactory method of measuring delay. The error range has been successfully decreased from +/-56m to +/-6.45m, which is a vast improvement.

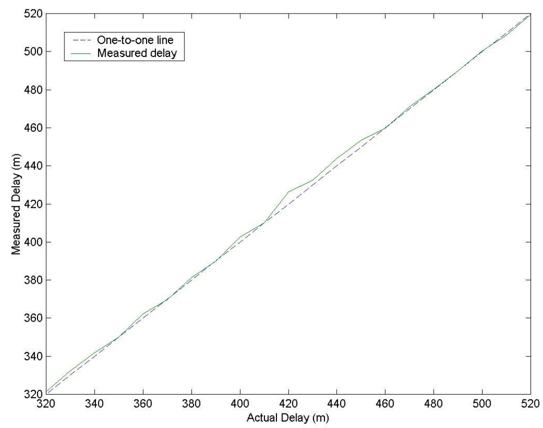


Figure 4: Actual delay vs regression estimation

Actual Delay (m)	*Estimated Delay (m)*	*abs(Actual-Estimated) (m)*
320	321.40	1.4
330	332.29	2.29
340	341.80	1.8
350	349.99	0.01
360	362.32	2.32
370	369.68	0.32
380	381.33	1.33
390	389.78	0.22
400	402.62	2.62
410	409.94	0.06
420	426.45	6.45
430	432.51	2.51
440	443.80	3.8
450	453.35	3.35
460	459.70	0.3
470	471.26	1.265
480	480.12	0.12
490	489.86	0.14
500	500.32	0.32
510	508.79	1.21
520	519.58	0.42
	Std Dev	***1.6141***

Figure 4: Estimated Delays {are these "one-shot estimates or averages as per the previous figure?}

CONCLUSION AND FUTURE WORK

In conclusion, a mathematical function that provides an oceanographic altimetry measurement has been successfully derived {surely this exists in earlier literature – you can't claim to have derived it}. The function uses quantities that are determined from a GPS signal with a LOS and single multipath component. The GPS signal is transmitted from only one satellite. Research of past literature suggests this approach is extremely novel.

The functions input quantities are the satellite altitude, and the delay between the LOS and multipath component. A NN receiver measures altitude, but the delay quantity is not easily determined. By using cross correlation and linear regression estimation, a method has been devised that measures the delay with an error range of +/-6.46m. This renders this approach to be a viable way of performing oceanographic altimetry measurements. {Is this accurate enough? A tsunami has to be more than 6m high to e detected?}

The following items are the future direction of our research. Field readings from a receiver that has physically been raised some height above sea level must be obtained to see the effectiveness of this papers method in the real world. When operating in the real world, factors that have been neglected during analysis thus far need to be considered. One would be signal scattering due to an uneven ocean surface. Another would be the effect of multiple reflections on measurements.

Furthermore, physical aspects need to be considered for experiments in the field. These include the best way to mount the receiver and the correct direction to point it. Delay calculations from a correlation plot where the maxima aren't distinct must also be investigated. This occurs when the delay between the LOS and multipath components of the signal are separated by a small distance.

This paper was inspired by the recent tsunami disaster in South-East Asia. Its intention was for the height measurement technique to be used in a disaster early warning system. For this to be a realistic expectation, the delay measurement error bound needs to be in the cm range. Some possible techniques that can improve the error bound include the use of the GPS pseudorange error plot and possibly interpolating the correlation plot. Their use at this stage seems viable but their effectiveness must be determined.

{OK what is missing here is a comprehensive list of the weaknesses in your technique – i. it requires the delay to be so long the two paths have "separate" correlations – i.e. 100s of meters, ii. You manually assigne the points for regression – at least describe how this can be done automatically, iii. You assume a high SNR – you should show a relationship between SNR and your accuracy results. You should also be able to show now the difference between a not using regression b using one regression and c using an average of several regressions. Also mention why your method is so great when you have refered to a method that give cm level accuracy. You should also mention in the references other similar multipath techniques that use the slope of the correlation function – Novatel's MET and PAC for instance. You should also mention their MEDLL which isolates several multipath signals.}

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