NLMS Adaptive Filter Algorithm Method for GPS Data Prediction

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ABSTRACT

This paper proposes a method for the prediction of GPS data using Normalized Least-Mean-Square Algorithm (nlms) was used as application of adaptive filter. Four different scenarios were taken to predict the GPS data. The first one was without blocking of data and the three others with blocking for (3, 6, and10 seconds, respectively), with implementation in MATLAB. The prediction process of the GPS receivers is required for different reasons, such as maneuvering, founding obstacles, and also the time of booting may be too long due to the difficulty in obtaining the satellite's position, hence in such cases one can use the GPS prediction data in order to solve these problems and reduce the booting time and avoid losing of the GPS data for any reason.
Keywords: NLMS, GPS data, prediction, adaptive filter, blocking

INTRODUCTION

In the last thirty years significant contributions have been made in the signal processing field. The advances in digital circuit design have been the key technological development that sparked a growing interest in the field of digital signal processing. The resulting digital signal processing systems are attractive due to their low cost, reliability, accuracy, small physical sizes, and flexibility. [1]

The digital filters are used in a wide variety of signal processing applications such as spectrum analysis, pattern recognition, military fields, processing the speech and pictures, industrial, engineering fields, and medical technology, digital filters eliminate a number of problems associated with their classical analog counterparts and thus are preferably used in place of analog filters. Digital filters belong to the class of discrete-time LTI (Linear Time Invariant) systems. [2]

The idea of the study is that when we consolidating of this high level control technique (the adaptive filters) due to the powerful digital signal processors and the increase of advanced adaptive algorithms there are a large number of different applications in which adaptive filters are used. The number of various applications in which adaptive techniques are being successfully used has increased immensely during the two decades ago. There is an extensive variety of grouping that could be applied in various fields such telecommunications radar, sonar, video and audio signal processing, noise reduction, between others.

The effectiveness of the adaptive filters for the most part depends on the purpose of the technique is used and the algorithm of adaptation. The adaptive filters can be found as analogical designs, digital design or can be found as a mixed from two types.[3]

Adaptive Filter

Digital filtering is a signal treatment working that maps the input discrete-time signal to another output signal assists the obtaining of the required information contained in the input signal. In this case, the required information is the future value of GPS data. For time-constant filters the internal variables and the design of the filter are constant, and if the filter is linear, the output signal is a linear function of the input signal. An adaptive filter is wanted when either the system detailing are unknown or the detailing cannot be gratified by time-constant filters. In the present study, the input signal is the GPS data from the satellite receiver. The GPS data, being a highly dynamic and time-constant system, does not lend itself to time- constant information and hence, the only practical solution is adaptive filters. An adaptive filter is a filter that auto-regulates its response according to an optimizing algorithm. Adaptive filters adjust their response depend on the change in input signal. The operating of adaptive filters in the most essential form can be seen in Fig. (1), In Fig. (1),*x (k)* is the input signal at instant *k*, and *Y (k)* is the output of the filter. The desired response is denoted by *d (k)* and the error [4]

e (k) =d (k)-y (k). (1)

The adaptive algorithm calculates the updating of the filter coefficients used to design the filter output.

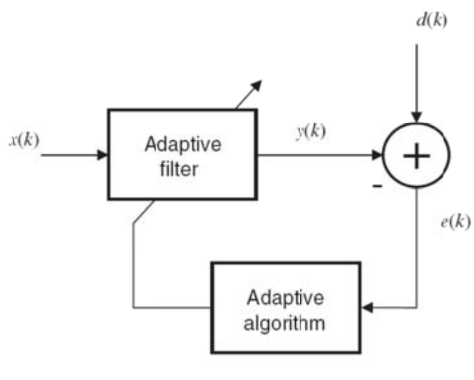
From suggests name, adaptive filters are filters with the capability of adaptation to an ambiguity environment. This family of filters has been excessively applied because of its variation (capable of working in an ambiguity system) and low cost (hardware cost of application, as compared with the non-adaptive filters, expressible in the same system).

Important of adaptive filter

The capability of working in an ambiguity environment added to the ability of tracking time difference of input statistics makes the adaptive filter an industrial-strength device for control applications and signal-processing. Indeed, adaptive filters can be used in various applications and they have been successfully used over the years. The applications of adaptive filters are various. Therefore, applications are divided in to four essential portions: identification, inverse modeling, prediction and interference cancelling.[5]

An adaptive filter is a system with a linear filter that has a transfer function controlled by variable parameters and a means to adjust those parameters according to an optimization algorithm. Adaptive filters are required for some applications because some parameters of the desired processing operation are unknown in advance or are hanging. [6]

An adaptive filter is able to auto-correct its transfer function according to the optimization rule. Since the path of anaerobic motion is unlikely to be represented by a uniform transfer function even if the respiration is normal, the adaptive filters are more acceptable than the non-adaptive filters in the prediction of aerobic motion. Among the adaptive filters is NLMS, oftentimes used in prediction. [7]



Figure(1):Adaptive Filtering

Linear Prediction

The linear prediction estimates the values of a signal at a future time. Linear prediction is widely used in speech processing applications such as speech coding in cellular telephony, speech enhancement, and speech recognition.

In this configuration the desired signal is a forward version of the adaptive filter input signal. When the adaptive algorithm convergences the filter represents a model for the input signal and can be used as a prediction model.[8]

Prediction performance is evaluated by the following measures

1. root-mean-square error between predicted and measured signal
2. Maximum error between predicted and measured signal
3. Spectrum power of the error signal at the major respiration frequency [9]

Prediction with Known Models

If a model for the evolution of the time series of interest is known, it is possible to construct suitable predictors from the model see equation (2-4). In fact, in the case that the model is linear and finite-dimensional, suitable predictors can be obtained by simple algebraic manipulations of the model. We show how this is achieved below.[10]

In this structure, the function of the adaptive filter is to provide the best prediction of the present value of the input signal from its previous values, the configuration shown in figure(1) above are used for this purpose, where the desired signal, *y (n)*, is the instantaneous value and the input to the adaptive filter is x (n)or the same signal. [11]

When the input signal vanishes and reappears after a long period of time, the algorithm may diverge because of these nonzero values of the predictor. In other words, the algorithm is not well initialized when the signal reappears. In such conditions, it might be preferable to have the forward predictor. [12]

The linear prediction system is shown in figure (3).

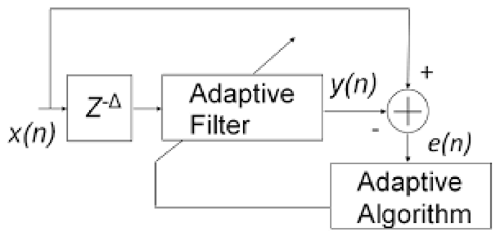


Figure (2): Adaptive filter for linear prediction

The predictor output y (n) is expressed as; [13]

$$Y(n)=\sum_{l=0}^{L-1} w1(n)x(n-\Delta-1) \quad (2)$$

Where Δ is the number of delay samples, so if we are using the LMS algorithm the coefficients are updated as;

$$W(n+1) = w(n) + \mu\, x(n-\Delta)e(n) \quad (3)$$

Where: $X(n-\Delta)= [x(n-\Delta)x(n-\Delta-1) \ldots\ldots x(n-\Delta-L+1)]^{T}$ (4)

Normalized Least-Mean-Square Algorithm (NLMS)

To increase the convergence speed of the least-mean-square (LMS) algorithm without using estimates of the input signal, a variable convergence factor is a solution. The normalized least-mean-square (NLMS) algorithm usually converges faster than the LMS algorithm, since it utilizes a variable convergence factor.[14]

The main drawback of the "pure" LMS algorithm is that it is sensitive to the scaling of its input. This makes it very hard to choose a learning rate μ that guarantees stability of the algorithm. The *Normalized least mean squares (NLMS) filter* is a variant of the LMS algorithm that solves this problem by normalizing with the power of the input. [15]

NLMS provides an automatic adjustment in step-size. It is based on the criteria of selecting the best step-size for a given iteration. The term best is explained as follows. If error during the iteration is large, step size is kept large so that the algorithm can quickly catch up with true solution. If the error decreases, step-size is lowered to allow the algorithm to zoom into the true solution. Hence, NLMS tries to select a step-size that minimizes the error in each iteration.[16]

The NLMS algorithm has been implemented in Mat lab. As the step size parameter is chosen based on the current input values, the NLMS algorithm shows far greater stability with unknown signals. As the NLMS is an extension of the standard LMS algorithm, the NLMS algorithms practical implementation is very similar to that of the LMS algorithm.[17].The Normalized LMS(NLMS) introduces a variable adaptation rate. It improves the convergence speed in a non-static environment. In another version, the Newton LMS, the weight update equation includes whitening in order to achieve a single mode of convergence.[18]

In the LMS algorithm, the tap-weight input has a correction 2μ (n) and x (n) which is directly proportional to the size of x (n), when the size of the x (n)is large; the LMS algorithm experiences a gradient noise amplification problem. In order to solve this problem, the normalized least-mean-square (NLMS) algorithm was developed, table (1) explain the summery steps of NLMS algorithm that it used in the prediction for GPS data.

The increase of the input *x (n)* makes are very difficult (if not impossible) to choose a μ that guarantees the algorithm's stability. Therefore, the NLMS has variable step-size parameter given by; [5]

$$\mu=\frac{\bar{\mu}}{\delta+\|x(n)\|^2} \tag{5}$$

Where: δ is a small constant,$\bar{\mu}$ is the step size parameter of the NLMS $0<\bar{\mu}<2$ and$\|x(n)\|$ is the Euclidean norm. The tap-weight *w (n)* is now presented as:

$$W(n+1) = w(n) + 2\mu\, e(n)\, x(n) \tag{6}$$

$$W(n+1) = w(n) + 2\frac{\bar{\mu}}{\delta+\|x(n)\|^2} e(n)\, x(n) \tag{7}$$

Table (1), presented a summary procedure of the NLMS algorithm[5]

Inputs	Tap-weight vector *w(n)*, Input vector *x(n)*, and desired output *d(n)*
Outputs	Filter output *y(n)*, Tap-weight vector update *w(n+1)*
Parameters	*M = number of taps* *δ = small constant* *$\bar{\mu}$=step- size parameters of the NLMS algorithm*
initialization	Having prior knowledge, use it to compute the *w(0)*, otherwise set*w(0) = 0*
Step 1: Filtering: $Y(n) = W^T(n)\, X(n)$ Step 2 : Error Estimation $e(n) = d(n) - y(n)$ step 3 :Tap – weight vector adaptation : $w(n+1) = w(n) + 2\frac{\bar{\mu}}{\delta+\|x(n)\|^2} e(n)\, x(n$	

Adaptive NLMS filter

Adaptive NLMS filter is a member of the family of Adaptive LMS filters. In the LMS filter, iterative procedures are employed to make successive corrections to the weight Vector in a direction opposite to that of the gradient vector and to eventually minimize the mean square error. The Weight vector in NLMS algorithm is [7]

$$W(n) = w(n-1) + \frac{\mu x(n) e(n)}{X(n)^H X(n)} \tag{8}$$

Where*:* μ is the learning rate, *E (n)* is the error between the desired values *d (n),*the adapted (output) value *y (n)*, $X(n)^H$ is the Hermitian transpose of X *(n)*.

The filter adjusts the weight vector in order to minimize the error between the desired and output value.

An adaptive filter responds to changes in its parameters, like for example: its resonance frequency, input signal or transfer function that varies with time. This behavior is possible due to the adaptive filter coefficients vary over time and are updated automatically by an adaptive algorithm.[19].

Calculation cases and analysis

In order to show the difference between the four cases of the predictor data , computer simulation package in mat lab 2014 are used to estimate the suggested system , each case represented (x,y,z) coordinate by 60 points ,GPS receiver gave us 60 point of (x,y,z) each of one second apart , then the NLMS algorithm generate 600 points each of 0.1 second , the result data from GPS receiver and the generating data from the NLMS algorithm are used to estimate the errors between the two data .

Tables (2 to 4) are show below; presented the comparison of R.M.S. errors calculations of the NLMS prediction methods in the three coordinate (Table 1: X-axis, Table 2: Y-axis, Table 3: Z-axis) in four cases (without blocking , with 3 sec blocking , with 6 sec blocking and with 10 sec blocking).

In this work the description of using the NLMS adaptive filter theory for GPS data predictor are presented, GPS data prediction is required for different reasons or delay in GPS data receiver.

Different scenarios are taken to evaluate the predicted GPS data in the three directions (X, Y, Z), where:

Scenario (I): Figure (4), representing the first cases of the prediction in this research without blocking of the data.

Scenario (II): figure (5), representing the prediction with3 seconds of data blocking to prevent the data loosing during the blocking time.

Scenario (III): figure (6), representing the prediction with 6 seconds of data blocking.

Scenario (IIII):figure (7), representing the prediction with 10 seconds of data blocking to stay away from data loosing for longer time.

Tables (2, 3 and 4)represent the calculated values of the RMS max, RMS min, variance and standard division for all the fourth cases of the prediction in three directions (X, Y, Z).So the important parameters, (RMS error), from the above result and according to the shown figures, the value of the (RMS error) in three direction is increase as the period of the data blocking is increase, the smallest value of the (RMS error) in scenario (I) at no data blocking and the largest of the (RMS error) in scenario (IIII) when the time of data blocking is (10 second).

Table 2: presented the value of the R.M.S. errors in X-axis

No.	parameters	no blocking X-axis	3sec blocking X-axis	6sec blocking X-axis	10sec blocking X-axis
1	RMS max	50.5118	56.1242	67.3491	72.9615
2	RMS min	0.2067	0.2296	0.2756	0.2985
3	Variance	231.8119	297.2185	443.2379	547.1906
4	Standard Deviation	15.2254	17.2400	21.0532	23.4049

Table 3: presented the value of the R.M.S. errors in Y-axis

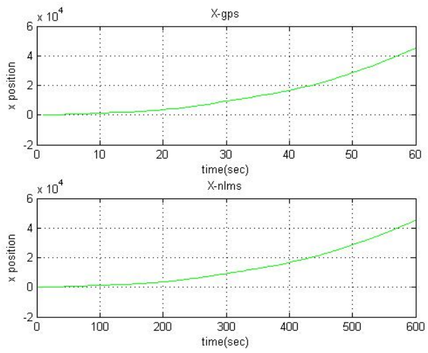
No.	Parameters	no blocking Y-axis	3sec blocking Y-axis	6sec blocking Y-axis	10sec blocking Y-axis
1	RMS max	51.7973	57.5638	69.0765	74.8329
2	RMS min	0.3309	0.3677	0.4412	0.4780
3	Variance	211.4312	267.3045	392.6649	474.1906
4	Standard Deviation	14.5407	16.3494	19.8158	21.7759

Table 4: presented the value of the R.M.S. errors in Z-axis

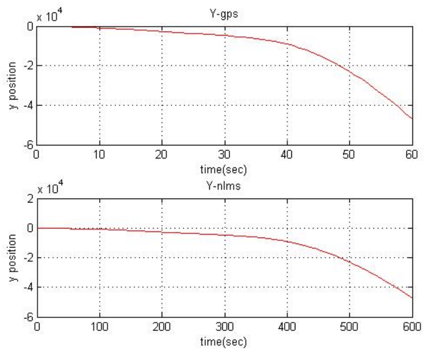
No.	Parameters	no blocking Z-axis	3sec blocking Z-axis	6sec blocking Z-axis	10sec blocking Z-axis
1	RMS max	52.0402	57.8478	69.4173	75.2021
2	RMS min	0.1385	0.1539	0.1847	0.2001
3	Variance	260.1036	351.1960	540.6662	688.8567
4	Standard Deviation	16.1277	18.7402	23.2522	26.2461

As well as the figures bellow show the data comparing between from GPS receiver and the generating data from the NLMS algorithm :

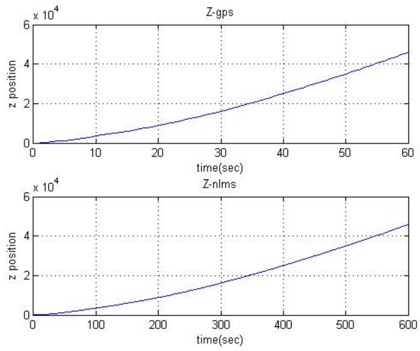
Comparing figures between GPS reading data with and without prediction (assuming no blocking using NLMS algorithm)



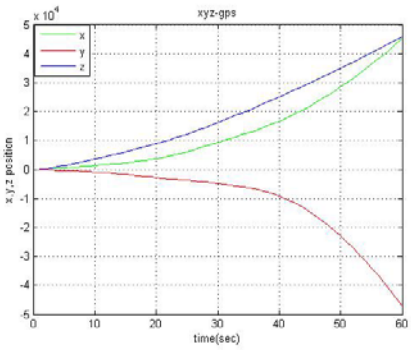
(a) X position from GPS and NLMS

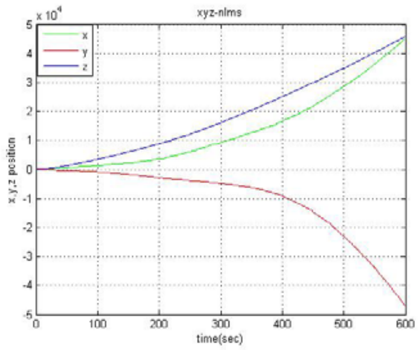


(b) Y position from GPS and NLMS



(c): Z position from GPS and NLMS

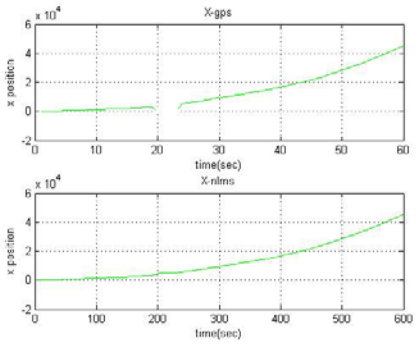


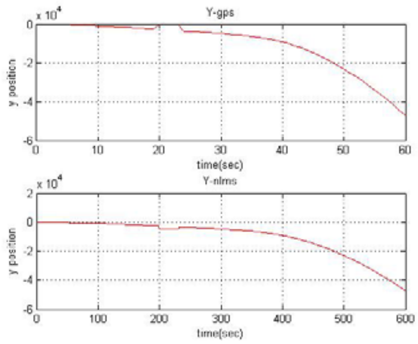


(d): X, Y, Z position before NLMS **(e) X, Y, Z position after NLMS**

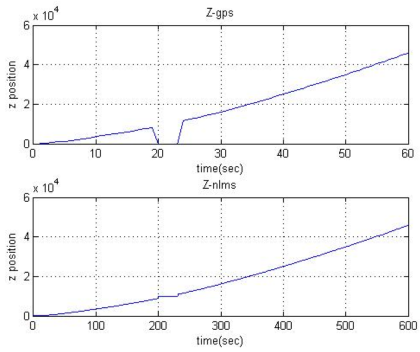
Figure.(3) represent the figures (a,b,c,d, e)

Comparing figures between GPS reading data with and without prediction (assuming blocking for (3 second) using NLMS algorithm).

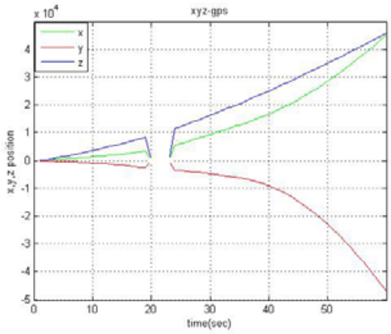


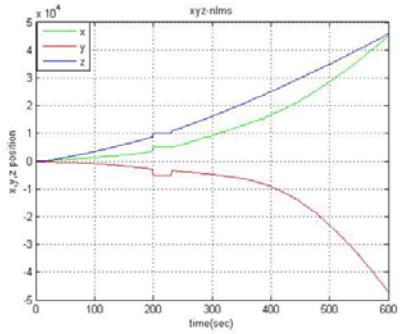


(a): X position from GPS and NLMS **(b): Y position from GPS and NLMS**



(c): Z position from GPS and NLMS

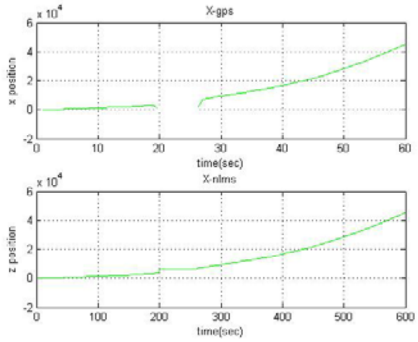


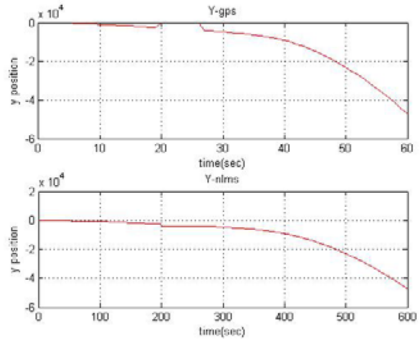


(e):X, Y, Z position before NLMS **(d): X, Y, Z position after NLMS**

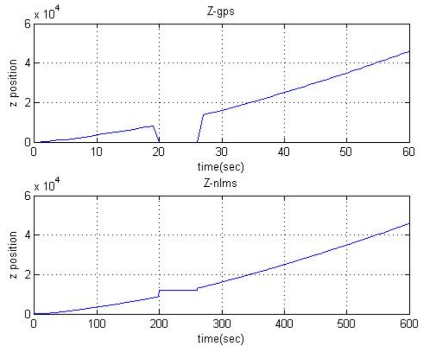
Figure.(4) represent the figures (a,b,c,d,e,)

Comparing figures between GPS reading data with and without prediction (assuming blocking for (6 second) using NLMS algorithm)

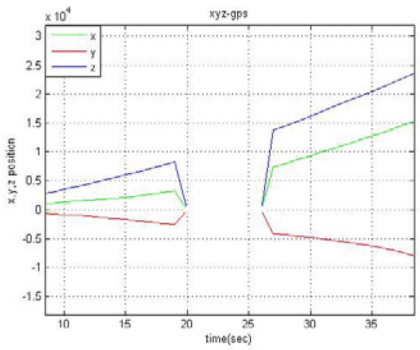


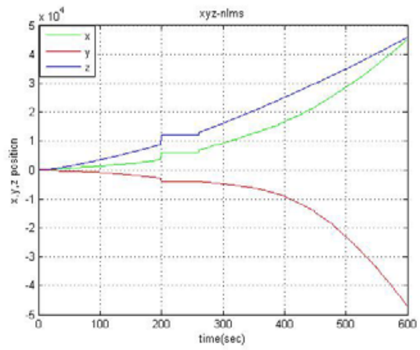


(a): X position from GPS and NLMS **(b): Y position from GPS and NLMS**



(c): Z position from GPS and NLMS

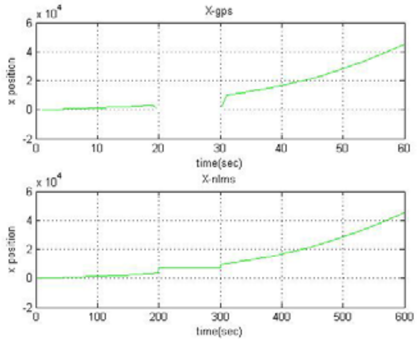


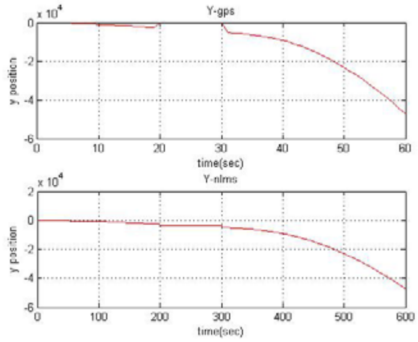


(d): X, Y, Z position before NLMS **(e): X, Y, Z position after NLMS**

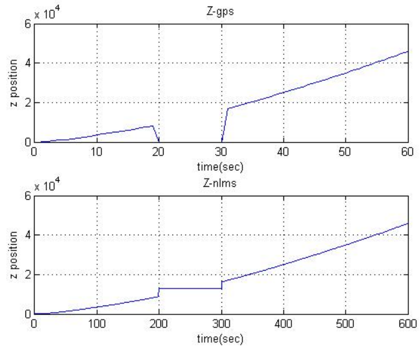
Figure.(5) represent the figures (a,b,c,d,e)

Comparing figures between GPS reading data with and without prediction (assuming blocking for (10second) using NLMS algorithm)

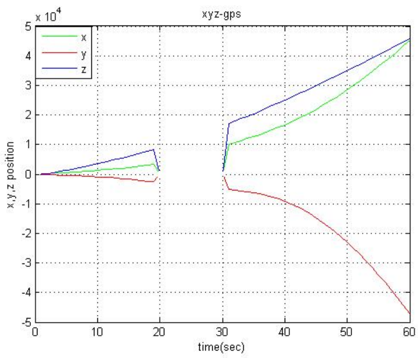


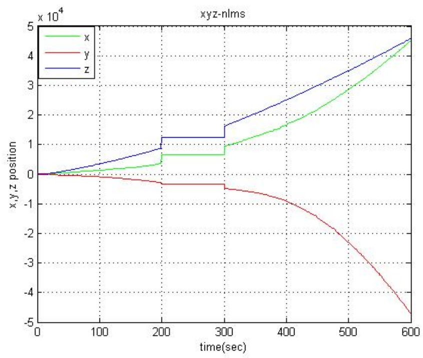


(a): X position from GPS and NLMS **(b): Y position from GPS and NLMS**



(c): Z position from GPS and NLMS





(d): X, Y, Z position before NLMS **(e): X, Y, Z position after NLMS**

Figure (6) Represent the figures (a,b,c,d,e)

CONCLUSION:

The application results of the NLMS algorithm divided in four groups , the first group is represent the position of the prediction data before blocking which are described in figures (4(a,b,c,d,e)), the second group explain the position of the prediction data after blocking for (3second) which are stated in the figures (5(a,b,c,d,e)), the third group is represent the position of the prediction data after blocking for (6 second) which are described in figures (6(a,b,c,d,e)), and finally fourth group explain the position of the prediction data after blocking for (10 second) which are stated in figures (7(a,b,c,d, e)) , while tables (2,3 and 4) are explained the error between the input data and the prediction data , as well as the values of the (RMS max, RMS min, variance and standard division) in the coordinates (X,Y,Z) for all the fourth cases of prediction above, and we can see that the R.M.S error are increases when the period of the blocking is increase . Hence, from the above results, one can conclude that the NLMS algorithm is considered suitable method for GPS data prediction.

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