HANDLING THE DATA RATE DIFFERENCE BETWEEN INS AND GPS SYSTEMS

* SALAM A. ISMAEEL and ** AHMED M. HASSAN

*Informatics Institute for Postgraduate Studies, Iraqi Commission for Computers and Informatics, salam_ismaeel@yahoo.com

**Control and System Eng. Dept., University of Technology, ahmedmudher@yahoo.com

ABSTRACT

Global positioning system (GPS) and inertial navigation system (INS) can be integrated together to provide a reliable navigation system. GPS provides position information and possibly velocity when there is direct line of sight to four or more satellites.

The integration between the GPS and INS leads to accurate navigation solution by overcoming each of their respective shortcomings. And to make this integration possible the difference between the GPS and INS systems in sampling rate must be solved before any integration can be work properly. Three methods were used in this paper (Newton, Spline, and artificial neural network (ANN)) to solve the mismatching in data rate between the GPS and INS systems.

Keywords: GPS; IMU; Sensor Integration; Integrated Navigation; Neural Network

1. INTRODUCTION

Since 1940's the navigation systems have become important components in military and scientific applications. In fact GPS is now standard equipment on most planes, ships, and submarines.

INS technologies are based on the principle of integrating specific forces and rates measured by accelerometers and rate of gyros of an inertial measurement unit (IMU) fixed on the moving body [4].

On the other hand, the GPS relies on the technique of comparing signals from orbiting satellites to calculate position (and possibly attitude) at regular time intervals [3, 6]. But being dependent on the satellites signals makes GPS less reliable than self contained INS due to the possibility of drop-outs or jamming [4].

The combination of GPS and INS has become increasingly common in the past few years, because the characteristics of GPS and INS are complementary. This paper looks at ways to handle the difference in data rate between GPS and INS systems in order to make the integration possible.

2. PROBLEM STATEMENT

The INS is very fast system and produce data at a high data rate while the GPS receiver is slower than the INS [4]. Hence, there is gab between the two systems reading data. Some articles overcomes this problem by choosing the GPS and INS systems with the same sampling rate as in [5], or can extrapolate the GPS data to be matched with the INS data to make the integration possible as done in this work, unlike [2], which use Kalman filter to predict the sampling between instants these methods are used.

3. HANDLING THE DATA RATE DIFFERENCE BETWEEN INS AND GPS SYSTEMS

For GPS/INS system integration, synchronization must be provided between them, to make it possible to compare the reading data of both systems.

Predicting or extrapolating the missing reading data of the GPS to be compatible with those of the INS data can accomplish to solve the difference in sampling rate problem between the two systems.

Different methods are used to predict the GPS data (data at intermediate times). Two data sets were used; first data set without denoising the GPS data and the second data set was denoised before extrapolation process was accomplished to show the effect of denoising process on the extrapolation for more investigation and research.

The following algorithm produces the general extrapolation process for GPS data prediction:

Step 1: Read the GPS data from the GPS receiver.

Step 2: Calculate the number of samples between time intervals of the GPS data to be extrapolated, depends on the data rate of the INS and GPS systems (i.e. if the INS and GPS data rate is 10 and 1 Hz, respectively, then the INS and GPS provide data at each 0.1 and 1 second respectively). Then the number of sampling instant, to be predicted is 10 points between each two reading samples.

Step 3: Use one of the three methods mentioned above to extrapolate the GPS data.

Step 4: Use the extrapolated GPS data with the INS data to compare and manipulate them in the proposed integrated GPS/INS system.

The data used in this work was generated from six degree of freedom (6DOF) missile simulation based in matlab so, the results may be differ if real data used (i.e vehicle trajectory instead of missile).

3.1 Newton-Gregory Forward Extrapolation

This method was used to extrapolate the GPS data. Table (1) shows the results obtained using Newton method with and without GPS error; the Newton procedures can be reviewed in [1].

From table (1) it was found that the results are not emulous so, spline method will be used as a second approach in the hope of getting better results.

The Newton method was implemented according to the pseudo-code as follows:

```
Procedure of Newton Extrapolation
Initialization
Read GPS data (T_GPS) of n-samples
begin
Read new GPS sample number i
   t = i - 3 to i
Obtain the last four samples for GPS data
   T_check = T_GPS (t)
   for j = 0 to 0.9 (step 0.1)
       k = k + 1
       Compute the forward difference table
coefficients
       Obtain the predicted point (Xp)
       Obtain the nearest point to the
predicted point (Xo)
       H = 1
       P = (Xp - Xo)/H
       f = P
       for ii = 1 to 4 - 1 (step 1)
                 T_Newton = T_Newton + f * (specific
         difference value from          difference table)
         f = f * (P - ii)
       end
   end
End
```

3.2 Spline Method

Spline method was implemented to extrapolate the GPS data, from table (2) it can be seen that spline method is better than the results obtained from Newton method but the time required for the extrapolation process in spline method was large than the time required in Newton method.

The Spline method was implemented according to the pseudo-code as follows:

```
Procedure of Spline Extrapolation
Initialization
Read GPS data (T_GPS) of n-samples
Extrapolation process
begin
Read new GPS sample number i
  t = i - 1 to i
Obtain the last two samples for GPS data
  T_check = T_GPS(t)
    For j = 0 to 0.9 (step 0.1)
      K = k + 1
      T_extrapolate (k) = spline (t, T_check,
i+j)
       end
End
```

3.3 Artificial Neural Network Method

The history of Artificial Neural Networks (ANN) comes from attempts of modeling a system by simulating the most basic functions of human brains. In fact, the motivation of studies in ANNs comes from the flexibility and power of information processing that conventional computing machines do not have. The successes of ANNs in many application areas due to some features, such as the ability to learn, understand and adapt. The ANN system can "learn by examples and experience" and perform a variety of nonlinear functions that are difficult to describe mathematically [7].

Artificial neural network was developed to extrapolate GPS data for different rate systems where Multi-layer perceptron was trained using a Feed Forward Back Propagation algorithm and utilizing the Levenberg-Marquardt learning rule.

Three layers was used in the proposed ANN (one hidden layer, one output layer) with 10 neurons in the hidden layer and one neuron in the output layer. The proposed Network has 2 inputs (one input for the trajectory and the other input for the time instant).

The proposed ANN architecture is shown in figure (1); the results obtained by using this method given in table (3).

It is clear from this table that the prediction process using ANN is very promising when compared with the other two methods. The main difference between the neural method and the other two methods is that it requires prior learning to the trajectory before it can be applied to GPS data. To solve this problem a database must be built for the selected trajectories to be used (i.e roads in the city for the moving vehicle). Figures (2), and (3), show the error between the three methods used to extrapolate GPS data for position and velocity with and without GPS error respectively.

5. Conclusions

From the three methods used to extrapolate the GPS data, the following conclusions are drawn:

1. The performance of the standard deviation of the position and velocity components is inversely related with the time required for the extrapolation process.
2. Extrapolation of GPS data with error results in unreliable velocity compared with those obtained when GPS data without error is used.
3. The Newton and Spline methods can work without the need for a previous knowledge of the trajectory while the neural network must be trained on the trajectories to save the network parameters in order to be able to extrapolate the GPS data. This problem can be overcomed by building a database for various trajectories.

6. References

[1] Gerald C., and Patrick W., *Applied Numerical Analysis*, World Student Series Edition, 1984.
[2] Ismaeel S. A., "Design of Kalman Filter of Augmented GPS to INS Systems," *Ph.D. Thesis, Computer Engineering Dept., College of Engineering, Al-Nahrain University*, 2003.
[3] Laura C., "GPS Receiver Analysis," *M.Sc. Thesis, California State University, Electrical Engineering Dept.*, 2001.
[4] Lukman, N., "Low Cost INS-GPS Integration for Navigation (INS Software Implementation)", *Commonwealth of Australia*, 1996.
[5] Mayhew D. M., "Multi-rate Sensor Fusion for GPS Navigation using Kalman Filtering", *M.Sc. Thesis, Virginia Polytechnic Institute and state University, Electrical Engineering Dept.*, 1999.
[6] Wellenhof, B. H., Lichtenegger H., and Collins J., *GPS Theory and Practice*, by Springer-Verlag / Wien, 2001.
[7] Ham F., and Kostanic I., *Principles of Neuro computing for science and Engineering,* McGraw-Hill companies, Inc. 2001.

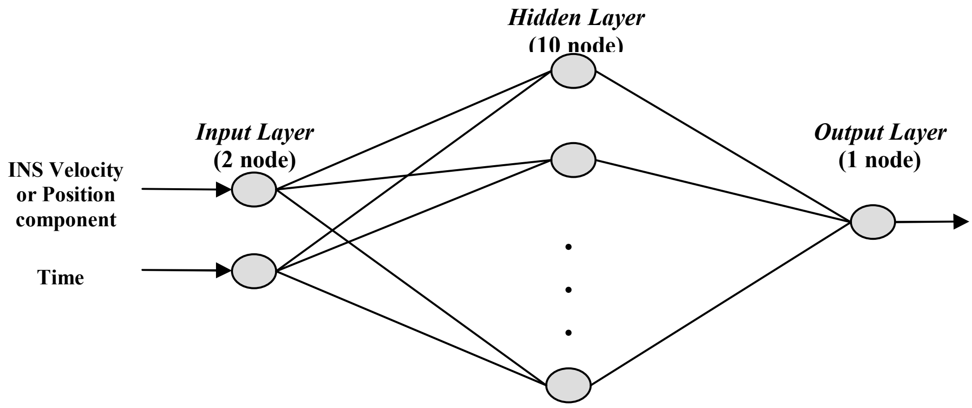

Figure (1): The Architecture of An Artificial Neural Network for each component of position (X, Y, and Z) and velocity (North, East, and Down)

Table (1): Performance of Extrapolation using Newton method

		Position (m)			Velocity (m/s)		
		X-axis	Y-axis	Z-axis	North	East	Down
With GPS error	**STD**	214.33	385.45	279.38	767.70	764.73	766.04
	Mean	462.21	774.94	617.93	-26.31	-20.03	-57.78
	Time elapsed (s)	1.22	1.04	1.03	1.03	1.0510	1.03
	Prediction time (µs)	339	289	286	286	291	286
	Total time (s)	4.69		Total Prediction time (s)		0.0013	
Without GPS error	**STD**	211.39	385.15	277.86	23.17	0.51	16.20
	Mean	462.51	775.24	618.23	1.30	7.57	-30.17
	Time elapsed (s)	0.97	0.96	0.97	0.94	0.85	0.95
	Prediction time (µs)	284	280	283	275	249	278
	Total time (s)	5.42		Total Prediction time (s)		0.0016	

Table (2): Performance of Extrapolation using Spline method

		Position (m)			Velocity (m/s)		
		X-axis	Y-axis	Z-axis	North	East	Down
With GPS error	**STD**	73.88	129.90	96.56	301.41	301.15	301.52
	Mean	147.89	247.44	197.30	-35.64	-33.36	-46.69
	Time elapsed (s)	3.75	3.72	3.87	3.78	3.74	3.72
	Prediction time (s)	0.0010	0.0010	0.0011	0.0011	0.0010	0.0010
	Total time (s)	20.09		Total Prediction time (s)		0.0056	
Without GPS error	**STD**	73.30	133.12	97.52	9.89	0.49	9.39
	Mean	152.42	255.42	203.13	0.22	2.50	-10.62
	Time elapsed (s)	3.62	3.74	3.69	3.72	3.65	3.66
	Prediction time (s)	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
	Total time (s)	19.67		Total Prediction time (s)		0.0055	

Table (3): Performance of Extrapolation using Artificial Neural Network

		Position (m)			Velocity (m/s)		
		X-axis	Y-axis	Z-axis	North	East	Down
With GPS error	**STD**	0.0015	0.0015	0.0068	3.1053e-9	5.2232e-6	3.7759e-5
	Mean	12.94	13.00	14.97	17.78	22.37	22.46
	Time elapsed (s)	105.08	106.55	104.47	46.51	47.72	50.80
	Prediction time (s)	0.02	0.02	0.02	0.01	0.01	0.01
	Mean square error	1.5258e-11	1.2106e-11	1.8465e-11	0.002043	0.00323	0.00046
Without GPS error	**STD (m)**	4.99	0.79	0.10	0.0010	0.0000	0.0012
	Mean (m)	5.08	11.82	10.85	0.02	0.01	1.58
	Time elapsed (s)	4.60	12	6.38	48.60	48.12	48.92
	Prediction time (s)	0.0081	0.02	0.01	0.08	0.08	0.08
	Mean square error	3.4685e-12	9.8997e-12	9.5558e-12	2.1951e-6	6.5249e-9	6.0510e-6

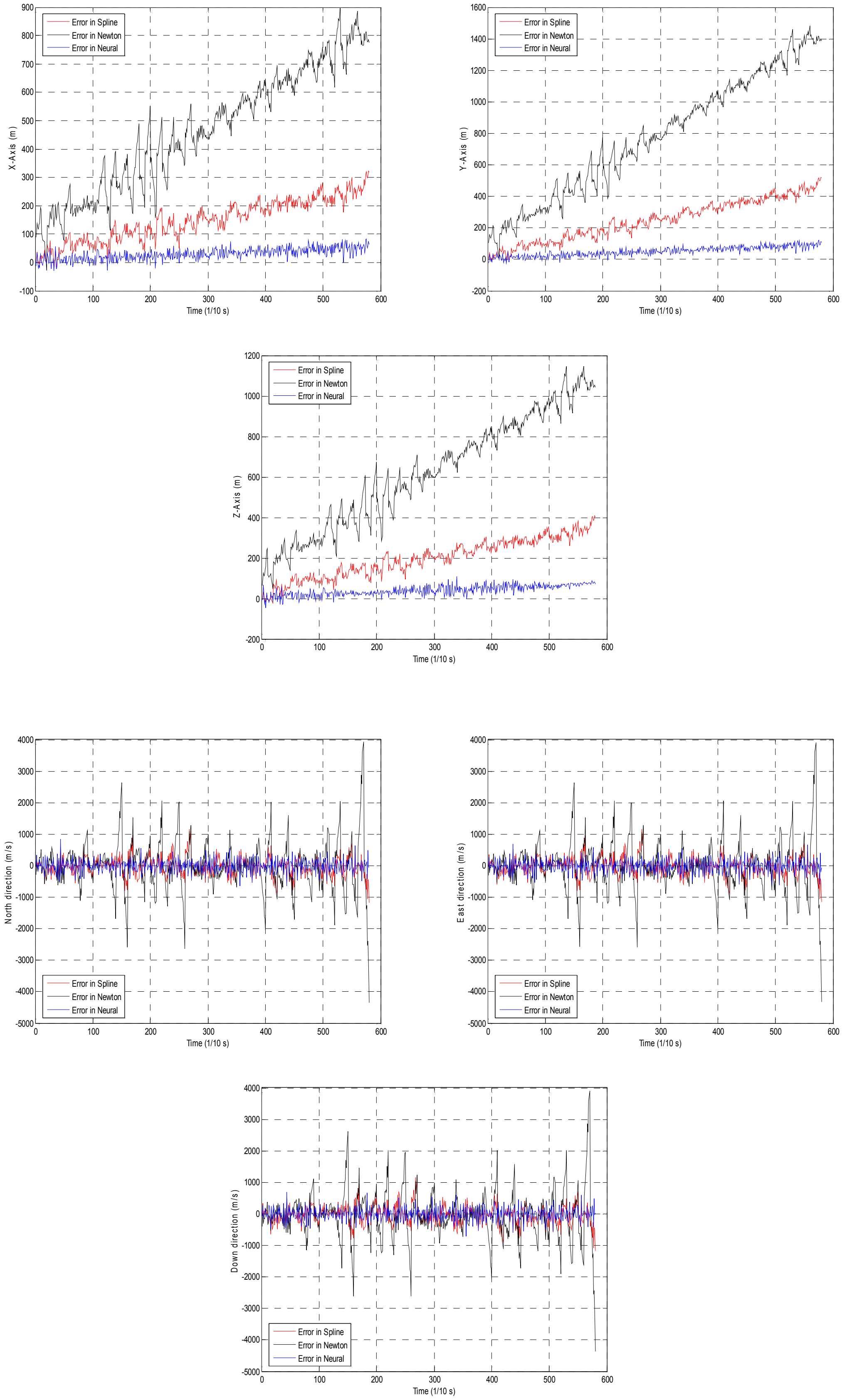

Figure (2): Extrapolation error using different methods with GPS error for Position and Velocity directions.

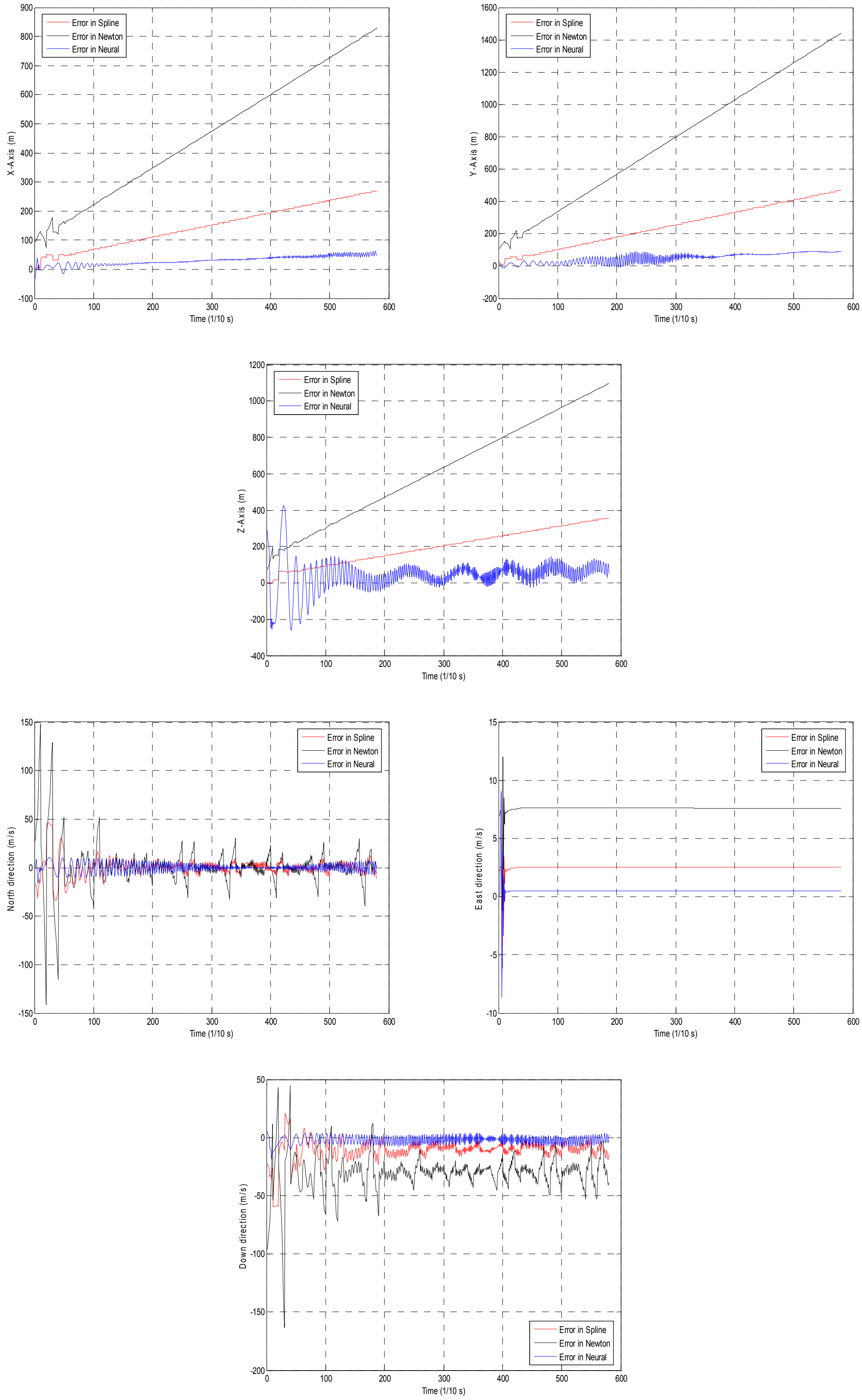

Figure (3): Extrapolation error using different methods without GPS error for Position and Velocity directions.