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DEVELOPMENT OF DATA PROCESSING ALGORITHM TO ESTIMATE UPPER AIR WIND PROFILE USING GPS SONDE

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Abstract

Many researchers over years have proposed many algorithms for differential processing of the GPS Measurements to improve the positional accuracies. DGPS however has certain specific data requirements because of which it is not suitable for this application. Also these algorithms are also very complicated to implement & hence a need for some simpler algorithm to improve the position accuracies was felt. Thus, the main objective of this paper is to develop a data processing algorithm to maximize the position accuracies determined by the GPS, so as to determine the wind speed & wind direction accurately. The positional data from the balloon borne GPS receiver will be taken as input and corrected to improve the position estimation of the balloon. The velocity can then be determined by taking the time differential of the estimated position. The Kalman filtering is used as an optimal estimation method that has been widely applied in dynamic data processing.

Keywords: Kalman filter, GPS, Radiosonde, Air wind profile, Navigation.

1. Introduction

There are two major methodologies to measure upper air wind profiles.

a) Remote sensing

b) In situ measurement

The first technique is based on measuring the pressure, temperature & humidity & then relating the effects to changes in wind profiles. This method heavily depends on RADIOSONDES. Radiosondes are crucial tools in meteorology for gathering data about the atmosphere at various altitudes [1]. As the radiosonde ascends into the atmosphere, it transmits measurements back to a ground station via radio signals. This data helps meteorologists understand weather patterns, track atmospheric conditions, and improve weather forecasting models. The parameters are sent to a ground station through a radio link [2-4]. These parameters are then correlated later to wind profiles. The major disadvantages associated with these methods are

a) The delay

b) Less accurate

The second method is also based on RADIOSONDES. However, in this method the winds are determined directly by measuring the drift of the balloon directly & radiosonde in this case is termed as RAWISONDES [5-7]. This technique has further been classified into three groups

a) Radar based

b) Optical Theodolite based

c) Navigation based

In the first approach, Radar is indeed used to track the flight of weather balloons equipped with radiosondes. The radar can detect the position of the balloon as it ascends through the atmosphere, allowing meteorologists to monitor its trajectory and calculate wind profiles at different altitudes. The radiosonde, equipped with a radio transmitter, is essential for this tracking process, as it enables the radar to detect the balloon's position despite its transparency [8-10]. This combination of radar and radiosonde technology provides valuable data for understanding atmospheric dynamics and improving weather forecasting.

In the second and perhaps one of the earliest methods of the group, the wind profiles are determined by visually or optically tracking the balloon. The balloon is tracked using a telescope. The small optical device measures the elevation & azimuth angles. If the balloons height can be determined its position can be determined by trigonometry. The balloons height is determined by assuming a constant ascension rate of the balloon [11-14]. A variant of this technique known as double Theodolite is still used. The third, and the most evolving method, is based on using some navigation method like LORAN-C (Long Range Navigation) or VLF systems to track the balloon. It is under this method that GLOBAL POSITIONING SYSTEM (GPS), a method based on determining the position using a constellation of 24 satellites, is finding increasing use due to its following advantages over other navigation methods [15-18]:

a) Global Coverage

b) Low cost

c) Ability to work even in urban canyons & in the presence of dense foliage.

d) Ability to provide tracking updates every second so that position can be ascertained in real time.

2. Kalman Filter based approach

The Kalman filter is a powerful mathematical tool used for estimating the state of a dynamic system based on a series of noisy measurements. It's particularly effective for systems that can be modeled with linear equations and subject to Gaussian noise. The filter recursively updates its estimate of the system's state based on new measurements and the system's dynamics, taking into account both the uncertainty in the measurements and the dynamics of the system itself. This makes it widely used in various fields, including aerospace, navigation, and signal processing, for tasks such as tracking objects, controlling systems, and fusing sensor data that is governed by the linear stochastic difference equation

$$x(t+T) = \Phi(T) + w(t)$$

$$Q(t) = E[w(t) + w(t)^T]$$

Where Φ(T) is the state transition matrix for the time interval T, and w(t) is the additive noise component, with a measurement that is

$$y(t) = Hx(t) + v(t)$$

$$R(t) = E[v(t) + v(t)^T]$$

Where H is the measurement matrix and v (t) is the measurement noise.

The model noise covariance matrix Q (t) =E [w(t)w(t)T] is assumed to be known, where Superscript T denotes a matrix transpose and E[ ] denotes statistical expectation. The measurement noise v(t) is assumed to have a known covariance R(t) = E[v(t) v(t)T]. The Kalman filter tries to estimate the state vector $X(t_k)$ at time t = t_k based on measurements y(t) taken at times t = t_n for n = 0,1,.,k. It is a sequential process in the sense that each new measurement updates the previous best estimate $\hat{x}(t_{k-1})$ by processing the new information $y(t_k)$ to form a new estimate $\hat{x}(t_k)$. This is accomplished by forming the innovation $z(t_k)$ as the difference between the actual measurement $y(t_k)$ and a prediction of it based on the previous measurements.

The actual equations for the simple Kalman filter can be written in the form

$$Z_K = y_K - H_K \hat{X}_K \quad \text{Innovation}$$

$$\hat{X}_K = \hat{X}_K + K_K Z_K \quad \text{Estimate}$$

$$\hat{X}_{K+1} = \Phi_K \hat{X}_K \quad \text{Prediction}$$

$$\hat{P}_{K+1} = \Phi_K \hat{P}_K \Phi_K^T + Q_K \quad \text{Prediction}$$

$$\hat{P}_K = [I - K_K H_K] \hat{P}_K \quad \text{Covariance}$$

For simplicity of presentation, the subscript notation $x_k = x(t_k)$ has been used. Here no conditions on the dimensionality of state transition matrix & measurement matrix are imposed.

3. Experiment outcomes and findings

The experiment was performed on the rooftop of the Civil Engineering Department at IIT Bombay. Trimble base station, on the rooftop of the department, was used as reference point.

Table 1.1 GPS base station co-ordinates

Reference Point A	
Latitude	19^0 7’ 57.18317”

Longitude	72^0 54' 57.18317
Altitude (mts)	-3.99816

A Trimble Geo Explorer3 GPS receiver was used as a roving receiver and it was used to collect position data of the GPS points. The distance between the reference station and the GPS points was measured using Trimble total station. In figure 1.1 the line in red color shows the distance estimated by acceleration model and the line in green color shows the distance estimated by Jerk model. Line in black and blue color shows the distance shows the actual distance and distance calculated with erroneous GPS positions respectively. Figure 1.2 below shows the error in distance estimated by both algorithms at every point. It can be seen that for initial 4 GPS points the performance of Jerk model is better however after 4 points acceleration model is superior because data was collected with discrete time interval i.e. not match with present state of art. Figure 1.3 shows the trajectory of the GPS receiver as given by the GPS receiver and as estimated by algorithms. Since, actual positions of GPS points are not known a comparison of trajectories cannot be done.

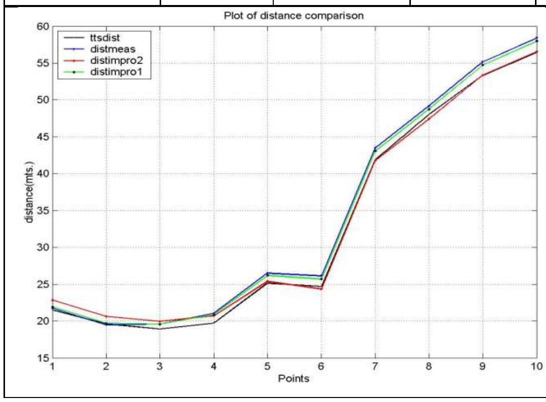
4. Conclusion

It is observed that Jerk model reduces the overall error variance to 1.023 from an initial error variance of 1.724 while acceleration reduces the overall error variance to 0.548 as shown Table 1.1. The average accuracy improvement provided by the Jerk model is 21.27% and the average accuracy improvement provided by acceleration is 68.63%.

Table 1.1: Table of Results

Points	Actual distance from A (mts.)	Distance from A with GPS positions (mts.)	Error with GPS position (mts.)	Distance from A as estimated by algorithm 2(mts.)	Error with algorithm 2	Distance from A as estimated by algorithm 1(mts.)	Error with algorithm 1
1	21.509	21.748	0.239	22.843	1.334	21.928	0.419
2	19.609	19.488	-0.120	20.631	1.022	19.700	0.0091
3	18.910	19.582	0.672	19.968	1.058	19.592	0.682
4	19.723	21.049	1.326	20.713	0.990	20.884	1.169
5	25.152	26.506	1.354	25.392	0.240	26.176	1.0249
6	24.686	26.132	1.447	24.359	-0.325	25.709	1.0243
7	41.905	43.490	1.588	41.774	-0.130	43.068	1.163
8	48.040	49.164	1.124	47.425	-0.614	48.742	0.702
9	53.334	55.171	1.837	53.362	0.0028	54.736	1.402
10	56.454	58.422	1.968	56.539	0.0085	57.975	1.521

Error Variance			**1.724**		**0.548**		**1.023**



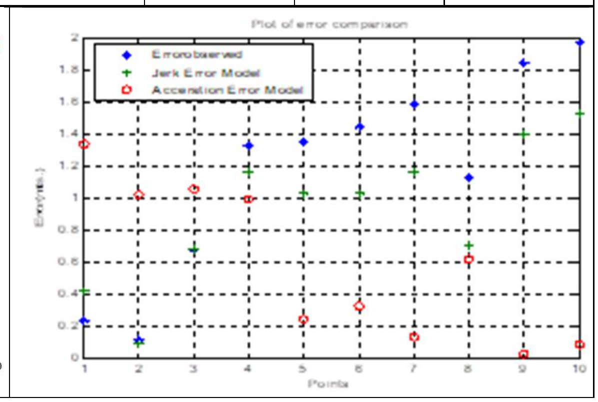


Fig 1.1 Plot of Distance Comparisons **Fig 1.2 Plot of error comparison**

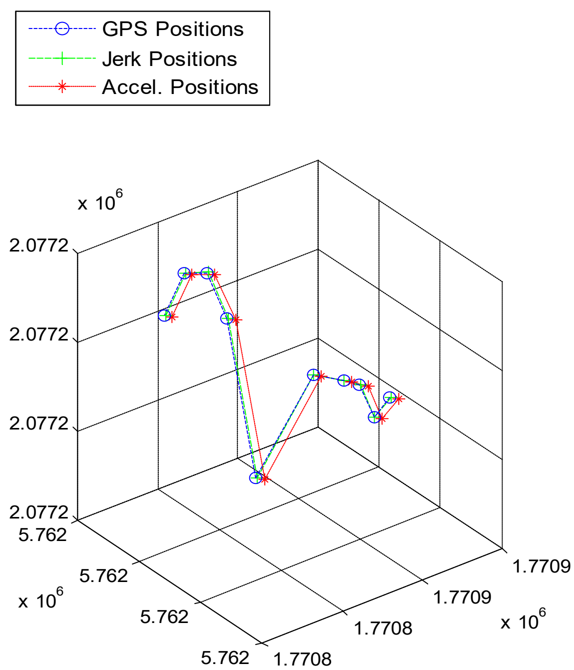


Fig. 1.3 Plot of GPS Receiver Trajectory

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