Hybrid Kalman Filter Design for Inertial Sensor Signal Processing

G Harish Babu, N Venkatram, N Giribabu

Abstract— ***Gyroscope is a rotation rate sensor. Olden days gyroscopes includes mechanical parts like motors, gimbals etc. which has suffered with noises and low accuracy. Developments in fiber optics has made the interferometric FOG practically realizable and reliable compared to mechanical gyroscopes. The fiber optic based gyro results in good stability, high disturbance rejection and ensure good tolerance to noises. Different noises like photon shot noise, quantization noise, filter noise, thermal noise and bias error many other noises degrades the gyro performance. Significant effect of these noise s result in random walk, bias unstability , power fluctuations etc .To overcome these noises denoising of gyro data play a crucial role in FOG. In this study kalman filter algorithm is used to denoise the FOG signal . The algorithm implemented here performs efficiently in both static and dynamic conditions. The existing KF algorithm is hybridized with adaptive moving average based dual gain kalman filter.In this study comparative study is made between different kf algorithms in both static and dynamic condition. In static condition three algorithms KF,ARMA KF & hybrid KF models are used for denoising the gyro data . Among all three algorithms hybrid model is provided to be more efficient. In case of dynamic condition kf algorithm is fails. ARMA model is used to identify the noise but fails in denoising the noise, where as hybrid kf model work efficiently this case. The denoising performance of hybrid model algorithm is validated on single axis FOG and three axis FOG with different input rotation rates.***

Index Terms—Adaptive moving average, auto regressive moving average ,fiber optic gyroscope, kalman filter

I. INTRODUCTION

The fiber optic gyroscope is the most important and critical component in the inertial navigation systems(INS).The gyroscope is a angular rotation sensor. Now a days different types of gyroscopes are available like spinning mass gyroscope ,rate integrating gyroscope ,electro static gyroscope, ring laser gyro scope ,mechanical gyroscope and fiber optic gyroscope. The fiber optic gyroscopes are preferred due to their low cost and high accuracy[1].It is works on the principle of sagnac effect. In inertial navigation system the accuracy and reliable measurement calculations is most important. In the bias test the angular rotation rate is fixed in static position and the measured data by FOG is noisy. This is due to measurement noise and noises due to optics and electronic.

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In static condition the algorithms like discrete wavelet transform (DWT) and kalman filer successfully denoise the fiber optic gyroscope signal. In the dynamic condition giving different angular rotation to FOG it describes random movement of the object[2]. In dynamic condition of fiber optic gyroscope bias drift and response rates are measured metrics for denoising algorithm .In case of dynamic condition the kalman filter and discrete wavelet transform algorithm is fails to denoise the fiber optic gyroscope signal properly. There is no single algorithm is available to denoise the signal in both static and dynamic condition fiber optic gyroscope.

II. KALMAN FILTER

kalman filtering is a basic linear unbiased estimator. It is a recursive algorithm used for filtering the signal in navigation system and other applications[3] .It is a recursive predictive filter based on the use of state space techniques and recursive algorithms. To improve the estimated state the kalman filter uses measurements that are related to the state[4]. This algorithm is eliminates random noises and errors using the knowledge about the state-space representation of system and uncertainties in the process: the measurement noise and process noise. The kalman filter assumes the state of a system at time k evolved from the prior state k-1 according to the equation

$$x_k = Ax_{k-1} + Bu_k + w_k \quad (1)$$

$$z_k = Hx_k + v_k \quad (2)$$

Where

x_k is the state vector at time k,

u_k is the optional control input at time k,

w_k is the process noise at time k,

v_k is the measurement noise at time k,

z_k is the measurement taken at time k,

A is the State transition matrix which applies the effect of each system state parameter at time k-1 on system state at time k,

B is the Control input matrix which applies the effect of each control input parameter in the u_k on the state,

H is the Transformation matrix that maps the state parameter into the measurement domain,

The kalman filter has two stages:

1. Time update equations
2. Measurement update equations

The kalman filter time update equations are defined as

$$\hat{x}_k^- = A\hat{x}_{k-1}^- + Bu_k \quad (3)$$

$$P_k^- = P_{k-1}^- A^T + Q_k \quad (4)$$

The above two equations are used to predict the current state vector and error covariance matrix before taking the new

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measurement.

The kalman filter measurement update equations are

$$K_k = P_k^- H^T (H P_k^- H^T + R_k)^{-1} \quad (5)$$

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - H \hat{x}_k^-) \quad (6)$$

$$P_k = (I - K_k H) P_k^- \quad (7)$$

These equations correct the predict values after calculating the gain K_k.

III. PROPOSED ALGORITHM (AMADGKF)

The propose algorithm is used to denoise the FOG signal in both static and dynamic condition. In this proposed algorithm has two gains, one gain is used to when the fiber optic gyroscope is stationary and other when the fiber optic gyroscope in dynamic condition(rotation rates). This algorithm has two phases 1) In the first stage finding the discontinuities in a single frame of the signal. 2) In the second stage filtering the signal with in the frame with kalman filter.

The implementation steps of the proposed algorithm is given below

1.consider N=1024 number of samples as one frame.

2. A q=10,q point simple moving average filter technique is used to suppress the noise in the signal. The denoised output is

$$y_t = \frac{1}{2q+1} \sum_{j=-q}^{q} x_{i+j} \quad (8)$$

Where 2q+1 is the moving average window length, y represents the denoised output data, x represents the input data.

3.This AMA technique is can be iterated by giving output as input for next iteration.

$$Y_t = \frac{1}{q_H(t) + q_T(t)} \sum_{i=-q_T(t)}^{q_H(t)} X_{t+i} \quad (9)$$

$$q_H(t) = \begin{cases} q, & if\ S'(t) < 0 \\ f(S(t))q, & if\ S'(t) \geq 0 \end{cases} \quad (10)$$

$$q_T(t) = \begin{cases} q, & if\ S'(t) > 0 \\ f(S(t))q, & if\ S'(t) \leq 0 \end{cases} \quad (11)$$

$$f(S(t)) = 1 - \frac{S(t)}{max(S(t))} \quad (12)$$

$$S(t) = |Z(t+q) - Z(t-q)| \quad (13)$$

$$S'(t) = S(t+1) - S(t) \quad (14)$$

4.Iteratively obtain the values of q_H *and* q_1 by giving the AMA filter output as input.

5.For obtaining the discontinuity locations the sample variances will be compared with a threshold value (λ) . The variance of the sample s is given as

$$\hat{\sigma}_t^2 = \frac{\sum_{i=q_T}^{q_H} \{Y_i - \bar{Y}_t\}^2}{q_T + q_H} \quad (15)$$

6. The threshold (λ) as 95 % of the upper tail of the exponential distribution with the expected value of the exponential distribution as the mean of the above calculated sample variance of the present frame.

7. Obtain discontinuity locations

$$\tau_i = t | \hat{\sigma}_t^2 > \lambda \quad (16)$$

Where t= 2q+1,2q+2,……N-2q-1.

8.If the number of discontinuity locations obtained it is smaller than one ,then it implies that there is no discontinuity in the present frame. Denoise the samples of frame using kalman filter with gain k1.The denoising of the current frame is completed and stops the process. 9.otherwise find the successive discontinuity locations. 10. Denoising the samples from starting location of the first discontinuity of the signal to ending location of the last discontinuity region of the signal using kalman filter with gain K2 .The remaining non discontinuity region filtered with kalman filter with gain K1. 11.iterate all the above steps for each frame.

IV. EXPERIMENTAL SETUP

The experimental data we are taken from the single axis closed loop gyroscope for analysis and testing. The data in the static condition for half an hour duration in a rate table with sampling frequency 400 hz at room temperature. In case of dynamic condition were apply different rotations with help of rate table ± 10 deg/sec and random rotations also .The kalman filter algorithm fails to denoise the signal in dynamic condition.

V. RESULTS

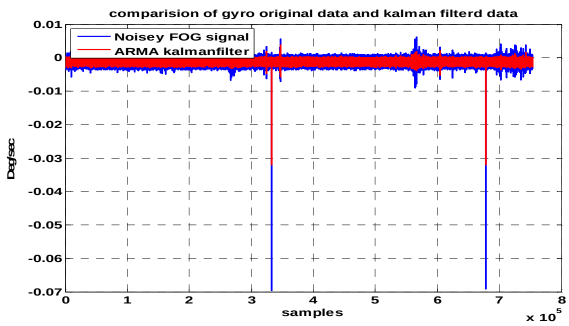

Fig1 :- denoising of the FOG signal in static condition with ARMA model KF

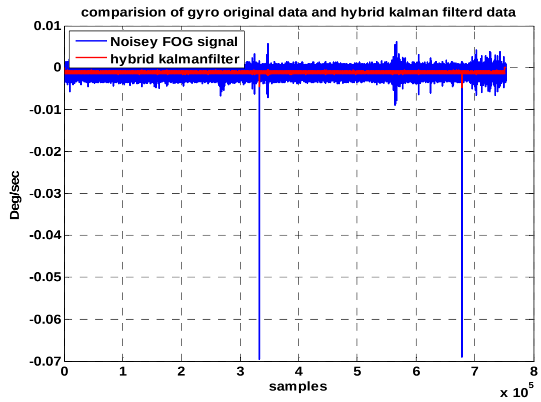

FIG2:-denoising of the FOG signal in static condition with hybrid kf

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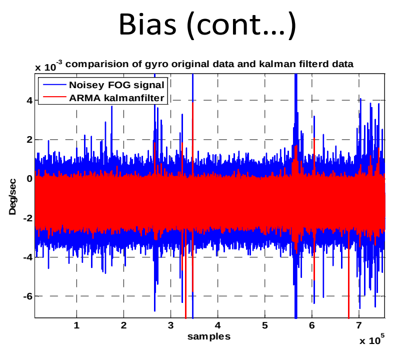

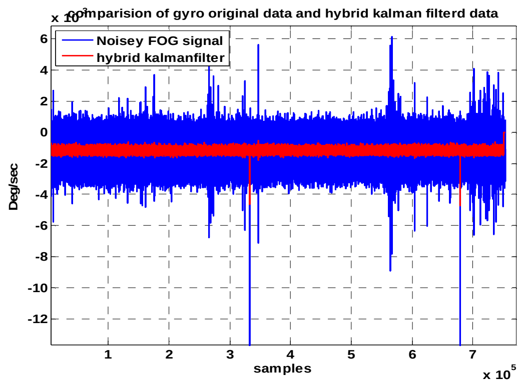

FIG3:-comaprision of noise reduction in ARMA model kf with Hvbrid kf when static condition gyro

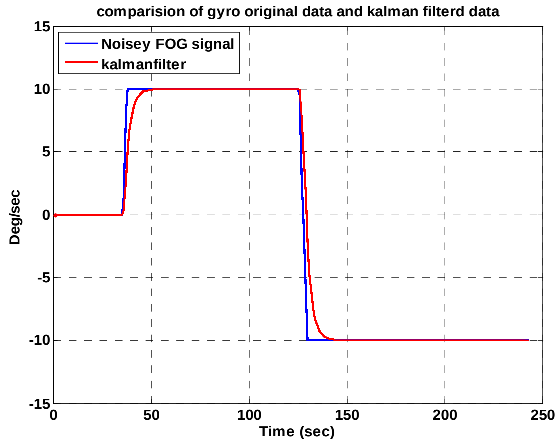

FIG 4:-denoising of gyro data in dynamic condition at double discontinuity with kalman filter

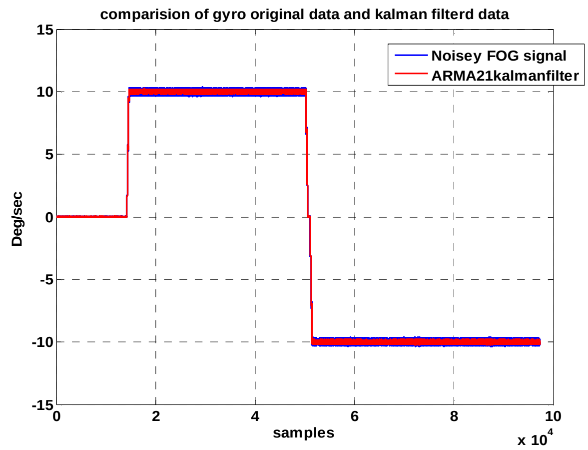

FIG 5-denoising of gyro data in dynamic condition at double discontinuity with ARMA model kalman filter

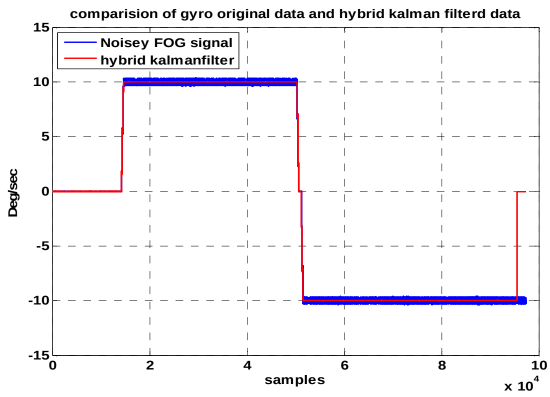

FIG 6-denoising of gyro data in dynamic condition at double discontinuity with hybrid kalman filter

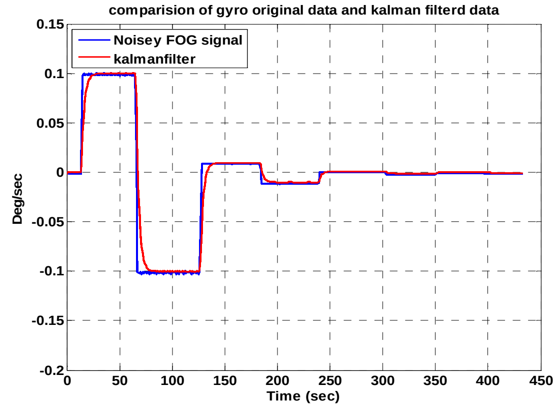

FIG 7:-denoising of gyro data in dynamic condition at mutiple discontinuity with kalman filter

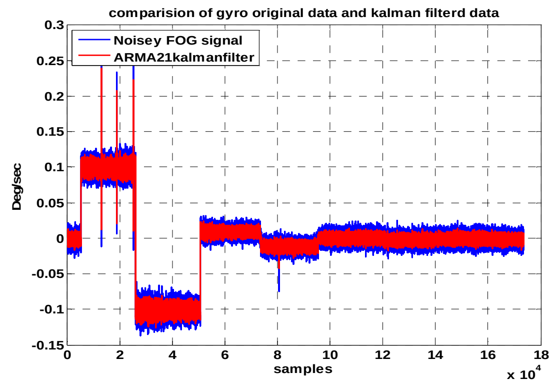

FIG 8:-denoising of gyro data in dynamic condition at mutiple discontinuity with ARMA model kalman filter

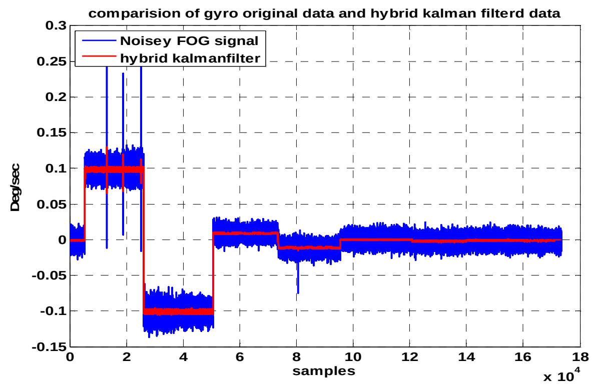

FIG 9:-denoising of gyro data in dynamic condition at mutiple discontinuity with hybrid kalman filter.

VI. CONCLUSION

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In this paper a hybrid kalman filter based on the adaptive moving average dual gain technique is proposed and used to denoise the fiber optic gyroscope signal in both static and dynamic conditions for single axis and three axis fiber optic gyroscope or IMU(inertial measurement unit). The performance of the proposed algorithm is with the ARMA (Auto regressive moving average) model kalman filter and standard kalman filter. The future work involves to test the system in online environments like in a single fpga board.

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