Defence Science Journal, Vol. 63, No. 2, March 2013, pp. 204-209, DOI: 10.14429/dsj.63.4265

RESEARCH PAPER

Approximation and Filtering Techniques for Navigation Data in Time-critical Electronic Warfare Systems

Vanitha D.* and Kundhavai R.M.

Defence Avionics Research Establishment, Bangalore– 560 093, India
**E-mail: vanitha@dare.drdo.in*

ABSTRACT

This paper presents a holistic solution to the navigation requirements in a time critical electronic warfare systems like missile warning systems (MWS). In a passive MWS using IR sensors the efficiency of the system is determined by attributes such as low false alarm rate, minimal response time and ability to track different IR radiating objects by association and correlation of consecutive detections through time. Such a system is required to be supported by a navigation system capable of accurate estimation of the aircraft position, attitude angles and altitude. In this paper, estimation techniques used to accurately calculate aircraft navigation data at the time of capture of IR frames are discussed. The paper discusses about synchronization of INGPS, IR sensors & Processor on to same timeline. The paper also intends to evaluate the performance of wavelet transform filter in effective elimination of noise in navigation parameters like acceleration and attitude angle rates for a better estimation of position and attitude.

Keywords: Missile warning systems, electronic warfare systems, electronic warfare

1. INTRODUCTION

Missile warning system (MWS) provides a key element in advanced self protection systems (SPS) for fighter aircraft, helicopter, transports and commercial aircraft. Pulse Doppler based missile warning system is an active MWS that works on a pulse Doppler radar system capable of detecting a target 3D location and its radial velocity. While it can measure distance and speed of approaching missile and determine the time to impact, the disadvantages are that active systems could compromise the aircraft's presence and increase its vulnerability. Also, detection range of small missiles with low radar cross section like MANPADS is limited and could result in marginal warning time and consequent late decoy dispensing[5]. UV-based and IR-based missile warning systems are the two types by passive missile warning systems. An ideal spectral band for passive missile warning system provides high missile signature, low scattered solar radiation, low natural background, good atmospheric transmission and mature technology. The advantages of IR MWS when compared to UV MWS include reasonable transmission for effective MANPAD condition, low attenuation and scattering, wider detection range and protected zone and more accurate direction finding. The main drawback of IR MAWS is the high solar clutter whereas UV MWS operates in solar blind UV spectral wavelength region and therefore has no natural (sun) false alarms. UV-based MAW systems therefore have a much reduced false alarm problem to solve compared to IR-based systems.

Dual colour missile warning system utilizes two spectral bands in the medium IR. The system's operation concept is based on the unique radiation spectral characteristics of a solid fuel motor, relative to sun reflection and ground clutter radiation. MWS detects and tracks an incoming missile's hot plume as it appears within a protective sphere surrounding the aircraft. The MWS system discriminates between threatening and non-threatening missiles, by evaluating the missile's trajectories.

The DCMWS includes dual colored electro-optical sensors mounted on the envelope of the aircraft, to provide spatial coverage in accordance with requirements, and a system processor. The sensor performs field of view imaging in a narrow spectral window in the medium infrared (IR) band, and sends a digital output of the signal of each pixel to the processor. The processor detects point source targets and rejects background clutter by spatial filtering and adaptive threshold. It also rejects random detection via a tracking algorithm, and distinguishes between threats and false targets by analyzing and comparing the parameters measured for each target with the specific characteristics of the threats in regard to motion and time. The System alerts the pilot of the existence of a threat and applies countermeasures.

2. INTEGRATED INS/GPS

The frames recorded by the electro – optical sensors need to be associated with the navigation data at the time of recording.

An integrated INS/GPS refers to the use of GPS

Received 14 September 2012, revised 08 February 2013, online published 23 March 2013

satellite signals to correct or calibrate a solution from an INS. This gives optimal hybrid navigation solution by the means of a statistical Kalman filter. It uses all the information available from various sensors like internal inertial sensor, external barometric sensor which provides pressure altitude and embedded GPS receiver. These parameters are blended into INS/GPS to compute an optimal navigation solution taking the benefit of the various sensors' characteristics. Barometric altitude external input shall be used in addition to the GPS data for hybridization with the inertial sensors to compute hybrid altitude. If pressure altitude input is invalid, hybridization will be achieved using GPS only.

When the INS/GPS is detected as being immobile, zero – velocity update is applied automatically to the navigation computation. This update supersedes any other observation especially GPS data, as long as the INS/GPS remains motionless. Zero velocity updates are irreversibly disabled once the aircraft takes off.

The 'GPS hybridization status' flag indicates whether hybridization with the GPS is active or not. During alignment or while immobile on the ground, before takeoff, GPS hybridization shall be shown as inactive, while superseded by zero velocity updates.

In addition, a figure of merit shall be made available on the 1553B bus to provide a quality factor giving the error range for the computed horizontal position (HYB_HFOM) and altitude (HYB_VFOM). These figures of merit, integer value between 1 and 9, shall be based on the error estimated by the Kalman filter on computed hybrid present position, and altitude.

3. IMPORTANCE OF NAVIGATION DATA IN IR FRAMES PROCESSING

Detections from the same source are associated over time to define a track. The track thus declared is subjected to discrimination algorithms and declared as a threat or rejected as a false alarm. The performance of the system is dependent on associating different detections in different frames. The navigation system provides the data to estimate the position of detection in the subsequent frame. The detections appearing at a distance lesser than a threshold value from estimation is considered to be from the same source. The accuracy of the estimation is dependent on the accuracy of the navigation system.

4. DESIGN OF NAVIGATION MODULE

DCMWS- Processor, IR Sensors and INGPS are independent systems working autonomously. Computation of INGPS occurs at a rate of 100 Hz. Data is transmitted over 1553B bus at 50 Hz rate. DCMWS transmits a discrete signal at 120 Hz. Sensors sample on receiving this synchronizing signal. The time at which this signal is generated is the reference for which navigation data is approximated in DCMWS. Since the processing of the frames happens approximately every 8.3 ms. The response time between the detection of a threat and time of impact needs to be higher than the minimum value of 1 s. These factors make the system a highly time critical system.

To use time accurate navigation data in the processing of IR image, it is required to work on common clock for all three systems. Processor and INGPS are connected via Mil-Std1553. These two systems are synchronized using 1553B protocol. IR sensors and processor are connected via fiber link and RS422 and discrete links. These systems are synchronized using discrete link.

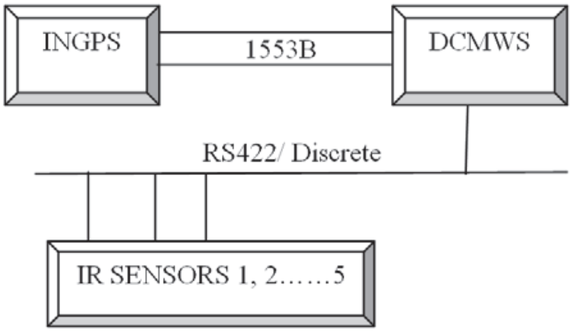

Figure 1. Interconnection Diagram of INGPS & DCMWS.

To synchronize DCMWS and INGPS to a common reference clock using Mil-std 1553B protocol, i.e. sync with mode-code message is used. This message would first synchronize INGPS and 1553B controller of DCMWS-Processor and then in turn system clock of processor. System-time is the reference clock for all the modules of DCMWS (processor and IR sensors). Data latency of INGPS data has to be computed in system-time reference to be usable by image processing modules. The expression for getting 'age of navigation data' or 'data latency of navigation data' in terms of system-time is as explained below. Frame time is the system-time of the IR frame from the IR sensors.

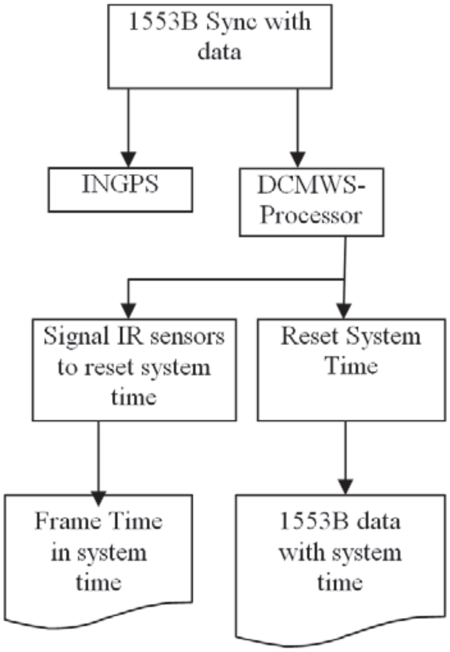

Figure 2. Synchronization process for system time and 1553B time-tag.

Data latency = Frame msg time (System time) - System time of navigation msg from INGPS

The navigation module has to provide navigation data corresponding to the capture time of IR frame images. This can be achieved by interpolating or extrapolating the raw navigation data to the system-time corresponding to IR frame. It is necessary that navigation system and DCMWS-Processor are synchronized to the same clock.

Navigation data is time-stamped by the INGPS with 1553B time-tag at the instant of validity of physical event. The system time for the same is calculated by subtracting the time interval between the 1553B time of reception and 1553B time-tag value from the system time at the time of reception. Thus navigation data is tagged with system time tag which is the time of instant of validity of the physical event. The frame time is compared with the time tags in the navigation data.

Interpolation is used when one navigation message which has a time tag smaller and a second navigation message has a time tag bigger than the frame time received. In this case, the navigation data received from both navigation messages is interpolated in order to get navigation data for the specific requested time.

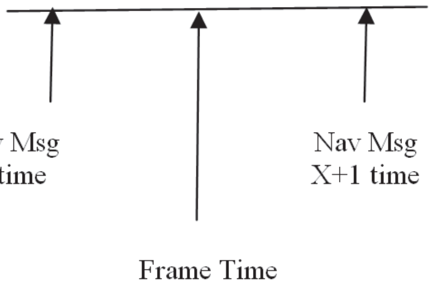

Figure 3. Interpolation of navigation data.

Extrapolation is used when there is only one relevant navigation message. In this case, the navigation data received from the navigation message is extrapolated in order to get navigation data for the specific requested time.

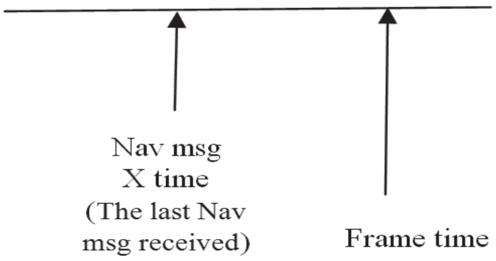

Figure 4. Extrapolation of navigation data.

5. INTERPOLATION

Lagrange's interpolation, a linear interpolation is used to find approximate values of a function *f(x)* for an *x* between different x-values x_0 , x_1,…., x_n at which the values *f*(*x*) are given. Linear interpolation is interpolation by the straight line through $(x_0,f_0),(x_1,f_1)$.Thus Lagrange polynomial p_1 is a sum

$$P_1 = L_0 f_0 + L_1 f_1 \qquad (1)$$

With L_0 the linear polynomial that is 1 at x_0 and 0 at x_1; Similarly, L_1 is 0 at x_0 and 1 at x_1.Thus

$$L_o = (x-x_1)/(x_1-x_2) \qquad (2)$$

$$L_1 = (x-x_1)/(x_2-x_1) \qquad (3)$$

For a platform with high maneuverability, which has navigation system with high computation and transfer rates, linear interpolation yields more accurate approximations compared to quadratic or higher order interpolations that use data across a longer time span.

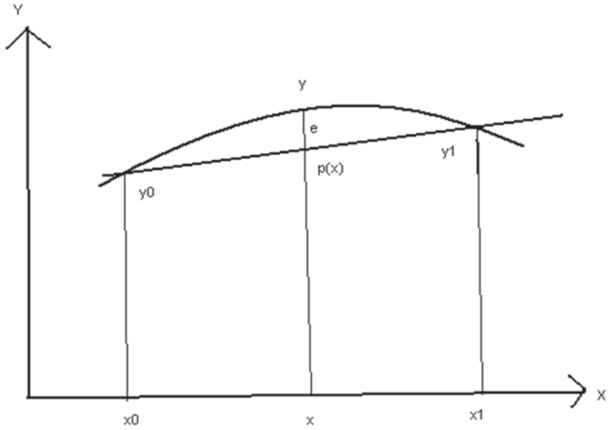

Figure 5. Linear interpolation.

6. EXTRAPOLATION

The attitude angles, velocity and position are approximated using attitude angle rates, acceleration and velocity respectively. The formulae for the same are given below. The data needs to be checked to identify stale data. If INGPS fails extrapolation is done using the most recent data. However there is a limit for the age of data to be used for extrapolation. On crossing this limit, the data cannot be used in which case INGPS failure is reported. Extrapolation gives more accurate approximations in stable flight scenario than when there are high maneuvers.

The attitude (Euler) angles are estimated by integrating the angular rate components over the data latency time with the received angles as initial values. Since the received angular rates are body rates they should be transformed to get the Euler angle rates, which will be used to estimate Euler angles.

$$\text{ESTIMATED\_ROLL} = \text{ROLL} + (\text{EulerAngularRate\_RollRate} * \Delta t) \qquad (4)$$

$$\text{ESTIMATED \_PITCH} = \text{PITCH} + (\text{EulerAngularRate\_PitchRate} * \Delta t) \qquad (5)$$

$$\text{ESTIMATED\_THEAD} = \text{THEAD} + (\text{EulerAngularRate\_HeadingRate} * \Delta t) \qquad (6)$$

The velocity components are estimated by integrating the acceleration components over the data latency time with the received velocities as initial values. Since the acceleration components are in body frame and velocity components obtained from INGPS are in inertial frame, the acceleration components have to be first transformed into inertial frame and integrated.

ESTIMATED_VNORTH =INGS_VNORTH +

(AccelerationComponent_North * Δt) (7)
ESTIMATED _VEAST =INGS_VEAST +
(AccelerationComponent_East * Δt) (8)
ESTIMATED _VUP =INGS_VUP+
(-AccelerationComponent_Down*Δt) (9)

The latitude and longitude components are estimated by integrating the velocity components over the data latency time with the received latitude and longitude as initial values

ESTIMATED _LATITUDE = INGS_LAT +
(ESTIMATED_VNORTH/RADIUS_OF_EARTH) (10)
ESTIMATED_LONGITUDE = INGS_LONG +
(ESTIMATED _VEAST/(RADIUS_OF_EARTH*
cos(ESTIMATED_LATITUDE))) (11)

7. WAVELET TRANSFORM FILTER FOR NOISE ELIMINATION

An inertial navigation system propagates two types of errors : deterministic and statistical. Even though the INS is a precision system , the deterministic and statistical errors will eventually dominate, and the navigation output will become useless. The errors are caused by hardware component biases and scale factors, permanent misalignments of the sensors causing errors in reference frame orientation, temperature and gravity anomalies and initial condition errors. Kalman filtering is a widely used estimation technique for integrated INS/GPS systems. However, Kalman filtering requires a dynamic model for both INS and GPS errors because it is usually difficult to set a certain stochastic model for each initial sensor, that works efficiently in all environments and reflects the long term behavior of sensor errors. In addition, there are several significant drawbacks such as sensor dependency, linearization dependency and observability[4]. Wavelet de-noising is effective in reducing unpredictable, short–term errors in navigation data.

Wavelet analysis exposes trends, breakdown points, discontinuities in higher derivatives, and self-similarity in the data. Wavelet analysis can often compress or de-noise a signal without appreciable degradation because of its different view of data. It transforms the data from a space–time domain to space–time–frequency domain.

Wavelet transforms are multi-resolution representations of signal and images. They decompose signals and images into multi-scale details[1].The basic functions used in wavelet transforms are locally supported; they are non zero only over part of the domain represented.

Wavelet transform filter is capable of preserving the sharp edges in data which makes it more suitable for navigation data. The filters we are exploring pass essentially all the signal at large scales. The signal at small scales is passed if it is around an identified edge; it is eliminated as noise if it is not around an identified edge. Because most noise power is confined to small scales, the reduction of signal at small scales reduces noise preferentially. However, to keep edges sharp, small-scale information is required. By passing small-scale data around identified edges, noise is reduced, and the identified edges stay sharp. The key to this technique is to identify edges. Edges are identified as features that have signal peaks across many scales. The noise in the navigation data is eliminated while preserving the edges due to sharp maneuvers.

Windowed Wavelet Transform reduces process time. The size of the window needs to be determined according to the nature of the platform. For larger and less agile platforms the window size is greater than the window size for highly maneuverable platforms like fighter aircrafts. A major advantage of this method is the ability to perform local analysis.

8. RESULTS

Navigation data generated in an interval of 20 ms by an integrated INS/GPS system was used to experiment with approximation techniques. Linear Interpolation is applied to approximate attitude angles, velocity and position at 8 ms interval. The approximated data thus generated has higher correlation with the original data compared to the data generated by quadratic interpolation and higher order interpolation techniques.

Wavelet transform filter was applied to the recorded navigation data samples. It can be inferred that the sharp edges in the roll rate and acceleration are retained in the approximation coefficients. The effectiveness of this technique is dependent on selecting the optimum parameters for the wavelet algorithm such as a suitable wavelet filter and optimum threshold selection rule. For optimum results wavelet parameters need to be selected for navigation parameters separately. Extracting the INS error is absolutely dependent upon the mother wavelet function, the order of the mother wavelet function, the suitable threshold selection rule, and appropriate level of decomposition. In INS/GPS error estimation, identifying the optimal mother wavelet function and its order with the best thresholding select rule and the level of decomposition are often selected empirically (trial and error)[4]. The following table shows the difference in standard deviation for different parameters when wavelet transform filter is applied using different wavelets.

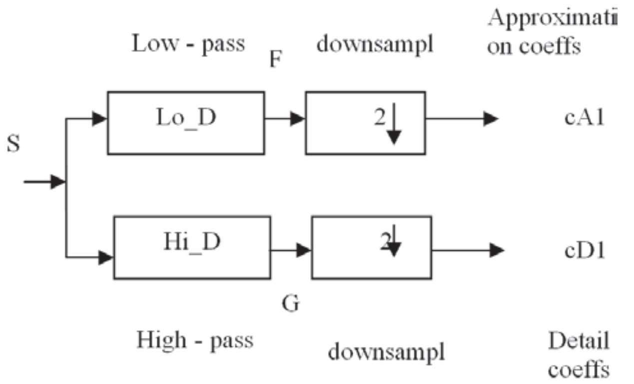

Figure 6. Wavelet transform filter.

Table 1. Wavelet transform filter

Nav data	Standard deviation	Wavelet name	Standard deviation
		Haar	0.1789
Acceleration X	0.1559	Db1	0.1789
		Db2	0.1895
		Haar	0.4456
Acceleration Z	0.3599	Db1	0.4456
		Db2	0.4421
		Haar	0.2450
Acceleration Y	0.2397	Db1	0.2450
		Db2	0.2513
		Haar	0.4468
Velocity north	0.3144	Db1	0.4468
		Db2	0.4555
		Haar	0.7370
Velocity east	0.5186	Db1	0.7370
		Db2	0.7511
		Haar	0.0855
Velocity up	0.0602	Db1	0.7370
		Db2	0.7511

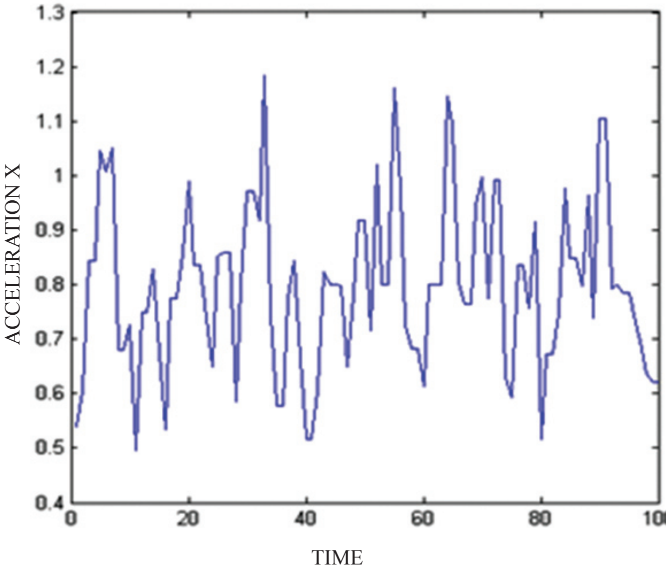

Figure 7. Raw data – acceleration X.

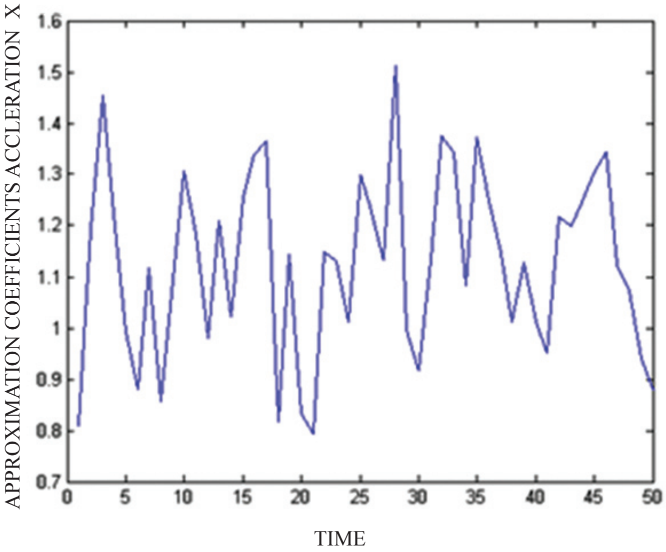

Figure 8. Approximation coefficients after wavelet transform filter -Acceleration X.

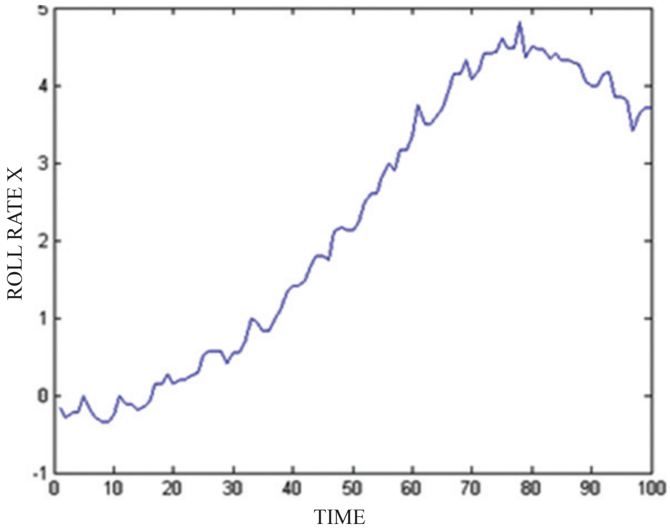

Figure 9. Raw data – Roll rate X.

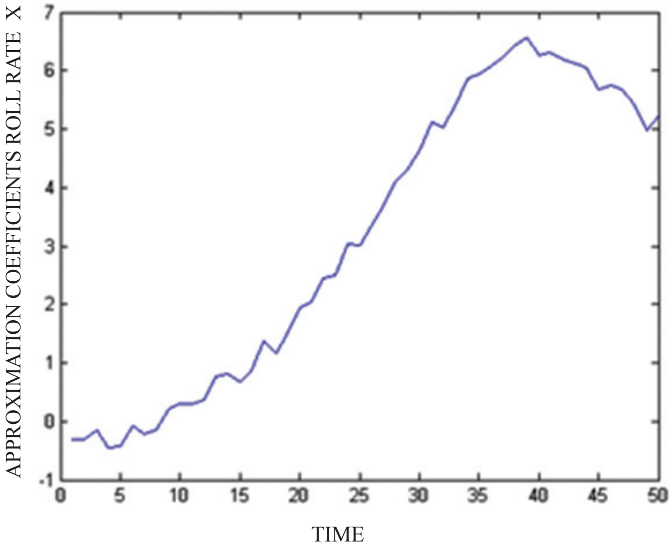

Figure 10. Approximation coefficients – Roll rate X.

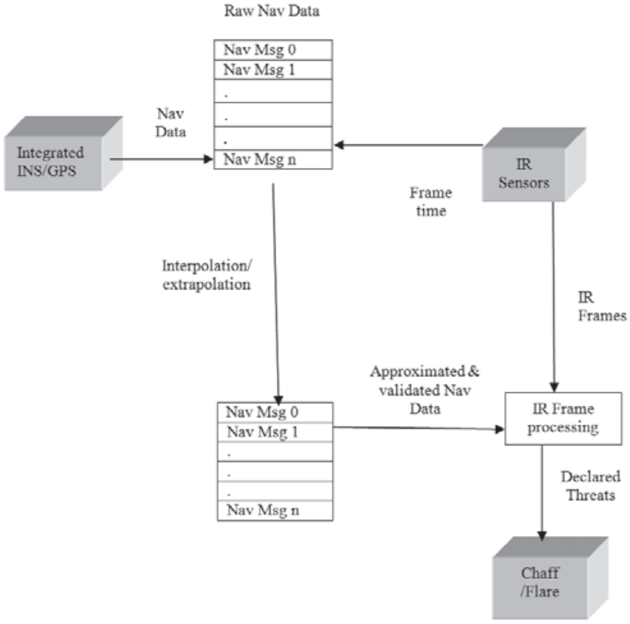

Figure 11. Design of navigation module.

9. CONCLUSIONS

In this paper we proposed a design for navigation module for a time critical electronic warfare system like Missile warning systems to decrease the false alarm rate and process time. In a highly maneuverable platform the sharp edges in the navigation data need to be distinguished from noise. Wavelet transform filter is proposed for eliminating high frequency noise in navigation data for more accurate estimation of position and attitude angles. An IR-based missile warning system aims at identifying the unique radiation spectral characteristics of a solid fuel motor, relative to sun reflection and ground clutter radiation. The processor eliminates the background clutter by temporal filtering and adaptive thresholding. Temporal filtering enhances the sensitivity of the system since there is a high correlation between pixel values in time domain. The accuracy of this module in terms of effective elimination of background and identification of possible detections is dependent on the accuracy of the navigation system in estimating the navigation data for each frame. Tracking and discrimination involve combining detections into tracks through time, and analyzing tracks to decide whether these tracks are threatening missiles or not. An important criterion for discriminating between a threat and a false detection is to ascertain if it corresponds to a moving target. This can be achieved by comparing the platform motion with the transformation of the track across frames. Thus the estimation of navigation data at the time of capture of IR images is one of the most important factors in determining the accuracy of the system.

ACKNOWLEDGEMENTS

We thank Shri PM Soundar Rajan, Outstanding Scientist & Director DARE and Ms Mini Cherian, Sc ‘F’, Group Director, Software and Firmware Group, DARE for their guidance and support. We thank Wg Cdr. Senthil Kumar for his valuable inputs and Ms. R. Anand Raji, Sc ‘E’, DARE for reviewing the paper.

REFERENCES

1. Xu, Yansun; Weaver, John B.; Healy, Jr., Dennis M. & Lu, Jian. Wavelet transform domain filters: A spatially selective noise filtration technique. *IEEE Trans. Image Proces.*, 1994, **3**(6), 747 - 758.
2. DiFilippo, David J. & Campbell, Lori L. Design and implementation of a tracking algorithm for active missile approach warning systems. Canadian Conference on Electrical and Computer Engineering, Airborne Radar & Navigation Sect., Defense Res. Establ., Ottawa, Ont., Canada, 1995. **2**, pp. 756 - 759
3. An, P.E.; Healey, A.J.; Park, J. & Smith, S.M. Asynchronous data fusion for AUV navigation via heuristic fuzzy filtering techniques. MTS/IEEE conference proceedings, OCEANS ’97. 1997, **1**, pp. 397 - 402.
4. Hasan, Ahmed Mudheher; Samsudin, Khairulmizam & Ramli, Abd Rahman. Intelligently tuned wavelet parameters for GPS/INS error estimation.*Int. J. Automation Computing,* 2011, **8**(4), 411-20.
5. Missile approach warning –Wikipedia, the free encyclopedia (http://en.wikipedia.org/wiki/Missile_Approach_Warning), (accessed on 12-03-2013).

Contributions

Ms D. Vanitha completed her MSc (Computer Science) from Mysore University, Mysore. Currently she is working as Sc ‘E’ in the Technical Team Lead and Software Project Manager in the Software & Firmware Group of Defence Avionics Research Establishment, DRDO, Bangalore. Currently she is working in the area of radar warning receiver controller, aircraft interfaces, pre-flight message data definition, etc. She has specialization in the real time embedded systems, software development processes and standards, etc.

Ms Kundhavai RM completed her BE (Comp. Sc. Engg.) from Madras Institute of Technology, Anna University. Currently she is working as Sc ‘B’ in the Software and Firmware Group in Defence Avionics Research Establishment, Bangalore. She has the development of application software for head-up display, digital map generator and navigation system interfaces.