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REVIEW ARTICLE

Sensor Fusion Techniques Using Extended Kalman Filter

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Abstract This paper discusses the marine sensor systems, its management and their relationships with the Fusion System and the coordination among these systems. Further it elaborates the need of the Fusion System for Sonar using the Kalman filters. Special emphases are put on system development considerations, especially on the unique requirements for submarines. It is very complicated and needs the fusion techniques in their own information processing. In sonar imaging the position and orientation divergence is of immense apprehension. Unknown motions can blur the reconstructed image and degrade image quality considerably. A quaternion type Extended Kalman filter is given based on a total state space model to fuse the data in sonar imaging applications. Considering the high sensitivity of imaging technique to sonar deviation, this research investigates a navigation solution. The conceptual view and architecture is demonstrated in this proposal to verify the capability of the sensor fusion strategy.

Keywords: sensor fusion, kalman filter, sonar, processing

I. INTRODUCTION

The data fusion provides effective presentation and intelligible output, which is functionally greater than the sum of its parts. Sensor fusion is a method to integrate the data provided by various sensors, in order to obtain the best estimate for a dynamic system's states. The strength of one type of sensors should be able to cope with the weakness of another type of sensors through proper selection and thus sensor data sources can be combined to produce more accurate information. The hybridization of sensors is known as sensor fusion [1]. Its algorithms are particularly useful in submarine applications, where acceptable performance and reliability is desired in a given limited set of inexpensive sensors. Figure 1 illustrates the nomenclature. The sensor fusion system provides, navigation data, failure detection and replaces failed sensor outputs with estimates. Detection of GPS spoofing and ability to navigate without GPS measurements can also be achieved. Fusion structures and algorithms have much attention in fusion system development. The coordinates selection and conversion, timing between different sensors and events, sensor management and data flow coordination techniques are more important. Without a reasonable arrangement of these systems and techniques, it is impossible for a fusion system to work smoothly and effectively. The entire information of submarines has many disadvantages, such as poor information quality, mostly passive type of information, miscellaneous information patterns and an enormous amount of information [2].

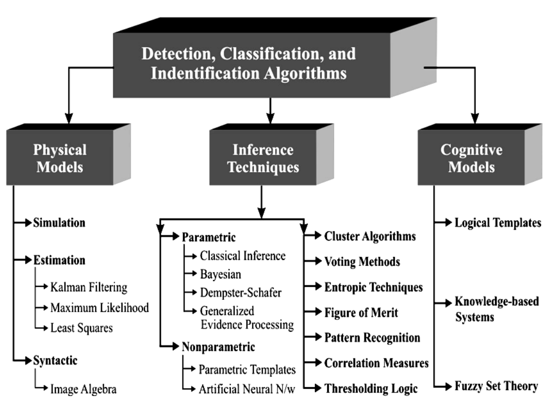

Figure.1 Nomenclature of Sensor Fusion

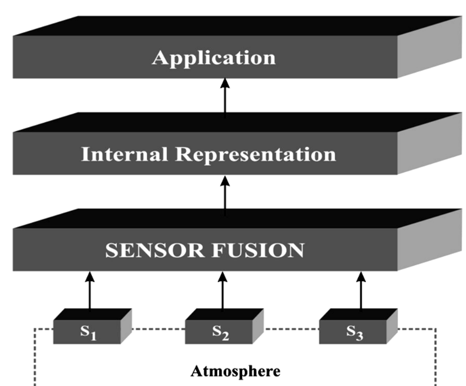

Figure. 2 Conceptual view of Sensor Fusion

In addition, there are many uncertain factors that may have an impact on the submarine information system such that the system may become very fragile and vulnerable to even minute errors. Figure 2 shows the conceptual view. Sonar system has high sensitivity to the position and orientation deviation. Unknown towfish motion varies the detected time delay and consequently degrades the process image quality [3]. However, if the towfish motion could be monitored, the blurring caused by the position and orientation deviation could be eliminated by post processing the signal data before image reconstruction

II. INFORMATION SENSORS

The positional and postural information is a reference frame for the entire sensor system that includes longitude, latitude, depth, course, speed, dip angles, etc. of the submarine [4]. The most important navigation sensors of onboard modern submarines are the GPS receiver and INS. GPS provides three-dimensional fixes with very high accuracy. INS enables the submarine with long time submerged navigation ability. The navigation sensors divided into, submerged sensors and surfaced sensors. The fusion system is divided into submerged fusion and surfaced fusion, exactly the same as for target information fusion. The fused submarine information finally should be input into target information fusion system, serving as a reference frame to target information. The navigation system here is treated as a support system to the fusion system. Another important submarine sensor is the self-noise monitor sonar that consists of several arrays located at different noise sensitive points on the submarine hull.

In fact, the information provided by the monitor sonar is an important factor in underwater sensor management, a basic function of the fusion system. Information sensors will provide hydrographic, oceanographic and meteorologic information and supports the fusion system in an indirect way. A unified coordinate system is needed when a fusion system is developed, and this is also important for spatial alignment of information [5]. Processing algorithms (Fusion or Tracking algorithms) have some special requirements for coordinates. A well-selected coordinate system should facilitate to satisfy these requirements. The time lag for the signals to travel from the target to the sonar array is difficult to estimate. For active sonars, the time lag is even larger due to the round trip of the acoustical pulse but can be easily determined. The difference in the data rates of different sensors may also cause problems in timing as well as communication organization. Some modern digital sensors have very high data rates and used in environment with higher real-time requirements. There are many other special problems in sensor timing. The data flow is very complicated, especially during a real engagement. The timing of the sensors is virtually the timing of the data flow, a very difficult task. The target cannot be recognized without the help from these data and algorithms may have to be initialized using these data. Artificial neural networks need to be trained by these data. Incidentally, collecting and processing such data is not an easy job. It is a painstaking and time-consuming effort [6]. The amount of data needs to be entered into a database for a fusion purpose varies, because several factors may affect it. The requirement of the user, the capability of the data base system, the ability to handle data itself are some of the major factors. Figure 3 shows the architecture and Figure 4 illustrates the information fusion models.

III. SENSOR MANAGEMENT

The basic concepts of sensor management are target assignment and target indication [7]. Target assignment is the initiation of observation channels by assigning a specific sensor, a specific target. Target indication is telling the assigned sensor where its target might be located, helping the sensor to catch the target quickly. Indication may be given by the possible position of the target, the possible direction in which the target may move or the possible sector in which the target may stay. Sensor management has to be concurrent with navigation and requires special posture to ensure their specified performances. To manipulate the submarine to avoid the blind zone is the obligation of the navigation. In addition, the time instant at which a specific sensor is used is another factor that should be considered. This is particularly true for the exposed sensors. To use them timely is critical for improving the observation and even the final results of an entire engagement. In submarine tactics, the use of an exposed sensor is always seen as an action that needs precautions. The support systems and techniques can be seen as an important integral part of the submarine sensor fusion system.

IV. KALMAN FILTER

The Kalman Filter (KF) is one of the commonly used sensor fusion technologies. The linear KF is an optimal observer that estimates the states of a linear dynamic system from noise-corrupted sensor measurements [8]. There are some variations of the linear KF, which can be used for state estimation of a nonlinear dynamic system, such as the extended KF.

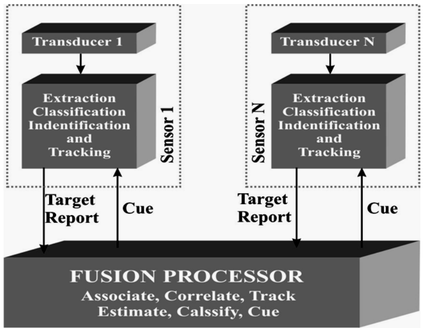

Figure.3 Sensor Fusion Architecture

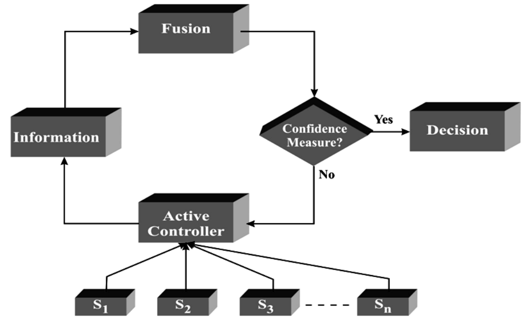

Figure. 4 Information Fusion Modules

Table I Comparison of the Different Approaches

Parameter	Particle Filter	Geometric (MAP[3])	Kalman Filter
Computational demands	Less	Average	Less
Convolution	Inherently solved	Hard	Simple
Space Size	Tiny	Infinite	Infinite
Number of dimensions	Less	2D	Infinite
Gaussian distributions	Viable	Viable	Viable
Non-Gaussian	If tiny	Viable	Nil
Negated Report	Nil	Viable	Nil
Uncertain Report	Nil	Viable	Nil
External Data	Nil	Viable	Nil
Alternative Paths	Less	Viable	Nil
Compute Centroid	Simple	Simple	Simple
Compute Maxima	Hard	Simple	Not viable
Multiplication	Inherently solved	Simple	Simple
Area of Potential	Hard	Simple	Not viable

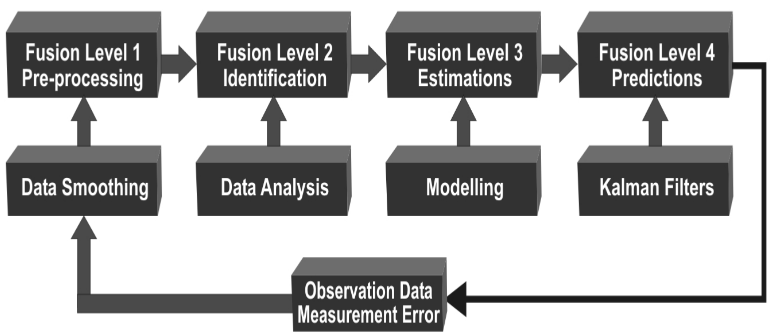

Figure.5 Various Fusion Levels

The KF is often used to estimate position, velocity, and orientation states from multi-sensor measurements. The motivation of the sensor hybridization is to combine the complementary aspects of each sensor. In practice, all sensors are prone to errors. A few common errors exist such as bias and scale factor uncertainty. These errors are of great concern. In order to obtain correct navigation information, initial sensor calibration is essential. A sensor fusion algorithm is required to hybridize these calibrated navigation data. The KF has been widely used in the area of autonomous or assisted navigation, which can be involved in the post processing to provide an optimal filter for optimizing the whole sensing system performance [9]. With the focus on orientation estimation, a quaternion-based extended KF is studied. It has been used in a wide range of engineering applications for almost a half-century to produce an optimal estimation for unknown states of a dynamic system from a variety of measurements corrupted by noise. Table I shows the comparison of different approaches. The KF is a recursive observer using two phases, the predict phase and the correct phase. It implements only the estimated state from the previous time step for computing the current state in the predict phase. In the correct phase, the measurements from the current time step are used to update the predicted result to achieve the final optimized state estimation of the time step.

A wide variety of KF have been developed based on the predict-correct philosophy, for example, the original linear KF, the extended KF and the unscented KF. It is the main analysis technique for inertial data and is used almost exclusively for inertial tracking. As inertial components have become more common in user interfaces, a number of variations on the original algorithms have been created to ensure robustness and accuracy when working with low-cost components and processing hardware. The strength of KF lies in its optimality, its minimal memory requirements for the state and its ability to include a model of the system dynamics. The most troublesome is that it is the linear optimal solution, including tracking, is non-linear. In such circumstances the Extended KF can be used, which, although it can no longer be proven to be optimal, it is still very successful in practical applications. Figure 5 shows the various fusion levels and Figure 6 shows the sallen key low pass filter circuit.

V. CONCLUSION

This investigation discusses a navigation solution for orientation and position tracking that includes the construction of the integrated sensing module, sensor calibration algorithm study and sensor fusion implementation. The data acquisition system and associated electronics can be able to correctly sample and transmit the navigation data to the towfish computer for post processing. Sensor calibration algorithms were studied and the stochastic properties of the sensors were analyzed. Sensor fusion is discussed based on the extended KF. The quaternion is used for the parameterization of the coordinate transformation. It can simplify the rotation and derivative calculations and will improve the fusion efficiency. The extended KF is based on a total state space model, which outputs the position, velocity, and attitude as well as the gyro bias. The total state space scheme provided a simple and efficient estimation method. It is also proven that the KF using the total state space model could provide accurate orientation estimation.

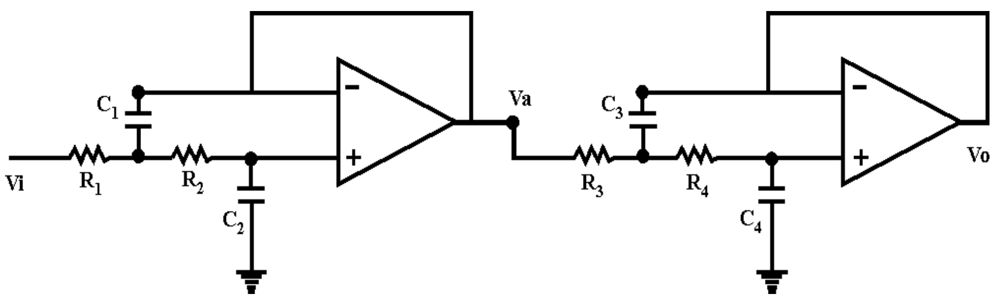

Figure. 6 Fourth order Sallen-Key LPF

The filter will give poorer estimation results when the platform had more manoeuvres. Compared to the total state space model, the error state space model has more advantages. The error model defines the errors of the sensors rather than the total states, such as position and velocity. The inputs for this model are the deviation of each defined total state. Because the error state space model only provides the correction for the sensor signals, it is more robust than the total state space model. However, because the error state space model contains more nonlinear terms, the complexity of the model is increased correspondingly. By applying the error state space model, the errors of the sensor parameters as well as the uncertainty of initial parameters can be estimated with improved accuracy. Moreover, different sensor fusion algorithm can be adopted, such as the unscented KF. The error state space model can also include the initial alignment error so that the initial values can be indirectly determined by the filter. The unscented KF can improve the tolerance towards the erroneous initial values so that large initial alignment errors are allowed. The system can also be improved by including velocity or position sensors, like Doppler velocity log (DVL).

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