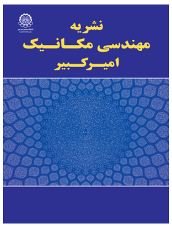

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Reliability Analysis of An Inertial Navigation System and its Active Fault Detection and Isolation Unit

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ABSTRACT: Inertial navigation systems are one of the main components in advanced equipment navigation systems such as drones and satellites. Therefore, their reliability is very important for system mission success. For increasing the reliability while developing advanced sensors, the issue of sensor placement and arrangement, the use of redundancy, and error detection should also be considered. This paper evaluates different sensor configurations and reliability analyses of fault detection and isolation of an inertial navigation system. First, the design of the navigation system is analyzed in terms of the location of the sensors, then the detection and fault detection unit based on the excess sensors. The system's reliability is calculated based on exponential distribution and reliability block diagram, and then the reliability fault detection unit is calculated using the Monte Carlo method. The sensitivity analysis has been performed, and the results show that the reliability depends on the noise value. Because the reliability of this system is a function of the fault detection and its threshold values, the optimal values for fault detection threshold are obtained using two iterative methods and estimating the minimum nonlinear squares.

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1- Introduction

Due to the increasing complexity and risk of modern control systems and the demand for increased quality, reliability, availability, and security, it has become necessary to pay attention to fault tolerance in control systems. The fault-tolerant control system is resistant to fault or failure. In many aerospace applications, the reliability requirements of inertial navigation systems are more stringent than those of single sensors; Using redundancy sensor configuration creates fault tolerance. The location of the sensors also directly affects the reliability and accuracy of the navigation system. The reliability of inertial measurement systems that use redundant sensors is much higher than measurement systems consisting of single sensors [1]. Many studies have been done to model navigation systems and different methods. It has been used for modeling [2-4]. However, their location has been less studied in terms of reliability.

Reliability can be expressed as probabilistic or definite. A definite statement of reliability must know how and why the system fails and how the system should be designed and tested to prevent failure.

This article examines fault detection, then the different arrangements that are presented, and the reliability of each arrangement is investigated.

2- Fault Detection and Isolation

Fault detection and detection are generally performed using mathematical modeling or data-based methods. Each of these methods has its advantages and disadvantages; for example, insufficient accuracy in mathematical modeling due to simplifications and assumptions made for the detector and error detection unit is a serious problem, on the other hand, lack of data and information poses a serious challenge to the use of method-based methods. Data-based methods are divided into two general categories: statistical methods and machine learning. Researchers have recently considered machine learning methods such as support vectors or convolutional neural networks. In this paper, the generalized probability method is used, which is one of the sub-branches of the statistical method. This method investigates fault detection and detection problems as combined hypothesis test problems.

2- 1- Fault detection process formulation

In this paper, according to the test hypothesis, the detection decision function is obtained as follows:

$$DF_D = p^T \left(VV^T\right)^{-1} p \quad (1)$$

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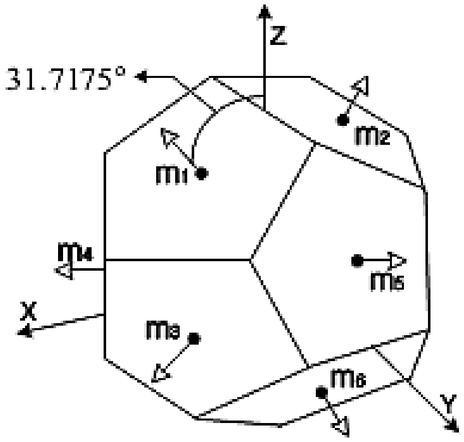

Fig. 1. The location of six sensors on a twelve-sided item

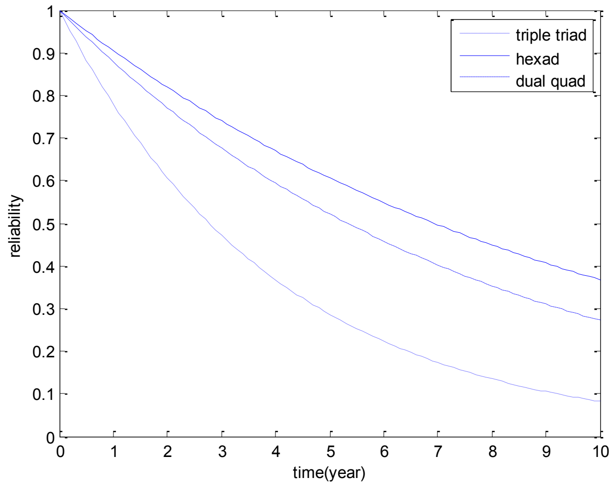

Fig. 2. Long-term comparison among the three architectures of the navigation system

2- 2- Formulation of the fault detection process

The fault detection is checked after the value of the detection decision function indicates an error. Assuming that the remainders of the equation are p equilibrium, the fault detection decision function is expressed as follows:

$$DF_I = \frac{\left(p^T \left(VV^T\right)^{-1} v_j\right)^2}{v_j^T \left(VV^T\right)^{-1} v_j} \quad (2)$$

2- 3- Location and the optimal number of excess inertia sensors

Optimal navigation system performance is a function of the location of inertial sensors. The location of inertial sensors directly impacts the accuracy and reliability of the navigation system. This issue is more important when using multiple Strap Inertial Navigation Systems (SINS) with redundant sensors. These depend on the mission's requirements. Three non-plane sensors are sufficient to collect three-dimensional space information. Adding a fourth sensor not aligned with any of the other sensors forms a quadruple array that allows error detection but does not detect the amount of error.

item

3- Reliability Analysis of Different Sensor Arrays

The reliability of several different architectures (triple, quadruple, and hexagonal arrays) of inertial sensors for an inertial navigation system is investigated. Reliability analysis is calculated by assuming that the failure rate of the components follows the exponential distribution, and a series structure is considered.

The reliability of the three architectures and their changes over a long time are compared in Figs. 2 and 3. The results show that the reliability of quadruple configuration and triple configuration in the 10-year performance range is less than the reliability of the six-configuration architecture. But the reliability of a six-configuration architecture over two years is less than the reliability of other architectures.

If results are checked with Ref. [5], the maximum error is less than 1%. Thus the proposed method is accurate.

Optimization of Detection Threshold Values and Error Detection

Because the reliability is affected by the values of the detection and error detection threshold, by changing these two threshold values determined in the design phase, the reliability also varies, so the optimal values of the detection and error detection threshold should be Achieve maximum reliability.

4- Conclusions

In this paper, first, the reliability of fault-tolerant navigation systems with different configurations of redundant inertia sensors was evaluated and compared. It was found that the redundancy structure with six sensors has the highest reliability in the long run but the short term. The duration may be less reliable than some configurations (Figs. 2 and 3).

Then, the detection and error detection unit based on the navigation system includes six sensors and was examined in more detail. Since the reliability of the detector and fault detection unit is a function of the values of the detection threshold and the fault detection threshold, their optimal values are obtained using iterative methods and nonlinear least squares. They are time-consuming but provide better results. Detection threshold and detection threshold have

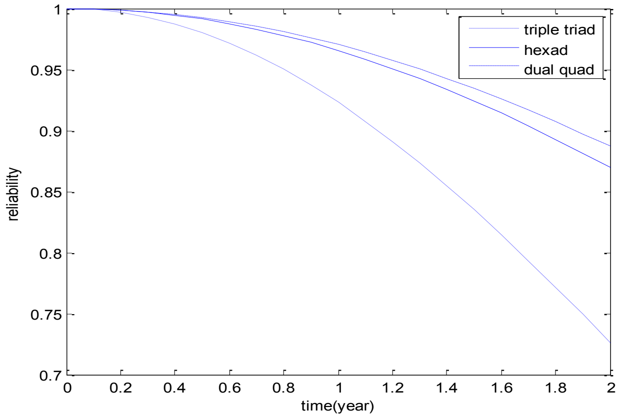

Fig. 3. Short-term comparison between the three architectures of the navigation system

also been performed in the noise sensitivity analysis. In the continuation of this modeling and analysis, the following research is suggested: Modeling and detection of faulty sensors, investigation of detection systems and adaptive fault detection, and detection and detection of multiple faults (more than two simultaneous failures) with different sizes. Also, checking the reliability by considering the issue of multi-state and multi-mission systems can help in more realistic modeling of the system.

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