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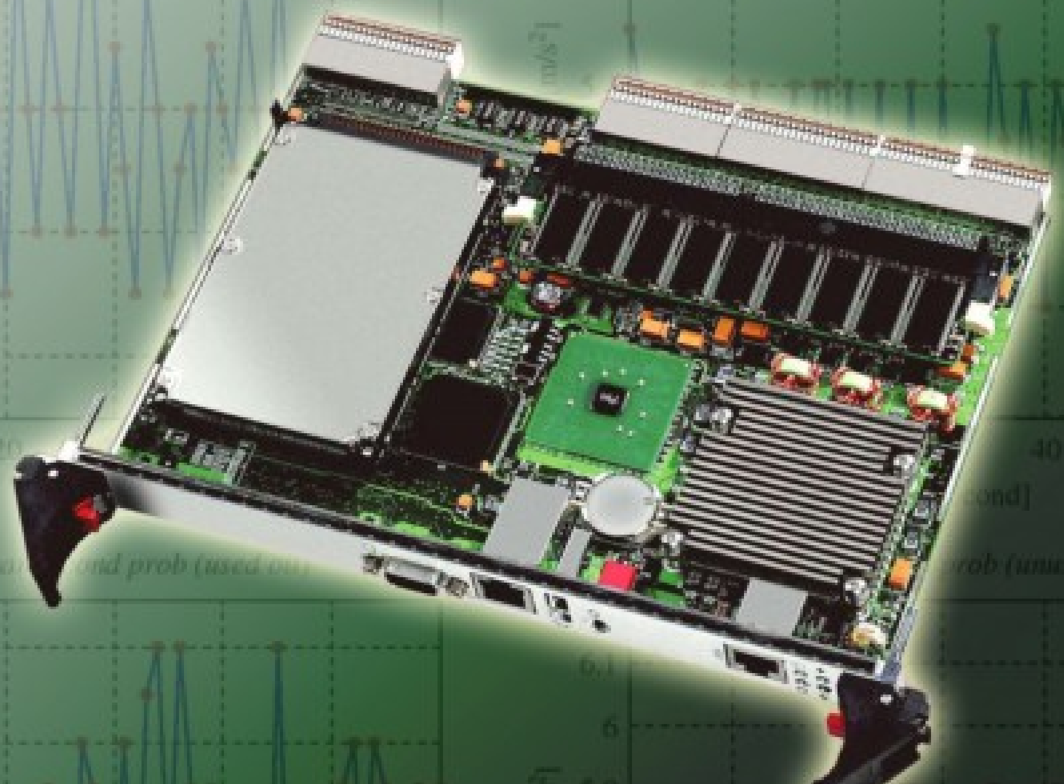

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Testability Analysis of Inertial Measure Unit Based on Multi-signal Model

Xing HE, Hongli WANG, Jinghui LU
Xi'an Research Inst. of Hi-Tech., Hongqing Town, Xi'an, 710025, China
Tel.: +86-29-84741361
E-mail: trees241@163.com

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Abstract: Inertial measure unit (IMU) which provides the information about speeds and positions for computer, is one of the most important components of aircraft control system. However, it is also very easy to go wrong. For the sake of locating and isolating the fault sources, the multi-signal model of IMU is built based on TEAMS, and its testability is analyzed and evaluated. Further, in order to eliminate the disadvantages of inherent testability, the measures based on adding test points and cutting off feedback paths are proposed. At last, the inherent test and the proposed test are simulated by TEAMS. Simulation results show that the testability of improved test enhanced markedly, the Percentage Fault Isolation is increased from 39.32 % to 48.72 %, and the ambiguity group size decreased from 16.47 to 2.3. The results also validate that the analytical method of testability based on multi-signal model is effective to improve the maintainability of equipments. *Copyright © 2012 IFSA.*

Keywords: Inertial measure unit, Testability, Multi-signal mode, TEAMS, Fault

1. Introduction

With rapidly development of the computer technology and information level, weapon system has become more and more complex, which enhance the battle capability, however, it also bring higher requirement to maintain ability. Testability has played a more and more important role in battle capability, viability, maneuverability and maintenance cost of the weapon system. According to American navy's survey, the use and maintenance cost of the four types of navy main airplane have reduced 30 % since improved more than 200 items testability technology [1].

In 1975, F. Liour et al put forward the concept of testability firstly [2]. Thereafter, testability was used to diagnosis circuit design and other fields [3-6], and developed rapidly at the end of the seventies of the last century. As testability developing, it is apt to use graph method to model complex equipments for testability analysis and fault diagnosis recently. IMU, one of the most important components in aerocraft control system, has generated many researchers' concern. Unfortunately, there is no effective monitoring and diagnosing method about IMU as its complexity inner structure.

In order to reduce the influence caused by blind maintenance. Based on the multi-signal modeling idea, this paper has constructed the multi-signal model of one IMU. After analyzed and evaluated the inherent testability, the improved measure has been put forward to eliminate the disadvantage, which can provide theory basis for system testability design.

2. Multi-Signal Modeling Method

Multi-signal modeling method was put forward by K. R. Pattipati et al [7] in 1994, and it defined the interrelation of every component by analyzing system principle and function. Further, they would be divided into the components of multi-signal model and expressed in different modules, by which the system testability can be analyzed and evaluated. The Multi-signal modeling method has such advantage [8]: more closed to system physical structure; makes modeling easier, when described system fault set, it can overcome the shortages that need to define quantitative relation; makes it feasible to model some big and complex systems with small distortion.

2.1. Modeling Ideas

Multi-signal model is a multi-layer modeling idea, in which the spread route of influence between one disabled mode and other modules can be find directly, So, it is convenient to carry on testability modeling of complex system, fault mode influence, risk analysis and fault diagnosis and so on[8]. Its main idea as follows:

1) Aimed at fault diagnosis, we only need to simulated how one fault spread to different test points. For testability, In order to identify the fault reason easily, it must ensure system considerable. Therefore, it is enough that construct the model in fault space.

2) The fault space of system isn't binary, namely, only pass or failure. The function space of system is multidimensional, so its fault space is also multidimensional.

3) Because the fault station maybe random, it is unnecessary to define accuracy quantitative model, instead of defining main systemic function properties (or function space dimension) which stand for signal, then connecting it with appropriate components and tests.

4) There are two different kinds of faults: functional fault and entirety fault. The former is the fault influencing system function operating; but the later is the catastrophic fault blocking the information flow, i.e., incidence exceeds normal tolerance degree. So, disabled modules influence either partial or all properties of the signals passed them.

2.2. Components of Multi-Signal Model

Multi-signal model includes a series of modules, signals, tests and so on, they can be described as follows [9].

1) $C=\{c_1,c_2,\cdots,c_M\}$ is the element module set, each element stands for a fault unit. The set indicates that system has *M* independent and relative entire modules.

2) $S=\{s_1,s_2,\cdots,s_L\}$ is the independent signal set of system, indicates that the system has *L* independent signals. The signal is the characteristic property which can describe the system function.

3) Finite set of test points $TP=\{TP_1,TP_2,\cdots TP_p\}$.

4) Finite set of available test points $T=\{t_1,t_2,\cdots t_N\}$.

5) Each test point TP_i can include a group of test $SP(TP_i)$.

6) $SC(c_i)$ is the signal set correlated or influenced by function module C_i.

7) $ST(t_i)$ is the subset of *S*, and can test by t_i.

2.3. Denotations of the Modules

There are two methods to denote multi-signal model: graphics method and matrix method [10].

Graphics method denotes the model using a particular direction graphics, whose detailed denotation as follows:

1) Model denotes by pane, each pane stands for a function module in practical system.

2) Test point denotes by circle.

3) And node denotes by the AND gate of circuit, which can denote the redundant structure of practical system efficiently.

4) Switch node denotes by the switch sign of circuit, which can denote many types of work mode in practical system.

5) Transmission relation of fault denotes by line with single arrow.

Matrix method denotes model by correlative matrix between fault types of component unit and signal detection, which is given in Eq.1.

$$D_{m\times n}=\begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix}, \tag{1}$$

When $d_{ij}=1$, it means that signal detection st_j is related to the fault type of component unit; oppositely, when $d_{ij}=0$, it means that signal detection st_j isn't related to the fault type of component unit.

3. Multi-Signal Modeling of the IMU

3.1. Structure and Function of the IMU

The IMU is a complex mechanical and electrical system that used to sense system movement station relative to inertial space. Fig. 1 shows the structure of one IMU, which is mainly composed of three parts, including the second power supply, electron box and noumenon. Many circuit boards, accelerometers, gyroscopes and others auxiliary circuits are fixed on them. They are connected to other with special cables. When system operating, the second power supply transforms DC from outside into multiform power supplies and provides power for other parts. The heated sheets, heat sensitive elements and temperature control circuits are able to actualize temperature control after received the power provided by the second power supply, which also provides power supply for accelerometers and gyroscopes to guarantees their operation in gear, based on the above, impulse output board transforms the analog signals from accelerometers and gyroscopes into impulse signals. Standard frequency board in the second power supply provides multiform frequency signals for impulse output board working. At last, the signals come from temperature control board, the second power supply and impulse output board are sent to outside test equipments by three cables. Through the above process, the IMU can be calibrated.

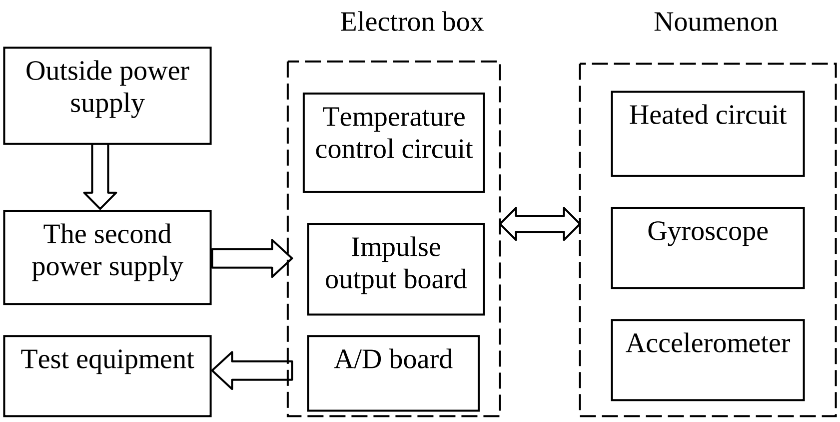

Fig. 1. Sketch map of the IMU.

When some faults happen in the process of calibrating, it is become very inconvenience to locate and eliminate as the system complexity and fault location relied on expert experience. So, it is very necessary to build the multi-signal model of the IMU, straighten out the dependent relations of every component, analyze and evaluate the system testability, further, to improve the inherent testability.

3.2. Multi-Signal Modeling of the IMU

The TEAMS (Testability Engineering and Maintenance System) is business software produced by American QSI company, which can carry on testability analysis and evaluation, diagnoses knowledge denotation and illation, maintaining data synthesis, and so on. In recent years, TEAMS has applied widely for condition monitoring, healthy management and diagnoses design in the fields of astronautics, aeronautics and industry, etc. This section would build the multi-signal model of the IMU based on TEAMS.

By analyzing the interaction of components and their functions of the IMU, taking no account of the fault of rough heated circuit, cables and electrical outlets, a three-layer multi-signal model which is comprised of 93 fault source modules is built in this paper. According the practical test equipment, there can be derived three points from ground test ports, telemetry ports and computer on missile respectively, includes 23 tests which are used to test temperature signals, the second power supply signals and impulse signals. No switch module and AND gate in the model. For the model complexity, here only the models of the second power supply (see as Fig. 2) and frequency inrush power supply board (see as Fig. 3) fixed in it are given.

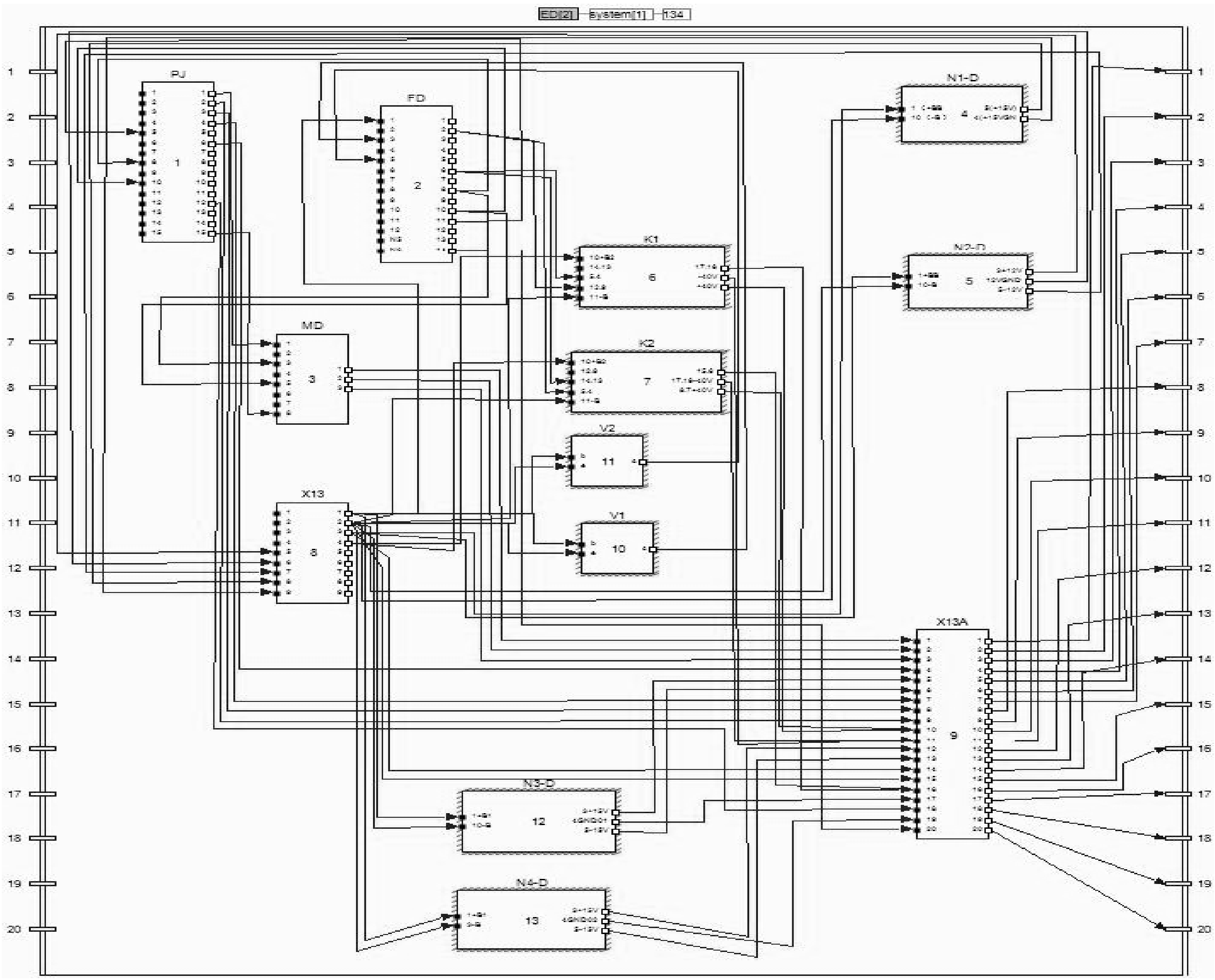

Fig. 2. The multi-signal model of the second power supply.

4. Testability Analysis and Improvement of the IMU

4.1. Inherent Testability Analysis

Aimed at the system testability analysis and evaluation, two suppositions are done as follows:

1) Single fault. Whenever the system is under fault station, we think that only one component fault is happened.

2) Every tested component has equal failure rate, and the test time and the cost are don't considered.

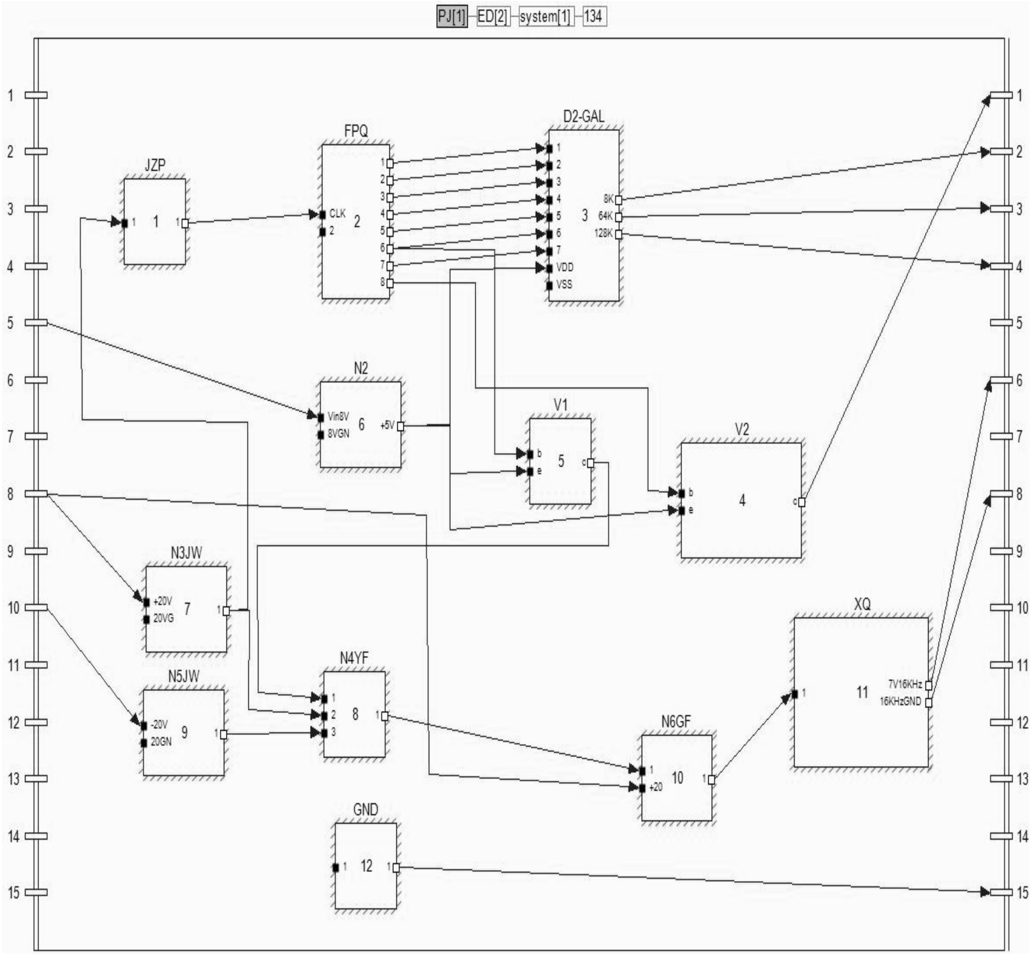

Fig. 3. The multi-signal model of frequency inrush power supply board.

According to the ideas and principles described in the last section, the multi-signal model of IMU is built by TEAMS. Taking no account of the normal condition of the IMU system, the inherent testability analysis results and the Ambiguity group distributing are derived and listed in Table 1 and Table 2.

Table 1. System testability analysis results.

Testability index	Result
Percentage Fault Detection	100 %
Percentage Fault Isolation	39.32 %
Percentage Retest ok’s	52.99 %
Avg. Ambiguity Group Size	16.47
Redundant Test	0

Table 2. Ambiguity group distributing of the system.

Ambiguity group size	1	2	3	4	5	6	42
Ambiguity group number	22	1	4	1	1	1	1

It can be seen from Table 1 and Table 2, in the case of inherent testability, i.e., only the test points in three external electrical outlets are used for testing. TEAMS testability analysis results show that there are no redundant test and good fault detection ability in the system, however, it can also be seen that there are weak isolation ability, big average ambiguity group size and high percentage retest ok's in the system, which indicates that the inherent test points are not enough for practical testability requirement. So, the system testability must be improved for the sake of better maintainability [11].

4.2. Improvement Ideas

Considering the shortage of the inherent system testability and practical case of equipments, the improved measures have been put forward to elevate system testability. To analyze the structure of IMU, it can be found that there are many essential test signals excluded in the inherent external electrical outlets, but in others closed electrical outlets. Considering feasibility and cost of engineering realization, three steps have applied to solve the above problems.

Step1. Some test points are chosen from others unused electrical outlets. After analyzing, there are thirteen test points from four electrical outlets within the second power supply and the noumenon, can be used.

Step2. Other test points are chosen from some function board ports. In order to actualize the fast maintenance, the system structure can't be changed largely, so all the increased test points are selected ports of the relative circuit boards which are easy to set wire. Here, there are sixteen test points set on four function boards fixed on the second power supply and electron box.

Step3. Influence of the feedback paths are eliminated. Inside of the IMU, there are a large number of feedback paths, which have may have a serious effect on fault location and isolation. Here, a heuristic algorithm from [7] is chosen for cut off the feedback paths, its detailed steps follows as where depth-first search algorithm referred from [12]. SCC stands for the strongly connected components, which denotes the sets consist of the all lines from one fault node to the other, in other words, fully feedback path. $f = \deg^{-}(u) \times \deg^{+}(v)$, u and v denote the start node and end node respectively, $\deg^{-}(u)$ denotes the numbers of arcs with end at u, $\deg^{+}(u)$ denotes the numbers of arcs with start at v. executing repetitively the steps showed in Fig. 4 until all SCC are cut off.

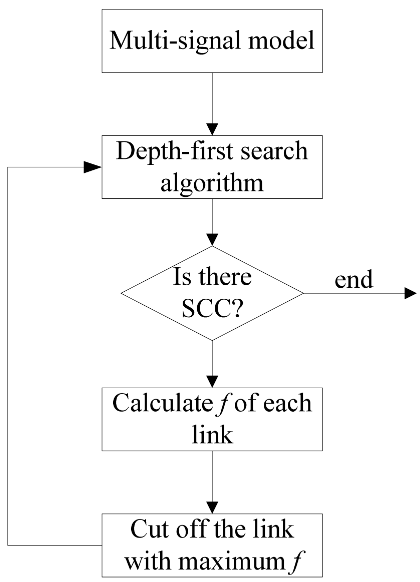

Fig. 4. Flow chart of the deconnected strategy for feedback paths.

According to the three proposed steps, the testability analysis results and the Ambiguity group distributing are showed in Table 3 and Table 4.

Table 3. Testability analysis results of the improved test.

Testability index	Result
Percentage Fault Detection	100 %
Percentage Fault Isolation	48.72 %
Percentage Retest ok's	35.90 %
Avg. Ambiguity Group Size	2.3
Redundant Test	3

Table 4. Ambiguity group distributing of the improved test.

Ambiguity group size	1	2	3	4	5
Ambiguity group number	33	2	10	4	2

It can be seen from the Table 3 and Table 4, there is better capability than original through the improved system test, its percentage fault isolation becomes bigger, oppositely, percentage retest OK's and ambiguity group size become smaller. Meanwhile, it can also be found from the distributing of the ambiguity group that the proportion of big ambiguity has declined greatly. It must be pointed out, although there are three redundant tests in the improved testability, however, they are all contained in the inherent tests, so it indicates that the increased tests are logical. The three proposed measures are helpful greatly to improve the inherent testability.

5. Conclusions

The system with nicer testability can not only provide excellent capability monitoring, fault detection and isolation ability, but also decrease the time of fault location, isolation and the cost of maintainer and maintenance. For the sake of improving the weak testability and conquering defect of testability analysis and evaluation, the multi-signal model of one IMU is built and its testability analyzed in this paper. Aimed at the disadvantages of the inherent test, the measures to improve the weak inherent testability are put forward. At last, the proposed measures are applied to locate and isolate the faults, the simulation results show that the testability of improved system is become much better. And it is also confirmed that testability analysis can provide the theory guide for health monitoring and repair of the IMU system.

Acknowledgements

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Guide for Contributors

Aims and Scope

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- Applications.

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