UDC 681.5.09

A.S. KULIK, A.G. CHUKHRAY, J.P. MARTINEZ-BASTIDA

National Aerospace University named after N.E. Zhukovzky «KhAI», Ukraine

A TEACHING PLATFORM FOR FAULT-TOLERANT SYSTEMS DEVELOPERS

In this paper the hardware-software complex is presented. It has been developed to teach developers of technical systems to effective fault-tolerant approach, applied to a gyroscopic sensors unit (GSU). The fault-tolerant method used on the complex has the ability to perform a complete diagnosis of the GSU, constantly monitoring its state by means of several comparisons, determining the possible existence of a fault in the unit. Once a fault in the unit has occurred, the method is able to find where the fault is located; allowing us to define what kind of fault has appeared in the unit and this diagnosis can lead us to perform the proper corrective actions to recover the optimal performance of the GSU.

Keywords: *fault-tolerant system, control system, fault-tolerant, gyroscopic sensors unit.*

Introduction

In the last decades many advances in the field of control systems have been developed [1-3], having a great impact in all kind of control disciplines. New theory, actuators, sensors, industrial process, computing methods, approaches or philosophies to improve in different aspects the control systems have been implemented. Actually the control systems are a medullar block in many spheres [4], looking forward to meet the autonomy in fields of aerial, land and maritime vehicles. In any of these spheres it is necessary to use stabilization and guidance systems [5, 6]. For example, unmanned aerial vehicles (UAVs) where an autonomous control system is used instead of a human operator, because the task of this vehicle could be hazardous or routine.

The UAV can realize searches, inspects long distance power lines, oil or gas pipelines and other recognition and monitoring environmental or meteorological variables, and many other tasks. The technological field of the UAVs demands the designing, testing of fault-tolerant control and guidance systems, then, the necessity of control and guidance systems able to keep working even under influences of noise, faults or other conditions that can alter the proper work of the system leading to a malfunction of the vehicle or a total crash of the unit.

The heart of many control and guidance system is the Gyroscopic Sensors Unit (GSU). And its effectiveness relies on how effective the system can response to constant or random faults that can occur during its function. The problem in practical scheme is that some sensor can fail or give a wrong sensed value, so the vehicle's performance is deteriorated and an immediate action to recover the lost performance must be applied to avoid mistakes on the control and guidance of the vehicle that can result in a wrong action or even the complete lost of the vehicle, either both, resulting in economical lost or even worst in lost of human lives.

Therefore, since many years ago the importance of developing a stabilization and guidance system has been relied on its reliability.

The workability of this kind of systems must be assured, especially when the accurate and correct response from the system is required; this is the case for the UAV, due to the navigation and control of the vehicle relies on this system, it is very important to give these systems the ability and "intelligence" to recovery itself in case of some possible fault.

So, the necessity to develop a platform for applying, studying and testing a fault-tolerant methodology that it will be used later. This is the aim of this work. The complex is built by software where the method is computed and it is in charge to emulate the faults in the system as well, a data acquisition block and the GSU. The GSU is constituted by two angular velocity sensors, angular velocity sensor 1 (AVS_1) and angular velocity sensor 2 (AVS_2) and one angle sensor (AS) [2-4].

The hardware-software platform has the ability to emulate faults in the GSU by software and applies the fault-tolerant method, showing the sensors' signals in real time.

The sensors are mounted on a moving platform that can emulate a real work situation for them.

The fault-tolerant method is based in hierarchical modules that are in change to carry on the proper and right detection of a fault, obtains a type of fault in the gyroscopic unit, passing through a phase of seeking the place where the fault has occurred in the unit. The method takes advantage of different techniques and approaches in order to realize the complete tasks to obtain a correct diagnose of the gyroscopic sensors unit and determine the suitable following action in case of the existence of a fault in the unit.

1. The teaching platform

A block diagram of the complete complex is depicted in Fig. 1, where it is shown the main blocks that form it.

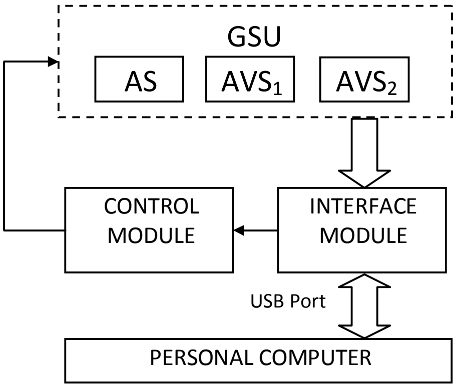
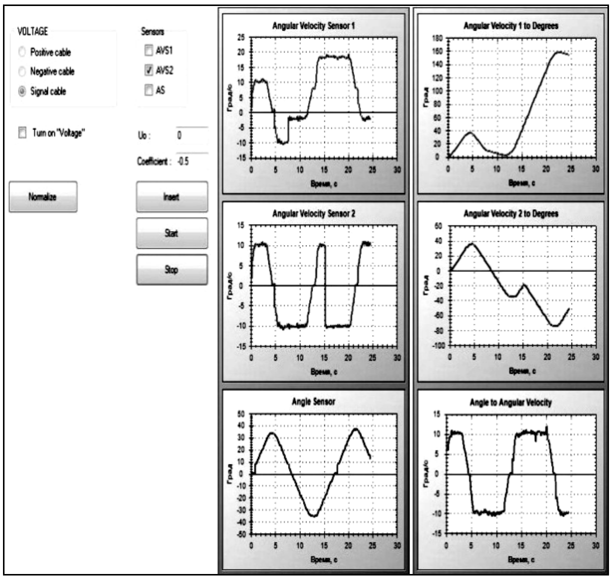


Fig. 1.Block diagram of the platform

The GSU is interconnected to a Personal Computer (PC) through an interface module. The PC is in charge to process and apply the support algorithm to the gyroscopic system and emulate the faults.

The analog signals from the sensors are digitalized by the interface module and are sent to a USB port in order to be shown in the computer's screen in real time. The Control Module is in charge of turning on and off the GSU's motor and change the direction of the platform. The graphic interface where the signals are depicted is show in Fig. 2 as well as the signals from the sensors.


VOLTAGE
○ Positive cable
○ Negative cable
● Signal cable

Sensors
☐ AVS1
☑ AVS2
☐ AS

☐ Turn on "Voltage"

Uo : 0
Coefficient : -0.5

Fig. 2. Graphic interface

The graphic interface is designed for the study of the fault-tolerant algorithm applied to gyro-sensors and it has different controls to emulate faults in the system and apply the diagnostic and the algorithm for recovering the system performance. In the interface the signals from the three sensors are depicted, from the top to down, the first on the top is the signal of Angular Velocity Sensor 1, following down; the signal of the Angular Velocity Sensor 2 signal and the next one in order is the signal from the angle sensor. Each signal has on its right side the corresponding transformation for the necessary operations that the method for recovering the system's performance needs.

In order to perform the method it is necessary to integrate the signals from the angular velocity sensors and derivate the signal from the angle sensor as it was explained above. The complete platform and its interconnection are shown in Fig. 3.

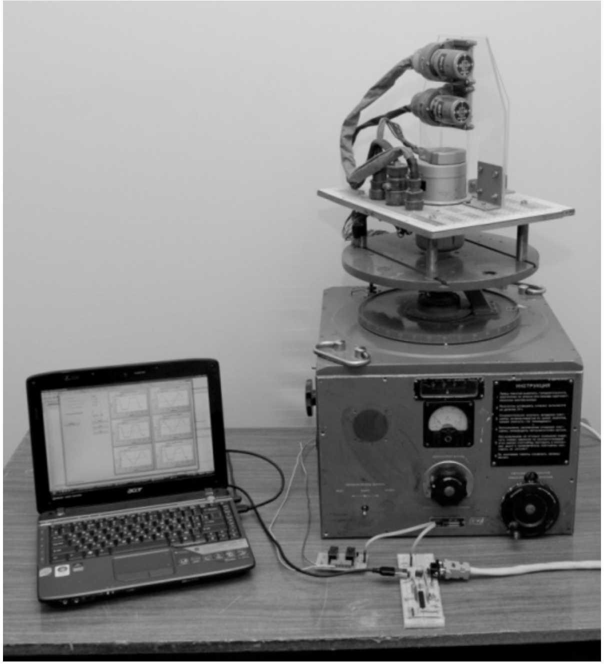


Fig. 3. The complete platform

The program is able to emulate different kind of faults as well as different faults can be inserted into the system at a time and in different sensors too. The Fig. 4 shows and example of this possibilities, in this figure we can appreciate how there is a fault in the sensor 1, shifting the voltage of the signal and in the sensor 2 the signal is inverted, proving an inversion of the transfer coefficient.

The Fig. 4 shows the principles of the platform. The platform can emulate faults in the system and watch how it responses to certain faults. This helps to explain the processes in the fault-tolerant system and to developers to understand how fault-tolerant concepts are applied to recover the system's performance in case that the faults permit it.

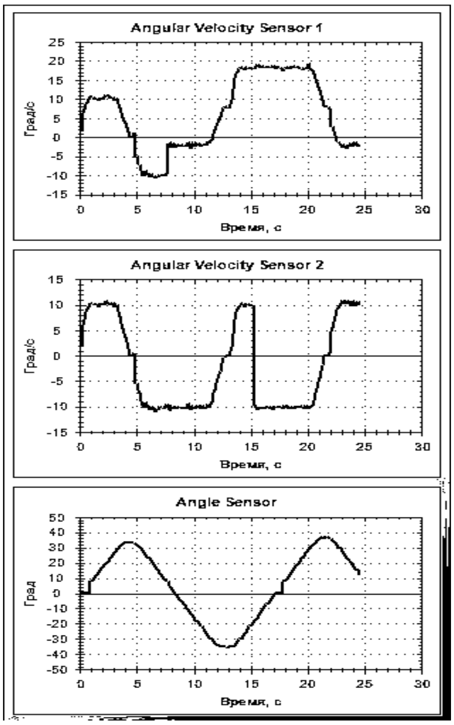


Fig. 4. Faults in AVS_1 and AVS_2

2. Diagnostic model for the GSU

The GSU is able to measure the angular velocity and the position angle due to the sensors on it. It is necessary to state one angle sensor and two angular velocity sensors as minimum to guaranty a diagnosis in the GSU, as it is shown in Fig. 5.

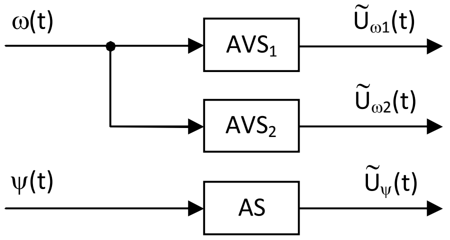


Fig. 5. Functional Scheme of GSU

The characteristic equations of the sensors are shown in (1):

$$\begin{aligned}&\tilde{U}_{\omega2}(t)=\tilde{K}_{\omega2}\cdot\omega(t)+U_0^{\omega2},\\&\tilde{U}_{\omega1}(t)=\tilde{K}_{\omega1}\cdot\omega(t)+U_0^{\omega1},\\&\tilde{U}_{\psi}(t)=\tilde{K}_{\psi}\cdot\psi(t)+U_0^{\psi},\end{aligned}\tag{1}$$

where $\tilde{U}_{\omega2}(t)$ – AVS_2 output;

$\tilde{U}_{\omega1}(t)$ – AVS_1 output;

$\tilde{U}_{\psi}(t)$ – AS output;

$\tilde{K}_{\omega2}, \tilde{K}_{\omega1}$, $\tilde{K}_{\psi}$, – transfer-Coefficient of the sensors;

$\omega(t)$ – angular velocity;

$\psi(t)$ – angle position;

$U_0^{\omega2}, U_0^{\omega1}, U_0^{\psi}$ – values of drift from zero.

In order to develop a reliable method for detecting and diagnosing faults in the GSU, it is necessary to build a methodology in base of the analysis of the input-output signals of the three sensors above described. We must use diagnostic signs of the system as well as parameters of faults. The fact of determining the existence of a fault in the GSU leads to find the place, class and kind of the fault, in Fig. 6 is shown the general scheme of the method. Once, that a fault has presented in the GSU and the complete process has been performed to obtain the diagnosis (a complete characterization and behavior of the system according to the current fault), we will be able to go on into the next and very important step, this step consists to determine the possibility of recovering the system reliability and its functional status.

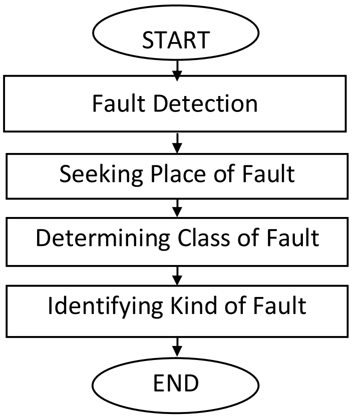


Fig. 6. Scheme of the method

According to the study and analysis of the GSU, there are very specific faults in the unit, leading us to understand the behavior of the system or even better, the sensors' behavior. The kinds of faults are determined by the letter "d" and are following defined:

d1 – positive power supply cable broken;
d2 – negative power supply cable broken;
d3 – signal cable broken;
d4 – irremovable positive voltage shift;
d5 – removable positive voltage shift;
d6 – removable negative voltage shift;
d7 – irremovable negative voltage shift;
d8 – change of the transfer coefficient;
d9 – reorientation of the transfer coefficient.

The following hypothesizes have been defined in developing the diagnostic process for the gyroscopic sensors.

1. Only can be one faulty sensor at the moment of diagnose.
2. Each sensor can present one or two kind of faults at a time.

3. Only “Shift” and “Coefficient” fault type can occur at a time in one sensor.

4. The input signal must be of the kind to determine the type of fault above described.

5. A kind of fault can independently appear from each others.

3. Recovering Method for the GSU

3.1. Fault Detection

First we must supervise the state of the GSU and identify the existence of a fault in the system. In the Fig. 7 is depicted the general scheme. The comparison between the three sensors Angular Sensor (AS), AVS$_1$ and AVS$_2$, is carried on by differences between their output values.

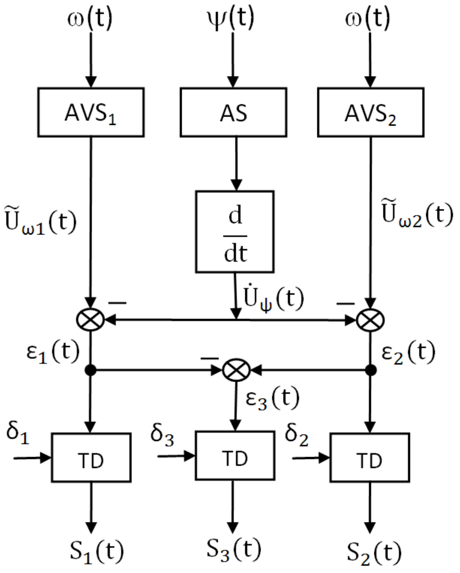


Fig. 7. Comparison diagram between the three sensors

The errors in Fig. 7 are represented by the following equations (2).

$$\begin{aligned} \varepsilon_1(t) &= \tilde{U}_{\omega 1}(t) - \dot{U}_{\psi}(t), \\ \varepsilon_2(t) &= \tilde{U}_{\omega 2}(t) - \dot{U}_{\psi}(t), \\ \varepsilon_3(t) &= \tilde{U}_{\omega 1}(t) - \tilde{U}_{\omega 2}(t), \end{aligned} \tag{2}$$

where $\varepsilon_1(t)$ – error between AVS$_1$ and AS;

$\varepsilon_2(t)$ – error between AVS$_2$ and AS;

$\varepsilon_3(t)$ – error between AVS$_1$ and AVS$_2$;

$U_{\omega 2}(t)$ – AVS$_2$ output;

$U_{\omega 1}(t)$ - AVS$_1$ output;

$U_{\psi}(t)$ – derived AS output.

After the calculation of the errors between the sensors, it is applied a Threshold Device (TD) that is in charge to determine the existence of a fault in the GSU in case that some error value is over the threshold value δ_{si}, we obtain with this, the value of the indicator S$_i$. This process is represented by the equations (3).

$$\begin{aligned} S_1[k] &= \left\{ \left| \tilde{U}_{\omega 1}[k] - \dot{U}_{\psi}[k] \right| > \delta_{s1} \right\}, \\ S_2[k] &= \left\{ \left| \tilde{U}_{\omega 2}[k] - \dot{U}_{\psi}[k] \right| > \delta_{s2} \right\}, \\ S_3[k] &= \left\{ \left| \tilde{U}_{\omega 1}[k] - \tilde{U}_{\omega 2}[k] \right| > \delta_{s3} \right\}, \end{aligned} \tag{3}$$

where $S_i[k]$ – indicator of presence of fault;

$\tilde{U}_{\omega 1}[k], \tilde{U}_{\omega 2}[k], \dot{U}_{\psi}[k]$ – sampled output sensors;

δ_{si} – threshold value.

Therefore, if one of the indicators S$_i$ has a value equal to 1, so there is a fault in the GSU, but if the result is 0, then the GSU properly works. If there is a fault in the GSU so we go on to the next stage of the process.

3.2. Seeking for Place of Fault

Once a fault in the GSU has been determined, we proceed to find the place where the fault has occurred, this means, which of the three sensors is not properly working.

Table 1

Indicator of faults’ place

	$\tilde{U}_{\omega 2}$	$\tilde{U}_{\omega 1}$	$\dot{U}_{\psi}$
S$_1$	0	1	1
S$_2$	1	0	1
S$_3$	1	1	0

In order to find the place of fault, we use the *S$_i$* indicators; the Table 1 shows the three possible combinations of the indicators when a fault has occurred, helping us how to determine the place of fault or which sensor is wrongly working.

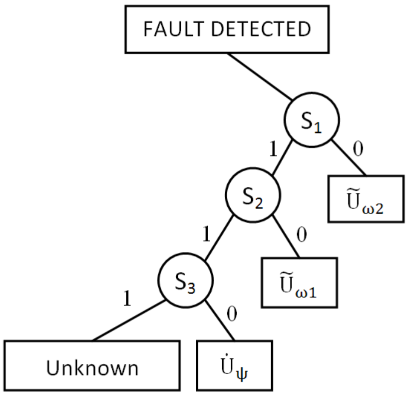


Fig. 8. Flow Tree for Seeking the Place of Fault

The flow tree for this procedure is shown in Fig.8. According to Table 1, it is possible to develop the three following statements for determining the place of fault. Once the place where the fault is found, the next step; it is to determine the class of fault.

If $S_1 = 0$ THEN fault in AVS_2,
If $S_2 = 0$ THEN fault in AVS_1,
If $S_3 = 0$ THEN fault in AS.

3.3. Determining the Class of Fault

In this stage of the method we will work with the signal of the faulty sensor, comparing its signal with the signals of the others sensors that are working well. This stage is based in the fact that only one or two classes of fault can occur in the faulty sensor at a time of the detection.

Class "Broken"

This class is characterized by constants voltages at the output of the faulty sensor, the mathematical model for determining this class is shown in (4).

$$Z_{Bi} = \left\{ \sum_{n=0}^{k} \tilde{U}_{vi}(n+1) - \tilde{U}_{vi}(n) > \delta_{Bi} \right\}, \tag{4}$$

where Z_{Bi} – indicator of class "Broken";

$\tilde{U}_{vi}(n)$ – output sample of the faulty sensor;

$\delta_{Bi}(n)$ – threshold value for class "Broken".

Every truly result of this statement is counted (N) times, and at the end of the process, it is compared to another threshold of reliability ρ_B, as is shown in statement (5).

$$Z'_{Bi} = \{N > \rho_B\}, \tag{5}$$

where Z'_{Bi} – indicator of reliability for class "Broken";

N – counter of truly result of Z'_{Bi};

ρ_B – threshold of reliability for class "Broken".

If N is bigger than ρ_B, so the class of fault is determined as "Broken".

Class "Shift"

This class is defined by a constant shift of the output voltage in the faulty sensor. Then, in the method we applied a comparison between the three sensors, taking samples during a period of time, these values were saved into variables defined by ε_i, which ones we are going to use to determine this class of fault.

As faulty sensor is defined, so we will use the values of the errors that do not work properly, and calculate a mean of them by (6).

$$\Delta\varepsilon_s = \frac{\varepsilon_{s1} + \varepsilon_{s2}}{2}, \tag{6}$$

where $\Delta\varepsilon_s$ – average value of the error out of tolerance;

ε_{s1} – first error signal out of tolerance;

ε_{s2} – second error signal out of tolerance.

Then, we apply the mathematical model presented in (7) in order to check if the class of fault is "Shift".

$$Z_{Si} = \left\{ \sum_{n=0}^{k} \left| \Delta\varepsilon_s(n+1) - \Delta\varepsilon_s(n) \right| > \delta_{Si} \right\}, \tag{7}$$

where Z_{Si} – Indicator of class "Shift";

$\Delta\varepsilon_s(n)$ – Sample of the average value of the two errors out of tolerance;

$\delta_{Si}(n)$ – Threshold value for class "Shift".

And counting every result above the threshold value δ_{Si}, this statement indicates if the voltage shift is constant as in this class of fault must behave; in that case the indicator for this class will be applied, as it is shown in (8).

$$Z'_{Si} = \{N > \rho_S\}, \tag{8}$$

where Z'_{Si} – Indicator of reliability for class "Shift";

N – Counter of truly result of Z'_{Si};

ρ_S – Threshold of reliability for class "Shift".

Class "Coefficient"

This class has a constant difference value from the right coefficient value when the sensor is properly working. We will use the average result of the output of the two sensors that work well, represented by equation (9).

$$\tilde{U}_c = \frac{U_1 + U_2}{2}, \tag{9}$$

where $\tilde{U}_c$ – average value of the two sensors that do work well;

U_1 – value of the first sensor that work well;

U_2 – value of the second sensor that work well.

It is necessary to obtain the average value of the change of the transfer coefficient by equation (10).

$$\Delta K = \frac{1}{m} \sum_{n=1}^{k} \frac{\tilde{U}_c(n)}{\hat{U}_i(n)}, \tag{10}$$

where ΔK – average values of change of transfer coefficient well;

$\tilde{U}_c(n)$ – average values of the two sensors that do work well;

$\hat{U}_i(n)$ – values of the faulty sensor.

And apply a threshold value to determine if there is a change in transfer coefficient. Moreover, we can obtain and index of change in the transfer coefficient by means of the errors that can be obtained by (11) and (12).

$$\Delta\varepsilon_c = \frac{\varepsilon_{c1} + \varepsilon_{c2}}{2}, \tag{11}$$

where $\Delta\varepsilon_c$ – average value of the errors out of tolerance;

ε_{c1} – first error out of tolerance;

ε_{c2} – sec ond error out of tolerance.

$$Z_{Ci} = \left\{ \sum_{n=0}^{k} \left| \Delta\varepsilon_c(n+1) - \Delta\varepsilon_c(n) \right| > \delta_{Ci} \right\}, \quad (12)$$

where Z_{Ci} – indicator of class "Coefficient";

$\Delta\varepsilon_c(n)$ – sample of the average value of the two errors out of tolerance;

$\delta_{Ci}(n)$ – threshold value for class "Coefficient".

We need counting (N) as well as every result above, the threshold value δ_{Ci}. Then, if a change in the transfer coefficient has occurred, so the difference between the values in Z_{Ci} will not be constant. Now, considering both results we can define the following statement:

If $\Delta K = 1$ & $N > \rho_c$ THEN class of fault is “Coefficient”.

The decision tree for defining the class of fault is depicted in Fig. 9.

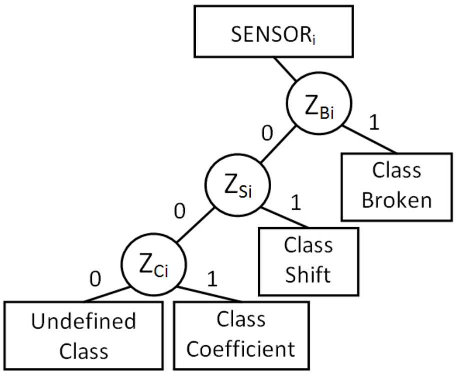


Fig. 9. Decision Tree
to determine the Class of Fault

3.4. Defining the Kind of Fault

Now it is necessary to define the kind of fault that has occurred in the GSU. In order to define the kind of fault, we will support on different sort of conditionals and indicators to define the fault respectively.

Type of fault “Broken”

In this kind of fault, we have three different types: Positive power supply broken, negative power supply broken and signal cable broken. The statements (13) define the corresponding kind of fault. We use a tolerance value called δ_{tb}. The Fig. 10 shows the decision tree to define what kind of fault ``Broken" is in the system.

$$\begin{aligned} Z_{1+} &= \left\{ U_{min} + \delta_{tb} > U_\delta > U_{min} - \delta_{tb} \right\}, \\ Z_{1-} &= \left\{ U_{max} + \delta_{tb} > U_\delta > U_{max} - \delta_{tb} \right\}, \end{aligned} \quad (13)$$

where Z_{1+} – indicator for positive power supply fault;

Z_{1-} – indicator for negative power supply fault;

Z_s – indicator for signal supply fault;

U_{max} – maximum voltage value;

U_{min} – minimum voltage value;

δ_{tb} – threshold value for this kind of fault.

The class “Broken” has been defined, then; the method starts looking for what kind of “Broken” fault is. The method uses the statements in (13) and follows the process defined in Fig. 10.

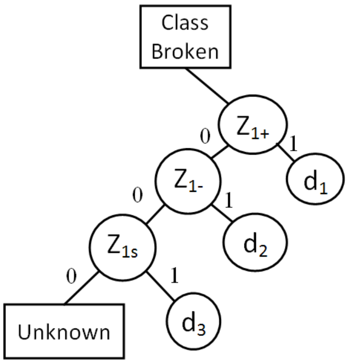


Fig. 10. Decision Tree
to define type of fault Broken

In Fig. 11, an example of this type of fault for a positive power supply fault has been performed in the signal of the AVS_2.

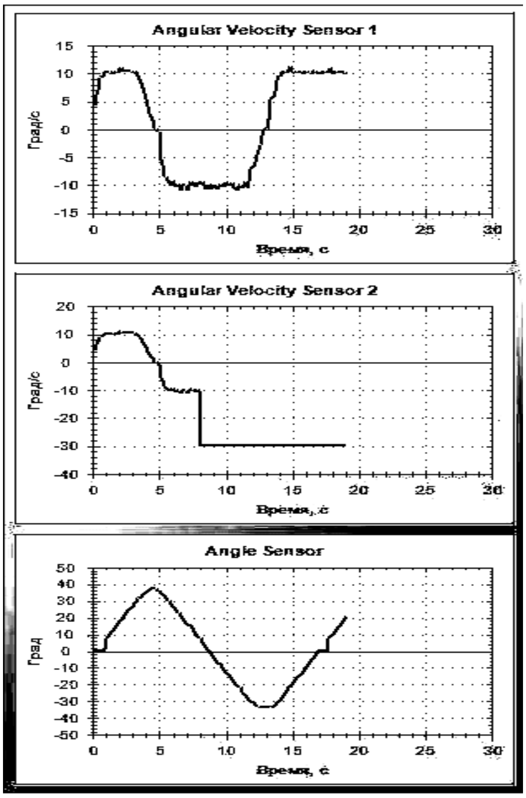


Fig. 11. Positive power supply fault in AVS_2

Unfortunately the method cannot recover from this type of faults due to one of the three cables is damaged.

Type of fault "Shift"

This kind of fault has four different types: Irremovable positive voltage shift, removable positive voltage shift, removable negative voltage shift and irremovable negative voltage shift.

The statements in (14) represent each case for defining this kind of fault.

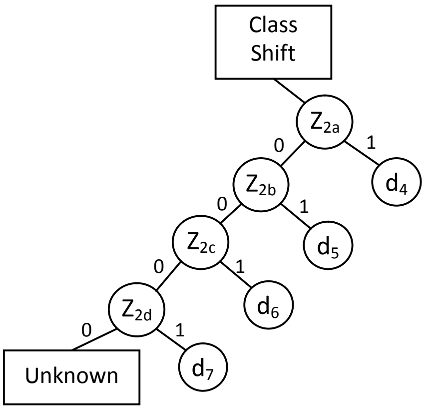


Fig. 12. Decision Tree to define type of fault "Shift"

The decision tree depicted in Fig. 12 shows the procedure to define what type of shift fault is in the system.

$$\begin{aligned} Z_{2a} &= \{\Delta\varepsilon > \delta_{max+}\}, \\ Z_{2b} &= \{\delta_{min+} > \Delta\varepsilon > \delta_{max+}\}, \\ Z_{2c} &= \{\delta_{min-} > \Delta\varepsilon > \delta_{max-}\}, \\ Z_{2d} &= \{\Delta\varepsilon > \delta_{max-}\}, \end{aligned} \qquad (14)$$

where Z_{2a} – irremovable positive voltage shift;

Z_{2b} – removable positive voltage shift;

Z_{2c} – removable negative voltage shift;

Z_{2d} – irremovable negative voltage shift;

$\delta_{max,min}$ – threshold values for this kind of fault;

$\Delta\varepsilon$ – average value of ε_1 and ε_2.

When the method has defined that this fault is removable, the method takes $\Delta\varepsilon$ value and added to the wrong sensor's signal rightly to recover the system's performance.

An example of this kind of fault is shown in Fig. 13.

This example shows the case of an irremovable negative voltage shift fault in the second sensor of angular velocity.

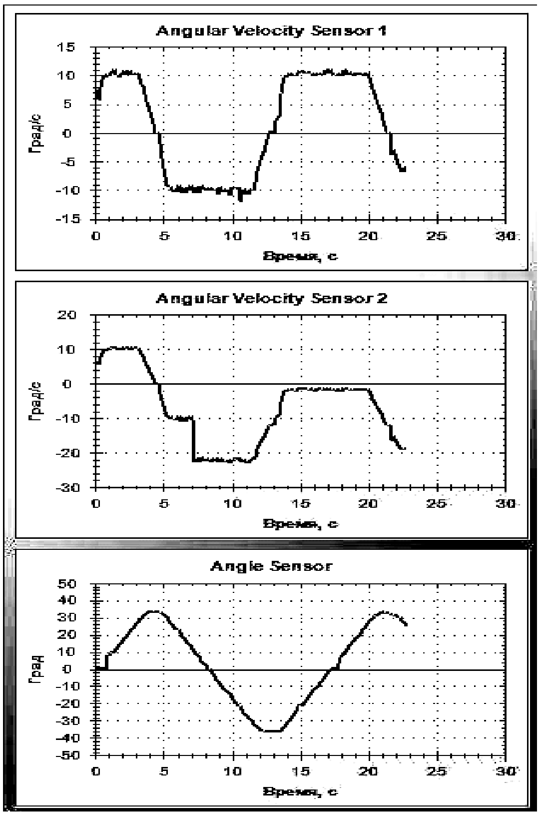


Fig. 13. Irremovable negative voltage shift fault in AVS_2

Type of fault "Change in Transfer Coefficient"

In this kind of fault, there are two different definitions: Transfer coefficient decreased and reorientation of transfer coefficient. Their corresponding statements are shown in (15).

$$\begin{aligned} Z_{3a} &= \{0 > \Delta K > K_i\}, \\ Z_{3b} &= \{-K > \Delta K > 0\}, \end{aligned} \qquad (15)$$

where Z_{3a} – transfer coefficient decreased indicator;

Z_{3b} – reorientation of transfer coefficient indicator;

ΔK – average value of the affected transfer coefficient;

K_i – coefficient value of the faulty sensor in normal state.

The decision tree for this process is shown in Fig. 14, where it is depicted how the method proceeds in the different cases that can be presented.

Once, the type of coefficient fault is defined, we proceed to compensate the wrong coefficient with the value of ΔK, accordingly and only if ΔK is less than the 10% of the correct value of the coefficient.

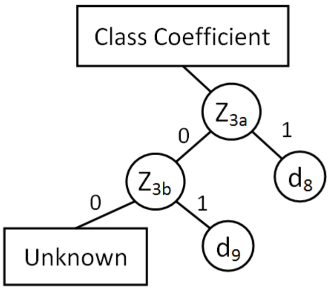


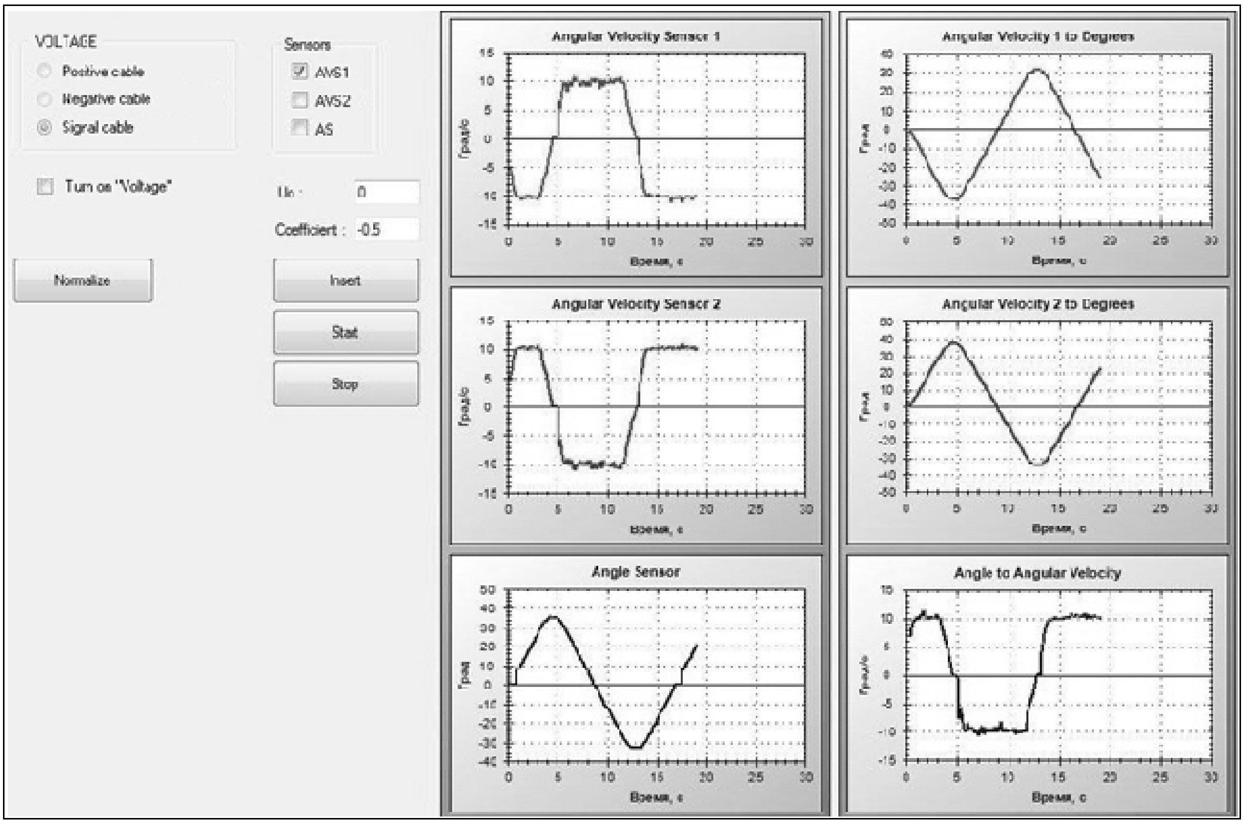
Fig. 14.Flow Tree to define type of fault "Coefficient"

In Fig. 15, we can appreciate a reorientation of the transfer coefficient in sensor one, AVS_1. It is possible to see how the signal has inverted according to the signals of the others sensors.

Conclusions

In the present work a complete complex for the study of a fault-tolerant system is presented. The complex works with real sensors, permits us to understand the behavior of this kind of system and how a method to recover or keep the system's performance is applied. The complex brings up a diagnostic model to different king of possible faults that can occur in the unit of gyroscopic sensors and dynamically emulates these faults. These faults are reflected on their signals; these signals are monitored in real time and depicted on the screen of a graphic interface in a computer.

A fault-tolerant method is proposed and developed and a complete complex has built to study the methodology of the diagnostic process.


VOLTAGE

○ Positive cable

○ Negative cable

● Signal cable

Sensors

☑ AVS1

☐ AVS2

☐ AS

☐ Turn on "Voltage"

Uс : 0

Coefficient : -0.5

Fig. 15. Reorientation of transfer coefficient in AVS_1

The signals from the three sensors are dynamically depicted the graphic interface in a personal computer program. This interface let us study the behavior of the unit and shows dynamically the current state of the sensors. This entire complex permits us to understand a reliable way to test and develops a fault-tolerant process applied to a gyroscopic sensors unit or even another kind of systems.

This complex is a useful tool in the comprehension of the concepts and processes that a fault tolerant method is involved and provides a feasible and graphics way to do it, everything in a dynamic and real interface.

References

1. Kulik, A.S. Fault Diagnosis in Dynamic Systems via Signal-Parametric Approach [Text] / A.S. Kulik // IFAC / IMACS Symposium of fault detection, supervision and a technical process – SAFE PROCESS 91, Baden-Baden. – 1991. – Vol. 1. – P. 157 – 162.

2. Kulik, A.S. Systems Fault-Tolerant support for a Gyroscopic-Sensor Unit [Text]/ A.S. Kulik, F. Kozij // Engineering Simulation. – 1996. – Vol. 13. – P. 955 – 965.

3. Кулик, А.С. Восстановление измерений навигационной системы в режиме реального времени

[Текст] / А.С. Кулик, С.Н. Фирсов, Куок Туан До, О.Ю. Златкин // Авиационно-космическая техника и технология. – 2008. – № 5 (52). – С. 28 – 33.

4. Кулик, А.С. Концепция активной отказоустойчивости спутниковых систем ориентации и стабилизации [Текст] / А.С. Кулик // Радіоелектронні і комп'ютерні системи. – 2009. – № 2 (36). – С. 101 – 108.

5. Stengel, Robert F. Intelligent Failure-Tolerant Control [Text]/ Robert F. Stengel // IEEE Control Systems, June 1991. – P. 14 – 23.

6. Guillaume, J.J. Fault-Tolerant flight Control and Guidance Systems [Text] / J.J. Guillaume // Springer-Verlag London Limited, 2009. – P. 3 – 16.

Поступила в редакцию 10.11.2011

Рецензент: д-р техн. наук, профессор, заведующий кафедры информатики А.Ю. Соколов, Национальный аэрокосмический университет им. Н.Е. Жуковского «ХАИ», Харьков, Украина.

ПЛАТФОРМА ДЛЯ НАВЧАННЯ РОЗРОБНИКІВ СИСТЕМИ ВІДМОВОСТІЙКОСТІ

А.С. Кулік, А.Г. Чухрай, Х.П. Мартінес-Бастіда

У цій статті представлено програмно-апаратний комплекс. Даний комплекс було розроблено для навчання розробників технічним системам для того, щоб вдосконалити підхід відмовостійкості, який застосовується у блоці гіроскопічних датчиків (БГД). Метод відмовостійкості, який застосовується у комплексі, може здійснювати повну діагностику БГД, спостерігаючи за його станом за допомогою декількох порівнянь, визначаючи можливе існування відмови у блоці. Як тільки відмова була виявлена у системі даний метод може знайти місце відмови, дозволяючи нам визначити вид відмови, виявленої у блоці, та це діагностування веде до виконання правильних дій для оптимального відновлення роботи БГД.

Ключові слова: система відмовостійкості, система управління, відмовостійкість, блок гіроскопічних датчиків.

КОМПЛЕКСДЛЯ ОБУЧЕНИЯ РАЗРАБОТЧИКОВ СИСТЕМ ОТКАЗОУСТОЙЧИВОСТИ

А.С. Кулик, А.Г. Чухрай, Х.П. Мартинес-Бастида

В данной статье представлен программно-аппаратный комплекс. Данный комплекс был разработан для обучения разработчиков техническим системам для усовершенствования подхода отказоустойчивости, применяемого в блоке гироскопических датчиков (БГД). Метод отказоустойчивости, применяемый в комплексе, может осуществлять полную диагностику БГД, наблюдая за его состояние с помощью нескольких сравнений, определяя возможное существование отказа в блоке. Как только отказ был обнаружен в системе, данный метод может найти место отказа, позволяя нам определить вид отказа, обнаруженного в блоке, и данное диагностирование ведет к осуществлению правильных действий для оптимального восстановления работы БГД.

Ключевые слова: система отказоустойчивости, система управления, отказоустойчивость, блок гироскопических датчиков.

Кулик Анатолий Степанович – д-р техн. наук, проф., зав. каф. «Системы управления летательными аппаратами», Национальный аэрокосмический университет им. Н.Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail: kulik@d3.khai.edu.

Чухрай Андрей Григорьевич – канд. техн. наук, доцент, доцент каф. «Системы управления летательными аппаратами», Национальный аэрокосмический университет им. Н.Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail:achukhray@gmail.com.

Мартинес-Бастида Хуан Пабло – аспирант каф. «Системы управления летательными аппаратами», Национальный аэрокосмический университет им. Н.Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail:jpbastida@hotmail.com.