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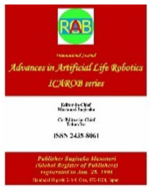

Research Article

Robust attitude control of micro-satellite based on Generation Adversarial Networks fault detection and Cerebellar Model Articulation Controller fault tolerant control

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ABSTRACT

This paper proposes a new robust attitude control architecture for microsatellites. Based on deep learning fault detection method, Cerebellar Model Articulation Controller (CMAC) is used as fault-tolerant control. Using the image recognition function of Generation Adversarial Networks (GAN), the microsatellite actuator fault wavelet spectrum is used as the basis of training generator and discriminator for real-time fault diagnosis and classification. When the system fault diagnosis determines that the fault occurs, the cerebellar neural network participates in the fault-tolerant control. Using the Gan learning ability of generating confrontation network, the problems of insufficient sample data and insufficient sample labeling are solved respectively. As a kind of local learning network, CMAC has the advantages of strong generalization ability, fast convergence speed and simple hardware and software implementation. The simulation results show that, compared with the traditional methods, the fault detection and fault-tolerant control of GAN method combined with CMAC has higher accuracy and robustness.

I. Introduction

Satellite attitude control system is an important subsystem of satellite, which requires relatively high performance and functionality. In the harsh mission environment, complex satellite attitude control system will inevitably have various types of failures, leading to system performance degradation or even system failure. Therefore, in the design of satellite attitude control system, fault diagnosis theory is considered to be a feasible point of view, from which engineers can seek effective solutions to ensure the reliable operation of the satellite when component faults or malfunctions may occur. Therefore, a lot of research work has been done on the fault diagnosis of satellite attitude control system.

In the process of microsatellite on orbit mission, the failure frequency of actuator is relatively high. The causes and types of failures are various, which can not be listed and avoided one by one. Therefore, the most common types are classified into various types, so it has theoretical and practical significance for microsatellite fault detection or diagnosis [1].

The Generative Adversarial Network (GAN) was proposed in 2014 [2]. The GAN continuously optimizes the network to achieve better results by using the mutual confrontation between generator and discriminator. There are many hidden deep learning network models in GAN, and it has good feature learning ability. At first, it is mainly used in data generation and image generation to solve the problem of insufficient sample data. Based on different research purposes, derivative models for GANs are constantly being proposed. A Semi-Supervised Learning with Context-Conditional Generative Adversarial Networks (SSL) is proposed, in which the generator structure remains unchanged and the discriminator is classified in two categories an output

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layer is added to achieve the multi classification function [3]. Since the SSL was proposed, it has been applied to speech generation and recognition, image recognition, sample classification and other fields [3]. The SSL is applied to human action recognition, and the images are captured by the video frame as the network input for action recognition [4]. In the above application, the SSL achieves the recognition effect.

The Cerebellar Model Articulation Controller (CMAC) was developed by Dr. J.S. Albus in 1975, based on the biological model of cerebellar cortex proposed by Marr in Medical Research Institute. CMAC are widely used because of characters of fast convergence speed, strong generation ability, it can overcome the local optimization problem of back propagation neural network (BP), simple structure, easy implementation by software and hardware. CMAC has been successfully applied in many application fields, such as fault detection and nonlinear control. In the classification task, Lin et al. [5], a parameter fuzzy CMAC neural network with mixed parameters is proposed. Learning algorithm composed of self-clustering genetic algorithm (GA) and improved GA for facial detection and breast cancer diagnosis.

In recent years, the research on motor bearing fault diagnosis has been widely concerned by scholars and engineers. The vibration analysis method is commonly used for bearing fault diagnosis, which analyzes and classifies the collected bearing vibration signals. However, bearing vibration signal has the characteristics of non-stationary, so it is very difficult to extract the characteristics of the bearing.

As a time-frequency analysis method, continuous wavelet transform can effectively extract the time-frequency characteristics of non-stationary signals. The function of wavelet transform is to take one-dimensional signal as input. The result of time-frequency analysis essentially reflects the two-dimensional spectrum of energy intensity of signal at different time and frequency, and the output is displayed in the form of time-frequency diagrams. At present, continuous wavelet transform has been widely used in the field of mechanical fault diagnosis [6]. In reference, a combination of wavelet transform branch support vector machine (SVM) and convolutional neural networks (CNN) was proposed. In reference [6], wavelet transform and back propagation neural network (BP) were used to realize fault diagnosis of different motors. In the application of the above literature, the feature vector is constructed artificially based on the time-frequency map, and the learning and expression ability of the selected neural network is limited [6].

The remainder of this paper is organized as follows: the section II introduces the basic theoretical background. The section III goes on the proposed method is introduced. In Section IV, detection fault and fault tolerant control in case of fault is simulated. Finally, Section V presents the conclusion.

II. Theoretical Background

In this section, the background theory of the techniques involved in the proposed diagnosis system is provided.

A. *Generative Adversarial Networks* (*GAN*)

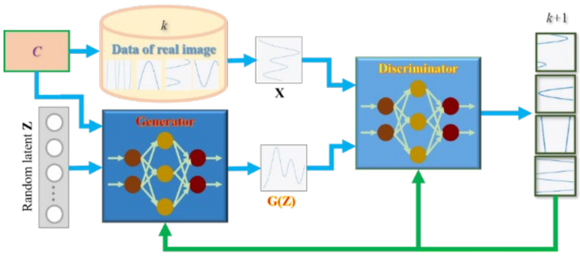

Fig. 1. SSL algorithm process and structure

The generator of the improved SSL consists of several deconvolution layers, excitation layers and extracted over fitting Fitting) and speeding up the training speed method, for the input *n*-dimensional noise signal connecting condition variables, the final output is almost the same as the real signal "false" signal, which can achieve the state of "false" with the real signal, which is conducive to expand the sample to achieve better training effect. The discriminator consists of several convolution layers, excitation layers, fully connected layers and classified output layers, as well as the corresponding methods to prevent over fitting and speed up the training. The discriminator takes the real signal, that is, the signal to be detected and the "false" signal generated by the generator, as the input at the same time. The flow chart of the improved generative countermeasure network algorithm is shown in Figure 1.

B. *Cerebellar Model Articulation Controller (CMAC)*

Shown in Figure 2, the basic structure of MIMO CMAC with three inputs and three outputs is shown Fig. 2.

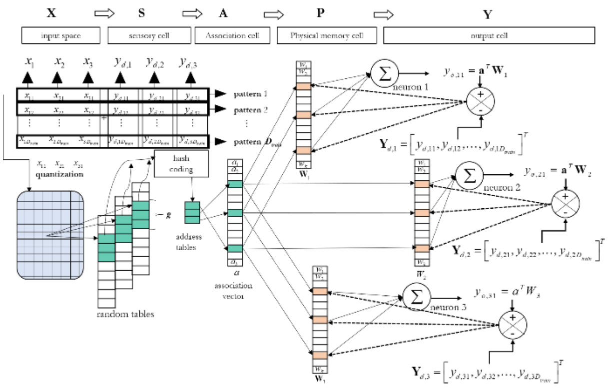

Fig. 2. The MIMO CMAC architecture

The five units of CMAC neural network consist of (i) input space (**X**), (ii) sensory cell (s), (iii) Association unit (**A**), (iv) physical storage unit (**P**) and (v) output storage cell (**Y**) using a series of images. Figure 2 shows the network topology vector of three inputs and three output vectors of CMAC neural network; the input is represented by $[x_1, x_2, x_3]^T$, and the actual output is $[y_{d1}, y_{d2}, y_{d3}]^T$. The figure shows three inputs $[x_1, x_2, x_3]^T$ and one desired output y_{d1}.

III. Proposed Method

An overview of the proposed detection system is shown in Figure 3. The proposed method uses a superposition matrix containing WT spectra as the input of the depth model to reveal the discriminative features. To be precise, based on the preprocessing results of wavelet transform, a GAN model that captures inherent information through convolutional layers is proposed.

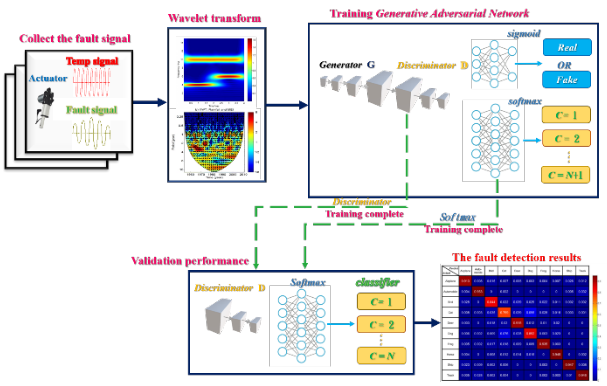

Fig. 3. The overview of the proposed detection system

IV. Fault Model Wavelet Transform

Case1.

$$f_{a_1} = \begin{cases} 0.5, & 40 \le t < 70(\text{sec}) \\ 0 \end{cases}, \; f_{a_2} = f_{a_3} = 0 \qquad (1)$$

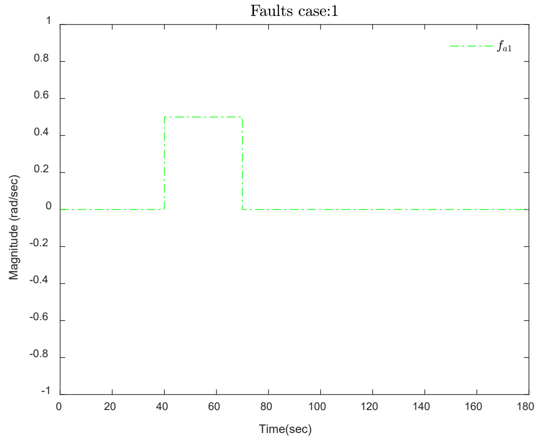

Fig. 4 Time response of fault case 1

Time response of fault case 1 is shown in Figure 4.

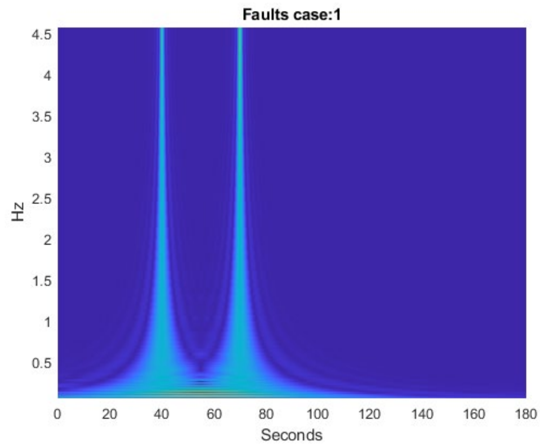

Fig. 5 wavelet transform coefficient diagram of case 1 attitude fault

The fault signal is transformed into frequency time wavelet coefficient graph (time-frequency diagram) to achieve time-frequency analysis of vibration signal and obtain more comprehensive and detailed information. The feature extraction and image recognition ability of deep learning GAN are used, and the compressed time-frequency diagram is used as input. The wavelet transform coefficients of case 1is shown in Figure 5.

V. Fault Estimated and Fault Tolerant Control Simulation of Microsatellite Attitude

The microsatellite dynamic equation is expressed as a nonlinear equation

$$J\omega = -\omega^{\times} J\omega + \tau_w + \tau_u \qquad (2)$$

where $J = \text{diag}\{J_x, J_y, J_z\}$ are inertia moments of the satellite along principal axes; $\boldsymbol{\omega}$ are the angular velocity of the body-fixed reference frame. $\boldsymbol{\tau}_w$ are space disturbance torques and $\boldsymbol{\tau}_u$ are the control torques along principal axes. For small attitude angles, the derivation of eq. (2) is as follows

$$\begin{cases} \dot{x}(t) = Ax(t) + g(t,x) + B_u u(t) + B_w w(t) + F_a f_a(t) \\ y(t) = Cx(t) + F_s f_s \end{cases} \tag{3}$$

where state vector $x = [\psi \quad \theta \quad \phi \quad \dot{\psi} \quad \dot{\theta} \quad \dot{\phi}]^T$, nonlinear term $g(t,x) = \begin{bmatrix} 0 \\ \omega_0 \\ 0 \\ (J_z - J_y)\omega_y\omega_z/J_x \\ (J_x - J_z)\omega_x\omega_z/J_y \\ (J_y - J_x)\omega_x\omega_y/J_z \end{bmatrix}$,

actuator fault matrix $F_a = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}^T$ and actuator fault vector $f_a = \begin{bmatrix} f_{a_1} & f_{a_2} & f_{a_3} \end{bmatrix}^T$.

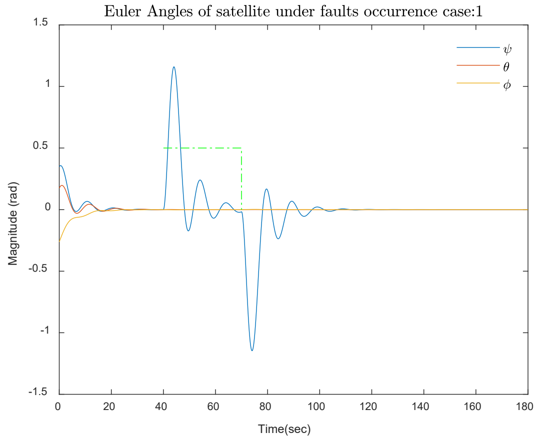

Fig. 6 Time response of case 1 attitude angle failure and recovery

Time response of case 1 attitude angle failure and recovery is shown in Figure 6.

VI. Conclusion

According to the numerical simulation results in the previous section, the feasibility of applying SSL to microsatellite fault estimated. Through SSL of GAN samples and training parameters, the CMAC has good generalization ability and stability under the brake fault model.

Acknowledgements

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Authors Introduction

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