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Design and Application of Fault Injection System for Testability Verification Test

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Abstract. A general fault injection system is designed for the problem that the existing fault injection equipment cannot meet the requirements of testability verification test. Firstly, according to the requirements of testability verification test for fault injection and state monitoring, an injection system framework including hardware platform and software platform is designed. The detailed design scheme of the system hardware platform, as well as the design architecture and operating principle of the software platform are presented. Then, various fault injectors are integrated, and the signal-oriented fault model is constructed to realize the effective simulation of the fault. Finally, the system is applied to the testability verification test of a control system, and 58 fault samples are actually injected, which shows that the system can meet the requirements of the testability verification test.

Keywords: Testability; Verification Test; Fault Injection; Fault Model; System Design.

1. Introduction

Testability verification test based on fault injection is an effective means to evaluate the testability level of equipment. The test evaluation needs to be carried out under the condition of equipment failure, and it is required to reproduce the possible failures in the test. Therefore, the fault injection is the supporting technology of the testability verification test. Various types of fault injectors have been developed abroad, such as MEFISTO-C [1] developed by Laprie and others from Chalmers University of Technology in Sweden, Messaline [2] developed by LAAS-CNRS hardware test center in Toulouse, France, FIAT [3] developed by Siewiorek of Carnegie Mellon University, etc. At the same time, the fault injection method has been widely applied in the design and testing of complex systems, such as the built-in test (BIT) verification test of APG-65 and APG-66 radar systems [4-5]. Various domestic units have developed a variety of fault injectors that can achieve a certain type of fault injection, but there is no generalized fault injection system, which cannot be used in testability verification test. In order to meet the requirements of fault injection in the testability verification test, a fault injection system was designed by utilizing various types of fault injectors, and the overall framework and detailed design scheme of the system are proposed.

2. Fault Injection System Design

2.1 Fault Injection System Framework

In the testability verification test, in addition to requiring the fault injection system to simulate common equipment faults, it should also have the functions of automatic test and fault monitoring to complete the test and diagnosis of equipment in the fault state [6]. Considering the versatility of the injection system, the comprehensive coverage of the fault and the operability of the equipment, a fault injection system consisting of hardware platform and software platform is designed. Its basic framework is shown in Fig. 1.

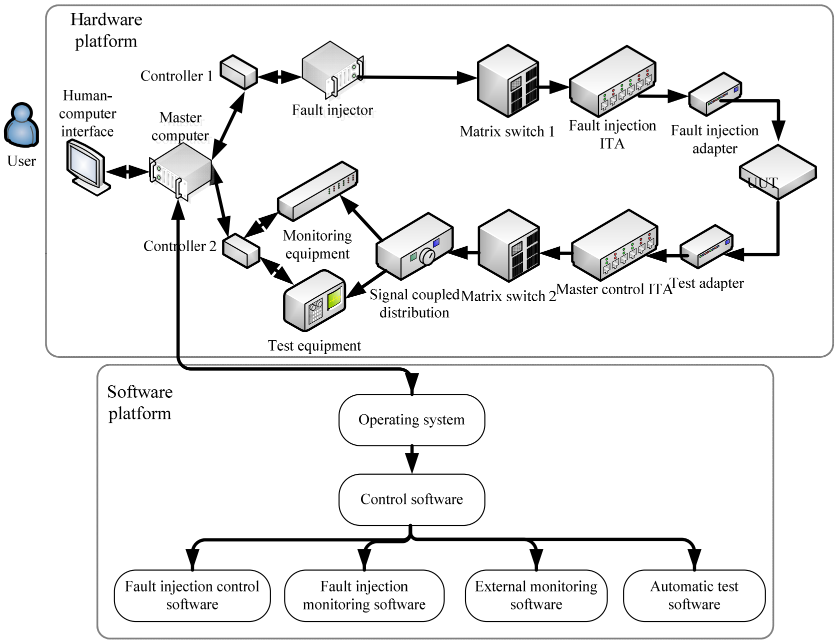

Figure 1. Basic framework of the fault injection system.

2.2 Hardware Design of Fault Injection System

The hardware platform of fault injection system mainly includes fault injection device and state monitoring device. Fault injection device is constructed based on LAN bus architecture, and the productized fault injector is used to realize fault injection function. Meanwhile, an external trigger input interface is designed for synchronous control. The state monitoring device is integrated with PXI bus instrument module and LAN bus instrument, including controllers, data acquisition cards, I/O modules and other modules.

The control of fault injection is completed by the industrial computer, which is also the controller of the whole platform. The industrial computer sends control commands through LAN to control each fault injector, and sends each failure mode information and fault signal parameters set by the user to the corresponding fault injector. According to the control command issued by the main control unit, the fault injector generates a corresponding fault signal, which is input into the adapter through the coupling and switching of the signal, and the other input is input into the monitoring system. The state monitoring system is composed of PXI embedded controller and corresponding supporting modules. The PXI controller is the monitoring main control computer. In order to meet the design requirements of the fault injection system, the AMC4100 series embedded controller is selected. The industrial computer can also remotely control the state monitoring system through the LAN bus. When it is necessary to test the object under test, the state monitoring system can be controlled by PXI controller. The monitoring system collects the corresponding fault signal information according to the fault signal monitoring point set by the user, and transmits it to the monitoring main control computer in real time. After data processing, the monitoring master computer is displayed in the software interface in real time. The operating principle of the hardware platform is shown in Fig. 2.

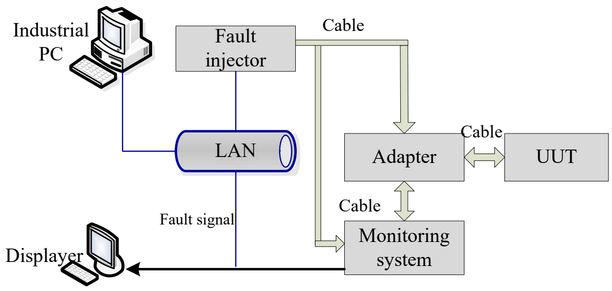

Figure 2. Operating principle of the hardware platform.

For electronic equipment, failure modes are complex and diverse, and it is difficult to generate these diverse failure modes by relying on independent fault injectors. For the requirements of different types of fault signal, various types of fault injectors are selected to realize the injection of common failure modes of electronic equipment.

The state monitoring device is connected based on the PXI bus and controlled by the PXI controller. The main modules include the digital multimeter module PXI4070 for monitoring power and level signals, the digital I/O module AMC4512A for monitoring digital signals, the 32-channel control switch AMC4606 for switching fault signal channel, bus signal channel multiplexing control and expansion, the 100KHz 16-bit scanning A/D module AMC4321A for multi-channel signal, high speed, high precision data acquisition. In addition, the PXI chassis has reserved slots to increase the monitoring module as needed. Since the signal type, signal quantity, connector type, and test flow of each object under test are different, it is impossible to directly connect the generalized hardware platform signals with different devices under test, so the hardware platform needs a standardized and open integrated interface combination, this interface combination must cover all the signals of the low-frequency input measurement, output excitation and control of the universal test platform. According to the requirements, a universal interface adapter is designed, including structure, internal cable and auxiliary cable for testing. The structure adopts a cage structure, and the internal cable is directly led out from the interface test adapter module to the adapter panel, and the auxiliary cables are customized according to specific test requirements.

2.3 Software Design of Fault Injection System

The fault injection system software mainly includes fault injection software and state monitoring software. The main function of which is to realize the signal input under different fault modes of various signals, with the function of fault mode editing. Its structure is shown in Fig. 3.

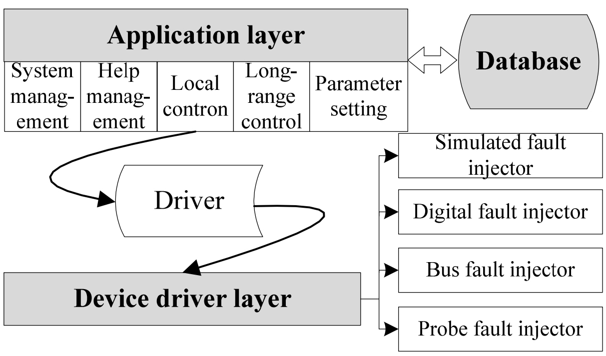

Figure 3. Structure of the fault injection software.

Main functions of the software include TPS development, TPS debugging, TPS operation, platform setup, instrument call, information sharing, comprehensive query, database maintenance, etc. These functions enable the functional modules to coordinately operate through the internal interface; interact with the existing network and the measured object information through the external interface. The architecture is shown in Fig. 4.

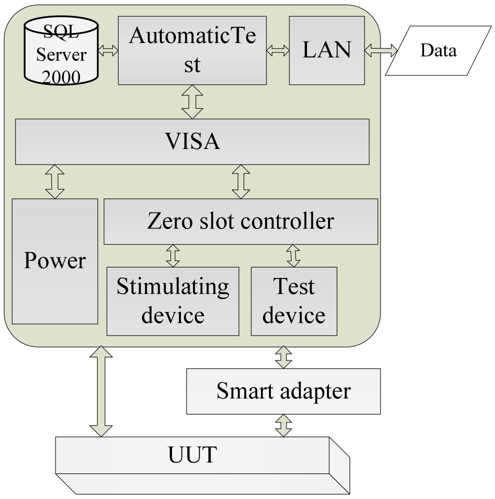

Figure 4. Architecture of the software system.

3. Signal-oriented Fault Model

In the fault injection test, the test signal must be defined and described according to the operating principle of the fault injection system platform, so as to achieve a general description of the test information, thereby improving the interchangeability of the instrument, the portability of the TPS, and the reuse of the program code, and can also achieve reusability of design information and interoperability of test equipment.

The signal to be simulated in the fault injection test includes two parts: the operating condition signal and the fault simulation signal, which are all equivalent to the electrical characteristics of the signal through software simulation and hardware simulation. The operating condition signal of the test object is derived from the cross-linking component, which is used to simulate the real operating environment of the subject and drive it to run. The fault analog signal is used to simulate the fault state and characteristic signal of the subject.

Based on the signal-oriented fault simulation technology, in order to realize the accurate reproduction of the fault state of the test object, the signal is refined into excitation signal and fault signal, and the test diagnosis information and the fault injection equipment information are introduced, then the fault model is

$$FI = I\left[f_1\left(A_{\mathrm{f}}, A_{\mathrm{t}}, A_{\mathrm{p}}, A_{\mathrm{c}}\right), f_2\left(A_{\mathrm{f}}, A_{\mathrm{t}}, A_{\mathrm{p}}, A_{\mathrm{c}}\right), E_{\mathrm{t}}, D\left(T, B\right)\right] \tag{1}$$

where, I is describing function, $f_1\left(A_{\mathrm{f}}, A_{\mathrm{t}}, A_{\mathrm{p}}, A_{\mathrm{c}}\right)$ is excitation signal characteristic, $f_2\left(A_{\mathrm{f}}, A_{\mathrm{t}}, A_{\mathrm{p}}, A_{\mathrm{c}}\right)$ is fault signal characteristic, A_{f} is signal category, A_{t} is signal types, A_{p} is signal parameter, A_{c} is signal connection, E_{t} is fault injector type, $D\left(T, B\right)$ is test diagnostic information, T is test point, B is fault behavior vector.

4. Application for Typical Equipment

In order to verify the testability of the control system, the fault injection system is used to perform fault injection. The control system includes a processor module, a multi-function module, an asynchronous communication module, a synchronous communication module, an AD conversion module, an I/O module, and a power module. According to the failure mode effect and critically analysis, the failure mode library of the system can be obtained, from which 63 failure samples are selected for fault injection.

According to (1), the fault model of 63 failure samples can be obtained, and then the fault injection system is used for fault injection based on the fault model. According to the fault injection result, this system can be used for fault injection, and the fault injection rate is 92%, which can meet the requirements of testability verification test. According to the test results, the estimated detection rate of the control system is 82.5%.

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