Fuzzy Approach to Multimedia Faulty Module Replacement

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Abstract----Faulty module replacement is to replace faulty module with a fault-free one. For non-real time multimedia systems, we present a fuzzy approach to replacing the faulty module. After analyzing the natures of random and pseudo-random test sequences applied to a module under test, we obtain the aliasing fault coverage between the random and pseudo-random sequences. The activity probability features of intermittent faults in the module under test are discussed based on Markov chain model. Results on real examples are presented to demonstrate the effectiveness of the proposed fuzzy replacement approach.

I. Introduction

If error occurs sometimes in a module of a non-real time multimedia system, is it worth to replace the faulty module? In the past, we made decisions based on our experience. In this paper, we deal with this problem based on fuzzy set analysis.

An error is incurred by a fault in the module (circuit). It becomes more and more difficult to detect faults of logic circuits with continually growing complexity. Therefore, a technique, called built-in self-test (BIST) was proposed to overcome the difficulty [1~3]. In the technique, two units: pseudo-random sequence generator and output response compactor have to be integrated into a chip under test. The pseudo-random sequence generated by the generator are applied to the input of module under test (MUT) for stimulating the faults, while the compactor is used for compressing the MUT output response into a signature.

In BIST technique, linear feedback shift register (LFSR) [2] is commonly used for generating the pseudo-random sequence, and multiple input shift register (MISR) [4] is generally applied to compressing the output response. After testing, the compressed signature will be compared with the expected reference value obtained from corresponding fault-free module. If they are the same, the MUT is considered fault-free; otherwise, the MUT is considered faulty.

Some previous efforts have researched on the pseudo-random testing [5-8]. These efforts used combinatorial analysis and differential solution for achieving detection probability, test length, and fault coverage. Results obtained from these efforts show that the random test model is not a better approximation to the pseudo-random testing. However, the relationship among the test length, the detection probability, the fault coverage, and test confidence was not derived in these efforts. Meanwhile, the aliasing fault coverage between the random and pseudo-random sequences was not discussed.

In this paper, we will analyze the relationship among the test length, the detection probability, and the fault coverage for the random and pseudo-random sequences. The aliasing fault coverage between the random and pseudo-random sequences will be estimated for permanent faults. Moreover, we will derive the expression of the aliasing fault coverage between the random and pseudo-random sequences for the intermittent faults. The activity probability of the intermittent faults will be obtained based on Markov chain model. The self-test functional diagrams for the intermittent faults will be designed in the case where the retry policy will be used in the intermittent fault detection. Finally, a fuzzy approach is presented to decide whether to replace the faulty module in non-real time multimedia systems.

II. Aliasing Fault Coverage

Paper [9] has proposed a relationship between the mean fault coverage and circuit detection probability. The relationship is only suitable for the pseudo-random sequence according to the analysis in [9], although the paper said the relationship is for the random sequence. Because it is known that the pseudo-random sequence is not pure random. In the pseudo-random sequence generated by LFSR, arbitrary two vectors within the period are not the same (n is the number of the LFSR output bits). Namely, the current vector applied to the circuit under test (CUT) is not the same as the previous arbitrary vector. For the random sequence, the current vector applied to the CUT is possibly the same as a previous vector with a probability. Then, what is the difference between the random and pseudo-random sequences? We, first, introduce the following definition.

***Aliasing fault coverage*:** the *aliasing fault coverage* between a random and a pseudo-random sequence is the difference of the fault coverages between the random and pseudo-random sequence applied to a CUT. Suppose the fault coverage for the random sequence is denoted as C_r, while the fault coverage for the pseudo-random sequence is denoted as C_p. The *aliasing fault coverage* C_a is represented as

$$C_a = C_r - C_p. \tag{1}$$

Formula (1) shows that if C_a is greater than 0, the test quality of the random sequence is better than that of the pseudo-random sequence; otherwise, the test quality of the random sequence is equal to or even worse than that of the pseudo-random sequence.

When *m* vectors are applied to the CUT, the *aliasing fault coverage* C_{am} is estimated as [3]:

$$C_{r2} - C_{pm} \le C_{am} \le -\frac{m-1}{2^n}\int_0^1 x(1-x)^{m-1}p(x)dx, \tag{2}$$

where *x* is the detection probabilities of the detectable faults, *p(x)* is the distribution of the detection probabilities of the detectable faults in a circuit, C_{r2} is the fault coverage of two vectors of the random sequence, and C_{pm} is the fault coverage of *m* vectors of the pseudo-random sequence.

In inequality (2), we can see that the test quality of the random sequences is worse than that of the pseudo-random sequence since C_{am} is less than or equal to 0. Moreover, the absolute value of the left hand side of inequality (2) will increase with growing *m*, which implies that the test quality of the random sequences becomes worse with increasing *m*. Fig.1 shows the relationship of the *aliasing fault coverage* against the input vector numbers in the simplest case where *p(x)*=1 and *n*=6. The shadow part in Fig.1 is the area between the best and worst curves.

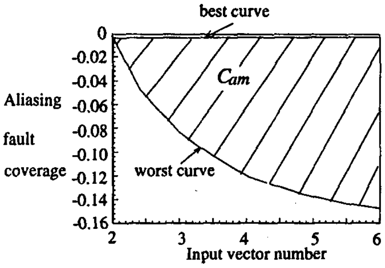

Fig.1. Aliasing fault coverage vs. input vector numbers

Table 1 demonstrates the simulation results for the circuit c17, one of the ISCAS-85 benchmark circuits [10], where *L* stands for the test sequence length. In Table 1, it is clear that the test quality of the pseudo-random sequence is really better than that of the random sequence. That is because, in the random sequence, the 11th and 12th vectors repeat the sixth and eighth, respectively.

Table 1. The fault coverage for the circuit c17

L	Pseudo-random	Random
1	0.294118	0.323529
2	0.323529	0.352941
3	0.588235	0.441176
4	0.735294	0.470588
5	0.764706	0.735294
6	0.852941	0.735294
7	0.882353	0.764706
8	0.911765	0.794118
9	0.911765	0.823529
10	1.000000	0.823529
11		0.863043
12		0.863043
13		0.970588
14		1.000000

III. Intermittent Fault Detecting

Papers [11,12] proposed the retry policy on the intermittent fault detecting. The test process of the policy is divided into 2 phases. In phase 1, the random input vectors are applied until fault is detected. In phase 2 (retry phase), the same input vector is applied repeatedly to determine the fault type (permanent or intermittent). However, in this policy, the influence of the random and pseudo-random sequences on the intermittent fault is not considered, and mean intermittent fault coverage is not estimated.

Inequality (2) is also suitable for the intermittent faults in the cases where the activity probabilities of the intermittent faults are considered. Therefore, for the intermittent faults, inequality (2) is slightly modified as follows

$$\alpha(C_{r2} - C_{pm}) \le C_{am} \le \alpha(-\frac{m-1}{2^n}\int_0^1 x(1-x)^{m-1}p(x)dx), \tag{3}$$

where α is the mean activity probability of the considered intermittent faults in a circuit. In inequality (3), we can also see that the testing quality of the pseudo-random sequence is better than that of the random sequence because of $\alpha \ge 0$.

Fig.2 illustrates the simulation results on the intermittent faults for the circuit c17. In Fig.2, we only consider the first time appearance of the intermittent faults because the retry policy described below is used in detecting the intermittent faults.

Since the testing quality of the pseudo-random sequence is better than that of the random sequence for the intermittent faults, we adopt BIST technique to design the self-test block diagram for a 5-input CUT. Fig.3 is the generator of the pseudo-random sequence and the same test vector repetition.

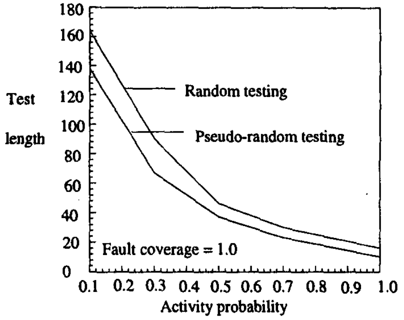

Fig.2. Test length vs. fault activity probability

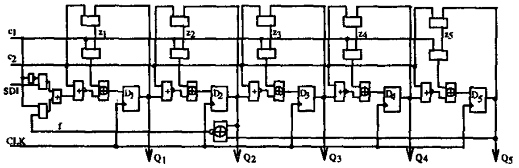

Fig.3. Generator

In Fig.3, SDI is scan input; CLK is clock; c_1 and c_2 is control inputs; and Q_i is output, which is connected to the input of the CUT correspondingly.

In the retry policy, two problems have to be resolved. The first is to determine the test sequence length needed to determine whether the circuit is faulty. The other is to determine the repetition number of the same test vector to decide whether the circuit fault is intermittent. The first problem has been resolved in paper [2]. The second depends on the confidence.

Confidence of fault type: the *confidence* of fault type is the trustful degree to consider a fault as permanent or intermittent fault.

To resolve the second problem, Markov chains are adopted to describe the testing process [11]. From the chains we can derive the following formula:

$$P_c = P_f^{\,L-1}(1-P_f), \qquad (4)$$

where P_c is the *confidence* to consider fault *f* as permanent, P_f is the activity probability of fault *f*. The fault activity probability can be obtained from the repetition number *L* of the same vector.

IV. Fuzzy Replacement Approach

When we found the fault and its activity probability in a module of a non-real time multimedia system, we can determine whether the module is worth replacement by means of the fuzzy set. Let *X* be the universe of discourse, where each element x_i is the influence factor on the performance of evaluated system. In this paper, we only consider the system¡fs fault-free performance, which is denoted as x_f. The other performances are wholly denoted as x_t. Therefore, we have

$$X = \{x_f, x_t\}. \qquad (5)$$

In order to determine x_f we introduce fuzzy membership function [13]. In this paper, the fuzzy membership function of x_f is estimated as

$$\mu(x_f) = 1 - P_f. \qquad (6)$$

P_f in equation (6) can also be obtained from statistics if there are no self-testing ability or external tester for the faulty module. Thus, the system¡fs general performance is evaluated as

$$Perf = w_f \times \mu(x_f) + w_t \times \mu(x_t), \qquad (7)$$

where w_f, w_t are weights associated with x_f and x_t, respectively. Moreover, $w_t \times \mu(x_t) = 1$ because the other performances are considered perfect. w_f can be determined by the usage probability of the analyzed module. Then, the proportion P_{pp} of the general performance of the system to its price is

$$P_{pp} = \frac{Perf}{P_r}, \qquad (8)$$

where P_r is the price of the system.

If the system has a faulty module, which price is P_m; the proportion P_{ppa} of the general performance to the price after replacing is estimated as

$$P_{ppa} = \frac{w_f \times 1 + 1}{P_m + P_r}. \qquad (9)$$

The difference of the two proportions, after and before replacing of the faulty module, is

$$D = P_{ppa} - P_{pp} = \frac{w_f P_r - P_m w_f \mu(x_f) - P_r w_f \mu(x_f) - P_m}{(P_m + P_r) P_r}. \qquad (10)$$

It is clear that the faulty module is worth replacement if *D* in equation (10) is greater than 0, otherwise the replacement is not worth. We obtained the statistical data from some non-real time multimedia systems, as shown in Table 2.

In Table 2, we can see that N-adapter in P1 is worth replacement, the other two faulty modules in P2 and S1 are not worth replacement. When we finish this paper, we visited the owners of above 3 multimedia systems again. The N-adapter has been replaced with a new one, and the M-adapter and the encoder in P2 and S1 are not replaced.

V. Concluding Remarks

In this paper, we proposed a fuzzy approach to replacing faulty modules in non-real time multimedia systems. The fuzzy membership function of the module fault-free performance is determined as one minus its fault activity probability, which can be obtained by analyzing the properties of the intermittent faults in MUT. The *aliasing fault coverage* shows that the testing quality of the pseudo-random sequence is better than that of the random sequence. The *confidence* of the fault type is achieved by applying Markov chain model to the intermittent fault detection. We designed the functional circuit of the intermittent fault self-testing based on the retry policy. Statistical data of the non-real time multimedia systems demonstrate the analytical ability of the presented approach to the faulty module replacement based on the fuzzy set.

As part of our ongoing work, the proposed analytical approach to faulty module replacement using the fuzzy set will be tested on more non-real time multimedia systems.

Table 2. Statistical data

S-name	P1	P2	S1
P_r	1050US$	1800US$	4100US$
M-name	N-adapter	M-adapter	Encoder
P_m	61US$	120US$	410US$
w_f	0.42	0.23	0.01
$\mu(x_f)$	0.36	0.75	0.15
D	1.816×10^{-4}	-1.139×10^{-5}	-2.036×10^{-5}

Note: S-name is system name, M-name is module name, N-adapter is network adapter, M-adapter is modem, P1 and P2 are multimedia personal computers, S1 is a small multimedia server.

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