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Hardware Overhead Analysis between Embryonics System and N Modular Redundancy System

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***Abstract*—Embryonics system is a new hardware with self-repair ability. Based on the analysis of Embryonics system and N modular redundancy system, the hardware overhead model has been built. The hardware overhead of Embryonics system has been analyzed with this model. From the analysis result of the target circuit with different scale and self-repair capacity, we can see that Embryonics system is more suitable for the target circuit with larger scale and high self-repair capacity, while the N modular redundancy system has superiority on the circuit with smaller scale and low self-repair capacity, and the hardware overhead can be reduced through optimizing assistant circuit design.**

Keywords-self-repair; embryonics system; hardware overhead; self-repair capacity

I. INTRODUCTION

Embryonic electronics (embryonics) system is a new hardware with self-repair ability inspired by multicellular organism and embryonic development process[1]. Its structure [2], self-repair mechanism[3] and experiment system[4] has been researched deeply, and a variety of embryonics system has been proposed[5, 6]. Based on the structures, self-repair mechanism, some small-scale circuit's self-repair experiments have been realized.

The hardware overhead is an important issue during self-repair, and there is less research on embryonics system's hardware overhead. The lack of hardware overhead analysis on system level influence the embryonics system's research and application.

In this paper, a hardware overhead model of embryonics system has been built, according to its structure and self-repair mechanism. And the hardware overhead of embryonics system and triple modular redundancy system was compared. The embryonics system's application scope was confirmed through analysis, and embryonics system's design and application can be guided.

II. N MODULAR REDUNDANCY SYSTEM AND EMBRYONICS SYSTEM

A. N Modular Redundancy

N modular redundancy is an addition fault tolerance technology. Its basic idea is majority decision, and thinks that the most opinion is correct. The structure of N modular redundancy system is shown as Fig. I.

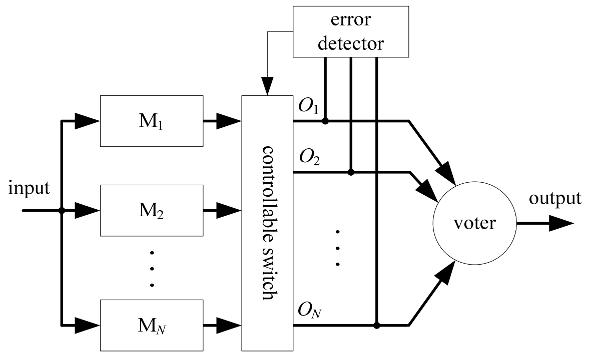

FIGURE I. FRAMEWORK OF N MODULE REDUNDANCY SYSTEM.

When the circuit realized with N modular redundancy system, N identical modules M_1, M_2, ..., M_N is used, and their output O_1, O_2, ..., O_N is connected to voter and an error detector through controllable switch. The most same output of O_1, O_2, ..., O_N will be output as the system's output through voter. The modules can be detected with error detector, and faulty module's output can be cut off by controllable switch according to error detector.

If M_i occurs fault, its output O_i is different from other modules' output and voter's output is the same as the other modules' output, and the faulty module's output does not influence the system's output. The fault can be detected by the error detector, and the detect result controls the controllable switch to cut off the Mi's output from system, and the system is degenerated to N-1 modular redundancy system.

B. Embryonics Bio-Inspired Self-Repair System

Embryonics system is a two dimensional array composed with same uniform electronic cells, as shown in Figure II. Electronic cell is a logical processor with certain data processing capability, and composed with address generator, genome memory, I/O router, logic block and Built-In test (BIT) unit.

Each electronic cell express a specific gene according to its position in system, and its logic function and I/O connection can be determined. Target circuit's function can be accomplished by the cells in system. The cells' state is detected by BIT during running process. When a cell fault is detected, a fault signal will be generated, and repair mechanism can be started triggered by fault signal. The faulty cell can be eliminated with repair mechanism. The repair mechanism includes row/column elimination self-repair and cell elimination self-repair according to the different methods of faulty cell eliminating.

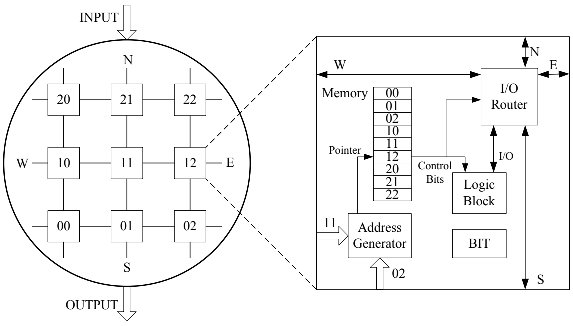

FIGURE II. BASIC STRUCTURE OF EMBRYONICS BIO-INSPIRED SYSTEM.

In row/column elimination, the failing of one cell provokes the elimination of the corresponding row/column, and the function of the row/column with the fault cell and the rows/columns after will be backward-shifted, until making use of a spare row/column. In cell elimination, spare cells replace faulty cells in two stages. First, spares located in the same row replace faulty cells. When the number of faulty cells in a row surpasses the number of spare cells, row elimination occurs.

III. MODEL OF HARDWARE OVERHEAD

The model of hardware overhead is built considering circuit's self-repair capacity, according to the character of embryonics system and N modular redundancy system.

When target circuit is realized with embryonics system, the target circuit's function is mapped to electronic cells. To realize the circuit's self-repair, besides function block and I/O router, the genome memory, BIT and address generator are needed in electronic cell. For the single function unit, its hardware overhead is increased.

If a target circuit is composed with $m \times n$ basic units, and each basic unit's hardware is ω. When the basic unit's function is realized by electronic cell, the genome memory, BIT and address generator is increased. Suppose the ratio of additional circuit and the basic unit is α, and its value depends on the circuit design level and self-detection fault coverage.

The hardware overhead of the target circuit composed with basic unit is $mn\omega$, while the embryonics system's hardware overhead is $mn\omega(1+\alpha)$ to implement the target circuit's function.

When the target circuit is realized with N modular redundancy system, suppose the system's self-repair capacity is S_{RC}, then there need $q = S_{RC} + 2$ identical modules. Ignoring the hardware overhead of voter and error detector, the system's hardware overhead is

$$H_{NMR} = mn\omega q = mn\omega(S_{RC} + 2) \tag{1}$$

When the embryonics system is used to implement target circuit and the column elimination self-repair mechanism is employed, a column of electronic cells is needed to repair a fault. S_{RC} redundancy column electronic cell are needed to achieve the self-repair capacity S_{RC}, and system's hardware overhead is

$$H_{EM} = m(n + S_{RC})\omega(1 + \alpha) \tag{2}$$

From Eq. (1) and Eq. (2) we can see that, for the same target circuit, when it realized with N modular redundancy system and embryonics system, the hardware overhead is different to achieve same self-repair capacity. And the ratio of embryonics system's hardware overhead and N modular redundancy system's hardware overhead is noted as P, then

$$\begin{aligned} P = \frac{H_{EM}}{H_{NMR}} &= \frac{m(n+S_{RC})\omega(1+\alpha)}{mn\omega(S_{RC}+2)} \\ &= \frac{(1+\frac{S_{RC}}{n})(1+\alpha)}{S_{RC}+2} \end{aligned} \tag{3}$$

IV. SIMULATION AND ANALYSIS OF HARDWARE OVERHEAD

As can be seen form Eq. (3), P is related to target circuit's column number n, self-repair capacity S_{RC} and electronic cell's additional circuit ratio α. In this section, embryonics system's hardware overhead is analyzed compared to N modular redundancy system through simulation experiment.

A. *Hardware Overhead of Fixed α*

When the target circuit's column number n is changing in [10, 100], its self-repair capacity S_{RC} is changing in [1, 20], if the electronic cell's additional circuit ratio α is fixed as 0.2, 1.0, 3.0, 5.0, then P is changing with n and S_{RC} as Fig. III.

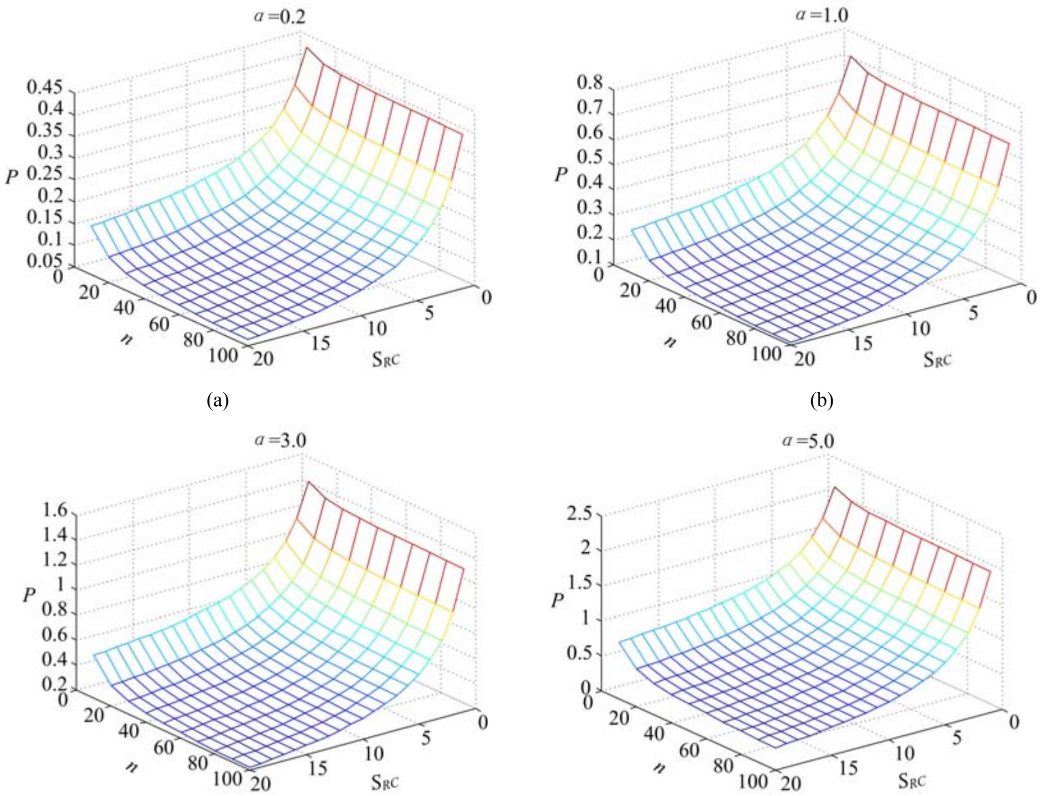

FIGURE III. CHANGING OF P WITH TARGET CIRCUIT'S COLUMN AND SELF-REPAIR CAPACITY.

From Fig.III we can see that, hardware overhead ratio P is increased as electronic cell's additional circuit ratio α increasing, and it is decreased as the increasing of target circuit's column number n and self-repair capacity S_{RC}. At the same design technology of electronic cell, when the target circuit's column number is bigger and its self-repair demand is more, and the P value is smaller, and embryonics system's advantage is more obvious. Because the entire module is eliminated to repair fault in N modular redundancy system, and only a column electronic cell is eliminated in embryonics system, so embryonics system is more suit to the circuit with larger-scale, big self-repair capacity demand.

For the target circuit with same scale and self-repair capacity, the bigger α caused to bigger P, and the small-scale circuit is influenced more. When $\alpha \geq 2.0$, the $P \geq 1.0$ for the target with $n \leq 20$ and $S_{RC} \leq 5$. Then the hardware overhead of embryonics system is bigger to N modular redundancy system. But for the circuit with $n \geq 20$ and $S_{RC} \geq 10$, the P value is still less than 1.0 even when $\alpha = 5.0$. It means that the embryonics system is better than N modular redundancy system in hardware overhead, when the hardware overhead of genome memory, BIT and address generator in electronic cell is five times to the basic unit.

B. Hardware Overhead of Target Circuit with Fixed Scale

To further investigate the relationship between electronic cell's additional circuit ratio α and P, the P value is calculated when α changing in [1, 20], S_{RC} changing in [1, 20], the n is 10, 50, 100, 200. The results shown in Fig. IV, and the black line is the position $P = 1.0$.

From Fig.IV we can see that, the P value is smaller when target circuit's scale n is bigger with the same α and S_{RC}. At the same time, the range of α and S_{RC} is bigger that make $P < 1.0$. When $n = 200$, $P < 1.0$ even $\alpha = 20$ for the application that demand $S_{RC} > 20$. It means that the embryonics system is still better even the hardware overhead of genome memory, BIT and address generator is twenty times to basic unit.

When the target circuit's scale is small, such as $n = 10$, the range of α and S_{RC} and is smaller that make $P < 1.0$. In this case, if $\alpha > 5$, the embryonics system has no advantage respect to N modular redundancy system.

The analysis on Fig. III and Fig. IV shows that, embryonics system is more suitable for the circuit with larger scale and demands big self-repair capacity. At the same time, the design of genome memory, BIT and address generator in electronic cell influence the embryonics system's hardware overhead and application. Electronic cell should be designed optimally to reducing additional circuit ratio α during embryonics system's design process.

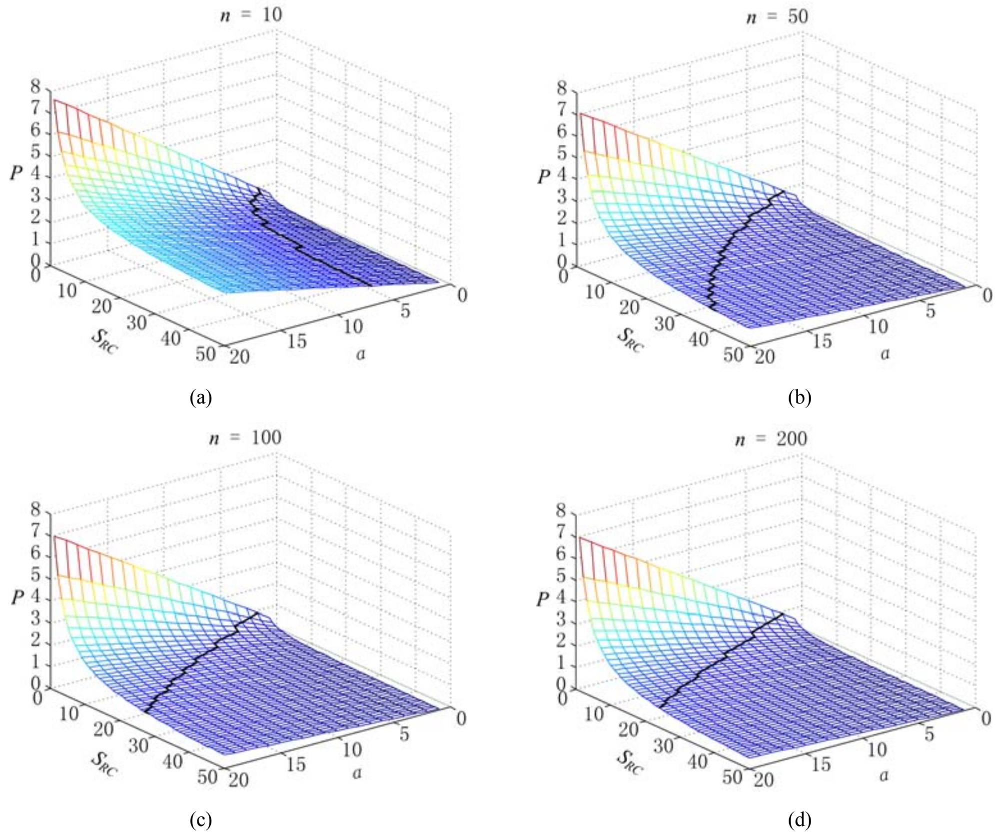

FIGURE IV. CHANGING OF *P* UNDER SELF-REPAIR CAPACITY AND ASSISTANT CIRCUIT PROPORTION.

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