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Real-Time Fault Detection in Microcontrollers

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Abstract

The innovation demonstrates an automated system of faults in microcontrollers detection and diagnostics and provides prolonged assistance in the production line testing and maintenance. Its usage encompasses a range of microcontroller systems that make use of several units, in which substitution of entire boards create electronic waste. It will assist with an ESP32 CAM module to capture the image of the microcontroller to compare it with the test images stored on SD cards and perform physical fault checks. In case of success and a pulse is transmitted to Arduino UNO, which also checks the controller with logical errors. The UNO has a few other tests such as pin input/output and timer functions, the results of which are displayed on the Serial Monitor of the Arduino IDE. These two processes are to be integrated. Integration of these two processes not only streamlines the fault detection processes, but it promotes sustainability instead of replacing whole boards by reducing e-waste. This innovation has a higher potential to provide significant advancement in microcontroller fault detection technology and drive efficiency in electronic system management.

Keywords

Fault detection, Microcontroller, Error detection, Error diagnosis, Image processing

Introduction

In this study, Alexandru Buturugă showcases one of the software-based adaptable SOC testing approach. This method used embedded microprocessors and their memories to enable at-speed testing. Timer differences used two techniques –internal and external- both are examined. The main difference was that external testing was simple but produced lower accuracy results at greater expense, internal testing is more accurate but requires utmost work. Both listed approaches had

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potential for evaluating microcontroller performance, especially their timing code executions (Buturuga et al, 2017).

The work of Nikam and Sawant (2017) throws light on an image processing method that is also automated for detecting defects in PCBs. This approach uses a stored set of verified PCB templates and compares it with test PCBs. It uses processes of environmental conditioning, image processing and background subtraction. It has proven to be effective in finding paths and holes producting qualification reports. This offers a more efficient and cost-effective alternative to traditional defect detection practices.

This paper suggests usage of TMR for fault masking and macros for detection. It provides a unique method for online microcontroller testing and diagnosis. It gives us a way of decreasing complexity in comparison to functional testing for microcontroller fault detection. This also guaranteed fault tolerance and improved mean time to failure (Elshafey and Elhosiny, 2006). The research proposes Resolution Synthesis (RS), an innovative picture scaling technique for MMSE-based high-res image production that classifies pixels according to context. Estimation of parameters is done by EM, which improves performance for non-training images. Demonstration of superior image quality and scaling capabilities can be done with the help of RS and ERS (Enhanced Resolution Scaling).

To ensure efficient process of optical images, this research implements the use of Photosensitive PNLC sheets for addition-subtraction and edge enhancement. Their viability is confirmed as quick and low power substitutes for traditional techniques from tests conducted, providing affordable options for optical image processing (Shih et al., 2001).

This paper addresses the consequences of occasional device failures and diagnosis of faults in the context of automated microcontroller testing. It sees through integrating hardware and software failure tools and validates common failure types to validate testing. It shows a great method for general purpose microcontrollers. Future works of this included increase of average time between microcontroller system failures (Pankov and Denisova, 2019).

Methodology

The block diagram of the project along with its components is shown in Figure 1. The system starts its work with the ESP32-OV2640 camera module which captures a picture and checks it. This produces an input for the Arduino, and it provides a pulse to the microcontroller which is being tested. This enables the testing of input and output, and timer functions of the microcontrollers. The result is sent back to the Arduino which is received and then displayed in the serial monitor enabling the user to identify the fault in the microcontroller if there is any present.

The system's workflow is designed in such a way that the inspection and validation of the microcontrollers is ensured by combining both physical and logical checks (Figure 2). The process initially begins with a physical examination using the ESP32-OV2640 camera module. This captures an image of the microcontroller, which is then processed and compared with existing images on the SD Card connected to ESP32-OV2640. This comparison is done to identify any physical defects such as missing pins, burnt surfaces or visible damages.**Error! Reference source not found.**

If any physical faults are detected during this comparison, the system halts further processing mentioning there is a physical issue that require concern.

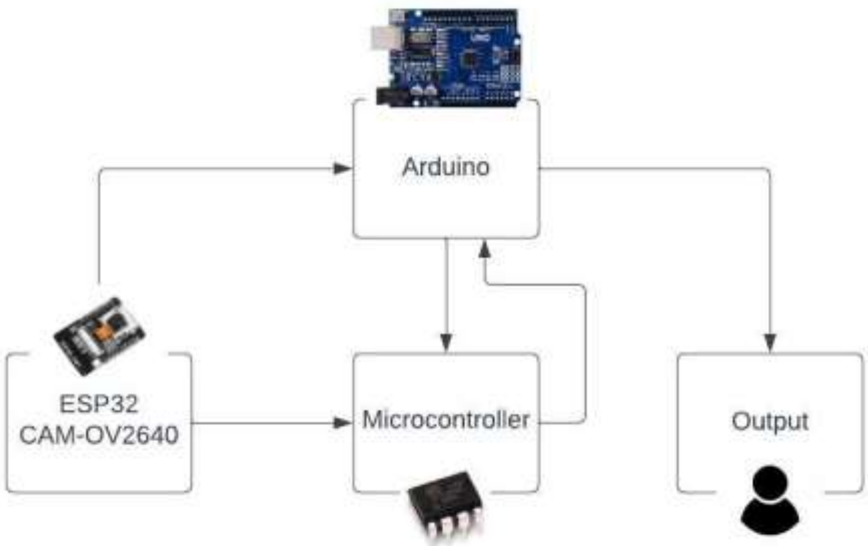

Figure 1. Block diagram of the project

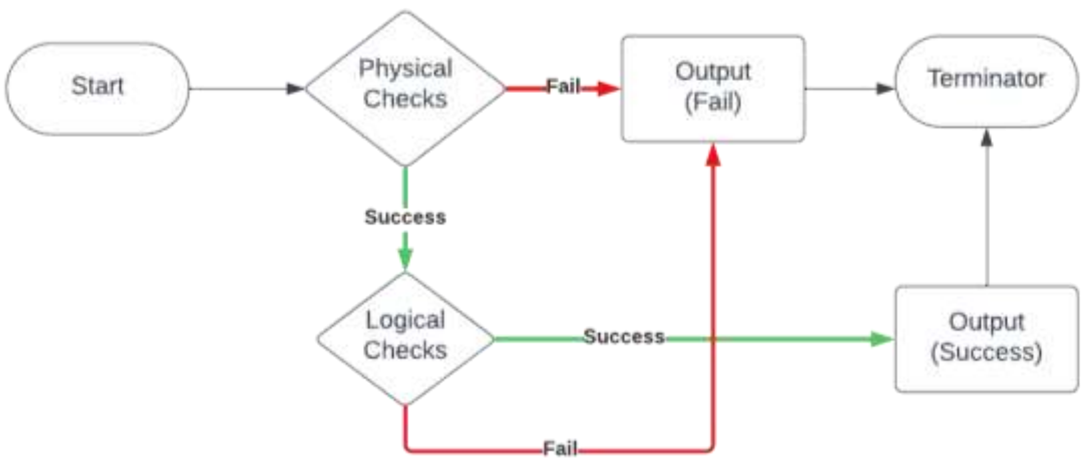

Figure 2. Workflow diagram of the system

Upon passing the physical inspection, the workflow then drives into the logical checks. Testing the functionality and performance of the microcontroller by a series of already defined tests and diagnostic routines are involved in this stage. This ensures the microcontroller operates without any error, meets the systems specified criteria, and performs the functions it was supposed to do without any errors. In any stage if the microcontroller fails the logical tests, the system produces an output failure. However, if no error occurs and everything is passed, a success output is generated which confirms the full operation ability and function of the microcontroller and being free of errors. These two staged approaches ensure that every microcontroller is physically intact without any damage, and functionally sound is deemed acceptable, enhancing the reliability of the final product.

The new methodology introduced in this paper shows improvement in fault detection within electronic systems. Usually, if a microcontroller fails within a system, the only solution would be replacing the whole system without any diagnosis since diagnosis is often complex and costly (Pankov and Denisova 2019). Not only is this process expensive, but also causes a significant downtime, which results in a crater in the productivity and efficiency. Nevertheless, the solution offered facilitates accurate determination of the faults in the microcontrollers, which is useful in differentiating between them and other system potential system failures.

This checking method with the assistance of state-of-the-art image processing software can enable identification of physical damage or faults in the microcontroller. ESP32- OV2640 camera module enables the imaging of the microcontroller and the capture of the digital information. The image obtained is processed and compared with an image of a fully operating microcontroller that does not have any physical defects as the reference image. Such a comparison is well needed to identify any physical error, which could be either lack of pins, bad solder mask, or damage that are visible to the naked eye, and thus render the microcontroller unusable.

This degree of physical inspection adds considerable power to the sphere of diagnosis of the system, which guarantees that only microcontrollers that are not physically damaged are moved to the next phase of testing. To add to the physical inspections, the methodology incorporates special testing on logical errors to make the fault detection strong. This entails a set of tests on how the microcontroller works and its inputs, outputs and timers. It is achieved through the help of another development board that conducts the impulse to the first pin of the microcontroller, and a walking test is performed over all the microcontroller pins. Then the development board plays an ISP role and verifies all timers of all the possible modes to guarantee that there is no failure.

Any malfunction in these logical tests would mean something was wrong in the internal working of the controller and it invariably results in a failure output and will not allow the use of a faulty unit. The combination of Arduino UNO and ESP32-OV2640 in this gives a comprehensive and dependable test of the operability of the microcontroller. UNO is the platform which performs all the logical checks and ESP32- OV2640 is the one which performs physical inspection with the help of image processing.

This is a two-fold method that ensures that the microcontroller is both physically and logically tested in every strict sense. The findings of these performed tests are recorded and tabulated which inevitably presents an explicit indication of the effectiveness and trustworthiness of the strategy put across. The tabulated data would prove the proficiency of the system to pinpoint and remove faults properly; thus, it would be a huge step towards fault detection and system maintenance in electronic systems.

The results of these tests conducted are documented and tabulated which invariably provides clear evidence of the efficacy and reliability of the approach proposed (Moro et al., 2013). The data which are tabulated would demonstrate the capability of the system to accurately identify and isolate faults, thereby it promises a significant advancement in fault detection and system maintenance within electronic systems. This methodology not only reduces the cost of replacements by minimizing downtime, promotes sustainability and enhances overall reliability and efficiency.

Results and Discussion

The details of hardware issues and each entry correspond to a specific fault identified within the microcontroller hardware are shown in table 1. The "Figure No." column is the figure number associated with each observation in the images listed. The "Pins" column specifies the pins broken or not usable by the identified issue and pinpoints the exact location of the fault in the microcontroller. The "Reason" column mentions the nature of the issue; it can be a broken pin or a substrate breakage. Lastly, the "Percentage" column quantifies the severity of the breakage of each issue, providing insights into the distribution of hardware faults across the microcontroller samples tested.

Table 1. Percentage Difference of the Tested Microcontrollers

HARDWARE ISSUES			
Figure No.	Pins	Reason	Percentage
3a	2 & 4	Broken	34.80
3b	1 & 3	Broken	40.82
3c	-	No Issues	0.00
3d	3,5&8	Broken	38.09
3e	1 & 5	Broken	35.77
3f	-	No Issues	0.00
3g	5 & 7	Broken	40.77
3h	-	Substrate Broken	89.98
3i	1 & 6	Broken	26.99
3j	-	No Issues	0.00

The image to the right is compared with the one to the left. Figure 3a shows that pin number 2 and 4 are broken. Thus, physical damage is identified. Figure 3b indicated that pins 1 and 3 are broken. Thus, physical damage is identified. Figure 3c shows no physical fault in the microcontroller. Thus, no physical damage is identified. Figure 3d indicated that pins 3, 5 and 8 are damaged, but only pins 5 and 8 are damaged. Thus, better image processing algorithms can be applied in future work to produce a more effective output. Figure 3e shows that the pins 1 and 5 are damaged. Thus, physical damage is identified. The output in Figure 3f does not indicate any physical damage. The output in Figure 3g shows the pins 5 and 7 are damaged. A small section of the pin 4 is also shown as damaged. This false positive can be rectified using better image processing methods or even with the help of other pre-processing methods. Figure 3h shows the substrate of the microcontroller is broken and thus, physical damage is identified. There is also some minor noise which is also detected in this image processing algorithm. Figure 3i indicated that the pins 1 and 6 are damaged. Thus, physical damage is identified. Figure 3j shows no difference because there is no physical fault in the microcontroller. Thus, no physical faults are identified in the microcontroller. The results of the hardware damage that has happened to the microcontroller and the percentage difference from that of the actual image are shown in Figure 4.


Figure 3a. Pins 2 and 4 are damaged

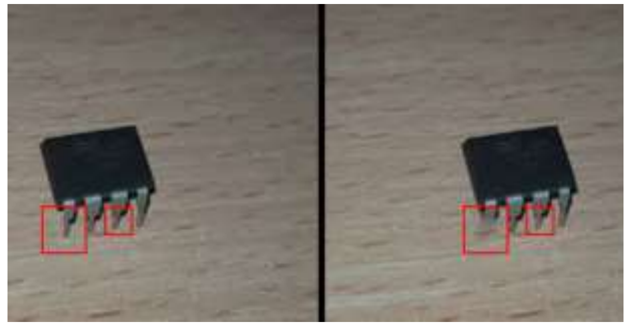
Figure 3b. Pins 1 and 3 are damaged

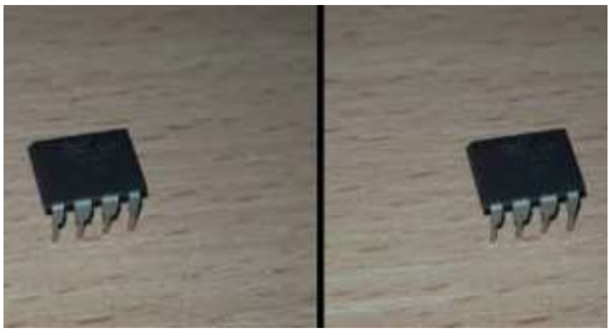
Figure 3c. No pins are damaged

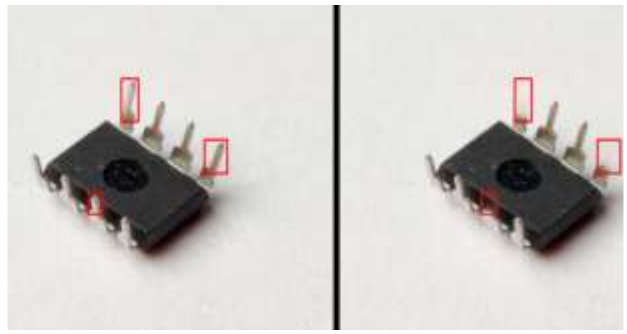
Figure 3d. Pins 3, Pin 5, and Pin 8 are damaged

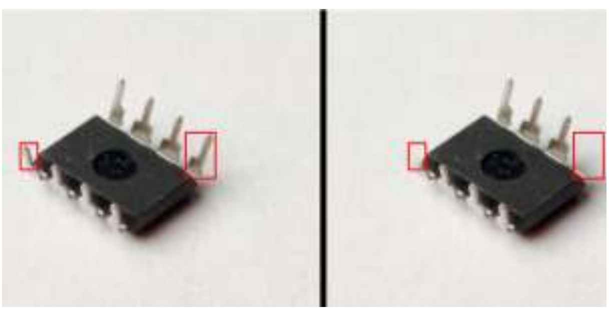
Figure 3e. Pin 1 and Pin 5 are damaged

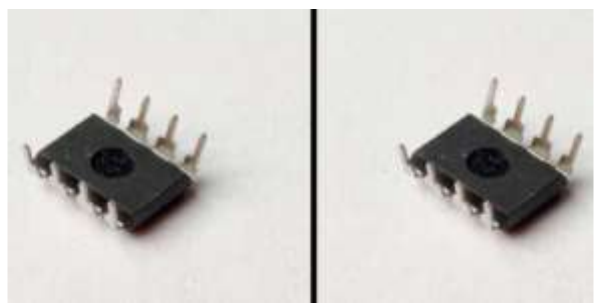
Figure 3f. Microcontroller with no damage

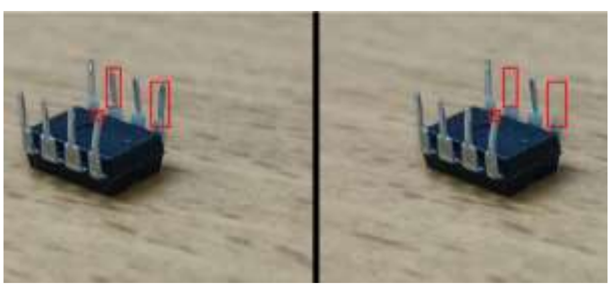
Figure 3g. Pin 5 and Pin 7 are damaged with false positive

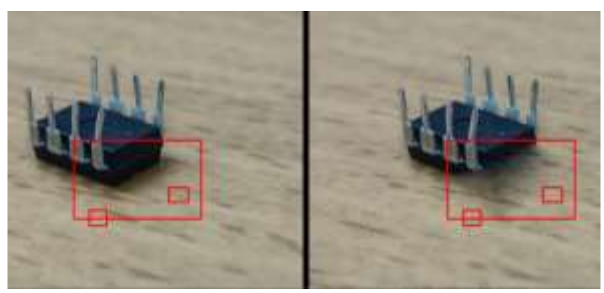
Figure 3h. Substrate of the microcontroller is broken

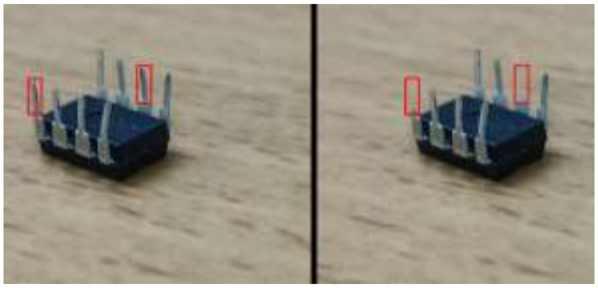

Figure 3i. Pin 1 and Pin 6 are damaged

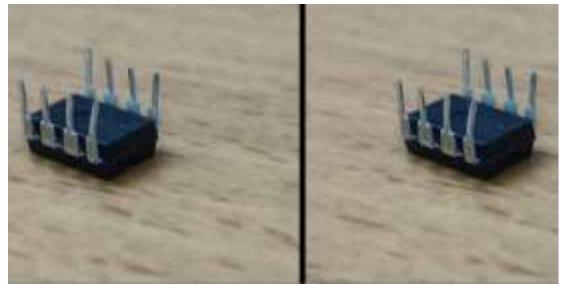

Figure 3j. Microcontroller with no damage

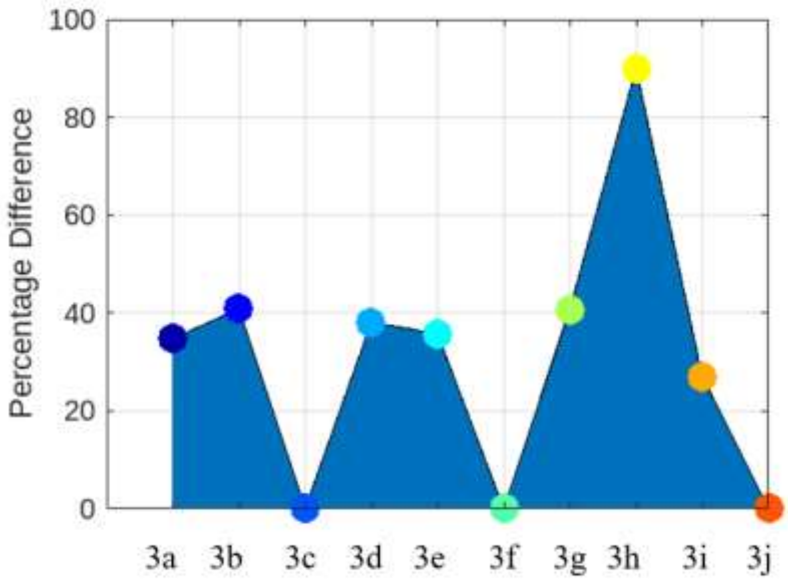

Figure 4. Graph showing the percentage of difference between the microcontrollers shown in the figures indicated in Figure 3.

The error free images have a very low percentage difference which is very close to zero. Even if there are no physical faults, there can be logical errors in the microcontroller. Table 2 shows all the possible test cases of software issues that can occur in a microcontroller. This study brings out an innovation for testing the microcontroller which can be used both in fields of service and production lines. This idea can be developed further by using better image processing algorithms, improving the range of software tests and detection of abnormal heat generations etc., This currently focuses on only the I/O checks and Timer checks for a microcontroller, further developments can be done in order to improve the range of testing of the Microcontrollers by including watch dog timer checks, PWM checks and many more.

Table 2. Possible software test cases

SOFTWARE TEST CASES			
I/O Checks	Timer 0	Timer 1	Reason
FAIL	FAIL	FAIL	Pins Broken/ Logical Error
FAIL	FAIL	OK	Logical Error

(Table 2 Continued)

FAIL	OK	FAIL	Logical error
FAIL	OK	OK	I/O Error
OK	FAIL	FAIL	Logical Error
OK	FAIL	OK	Logical Error
OK	OK	FAIL	Logical Error
OK	OK	OK	No Error

Conclusions

In short, the given initiative is a remarkable step in the context of the maintenance of the system as it offers an in-depth method of identifying and eliminating the problems related to the microcontrollers operation. With the use of modern techniques in image processing and logical test strategies, the project streamlines fault detection operations to enhance reliability of its system and decreases downtime. The project is based on such borrowed components as ESP32CAM - OV2640 module and Arduino Uno platform, focusing on the aspects of accessibility, flexibility, and sustainability. Also, it promotes cost-efficiency and environmental concern, reducing the necessity to redesign the entire system and reducing the amount of electronic waste. This project symbolizes the power of innovation in addressing practical issues, which shows that it can improve productivity and efficiency in various industries. As we continue, the experience gained in the project will pave the way to further developments in fault detection technology as we head to a future where sustainability, reliability and efficiency of microcontroller-based systems will be enhanced.

This project may explore different avenues in the future to improve fault detection in microcontrollers. One of the viable aspects that could be focused on could be enhancement and additional functioning of the image processing algorithms to enhance the accuracy and performance of the detection of physical defects. In addition, the incorporation of machine learning techniques may enable the system to adapt and be able to learn previous instances of fault detection and as time goes by, the ability of the system to detect and label faults increases. Also, the expansion of the scope of logical testing procedures to include additional parameters and features are possible to enhance the flexibility and suitability of the project to other microcontroller systems. Moreover, the implementation of real-time monitoring and remote diagnosis might help to identify and solve faults earlier minimizing the system downtime and enhancing its overall stability. The continued innovation and introduction of new technology will help this project remain top in fault detection of the microcontroller systems to ensure continued improvement and efficiency in maintaining the electronic systems.

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