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# An Intelligent CI/CD-Oriented Automated Testing Framework For Failure Analysis

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## ABSTRACT

Continuous Integration and Continuous Deployment (CI/CD) have transformed software development by enabling teams to deliver updates more quickly and frequently. However, as release cycles accelerate and application complexity increases, maintaining consistent software quality becomes more challenging. This paper presents an automated testing framework specifically designed for CI/CD environments, utilising the Robot Framework. The framework ensures dependable test execution and features structured failure analysis through a straightforward rule-based system that identifies and categories common issues, such as missing elements, timeouts, or assertion failures. It also provides actionable recommendations to minimise manual debugging. The framework was evaluated using real-world web applications, including a student management system and a grocery ordering platform. The project integrate seamlessly with tools like GitHub Actions and Jenkins, enhancing test maintainability. Experimental results demonstrated a 65% reduction in the time required to investigate failures compared to conventional setups.

**Keywords**—CI/CD, Automated Testing, Robot Framework, Failure Analysis, Test Flakiness, GitHub Actions.

## I. INTRODUCTION

The adoption of Continuous Integration and Continuous Deployment (CI/CD) practices has significantly transformed modern software development by enabling faster releases and frequent updates. As development cycles become shorter and applications grow in complexity, ensuring consistent software quality has become increasingly challenging. Automated testing has therefore emerged as a critical component of CI/CD pipelines, allowing teams to validate functionality continuously and detect defects early in the development lifecycle. Despite these advantages, existing automated testing frameworks primarily focus on test execution and reporting, while offering limited support for systematic failure analysis. In practice, a large portion of test failures occurring in CI/CD pipelines are not caused by actual defects but by issues such as changes in user interface elements, synchronisation delays, unstable test environments, or configuration inconsistencies. These failures require manual inspection of logs and reports, increasing debugging effort and reducing confidence in automated test results. Another challenge lies in the lack of generalisation across applications. Automation frameworks are often developed for a single project, resulting in duplicated test logic, inconsistent failure handling, and reduced reusability when applied to different domains such as academic management systems or online retail platforms. As test suites grow, the absence of a structured mechanism to categorise and

interpret failures further limits the effectiveness of automation within CI/CD workflows. This work presents an intelligent CI/CD-oriented automated testing framework designed to address these limitations by combining robust test execution with structured failure analysis. The framework is built using the Robot Framework due to its keyword-driven approach, readability and strong support for web automation. Test execution results are systematically analysed using a rule-based classification mechanism inspired by expert system principles. Common failure patterns—including element-not-found errors, timeout issues, browser session failures, data inconsistencies, and assertion mismatches—are automatically identified and categorised. By providing categorised failure insights and corresponding diagnostic recommendations, the framework reduces the manual effort required for failure investigation. The approach has been validated across multiple web applications, including a student management system and a grocery ordering application, demonstrating improved test maintainability and clearer failure interpretation within CI/CD pipelines. The framework is compatible with widely used CI/CD tools such as GitHub Actions and Jenkins, enabling seamless integration into existing development workflows. Through its emphasis on intelligent failure analysis rather than test execution alone, this framework contributes toward more reliable and maintainable automation practices, supporting faster feedback and improved software quality in continuous delivery environments.

The contributions include:

- A reusable Robot Framework library with failure classification rules.
- CI/CD integration for automated analysis in GitHub Actions.
- Quantitative metrics showing reduced debugging time.

The proposed system therefore offers a compact and reliable method for enhancing test reliability in resource-constrained CI/CD environments.

## II. LITERATURE SURVEY

### Evolution of Automated Testing in CI/CD

Automated testing frameworks like Selenium, JUnit, and Robot Framework have been integrated into CI/CD pipelines to improve code quality and deployment speed [3],[6],[14]. A 2022 study found that such integration increased code coverage by 32.8%, bugs detected per build by 74.2%, and reduced production critical bugs by 71.4%, while cutting build times by 51.1% [8], [9]. Robot Framework specifically excels in keyword-driven testing for web applications, with extensions enabling self-healing locators using large language models to handle UI changes dynamically [6], [14].

### Rule-based expert systems provide deterministic failure

Rule-based expert systems provide diagnosis in testing environments[16], [17]. These systems use predefined patterns to classify failures into categories like assertion errors or timeouts, avoiding probabilistic errors common in ML approaches [16]. A combinatorial testing study demonstrated rule-based identification of failure-inducing parameter combinations, reducing debugging effort by systematically linking faults to specific interactions [21]. Verification of such systems emphasises reliability, as failures in control applications can be catastrophic, aligning with the need for >95% accuracy in classification [15].

### AI-Driven Failure Analysis in CI/CD Pipelines

Recent advancements incorporate AI for semantic failure analysis [10]. LogSage, an LLM-based framework, analyses CI/CD logs to classify failures (e.g., build, runtime, deployment errors) and achieves 47.4% auto-resolution success by rerunning with fixes, covering 22.4% of failure types [11]. Semantic automation tools retrieve code context, assess impact, and generate intelligent tickets, addressing manual investigation delays in large codebases [18]. Self-healing frameworks predict faults and adapt scripts, improving regression testing accuracy [14].

### Research Gaps and Project Positioning

While frameworks like Robot Framework handle execution, few integrate rule-based expert systems specifically for multi-application failure categorisation (>95% accuracy target) within GitHub Actions pipelines [6], [12]. Existing works lack emphasis on security (e.g., log sanitisation) and portability across 10+ apps [18]. This project fills the gap by combining Robot Framework automation, rule-based classification (6 categories, 30+ patterns), and CI/CD

orchestration, achieving measurable NFRs like <30-second analysis [6].

## III. RELATED WORKS

Research on CI/CD test automation emphasises execution speed but often overlooks flakiness and failure diagnosis.

### A. Hybrid Test Frameworks

Proposes MHTAF, a Page Object Model-based framework for CI/CD environments. It focuses on maintainability through modular locators but lacks automated failure categorisation, requiring manual log review for UI changes.

### B. UI Testing in GitHub Workflows

Conducts a comparative analysis of UI frameworks in GitHub CI/CD, identifying flakiness from locators and timing. No built-in classification—developers manually triage.

### C. Test Flakiness Challenges

Examines flakiness/maintenance in UI testing, reporting 20-30% false failures in pipelines. Recommends retries but not intelligent parsing.

### D. CI/CD Impact Studies

Evaluates CI/CD on quality/deployment, showing faster cycles but higher flake rates without analysis tools. studies open-source migration to CI/CD tools, noting inconsistent failure handling across projects.

### E. Summary

Existing works enable execution/reporting but lack rule-based failure classification for non-defect issues (e.g., timeouts). Our framework bridges this with Robot-integrated parsing.

## IV. PROPOSED SYSTEM

The proposed framework adopts a layered architecture integrating test automation, failure parsing, and CI/CD orchestration to deliver intelligent diagnostics. Designed for reusability across web apps, it minimises manual intervention by automating 80% of common flake triage.

### A. System Overview

At its core, the system operates on a query-and-retrieve model enhanced by persistent state. Users can interact with the system in two modes:

- **Test Execution Engine:** Robot Framework with SeleniumLibrary for cross-browser web tests.
- **Failure Analysis Engine:** Post-execution Python parser classifying logs via regex/rules.
- **Reporting Module:** Generates HTML dashboard with categorised insights which are downloadable.

### B. System Overview

At a high level, the proposed system operates in a test–analyze–report cycle triggered automatically within a CI/CD pipeline. The system consists of three logical subsystems:

1. Automated Test Execution Subsystem
2. Failure Analysis and Classification Subsystem
3. CI/CD Orchestration and Reporting Subsystem

Each subsystem operates independently but communicates through structured artifacts generated during pipeline execution.

### C. Automated Test Execution Subsystem

The Automated Test Execution Subsystem is implemented using Robot Framework with SeleniumLibrary for browser automation. A keyword-driven testing methodology is employed to improve readability, maintainability, and reuse across applications.

Key characteristics include:

- Platform-independent execution
- Support for headless browser execution
- Environment-specific configuration via external variables
- Generation of structured execution artifacts (output.xml, log.html, report.html)

This subsystem ensures consistent and repeatable execution of functional UI test cases across multiple CI/CD runs.

### D. Failure Analysis and Classification Subsystem

The Failure Analysis Subsystem represents the core intelligence of the proposed framework. It is implemented as a Python-based post-processing

engine that analyzes test execution artifacts immediately after test completion.

**1) Failure Parsing**

Execution logs and result files generated by Robot Framework are parsed to extract:

- Error messages
- Stack traces
- Failure keywords
- Timing information

These extracted signals form the input to the classification engine.

**2) Rule-Based Classification Engine**

A deterministic, rule-based expert system is employed to classify failures. Each rule consists of:

- A failure signature (regex or keyword pattern)
- A mapped failure category
- A predefined diagnostic recommendation

Failures are classified into the following categories:

- Element Not Found
- Timeout / Synchronization Failure
- Assertion Failure
- Browser or Session Failure
- Data Validation Error
- Environment or Configuration Issue

This approach ensures consistent classification behavior and avoids the unpredictability associated with probabilistic machine-learning models.

**3) Diagnostic Recommendation Mapping**

For each failure category, the system provides actionable recommendations, such as:

- Updating UI locators
- Introducing explicit waits
- Verifying test data integrity
- Validating environment configuration

These recommendations reduce the cognitive load on developers during failure investigation.

**E. CI/CD Orchestration and Reporting Subsystem**

The CI/CD subsystem integrates the framework into automated pipelines using tools such as GitHub Actions and Jenkins.

Workflow Summary:

1. Code commit or manual trigger initiates pipeline
2. Test suites are executed using Robot Framework
3. Failure Analysis Engine processes execution logs
4. Categorised failure reports are generated
5. Reports are published as CI artifacts

The reporting output includes structured summaries and categorised insights, enabling developers to identify root causes without manual log inspection.

**F. Design Considerations and Advantages**

The proposed system was designed with the following considerations:

- Reusability: Applicable across multiple web applications
- Explainability: Deterministic rules ensure transparent diagnostics
- Low Overhead: Minimal computational and infrastructure cost
- CI/CD Compatibility: Native integration with existing workflows

By shifting focus from execution-only automation to intelligent failure analysis, the system improves trust in automated testing and accelerates feedback cycles.

**G. Summary**

The proposed framework extends conventional CI/CD testing pipelines by embedding structured failure intelligence directly into automated workflows. Through the integration of Robot Framework execution, rule-based expert classification, and CI/CD orchestration, the system delivers faster, clearer, and more reliable test feedback. This approach significantly reduces manual debugging effort and enhances the effectiveness of automated testing in continuous delivery environments.

## V. IMPLEMENTATION

The proposed Intelligent CI/CD-Oriented Automated Testing Framework was implemented using a modular and extensible software stack to ensure portability across different web applications and CI/CD environments. The implementation focuses on seamless automation, deterministic failure analysis, and minimal configuration overhead.

### A. Test Automation Implementation

The test execution layer was implemented using Robot Framework with SeleniumLibrary to support browser-based automation. A keyword-driven approach was adopted to improve test readability and reusability across multiple applications.

Key implementation aspects include:

- **Reusable Keywords:** Common UI actions such as login, navigation, form submission, and validation were abstracted into reusable keyword libraries.
- **Cross-Browser Execution:** Tests were executed in headless Chrome to support CI/CD environments without GUI dependencies.
- **Structured Output Generation:** Robot Framework automatically generates output.xml, log.html, and report.html, which serve as structured inputs for failure analysis.

The test suites were executed against two real-world applications: a Student Management System and an online Grocery Ordering platform.

### B. Failure Analysis Engine Implementation

The Failure Analysis Engine constitutes the core intelligence of the framework. It was implemented as a Python-based post-processing module that operates immediately after test execution.

Key Functional Components:

- **Log Parsing Module:** Parses Robot Framework's output.xml and console logs.
- **Rule-Based Classification Engine:** Uses predefined regular expression patterns and decision rules to classify failures.
- **Category Mapping:** Each failure is mapped to one of six predefined categories:
  - Element Not Found
  - Timeout / Synchronization Failure
  - Assertion Failure
  - Browser Session Failure
  - Data Validation Error
  - Environment / Configuration Issue
- **Recommendation Generator:** Associates each failure category with corrective recommendations (e.g., locator update, explicit waits, environment validation).

This deterministic rule-based approach ensures consistent results and avoids the uncertainty and overhead associated with probabilistic machine-learning models.

### C. CI/CD Pipeline Integration

To enable continuous validation, the framework was integrated with GitHub Actions.

CI/CD Workflow:

1. Code commit or manual trigger initiates the pipeline.
2. Test environment is provisioned automatically.
3. Robot Framework test suites are executed.
4. Failure Analysis Engine parses logs and classifies failures.
5. Categorised reports are generated and stored as CI artifacts.

This integration ensures that failure insights are available immediately after pipeline execution without manual intervention.

## VII. COMPARATIVE ANALYSIS

This section compares the proposed Intelligent CI/CD-Oriented Automated Testing Framework with existing CI/CD testing approaches reported in the literature, focusing on failure handling effectiveness, debugging effort, flakiness management, and CI/CD suitability. The comparison is supported by quantitative observations derived from controlled experimental evaluation.

### A. Comparison with Conventional CI/CD Test Automation

Traditional CI/CD testing frameworks primarily emphasize automated test execution and result reporting. When failures occur, developers rely on manual inspection of logs, screenshots, or videos to determine root causes. In the experimental evaluation conducted as part of this work, conventional pipelines required an average of 18–22 minutes per failure for manual investigation.

In contrast, the proposed framework reduces this investigation time to 6–8 minutes per failure, resulting in an approximate 65% reduction in

debugging effort. This improvement is achieved by automatically classifying failures into predefined categories and providing actionable diagnostic recommendations. Unlike conventional pipelines, which treat all failures uniformly, the proposed system enables developers to immediately distinguish between genuine defects and non-deterministic failures.

### B. Comparison with Hybrid and Maintainability-Focused Frameworks

Hybrid automation frameworks, such as Page Object Model–based designs, improve test maintainability and reduce script duplication. However, these frameworks still rely on manual triage when failures occur. As test suites scale, this limitation results in increased debugging overhead despite improved script organization.

The proposed framework complements maintainable test design with post-execution failure intelligence. Experimental results show that out of 60 manually labelled failure instances, the framework correctly classified 58 failures, achieving a classification accuracy of 96.6%. This level of automated interpretation is not provided by maintainability-focused frameworks, which continue to depend on developer expertise for failure diagnosis.

### C. Comparison with AI-Driven Failure Analysis Approaches

Recent research has explored AI-based log analysis and large language models for failure diagnosis. While these approaches offer semantic insights, they introduce non-deterministic behavior, higher computational overhead, and limited explainability—factors that are undesirable in continuous integration environments.

The proposed framework adopts a deterministic, rule-based expert system approach. Although less adaptive than learning-based models, this design ensures predictable behavior, transparent reasoning, and low computational cost. The framework introduces less than 30 seconds of additional CI/CD pipeline overhead, whereas AI-driven approaches often incur higher latency due to model inference and contextual analysis.

### D. Handling of Test Flakiness

Test flakiness remains a major challenge in UI-based CI/CD automation, with prior studies reporting 20–30% false failures in continuous pipelines. Existing solutions often mitigate this issue using retries or increased timeouts, which mask underlying causes.

During evaluation, the proposed framework analysed 74 failure instances, of which 41 were non-defect (flaky) failures caused by synchronization delays or transient environment conditions. The framework correctly identified 38 of these cases, achieving a flakiness identification precision of 92.6%. By explicitly categorising flaky failures, the system reduces false defect reporting and improves developer trust in automated test results.

### E. Practical Suitability for CI/CD Environments

Many existing academic solutions demonstrate conceptual effectiveness but lack seamless integration with widely used CI/CD tools. The proposed framework is designed for direct integration with platforms such as GitHub Actions and Jenkins, ensuring that failure analysis occurs within the same pipeline context as test execution.

Additionally, the lightweight nature of the framework makes it suitable for resource-constrained environments, where heavy AI-based solutions may not be feasible. The deterministic classification engine requires no training data and remains stable across applications, improving portability and reproducibility.

### F. Summary of Comparative Insights

Overall, conventional CI/CD automation focuses on execution rather than interpretation, hybrid frameworks improve maintainability but not diagnosis, and AI-driven approaches introduce complexity and unpredictability. The proposed framework provides a balanced alternative by delivering automated, explainable, and low-overhead failure analysis, resulting in measurable reductions in debugging time, improved handling of test flakiness, and minimal impact on CI/CD pipeline performance.

## VIII. LIMITATIONS AND FUTURE WORK

Although effective, the current framework relies on predefined failure rules. Future work will explore:

- Hybrid rule + ML models for unseen failure patterns
- Self-healing test actions based on failure category
- Integration with additional CI/CD platforms such as GitLab CI
- Security enhancements through log sanitization and access controls

## IX. CONCLUSION

This paper presented an Intelligent CI/CD-Oriented Automated Testing Framework focused on structured failure analysis rather than test execution alone. By integrating Robot Framework automation with a rule-based expert system and CI/CD orchestration, the framework significantly reduces debugging effort and improves test reliability.

Experimental results demonstrate high classification accuracy and a substantial reduction in failure investigation time. The framework offers a compact, reliable, and reusable solution for enhancing automation effectiveness in continuous delivery environments.

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