Automated and Orchestrated CI/CD Pipelines in Industrial Protocol Certification Testing

Omar Lone
Institute of Embedded Systems
ZHAW
Zurich, Switzerland
lone@zhaw.ch

Thorvin Stasiak
Institute of Embedded Systems
ZHAW
Zurich, Switzerland
stsh@zhaw.ch

Hans Dermot Doran
Institute of Embedded Systems
ZHAW
Zurich, Switzerland
donn@zhaw.ch

Abstract—**The industrial automation industry is rapidly evolving, and with it, the way that industrial communication protocol certification testing is conducted. Protocol providers offer field device manufacturers conformance testing suites with integration interfaces, enabling them to embed these tests into their development cycle. However, there is a lack of clear instructions and readily available literature on how to build such integrated testing frameworks. This paper discusses the integration of two certification software suites, PROFINET and EthernetIP, into a regression test environment utilizing CI/CD pipelines and Azure DevOps cloud-based infrastructure. Automated orchestration facilitates the creation of a unit-to-validation test environment, accelerating time to market. Upon completion of this work, significant implications emerge regarding the traditional V-Model and the certification procedure. This paper details the work-achieved towards providing a complete verification and validation framework, presents performance characteristics to underline our arguments, and discusses the resulting impact on the traditional V-Model.**

Keywords—CI/CD, pipelines, industrial protocol, certification, automated, cloud-based, PROFINET, Ethernet/IP, testing, orchestrated, regression

I. Introduction

The industrial automation landscape is undergoing rapid transformation, driven by the confluence of Industry 4.0 technologies and the ever-increasing need for connected, intelligent systems [1 - 4]. Communication protocols underpin the functionality of this interconnected ecosystem, enabling an interaction between diverse devices and systems. As the advancement and complexity of industrial devices continues to evolve, the role of industrial communication protocols, such as PROFINET and EthernetIP, is becoming ever more critical to ensure seamless interoperability and data exchange [5 - 8].

Developing and conformance testing industrial devices, however, presents a set of challenges. Historically, verification and validation processes have followed the known V-Model methodology [9]. Unit testing, see Fig. 1, typically focuses on individual components and their functionality in isolation. This approach works well for identifying small-scale issues. However, when integrated into the larger system during subsequent integration and system testing phases, unexpected interactions and errors often emerge, see Fig. 2. These late-stage discoveries not only require major resource expenses for fixes but also delay project timelines.

The limitations of traditional testing become even more evident in the context of industrial communication protocols. Due to the complex nature of protocol stacks and network interactions, thorough verification and validation necessitate specialized software suites often provided by protocol promoters. While these suites offer pre-built tests and certification capabilities, their operation remains a resource-intensive manual and local process. The traditional validation process entails running the certification tests both internally and again at the external certification institute, potentially leading to duplication of effort. In addition, compatibility testing with diverse third-party automation components, crucial for real-world application, typically occurs as a separate activity after formal certification.

Certification test suites have become more flexible and now, exemplified by PROFINET, offer integration interfaces for manufacturers allowing them to embed certification testing into their development pipelines. The PROFINET certification suite has transitioned from a closed-source, monolithic suite to a modular, user-friendly one that allows individual test execution via the command-line. It is also one of the first to provide access to the various certification tests' source code. Whether intentionally or not, these can also be used as a template to generate user-specific tests. There is a lack of examples and literature exploring how to leverage these integration interfaces and utilize the test source code to build an in-house integrated verification and validation framework. This in turn disguises the potential paradigm shift in the meaning of a protocol certification testing.

The act of overcoming these challenges of traditional testing and merging the certification test into in-house system tests reveals the paradigm shift in our approach to industrial communication protocol porting and testing. This is what this paper explores in this body of work by proposing a novel solution that leverages Continuous Integration and Continuous Delivery (CI/CD) pipelines and cloud-based infrastructure to automate and streamline the entire testing process within a unified framework. [10]. CI/CD in field device testing enables iterative development by deploying each implemented module/feature to the device for designated testing and integration into the working codebase upon successful test completion. The result of integrating the certification CI/CD into the V-model is that the semantics of certification changes, which we discuss in the conclusion.

Through this innovative approach, we aim to address the following key objectives:

- Reduced Time to Market: Accelerate validation and system testing, bringing products to market faster.
- Cost Efficiency: Leverage automation to minimize manual testing resource requirements.
- Reduce late-stage errors: By automating system and testing early in the development cycle, we aim to

This is the author's accepted manuscript version of a paper published by IEEE. The Version of Record is available in IEEE Xplore at https://doi.org/10.1109/WFCS60972.2024.10540983

identify and address potential issues before they become costly rework.

- Improved Quality: Derive additional system tests from validated test source code, enhancing overall system stability.
- Comprehensive Verification: Integrate compatibility testing with third-party automation components into the platform, ensuring wider ecosystem compatibility.
- Leverage certification resources: By utilizing the source code of validation (certification) tests, we can derive additional system tests, maximizing the value of existing resources.

This paper details the development of our proposed solution, showcasing its implementation and performance characteristics. By integrating two prominent certification software suites, PROFINET and EthernetIP, into a single CI/CD-driven test environment, we demonstrate the potential to revolutionize industrial communication protocol testing, paving the way for a more efficient, cost-effective, and quality-driven approach.

II. The Framework

A. Testing today

Today's in-house certification testing involves connecting the device under test (DUT) to a designated computer running the certification software. Specific protocols, like PROFINET, may require additional hardware for certain test sets. Nonetheless, a physical connection to the DUT is required from the testing software. The testing suite provides a graphical interface (GUI) for configuring network settings and loading relevant configuration files, such as the .gsd file for PROFINET devices and the .soc file for EthernetIP devices. The software allows for manual selection and execution of individual tests, and upon completion, generates log and result files stored locally on the computer. A basic command-line interface is included to start the software suites without the GUI. A testing engineer's primary objective is to achieve a complete pass on all tested features and modules using the certification software before proceeding to the certification authority, where the certification tests are done again as a form of validation [11, 12].

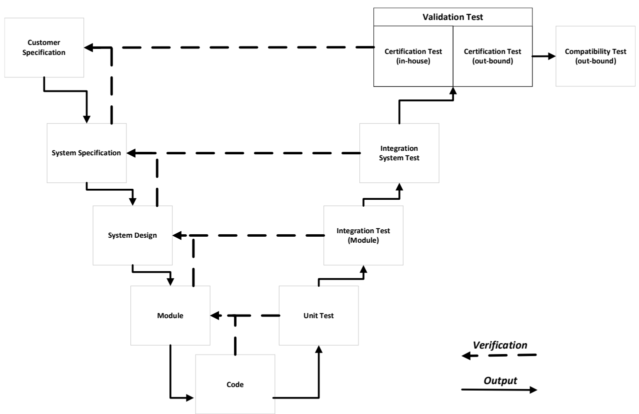

Fig. 1: Classic V-Model

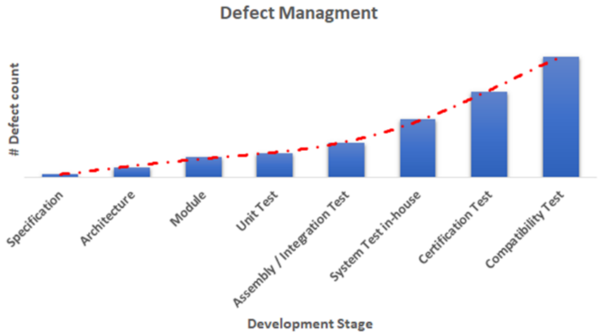

Fig. 2: Increasing defects, the further the development continues

B. Framework overview

The testing framework comprises two primary components: a local test machine and an Azure DevOps cloud platform [13]. The local machine serves as the execution environment for the certification software suites. Devices under test connect directly to it as mentioned in the previous chapter. Azure DevOps serves as a centralized repository for all test-related artifacts, including scripts, configuration files, and test results. The platform facilitates comprehensive data provenance, enabling the traceability of logs and reports to specific timestamps and device configurations employed during testing. An Azure agent acts as interface between the local and cloud environments. This agent retrieves required testing artifacts from the cloud, executes the desired tests on the local machine, and subsequently uploads the generated results back to the cloud repository, as seen in Fig. 3.

C. Automated Testing Pipelines in Azure DevOps

The testing framework leverages Azure DevOps to establish a suite of automated testing pipelines for industrial communication protocol certification. Three distinct pipelines exist, corresponding to the PROFINET Real-Time Tester (RT Tester), PROFINET Security Tester (Netload Tester), and EthernetIP certification testing suite. Each pipeline contains the full spectrum of available certification tests provided by the protocol provider, enabling manual or automated execution based on user preference. Users can choose to execute all provided tests or select specific ones for targeted evaluation.

Upon test completion, an artifact is automatically generated for each test instance. This artifact encapsulates critical data, including log files, console output, and detailed test results. In addition, the framework allows for user-defined tests to be triggered upon failures. These custom tests can offer deeper insights into potential issues, such as by capturing network frames for detailed analysis. Additionally, for protocols where the certification authority makes the source code of the certification tests available (e.g., PROFINET), users can leverage this code to create simpler, custom tests. These tailored tests provide granular insights into specific protocol interactions, facilitating a smoother transition from in-house testing to the official certification process. This approach empowers users to not only identify and diagnose issues effectively, but also prepare for formal certification with greater confidence.

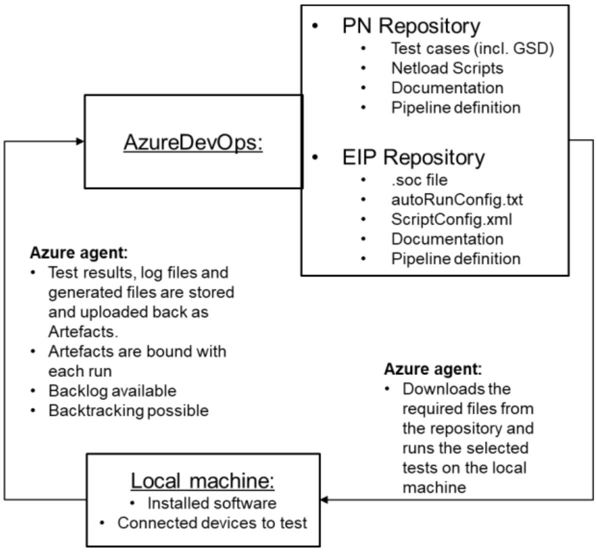

Fig.3: Overview Hardware & Software Setup

Crucially, all data generated within the testing environment, including test artifacts, configuration files, and results, are securely stored within the Azure cloud. This cloud-based storage system adheres to a version control approach similar to GitHub, enabling comprehensive time-stamping and tracking of historical data. This robust data management system facilitates seamless collaboration among team members and promotes transparency within the testing process.

III. RESULTS

The present work has culminated in the development of a framework within the Azure DevOps environment. This framework incorporates the certification tests, functioning as a platform for test execution and analysis. It is the primary outcome of the research. The framework is operational, enables individual module testing, parallel testing of multiple devices, and facilitates remote control and monitoring. It streamlines the transition from in-house systems to certification testing.

This research remains ongoing, the next stage entails the evaluation of performance characteristics. This will involve the creation of additional, custom-tailored tests derived from the provided certification test source code. The investigation will delve into error backtracking capabilities. It will explore the error detection capabilities of integrating certification tests into regression testing. This includes analyzing the types of errors identified and their traceability to specific development stages. This information aims to improve software quality by pinpointing weaknesses and implementing preventative measures. Aiming to identify and rectify potential issues within the early stages of the development process. Through the implementation of these measures, the research seeks to optimize the framework's effectiveness and establish its utility within the field of automated certification testing.

IV. CONCLUSION

This paper presented a novel approach to industrial communication protocol certification testing, leveraging the command-line interfaces of the testing suites, Azure DevOps, and cloud-based infrastructure. The proposed framework offers several key advantages:

A. Cloud environment & test execution

A decentralized architecture on Azure DevOps facilitates the efficient and automated execution of certification tests on local devices. Traceable data provenance simplifies analysis and collaboration. This approach eliminates manual file management, and enhances the repeatability and accuracy of test executions. PROFINET's test source code allows for user-specific tests, easing the certification transition. Further optimization through a comprehensive CLI, developed by protocol providers, could enhance user control and flexibility.

B. Impact on the V-Model and certification institutions

The framework articulates a potential paradigm shift in the traditional V-Model illustrated in Fig. 4. By enabling comprehensive system testing in-house, the framework encourages a proactive approach to system-level error detection and correction. By integrating certification tests, we firstly eliminate the need for duplicate in-house-created system tests and, secondly, simultaneously evolve what were previously validation tests into comprehensive and standardized system tests. This merge highlights the V-Model's typical differentiation between (in-house) verification and high-level validation typically conducted by certification institutes. This in turn raises the question as to what replaces the certification as a validation test, and with it the position of certification institutes within the industry. We contend that a compatibility test – an interoperability test with a multitude of off-the-shelf other devices - should become the new validation test.

Protocol promoters have played a crucial role in this shift. With promoters providing their testing suites encompassing all relevant tests, a certification test conducted at a certification institute becomes redundant as online certification is clearly viable. What is not viable for smaller device manufacturers seeking certification is the maintenance of the large number of third-party devices necessary to conduct comprehensive compatibility tests which in turn opens up an opportunity for certification institutions to focus on broader and costly system-wide assessments. This collaborative approach, combining robust in-house testing with centralized external compatibility validation by certification institutes, streamlines the certification process while ensuring robust and interoperable industrial communication devices. The implication being that, apart from issuing certifications to industrial device manufacturers, offering compatibility testing services would be a strategic expansion for certification providers in the future.

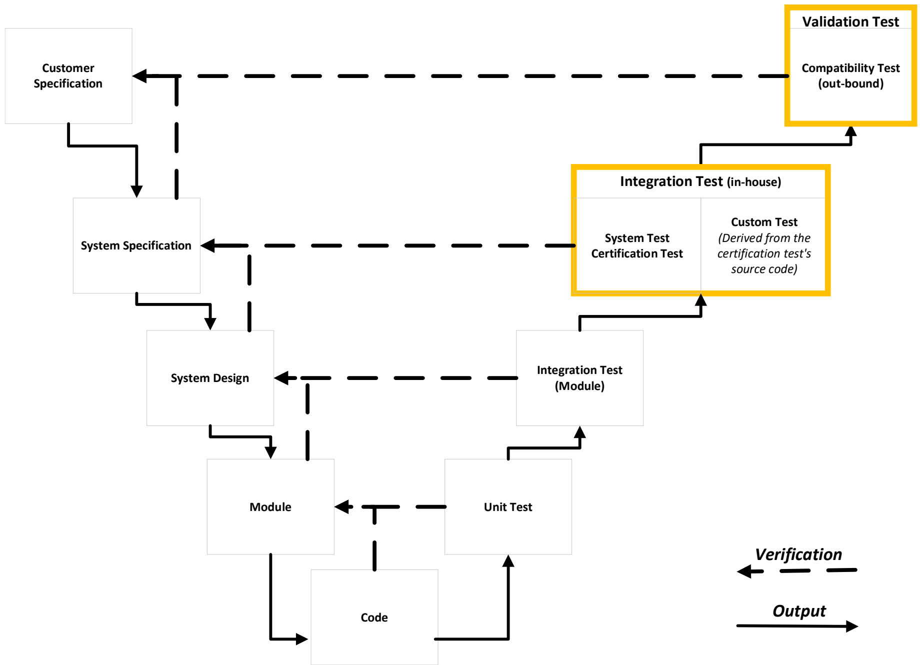

Fig. 4: New V-Model

ACKNOWLEDGMENT

We acknowledge and appreciate the contribution of George Fisher Piping Systems – Process Automation to this project. Their provision of Device Under Test (DUT) devices facilitated the testing and development of this automated certification framework, which they could utilize to certify a new device. Thanks also to PROFINET International for being one of the first to provide the source code of the certification tests and the architecture necessary to support CI/CD principles.

REFERENCES

[1] S. Vaidya, P. Ambad, and S. Bhosle, "Industry 4.0 – A Glimpse," *Procedia Manuf.*, vol. 20, pp. 233–238, Jan. 2018, doi: 10.1016/j.promfg.2018.02.034.

[2] A. K. Tyagi, T. F. Fernandez, S. Mishra, and S. Kumari, "Intelligent Automation Systems at the Core of Industry 4.0," in *Intelligent Systems Design and Applications*, A. Abraham, V. Piuri, N. Gandhi, P. Siarry, A. Kaklauskas, and A. Madureira, Eds., in Advances in Intelligent Systems and Computing. Cham: Springer International Publishing, 2021, pp. 1–18. doi: 10.1007/978-3-030-71187-0_1.

[3] K. K. H. Ng, C.-H. Chen, C. K. M. Lee, J. (Roger) Jiao, and Z.-X. Yang, "A systematic literature review on intelligent automation: Aligning concepts from theory, practice, and future perspectives," *Adv. Eng. Inform.*, vol. 47, p. 101246, Jan. 2021, doi: 10.1016/j.aei.2021.101246.

[4] I. H. Sarker, "AI-Based Modeling: Techniques, Applications and Research Issues Towards Automation, Intelligent and Smart Systems," *SN Comput. Sci.*, vol. 3, no. 2, p. 158, Feb. 2022, doi: 10.1007/s42979-022-01043-x.

[5] W. Xiang, K. Yu, F. Han, L. Fang, D. He, and Q.-L. Han, "Advanced Manufacturing in Industry 5.0: A Survey of Key Enabling Technologies and Future Trends," *IEEE Trans. Ind. Inform.*, vol. 20, no. 2, pp. 1055–1068, Feb. 2024, doi: 10.1109/TII.2023.3274224.

[6] C. Zunino, A. Valenzano, R. Obermaisser, and S. Petersen, "Factory Communications at the Dawn of the Fourth Industrial Revolution," *Comput. Stand. Interfaces*, vol. 71, p. 103433, Aug. 2020, doi: 10.1016/j.csi.2020.103433.

[7] "PROFINET." Accessed: Feb. 27, 2024. [Online]. Available: https://www.profibus.com/technologies/profinet

[8] "EtherNet/IP™ | ODVA Technologies | Industrial Automation," ODVA. Accessed: Feb. 27, 2024. [Online]. Available: https://www.odva.org/technology-standards/key-technologies/ethernet-ip/

[9] I. Graessler and J. Hentze, "The new V-Model of VDI 2206 and its validation," *- Autom.*, vol. 68, no. 5, pp. 312–324, May 2020, doi: 10.1515/auto-2020-0015.

[10] A. M. Mowad, H. Fawareh, and M. A. Hassan, "Effect of Using Continuous Integration (CI) and Continuous Delivery (CD) Deployment in DevOps to reduce the Gap between Developer and Operation," in *2022 International Arab Conference on Information Technology (ACIT)*, Nov. 2022, pp. 1–8. doi: 10.1109/ACIT57182.2022.9994139.

[11] "PROFINET Test Bundle." Accessed: Feb. 27, 2024. [Online]. Available: https://www.profibus.com/download/profinet-test-bundle?limit=all&cHash=d073d5b9cfc660434be564013f8e2c7c

[12] "Conformance Testing | Interoperability | ODVA Specifications," ODVA. Accessed: Feb. 27, 2024. [Online]. Available: https://www.odva.org/technology-standards/conformance-testing/

[13] "Azure DevOps Services | Microsoft Azure." Accessed: Feb. 27, 2024. [Online]. Available: https://azure.microsoft.com/en-us/products/devops