Orchestrated Electrical and Electronics DevOps Framework:

A Seamless Integration and Enahnced Flexibility of Develompent, Testing, and Validation Agents

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1. Management Summary

Being aware of the inefficient downtimes the electronic industry faces in product validation, our innovative Dev/Ops approach enhances the integration of operational development resources by creating a centralized data structure along a no-man-in-the-loop strategy while enabling independent real-time remote testing. Our methodology takes the traditional CI/CD pipeline and Continuous Testing concepts by enabling a comparable workflow through the orchestration of several automation systems focused on testing target software on target electric and electronic hardware. The workflow result will give the user a comprehensive automated test report that indicates the real time health status of the product at any development stage.

2. Aims / Objectives

The key objective of our solution is to improve product development in the automotive industry of embedded software by shifting from several isolated automation efforts to a centrally orchestrated workflow following the continuous testing approach from the DevOps methodology. The continuous testing is achievable by increasing efforts in the virtualization of the entire vehicle and the progressive integration of physical hardware using MiL, SiL and HiL methodologies therefore the efficiency of the validation effort of target software at all development stages is improved.

This solution is possible by applying ASAM XiL standards to implement a global test bench that includes various software, hardware tools and test resources decoupled from the test cases to seamlessly develop test automation and testing results. This approach enables our customers a full monitoring of product status and immediate feedback of software health of hardware and software maturity.

3. P3 Solution

This work introduces an orchestration approach to enhance the product development stage in industries with automated processes. The proposed orchestrator takes traditional DevOps and CI/CD methodologies to formulate five modular solutions that tackle key areas during the development of products. Along these solutions P3 oversaw and performed the following activities: full solution conceptualization, architecture, and methodology definition. P3 made the partnership selection and handling, project management, logistics and implementation within the orchestration environment to achieve the validation of the orchestration solution.
These solutions are described below and consist in, (i) Electric & Electronics DevOps for Embedded Development; (ii) Reliable Automotive System Integration Testing (V&V) (iii) HiL Integrations / Solutions; (iv) Integrated toolchain solutions of SiL, MiL and HiL and (v) Smart Robotic Testing Solutions. Ultimately the goal of our solutions is to define the orchestration workflow and automation framework by developing simulation models according to the customers test environment specifications and doing the integration of physical hardware by using MiL, SiL and HiL methodologies, **it is important to highlight that P3 is framework and tool agnostic.**

1. **Electric & Electronics DevOps for Embedded Development:**

Our innovative DevOps approach enhances the integration between operational resources by creating centralized data structure along with a No-Man-in-the-Loop strategy while enabling independent real time remote testing.

This solution takes the traditional IT DevOps and CI/CD pipeline concepts to enable a similar workflow that through the orchestration of several systems (target software in target hardware) and produces a comprehensive test report as a result that will give you the product health status in a real time dashboard of your product at early stages by testing the product automatically after the development team releases the code without any human intervention.
Our solution is scalable because our workflow can support complete farms of HiL racks, virtual ECU, models and robots at the same time in different parts of the world integrating various tools and software out of one common global test bench.

This approach promotes a cross functional collaboration and improves the organizational communication by giving transparency, agility and visibility to all the members within an organization by centralizing all the tests and tests results out of one same workspace.

2. Reliable Automotive System Integration Testing (V&V):

Our core experience is to perform end to end system integration tests for domains such as Infotainment, Connected Vehicle, AVs /ADAS. Based on the customer needs and the system infrastructure we create a scalable testing solution to best support a landscape of multiple vehicles, architectures & divers' cross functional stakeholders.

In our solutions we use agile methods and statistical approaches to close gaps in the testing process levering on the experience of our highly skilled technical experts with knowledge in the state-of-the-art frameworks, tools,

communication protocols and vehicle networks. Our team is continuously researching and training in the latest cutting-edge technology to help create stable and reliable test automation tool chains that support the development process. It is our deep understanding of the entire automotive development process that gives us a holistic view to identify best practices and scale our solutions based on our customer needs.

3. Flexible Hardware in the Loop Solutions:

Vehicles are evolving into complex systems that need robust test coverage to ensure safety for the driver and what surrounds them. Therefore, flexible and robust automation solutions are needed to face this rapid change in technology and ensure product quality and safety.

One of our partners takes part of the system setup and configuration and we as P3 handle the equipment commissioning, testing setup for real-time data acquisition, on-test data validation, post-processing and interpretation taking into the account the legacy test systems and perform a full migration. This way we can deliver a full turn-key solution to our clients.

The value of our hardware in the loop HiL methodology is about selecting the correct hardware and software solutions to create a full test automation framework that is flexible and scalable to support several vehicle architectures and topologies. Our solutions are adaptive for seamless integration within the costumer's existing infrastructure. We do the integration of functional models and virtual ECUs into real-time testing frameworks, the data collection and treatment to generate automatic and comprehensive test reports by applying ASAM XiL standards to integrate tests with different testing tool solutions.

4. Integrated toolchain solutions of SiL, MiL and HiL:

One of the biggest challenges the automotive industry is facing today is the increasing cost and shortage of electronic components. Thus, P3 target is to integrate the MiL, SiL & HiL methodologies by enhancing the communication a cross-functional groups to enable a full ECUs virtualization environment at different abstraction levels to increase testing effort before having the physical devices fully developed and to validate target software at all the product development stages.

We've developed a test framework for a seamless forward transition between functional models, virtual ECUs and Real ECUs into the test system. Applying a continuous testing of application software in virtual environment and doing the integration of functional models and virtual ECUs into real-time testing framework.

5. Smart Robotic Testing Solutions

The automotive industry is challenged by exponentially growing complexity of software and their respective hardware configurations within the lifecycle of a vehicle. Therefore, finding intelligent and flexible ways to automate testing of hardware in greater numbers is of great importance. P3 helps with the constant identification and selection of state-of-the-art tools and their implementation.

The implementation of a noninvasive automated HMI testing robot that uses advanced image recognition to detect HMI elements in an easy way is of great relevance. Our robotic solution can create comprehensive test reports with a user-friendly framework that any user with no coding skills can use for any geography. P3 identifies workflows that best fit our customers' needs ensuring a plug and play solution that takes care of the system interconnection by developing APIs and scripts in multiple programming languages as well as test case migration, creation, execution and result interpretation of the data post-processing. P3 works alongside a partner which is an expert on robotics and AI topics.

4. Context / Background

Nowadays product development process involves different testing stages as part of a defined verification and validation strategy. Often, it is possible for industries to invest more in hardware, software, and in the expansion of their workforce to meet tight and strict agendas and milestones. Nonetheless, such strategy can result in more human testing errors, and more training hours hindering the quality, quantity, and the pace of the workflow by creating bottlenecks in the development process, thus increasing the cost/effectiveness ratio of general development resources.

Usually there is a process where software under development must clear testing filters to reach an automated or productive test phase. When companies try shortening the gap between the commitment of code and its automated tests, certain efforts are put into man-involved processes such as manual and end to end testing. This not only increases the cost of the development phase by having to pay more personal and going through steep learning curves. For such motives this scenario increases the probability of including human-related errors while conducting tests, grading testcases, and creation of results reports, all of these without having a proper traceback communication with developers to correct and assess the ongoing issues.

On the same note, the validation pace of software under development can be hindered not only by human-related errors but also by being highly dependent on target hardware availability where in some cases, companies must fly over hardware to test new developments that are no longer supported by old

hardware; in doing so, companies are incorporating the problems of layover logistics into the test and validation processes, leading to delays in deliverables by missing crucial deadlines. It is also important to consider that software is being tested on later development process stages with sluggish feedback, meaning that if any change of hardware is detected and required by later testing states it would take longer to validate the software since there would be new hardware requests and new waiting times for the hardware to arrive.

Additionally, it is important to mention that automotive software complexity has been rapidly increasing in recent years to accommodate new emerging technologies and software-oriented architectures. This prompt evolution of automotive software introduces new problematics to the testing and validation paradigms, where testing and validation efforts are not able to match growing pace in complexity of software. Essentiality this scenario poses a disadvantage to current testing and validation strategies with a negative performance forecast that can lead to bigger bottle necks and causing even more delays in deliverables. For such motives, there is a current need of a strategy that minimizes tangible and intangible dependencies, that can lead to an improved cost-effective business strategy, and match the growing pace of software-oriented architecture while also enhancing test reliability and traceback communication between developers and independent testing agents.

To overcome such paradigms this work takes two of the most popular IT methodologies for product development, the methodologies are CI/CD which links product results to developers in a seamless manner, leading to a more agile

release of products to production testing. This approach can be adapted to incorporate CT (Continuous Testing) to add a key validation stage into the development and validation process. The goal of adding CT is to increase validation efforts at early stages of the software lifespan without the dependency on hardware availability. To achieve this, it is crucial to incorporate the development of Virtual Electric Control Units (VECUs) at different testing and validation levels such as MiL, SiL, HiL, and PHiL while also enabling a Centralized Information Manager (CIM) to better distribute feedback data between each methodology and improve the focalization in each of them, essentially making a more agile software validation.

Furthermore, CT and the virtualization of ECUs can be coupled to the DevOps methodology. DevOps is one of the key points of proposition in the agile product delivery competency. DevOps is born by combining development and operations, i.e., coupling what it once was two independent stages and having them work together to increase traceback communication which leads to faster delivery times in a highly operations dependent testing and validation system on the continues releases of software builds. Without DevOps, these two agents often collide with negative effects between the developers and those who support and maintain the products. At the end, DevOps makes organizational silos simpler while developing a Continuous Delivery Pipeline (CDP).

At the end consolidation between VECUs, CT, and DevOps can be managed by an Orchestrator that makes the testing more agile by not depending on real hardware and shifting this effort to its virtual counterpart to enable virtual environment for testing. The Orchestrator can also distribute testing efforts and resources between MiL, Sil, HiL and PHiL while being more agile and improving communications between testing and validation layers.

5. How was it organized and who was involved?

P3 has a wide network of experts and partners in many engineering fields, such network was used to assemble cross functional teams with tasks focused on giving support to the Orchestration workflow. This was achieved by developing different Application Program Interfaces (APIs) to carry on with the work of connecting necessary tools, automating tests, setting up and connecting HiL rack, and processing the data. These APIs were created using various programming languages, e.g., Python and C++.

In addition to the P3 network, P3 also had partners that contributed differently to the presented solutions' development. P3 resorted to agile methodologies to ensure effective communication by providing results visibility across the cooperation of functional teams. All the teams worked using agile methodologies like DevOps, SCRUM, and KANBAN to keep track of the activities, risks, and open items.

The automation strategy and framework architecture of the Orchestration workflow was designed and implemented by P3. This workflow illustrates at a high level the different parts of the process and actors needed to perform centrally orchestrated automatic testing for electric and electronics at different product maturity stages. Starting from the test plan definition up to the test sign off, this workflow is meant to be executed iteratively following the continuous exploration, continuous development and deployment methodologies used in DevOps. This workflow is illustrated in Figure 1.

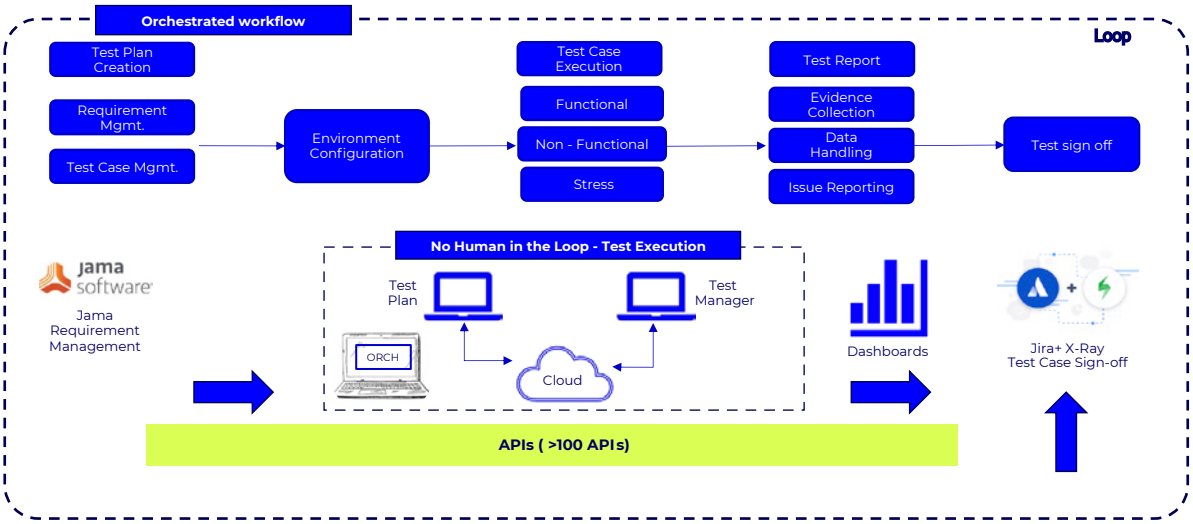

Figure 1. Orchestrated workflow diagram

6. What resources are needed?

For Consulting and Professional Services: what resources are needed, or what is involved?

As part of our professional service, we perform an initial assessment to build the best tailored solutions for each of our customers. During this assessment we need to access the following inputs:

- Customer current test management infrastructure
- Data flow, repositories, and I/O of each section
- Current tools in operation (external or in-house)
- Device/system technical requirements and constrains
- Test specifications
- Validation scope/method required (full: MiL, SiL, HiL, ViL, or partial)
- Laboratory infrastructure
- Device/System under test

7. Demonstration

Some key takeaways from the customers include that testing and validation strategies have always lacked flexibility, therefore by enabling a flexible HiL solution can be a “game changer” as quoted by one of the attendees of the demo presentation. The solution of giving flexibility of HiL system comes with the introduction of re-configurable and multi-functional port test systems for seamless hardware integration and test automation as showed by one of P3’s partners during the demo presentation. A second takeaway during the presentation of the robotic solution was the importance of having a good combination of the image recognition capabilities and the mechanical design that allows the robot to have accuracy while it presses the icons at high speed.

EE DevOps Demo:

The main objective of this demos is to illustrate the continuous testing process that happens during the product development to get a product ready for market. Figure 2 how the traditional IT DevOps methodology is being applied in the software development stage and the process of how our continuous testing approach will enable the automated workflow in a XiL environment.

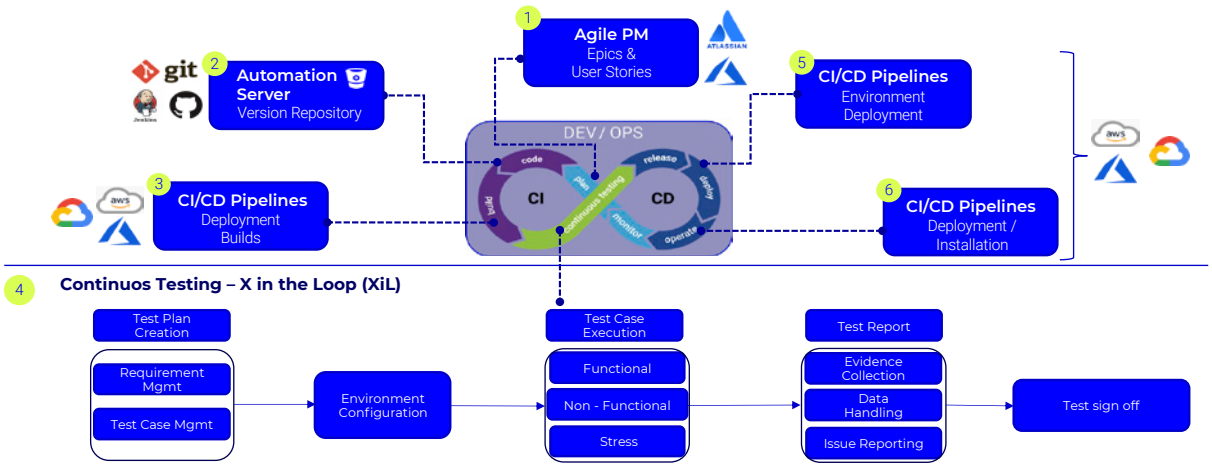

Figure 2. DevOps methodology being applied in the software development stage

Overall Continuous Testing XiL Process

The continuous test workflow starts with the preparation and configuration of our test orchestration system. This preparation activities include analysis of test requirements, test case and test plan creation as well as environment configuration and where the test system is being set up and ECU is being configured in other words a CI/CD pipeline has been created. After this preparation activities, the system is ready to be launched or automatically being triggered by a software drop at any given time required. After a trigger the tests cases are being automatically executed and the test report is being automatically created from the test evidence gathered from the test execution, the respective issues are being reported automatically and finally, after a manual assessment the software sign off is done where the product health is being portrayed by the results from the test report. Figure 3 shows the mentioned CT workflow.

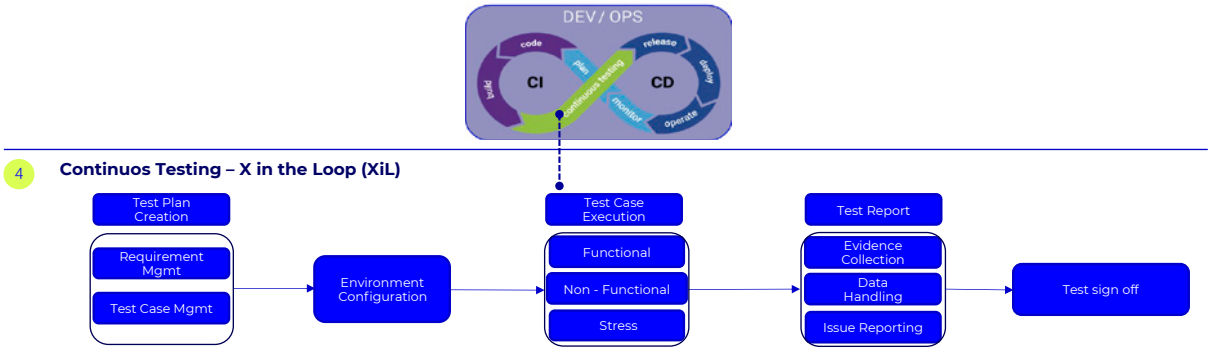

Figure 3. CT workflow.

To highlight this process P3 followed the customer's requirements and came up with three different uses cases, these use cases are: (i) HiL in the Cloud - non-real time scenario, (ii) HiL Testing – real time testing and (iii) E2E HMI testing – Robot implementation that show how the described approach of this case study is being applied by performing the implementation of an orchestrated workflow:

1. HiL in the Cloud: P3 the owned Proof of Concept (POC) solution focused on enabling non real time testing of ECU´s in the cloud. The test case comprised of testing interconnection between CAN-ETH via MQTT protocol in different parts of the world between two locations.
2. HiL Testing: P3 and its partner implemented the control of the speed of a brushless engine using a HiL Rack showcasing a software re-configurable and multi-function port test system for seamless hardware integration and test automation.
3. E2E HMI Testing – Robot: P3 and its partner implemented an end-to-end HMI using a robotic arm that uses advanced image recognition to detect HMI elements in a "Infotainment simulator" screen.

4. The Orchestration: Using an orchestration tool, we implemented the three described uses cases above to create the automation workflow in different tools. The orchestration tool can check which test bench is available according to the test needs and each bench resources in terms of software and hardware.

Additional Features to the CI/CD Demo:

The entire workflow is shown on the following diagram (Figure 4). To create a comprehensive workflow that properly integrates into the DevOps philosophy by not only integrating the automated test flow, but also its respective requirements to ensure a 360° traceability we did integrate with a requirement and issue management tools like JAMA and Jira respectively into our CI/CD workflow. The orchestration tool allows to visualize how the information flows from the automated test manager feature to the different test benches allocating correctly each test cases depending on the bench capabilities to do and execute the different test cases.

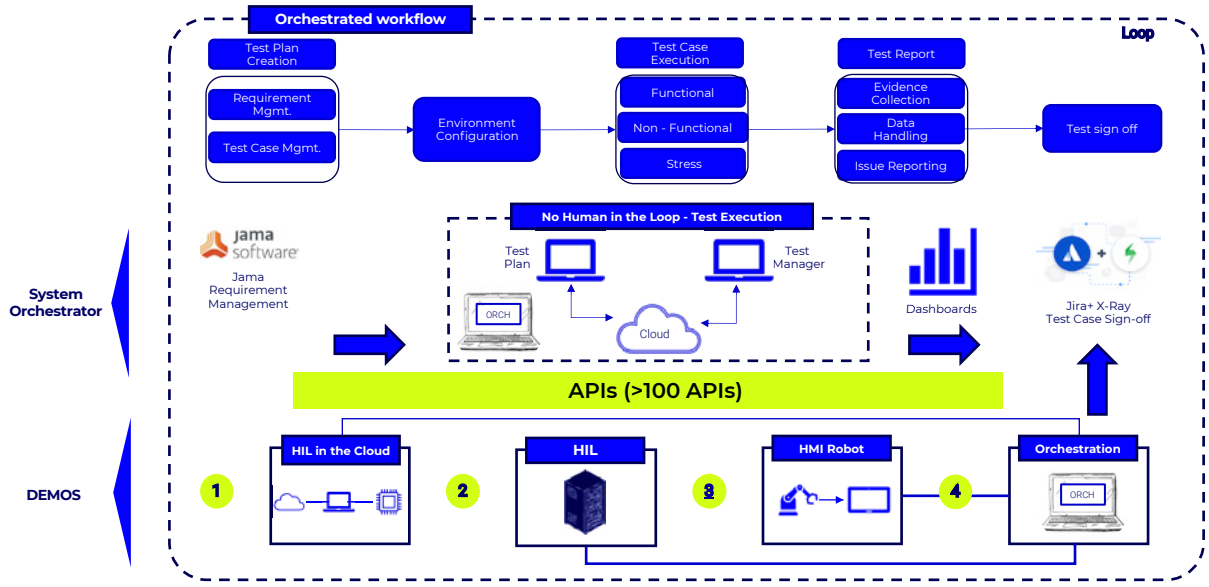

Figure 4. Complete Orchestrator workflow.

As mentioned in previous sections this approach of how the methodology is being used can be scalable to support complete farms of HiL racks, virtual ECU, models and robots at the same and time location independent by integrating various tools and software out of one common global test bench for different automotive domains such as Infotainment, Connected Vehicle, AVs /ADAS.

8. Roadmap for how the solution is offered or provided?

This solution was build in a modular way and can be offered either in parts or the whole solution presented. We develop tailored solutions from customer requirements analysis up to their full implementation to ensure the smooth workflow, our service scope includes the definition, implemenation and the actual execution of the orchestration worflow and automation framework. The details of this solution can be found in either the AWS Marketplace or in the “What work did P3 do (or were engaged to do)?” section of this case study:

1. Electric & Electronics DevOps for Embedded Development.
2. Reliable Automotive System Integration Testing (V&V).
3. Flexible Hardware in the Loop Solutions.
4. Integrated toolchain solutions of SiL, MiL and HiL.
5. Smart Robotic Testing Solutions.

As part of the solution we can integrate this kind of workflow and framweork in existing customer's infrastrecture based on legacy systems by building all necesary artifacts to make it work or build it from scratch. To guarantee this turnn key solution we offer the service of getting all the data migration from one system to another. Meaning that once we deploy this new workflow the customer will already have all the existing test cases, configurations and requirements already in their systems so we don't disrupt their normal operation process causing downtimes from a workflow change.

9. Key Learning Points

This work introduced five solutions that target different paradigms in current test and validation environments. These solutions were formulated by cross functional teams with the collaboration of partners. These collaboration between the agents within the P3 network and partners created some management and technical challenges that required special attention. Management challenges were mostly present at the initial stages of the project. These being the handling of sensitive information and coordination between internal and external agents to achieve the implementation of the presented solutions.

On the same subject, coordination challenges arouse mainly due to the geographical location diversity. By having multiple cross functional teams with different schedules, it was crucial to agree on constant checkpoint and working session meetings to review the progress and work on the solution of ongoing issues. Additionally, a base architecture was developed containing all

the base requirement for each solution of the project, by doing this, P3 stablished a shared staring point with a different end goal in mind for each team.

Then again, technical issues were also present during the realization of the presented solutions, e.g., specialized hardware was required during the development of the Smart Robotic Testing Solution, more specifically, an HMI test unit. To overcome the low availability of this piece of hardware, P3 developed a Power Aps application to embed the functionality of the HMI in an android tablet for E2E testing with the robot. This solution allowed for the involved team to keep the pace of their developing task instead of stopping due to hardware dependency. Also, technical challenges were introduced during the integration of independent solutions in an automated and orchestrated workflow without human interaction such as HiL in the Cloud. To solve this issue a LabVIEW API was developed to allow the orchestrator to interact with the tool's functionality, making its integration more agile. Additionally, an interface was designed and developed in Python between the orchestrator and the API of the robot to be able to integrate the robot actions in an automated environment. This development was required since the current framework for the robot does not allow a direct manipulation of its actions in an automated test environment. Furthermore, since one of the tasks of the robotic solution is to detect images though cameras, one of the main setbacks was the interference of external light sources that hindered the detection performance, this was solved by calibrating the camera to adjust the perceived brightness while adding Python-based subroutines to navigate back to a base position and validate that the movement of the robotic arm and detection of icons was being done correctly.

10. P3 Group

Contact for questions and remarks

Valeria Espinosa
Engineering Project Manager
v.espinosa@p3-group.com

Carlos Eguez
Senior Software Test Engineer
c.eguez@p3-group.com

Juan Roberto Lopez
Senior Software Test Engineer
r.lopez@p3-group.com

Christian Rangel
CEO P3 Mexico
c.rangel@p3-group.com

Disclaimer

Address:
P3 USA, Inc.
4900 O'Hear Ave Suites 100
Charleston, SC 29405
USA

Website:
www.p3-group.com