Embedded Controller Software Development Best Practices at the National Ignition Facility

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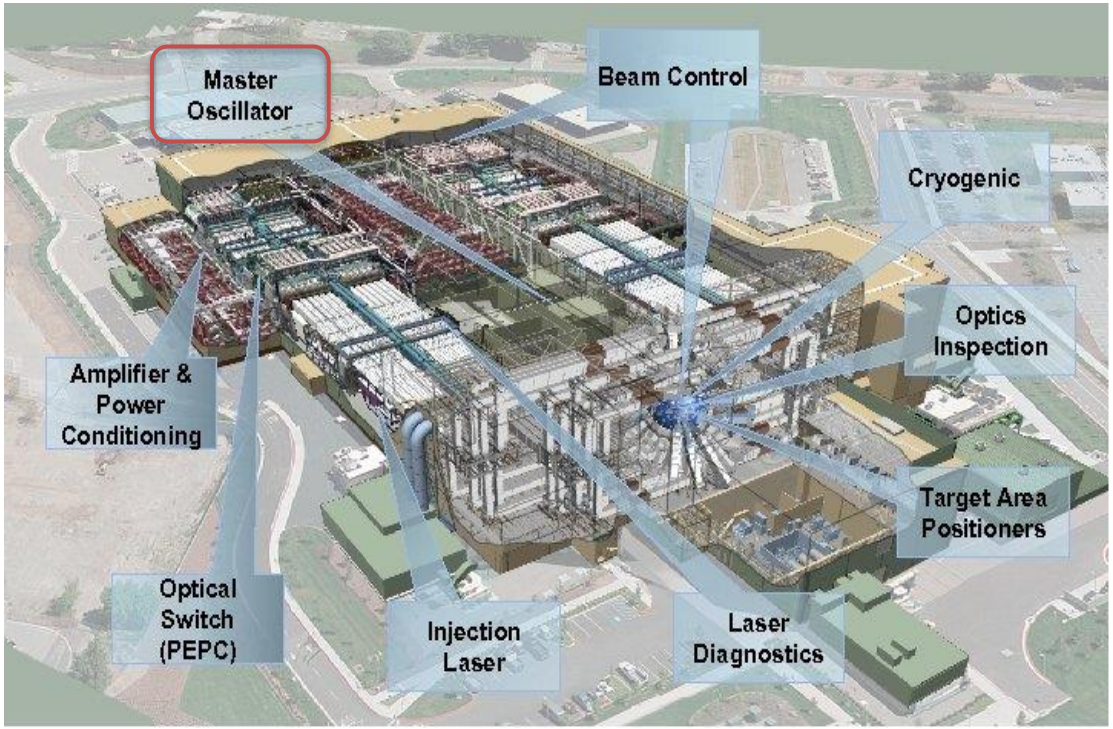
NIF Master Oscillator Room (MOR) Embedded Controllers

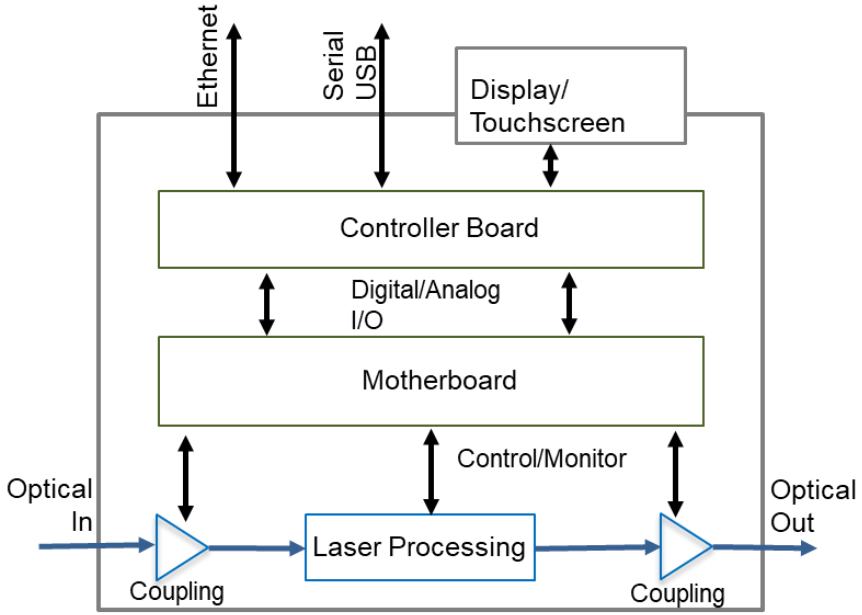


- NIF controls use embedded controllers in several critical subsystems such as Power Conditioning and MOR.
- Several MOR embedded controller types: optical amplifiers, failsafe switches, phase modulators, RF oscillators and RF switches.

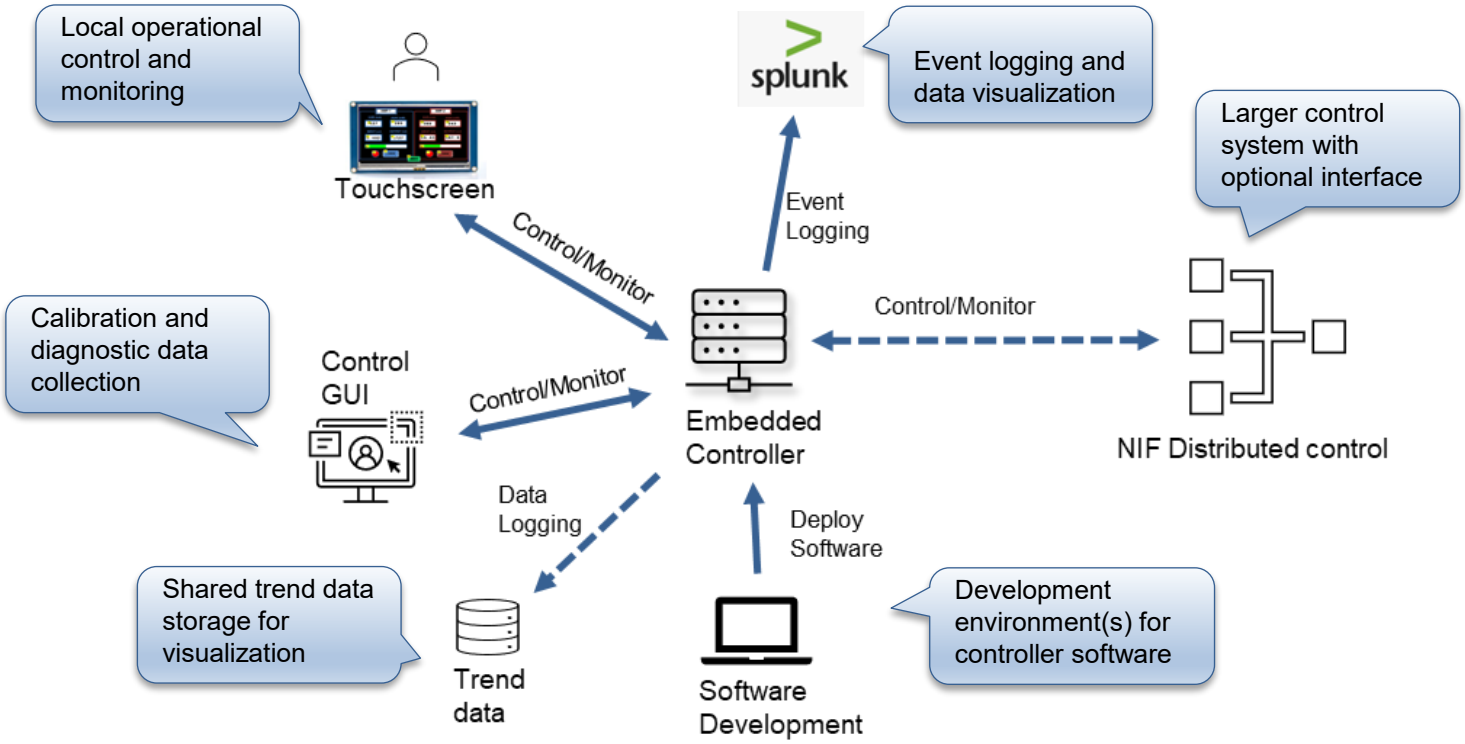
NIF controls employ ~1000 embedded controllers out of which, over a 100 are in the MOR.

Embedded Controllers (EC) - Generic Architecture

- Controller board
  - Handles primary logic and control operations
  - Communicates with the motherboard over Digital/Analog I/O
  - Provides external command/monitor interfaces
  - Facilitates software update
- Motherboard
  - Bridges the controller board to hardware components
    - Signal conditioning, ADC, DAC etc.
- Hardware components
  - Core hardware functions of the EC device
  - Includes devices such as pump diodes, which are driven by signals from the motherboard



Embedded Controllers - Operational ecosystem



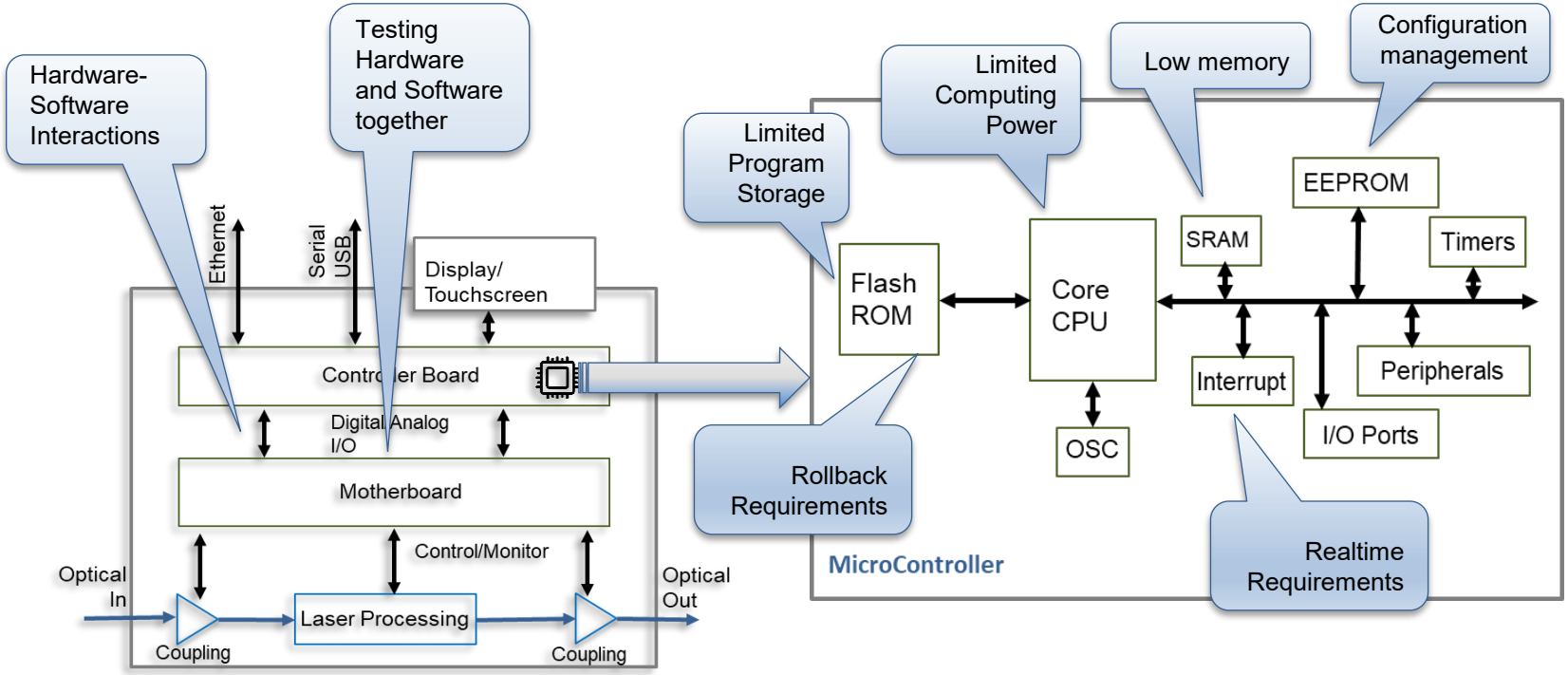
The operational ecosystem is designed to ensure robust operational control and autonomy

Complexity of the development ecosystem

- Embedded PCs, AVR, and PIC based designs
- Broad range of programming tools
- Extensive ecosystem of test and diagnostic tools
- Siloed development environments
- Challenges in compatibility, version control, and developer expertise.

There's a need for a unified development system that can solve the ecosystem's challenges

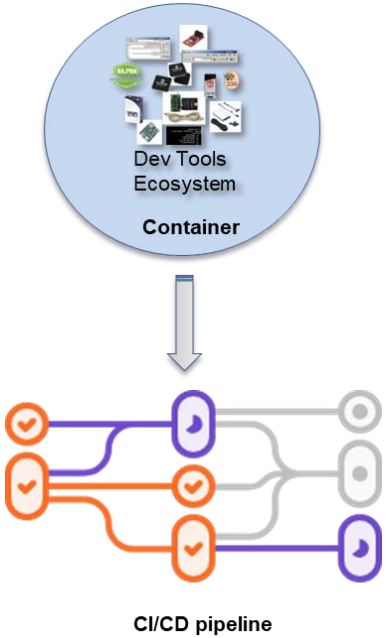
Embedded controller development challenges



The unified system must address additional challenges of the microcontroller-based system.

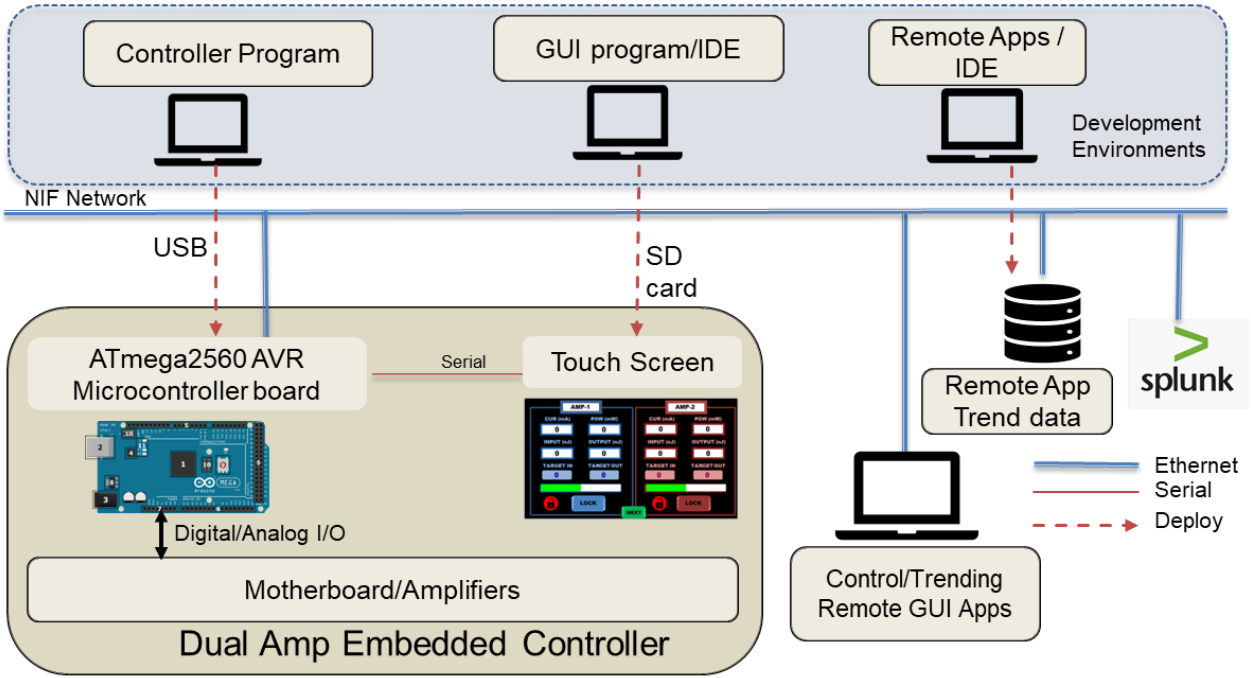
Best Practices Overall Strategy

- Utilizing Containers to Encapsulate Complex Development Tools Ecosystem
- A Streamlined Software Development Process based on CI/CD Best Practices
- Adopting Open-Source Components
- Coding Practices Tailored for Low Memory, Computationally Constrained Systems
- Simulation
- Hardware-in-the-Loop (HIL) Testing



By integrating containerized ecosystems with CI/CD pipelines and extensive automated testing frameworks, the embedded controller development challenge can be overcome.

MOR Dual Amplifier (DUAL-AMP) - Ecosystem

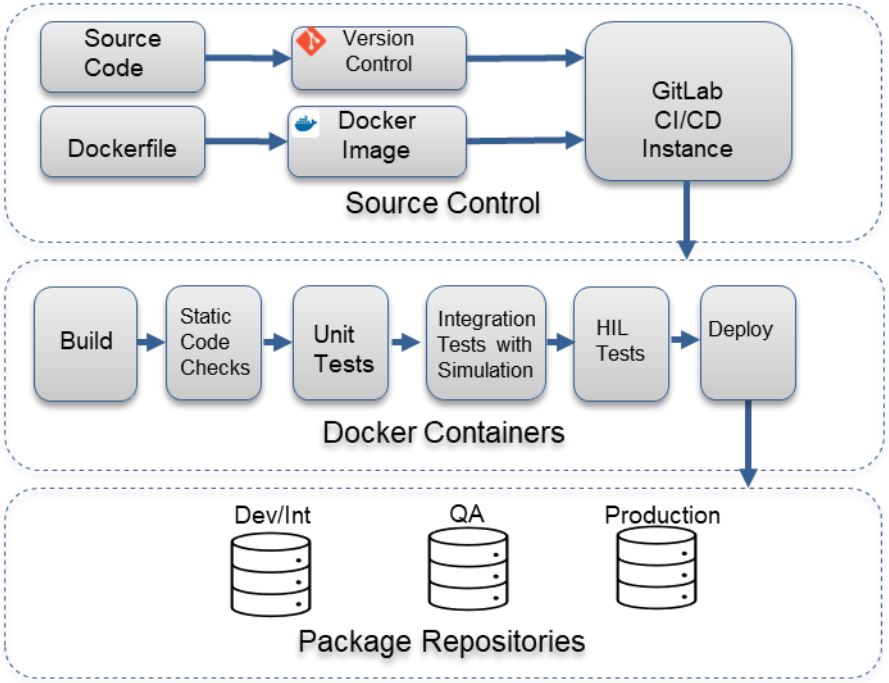


- **3 distinct software environments**
- **Complex ecosystem of programming tools, test and diagnostic tools**
- **A variety of hardware interfaces**
- **Real time performance requirements**
- **Resource constrained controller hardware**
- **Several deployment scenarios**
- **Challenges in version control and configuration management**

The DUAL-AMP represents the complexity and challenges encountered in embedded controller development

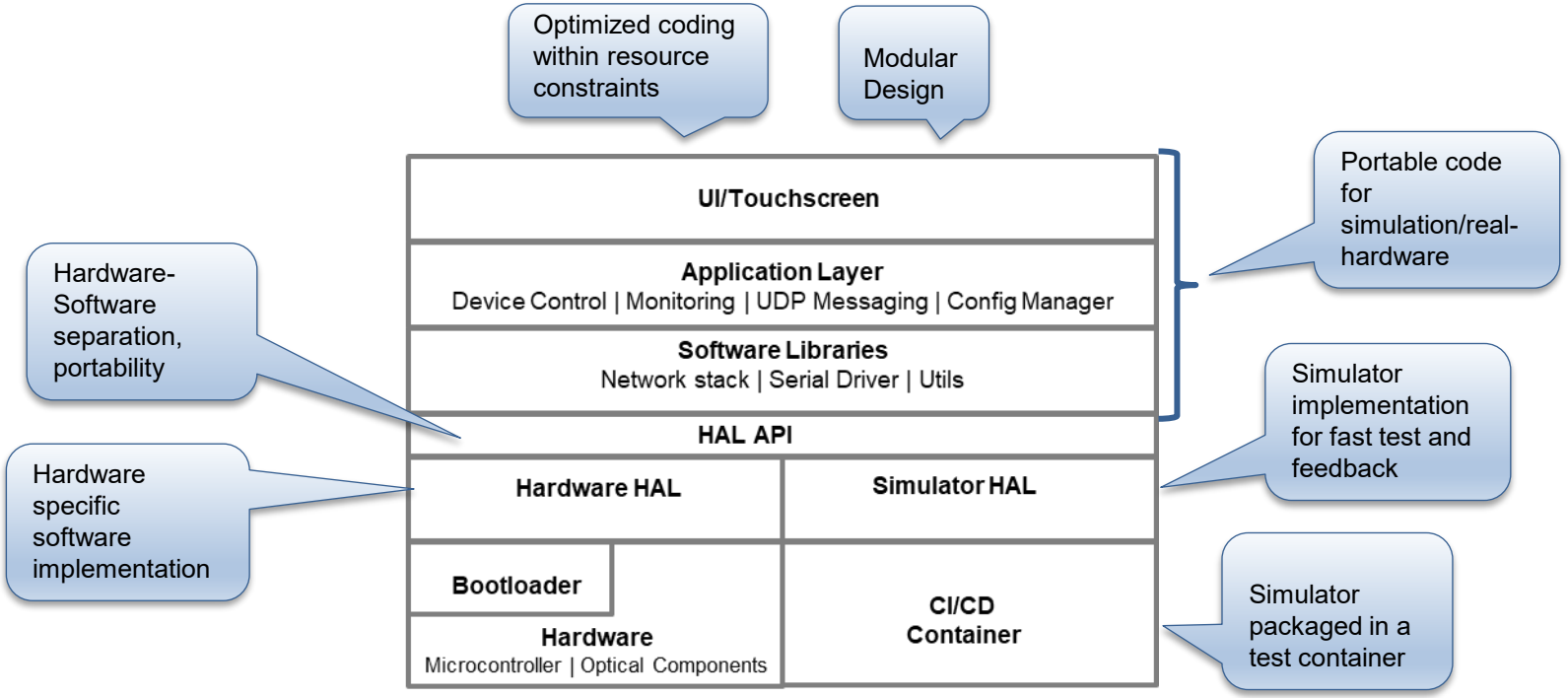
Building a CI/CD Pipeline

- Version control of all artifacts
- Docker container creation
  - Packaged ecosystem for all tools
- Integration of all process steps into the CI/CD pipeline
- Simulation and Hardware-In-the-Loop (HIL) testing
- Deployment configuration for offline and production environments



A robust CI/CD pipeline for embedded controllers requires careful integration and orchestration of several steps.

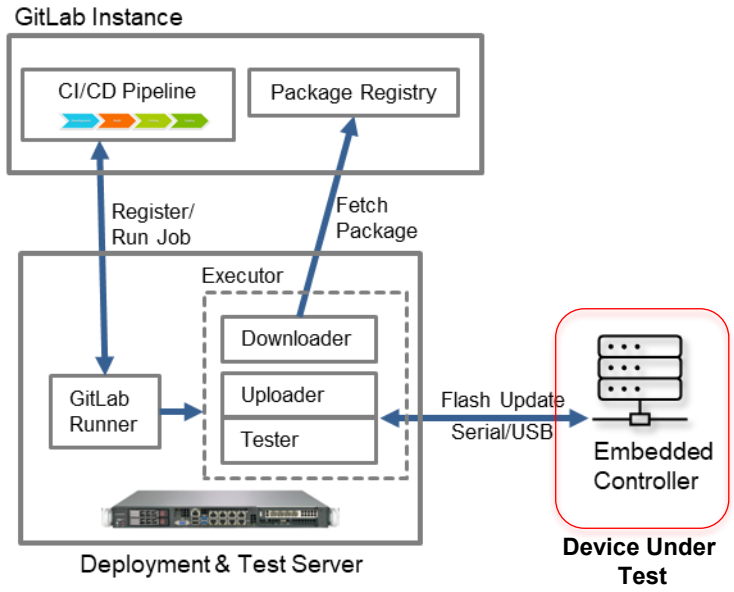
Software Architecture



Software modularity is essential for robust CI/CD pipelines to ensure testability.

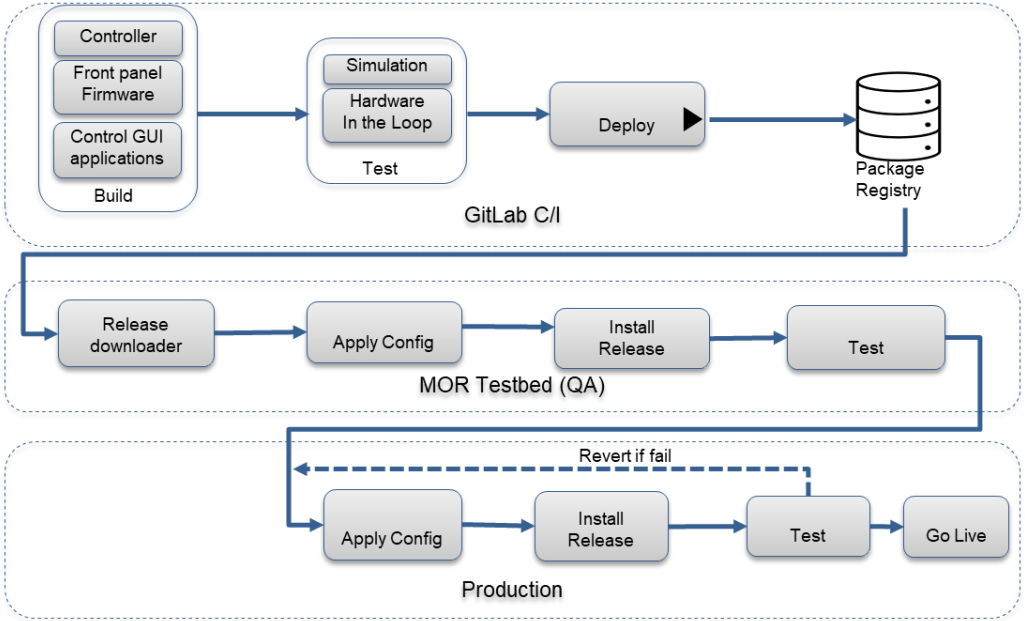
Hardware In the Loop (HIL) testing

- HIL Test Setup
  - Dedicated HIL Deployment and Test server
  - Direct interface with the embedded device through serial/USB connection
- GitLab Pipeline Job for HIL
  - Utilizes GitLab runner on the Deployment Server
  - Downloads software build package from GitLab package repository
  - Updates software in the controller via the serial/USB interface
- Post-Deployment Phase
  - Activation of automated test scripts
  - Evaluation of controller functionalities under various conditions
- Feedback and Logging
  - Results fed back into the pipeline
  - Flags results and logs test information on the GitLab server



HIL testing effectively makes ***continuous*** hardware integration a primary element in the CI/CD pipeline.

Software development life cycle

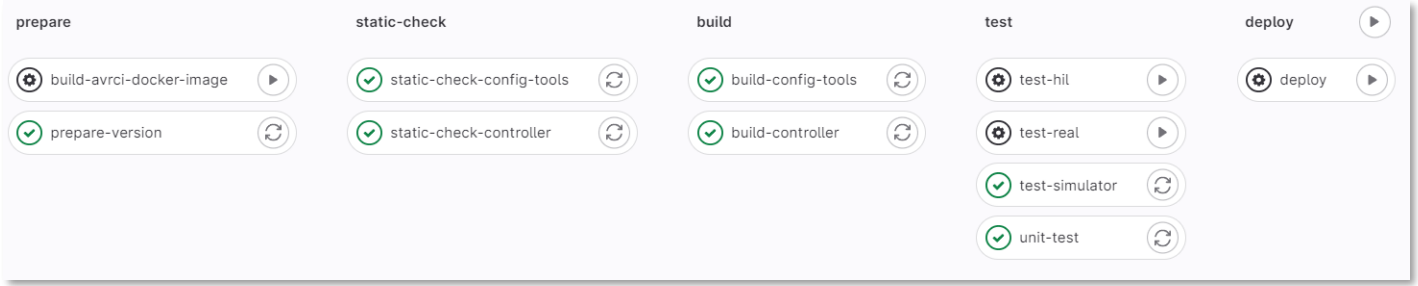


- **Post CI/CD: Rigorous QA Evaluation**
  - **Manual assessment in production-like setup**
  - **Two-step process:**
    - **Apply configuration data using config tool**
    - **Deploy actual image**
- **Production Deployment**
  - **Similar two-step process as QA**
  - **Allows straightforward revert strategy**
    - **Utilize previous release package**
    - **Follow the same two-step procedure**
- **Config Tool Features**
  - **Custom-built for the specific embedded controller**
  - **Manages EEPROM configuration :**
    - **Versioning**
    - **Integrity checks**
    - **Schema changes**
    - **Revert operations**

QA and production deployment processes add support for version management, configuration data management and rollback.

Results and Lessons Learned

- Successfully implemented a complete CI/CD pipeline for an MOR Dual Amp embedded controller using software best practices



- Modularization-Performance Tradeoff
  - A crucial balance had to be struck between optimizing runtime performance and preserving a modularized structure

- Increased Initial Time Investment
  - Extensive scripting and configuring for automation, establishing test environments, fine-tuning the pipeline for optimal performance

Future Directions

- Integration of Direct Network Update
  - Currently, through USB/serial
  - Potential for direct network updates with bootloader support
  - Requires additional network setup and support
- Enhancing Hardware-in-the-Loop (HIL) Testing
  - Full connectivity of all inputs and outputs
  - Generation of comprehensive stimulations
- Harmonization of Hardware Platforms
  - Consolidate to one or a few platforms
  - Aims to streamline processes and enhance efficiency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