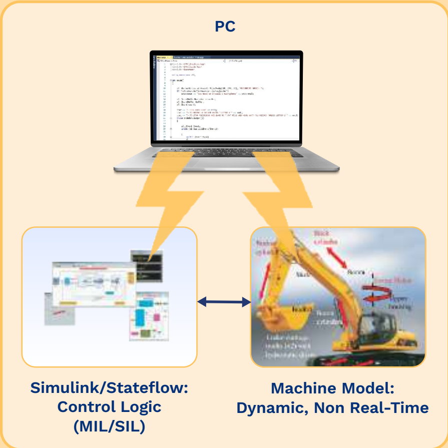
SERVOTECH

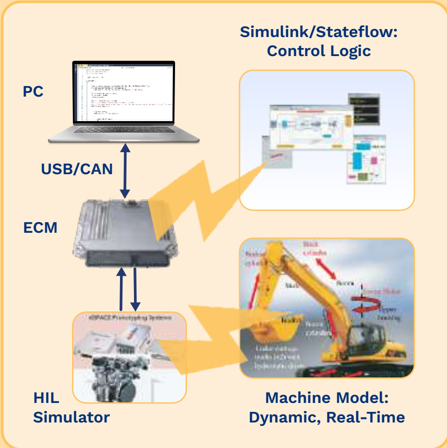
Embedded Control Software Development For Mechatronic Systems

Phase 1



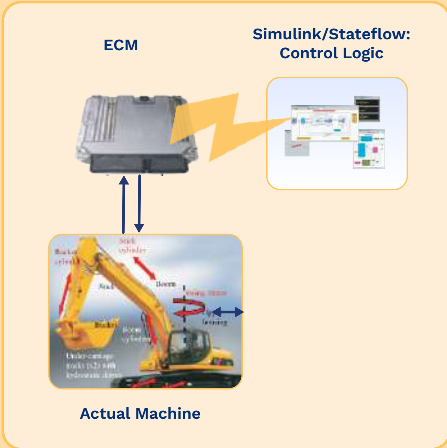
Modeling and Simulation in non-real time

Phase 2



Hardware-In-The-Loop (HIL) real-time simulation and testing

Phase 3



On Machine Testing

The trend in industrial practice is that the embedded control software development part of Modern mechatronics engineering involves three phases:

Phase 1: Control software development and simulation in a non-real-time environment.
Phase 2: Hardware-in-the-loop (HIL) simulation and testing in a real-time environment.
Phase 3: Testing and validation of the actual machine.

In **phase 1**, the control software is developed by using graphical software tools, such as Simulink® and Stateflow, simulated and analyzed in a non-real-time computer environment. The "plant model," which is the computer model of the machine to be controlled, is a non-real-time detailed dynamic model. Simulations and analysis are done in this non-real-time environment.

In **phase 2**, the "same control software" is tested on a target-embedded control module (ECM). That "same control software" is a C-code that is auto-generated from the graphical diagrams of Simulink® and Stateflow using auto-code generation tools such as Simulink® Coder, Embedded Coder, and MATLAB® Coder. That real-time controller software is run on the target embedded controller module (ECM) hardware in real-time, which can be connected to another computer that simulates the controlled process dynamics in real-time. This case is called the hardware-in-the-loop (HIL) simulation.

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This process allows the engineer to test the control software on the actual ECM hardware in real time. The computer which simulates the plant model in real time provides the simulated I/O connections to the ECM. The fundamental challenge in HIL simulations is the need to find a balance between the model accuracy (hence more complex and detailed models) and the need for real-time simulation. As real-time modeling capabilities improve, virtual dynamic testing and validation of complete machines using HIL tools will become a reality in engineering design and development processes for embedded control systems.

In **phase 3**, the ECM with the control code is tested on the actual prototype machine. First, all of the I/O hardware is verified for proper operation. The sensors and actuators (i.e., solenoid drives, and amplifiers) are calibrated. The software logic is tested to make sure all contingencies for fault conditions are taken into account. Then, the control algorithm parameters are tuned to obtain the best possible dynamic performance based on expert operator and end-user comments. The performance and reliability of the machine are tested, compared to benchmark results, and documented in preparation for production release.

HIL is the testing and validation engineering process between pure software simulation and pure hardware testing (100% actual machine with all its hardware and embedded software), where some of the components are actual hardware and some are simulated in real-time software. The pure software based simulation cannot capture sufficiently the real-time conditions to provide sufficient confidence in the overall system functionality and reliability. Pure hardware testing is quite often too expensive due to the cost of actual hardware, its custom instrumentation for testing purposes, and the team of engineers and operators involved in the testing. Furthermore, some tests (especially failure modes) can not be tested (or are very difficult to test, i.e., flight control systems) on the actual hardware. HIL simulation testing is an engineering process that is in the middle between pure software and pure hardware testing.

HIL tools have been developed rapidly in recent years in that some of the hardware components of the control system are included as actual hardware (such as electronic control unit (ECU), engine, transmission, and dynamometer), and some of the components are present in software form running in real-time and its results are reflected on the control system by a generic simulator (i.e., a dynamometer which represents the load on the powertrain based on the machine dynamics and operating conditions. Early versions of HIL simulations were used to test only the static input-output behavior of the ECM running the intended real-time control code, where I/O behavior is tested with a static I/O simulator. Modern HIL simulation and testing are performed for dynamic testing, as well as static testing, where the I/O to ECM is driven by dynamic and detailed models of the actual machine.