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Siemens Digital Industries Software

Taking control of robot complexity and cost

Using simulation and testing solutions to accelerate design of advanced robots

Executive summary

With the influx of new technologies – 5G, edge computing, machine learning (ML), artificial intelligence (AI) and advancement in vision capabilities, the robotics industry is poised to deliver on Industry 4.0 promises. But it is challenging to create robots that are autonomous and can handle small batches of work at high precision without compromising on safety. Manufacturers need a novel engineering approach to take control of complexity and cost. This white paper focuses on applying simulation and testing solutions to address engineering challenges such as sizing a robot actuator to the payload, validating control logics with virtual commissioning processes and achieving stricter targets for performance, reliability and safety.

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Abstract

This white paper highlights a holistic approach using simulation and testing solutions to advance robotics engineering. We discuss some of the key industry trends that drive the adoption of robots in manufacturing companies and major hurdles to broader deployment. Using several real application cases, pick-and-place robots and automated guided vehicles (AGVs), we demonstrate how using simulation and testing tools helps provides early insight into how to efficiently handle robotics engineering complexity.

Trends transforming the manufacturing industries

With the acceleration of digitalization adoption across factories, it is impossible to predict precisely what the future holds for manufacturing companies. But the industries are certain of one thing: The number of robots and the amount of automation will rise exponentially as 500,000 manufacturing jobs are going unfilled annually, 70,000 baby boomers are retiring weekly from the workforce and millennials are unexcited about joining the manufacturing trade.

The four key trends – flexible production, smartness, sustainability and cost-effectiveness – have a strong socioeconomic impact and are forging the manufacturing landscape of the future.

Flexible production

Superior machine performance has always been the foundation of success, but it is not enough anymore. Product manufacturing companies seek adaptable machines that can be easily customized to respond to changing consumer needs. The ability of manufacturing sites to adapt efficiently to changing products or processes is essential for future product manufacturing companies.

Smart machines

Connectivity, technology and the Industrial Internet of things (IIoT) are enabling seamless visibility into daily activities that product manufacturing companies longed for. Data analytics and artificial intelligence will help drive business decisions with quantitative insights into the current operation. Such real-time data interpretation, reconstruction of variables and parameters of the plant can result in faster diagnosis of issues and troubleshooting.

Sustainability

The global race to net zero emissions makes it imperative for companies to strive for minimal pollution and resource requirements to meet today's and future regulations and customer demand. Additionally, as products and functionalities are getting more complex, the need to deliver the same or better performance using the minimum resource is on the rise.

Agile and cost-effective

The changing landscape of innovation, customized products and trade shifts is exerting extreme pressure on the profit margins of small and medium-sized manufacturing companies. Leading manufacturing companies are investing in foundational digital manufacturing capabilities to become more nimble and cost-effective.

Industry 4.0 realization requires speed, flexibility and quality

The new trends in manufacturing bring new challenges to manufacturers and suppliers – growth in product complexity with increasing cost and delay in the product launch.

Mass production started over 100 years ago and evolved from laborious manual tasks into sophisticated automated assembly lines. Automation functions best in a fixed setup producing similar products in large quantities. But when the product changes frequently, such as during personalization operation, human intervention is unavoidable to ensure error-free manufacturing.

Concurrently, factory automation and digitalization technologies attract more investment to eliminate manufacturing inefficiencies and tackle new challenges. Robotics seems to be the only way to approach 4D jobs: dull, dirty, dangerous and difficult.

A flexible and autonomous production system is the holy grail that can fulfill future manufacturing needs. Advanced robotics is considered the key enabling element to address the needs of the future manufacturing industry. As conventional robotics struggles with fixed workflow setup, advanced robotics unleashes exceptional adaptability, permitting accurate and faster reconfiguration of workflow with minimum human intervention.

An analysis of communications from all major robotics firms confirms these megatrends: There is major support for customization, seamless interaction between man and machine, enhanced productivity and safety. By taking up new challenges, advanced robotics is rapidly evolving.

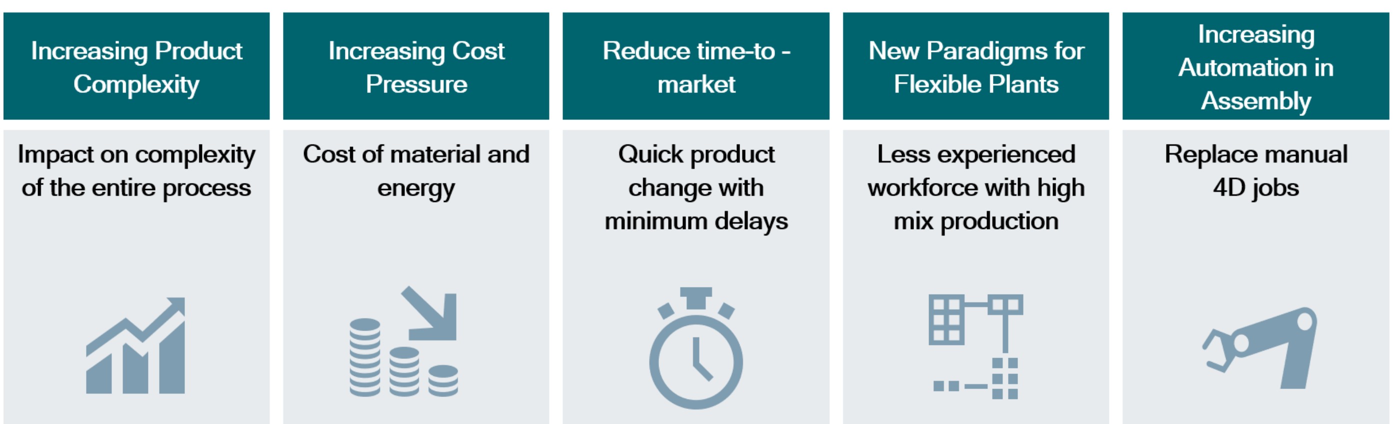

Figure 1. Product manufacturers and supplier confronted with new challenges.

Delivering impact at scale by adopting robotics

According to the International Federation of Robotics, nearly 4 million industrial robots are expected to have reached factories worldwide by 2021.

Integrating technologies to deliver on the flexible and reliable manufacturing promises using advanced robotics is a multifaceted, complex task. The following challenges are obstructing the wider adoption of robotics:

- Performance:
  Most robots on the factory floor are large machines performing a single or several repetitive tasks. To ensure positional accuracy and repeatability, the robotics arm is made of stiff and rigid materials. This can often lead to overdesign with the consequence of lower power-to-weight ratio as most of the motor power is used to lift the arms. For precision tasks, the number of sensors and a durable gearbox increase the weight and reduces the operational speed of robots. During the operation of robots, the mass distribution changes drastically and the motors enabling actuation are not optimized to ensure smooth operation over the full range of load cases and configurations. The robot's end effectors that are used to lift objects are inflexible and are not designed to hold different product shapes. However, interchangeable grippers offer a solution that increases the cost and the inconvenience of making changes between batches. Furthermore, robot manufacturers need to deliver energy-efficient automation systems with optimal performance configurations. The flexibility of the current state of robots needs to evolve to produce small batches of customized products with a high degree of precision and speed without compromising safety

- Technological innovation:
  Most robots deployed on the factory floor are unable to make decisions and cannot respond to changes in real-time. Deploying autonomous industrial robots capable of performing in unstructured and dynamic environments is still a complex research topic. Technological innovations are required on multiple fronts to realize the full potential of robots: For instance, to perform tasks autonomously and deliver control commands in no time with full compliance; for example, enable ultra-reliable, low latency robots using 5G networks, sensors, artificial intelligence and machine learning technologies

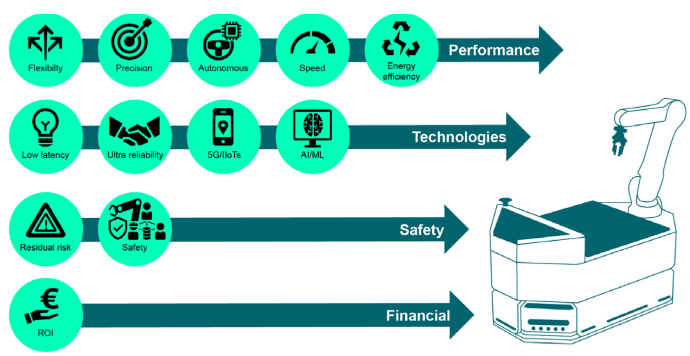

Figure 2. Major barriers to broader robotics adoption.

- Safety
  Deploying robots on the factory floor creates new safety hazards. It is critical to have extremely low or no residual risk to install robots on the factory floor outside of fences or cages. Regulations guiding the deployment of robots and humans on factory floor is often inflexible and failure to comply can cost manufacturers a fortune

- Return-on-investment:
  Although the price of robotics systems has steadily fallen in the last few decades, deploying robots in production is a capital-intensive operation and the gap between deployment cost of advanced robots and financial gain need to shrink substantially

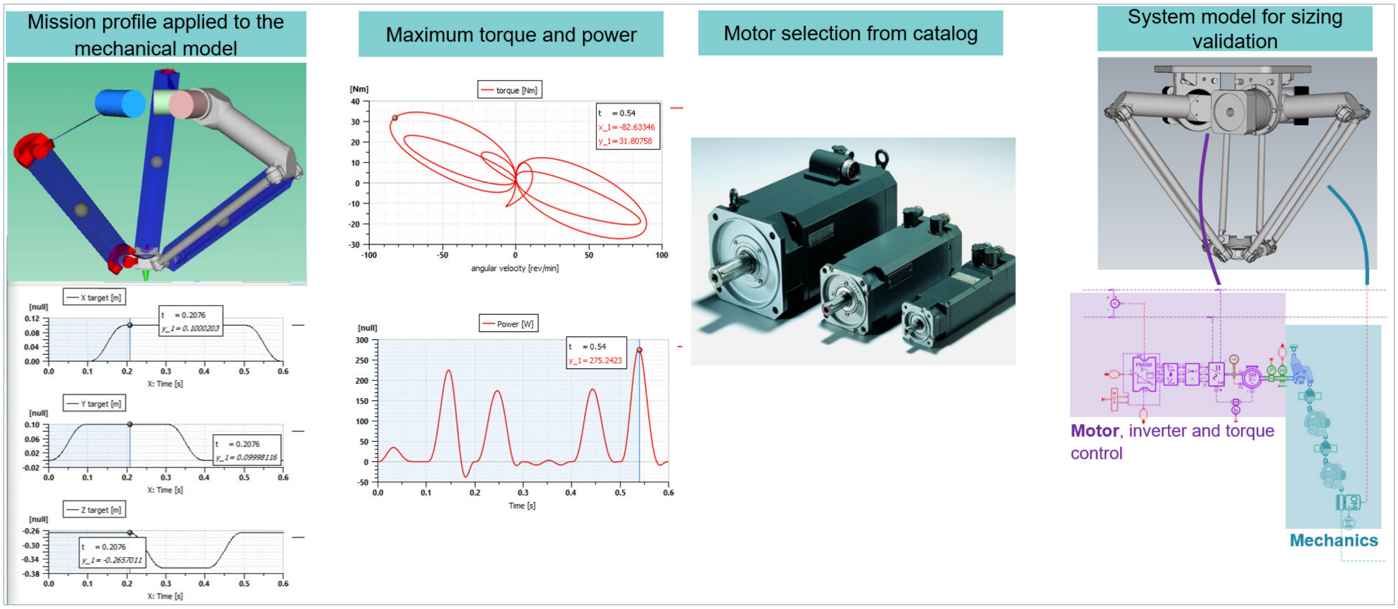

Figure 3. Using Simcenter Amesim to size a robotics actuator to meet requirements.

A holistic approach to advance robotics engineering

Robots will be part of factory automation but developing a smart, highly flexible robot and robotics system is a costly and challenging task. In this section, we will highlight some of the core areas that robotics manufacturers can accelerate with Siemens solutions.

System and actuator sizing

Industrial robotics systems are evolving from a rigid automation platform into a flexible and autonomous system. Such systems consist of sensors, actuators, electronic circuitry and a feedback loop that provides controllable motion, enabling multiple degrees-of-freedom (DOF). Engineers need to evaluate complex, nonlinear and coupled interactions of individual components and global system performance while making architecture choices and designing the above components.

Simcenter™ Amesim™ software, part of the Xcelerator™ portfolio, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, is a system simulation tool that engineers can use to predesign robotics system architecture with actuators and motion control systems, perform what-if analysis and balance system performances concurrently, taking into account the speed and torque or positional requirements. Such conceptual evaluation under multiple load scenarios helps them understand system extremities and size the robot's actuators accordingly.

Kinematics and dynamics

Robots are an articulated system and are built by kinematic linking of rigid and deformable structures involving sophisticated joints. It is critical to be able to access the robots' working envelope, load-carrying capacity and possible positions of end effectors to develop a collision-free, safe and customizable control algorithm. Using Simcenter 3D Motion software, a multi-body dynamics (MBD) solver, engineers can evaluate the swept volume of a robot and avoid collision risk in the operating environment.

Furthermore, using co-simulation features, such as the MBD model can be coupled with the actuator's multiphysics simulation model to evaluate the impact of operational loads on the torque and the speed of the actuator. Robot manufacturers can study the mechanism and dynamics of the system in a cost-efficient way, implement proper stabilization feedback loops evaluating torque, acceleration, etc., while lifting heavy objects and moving and releasing loads.

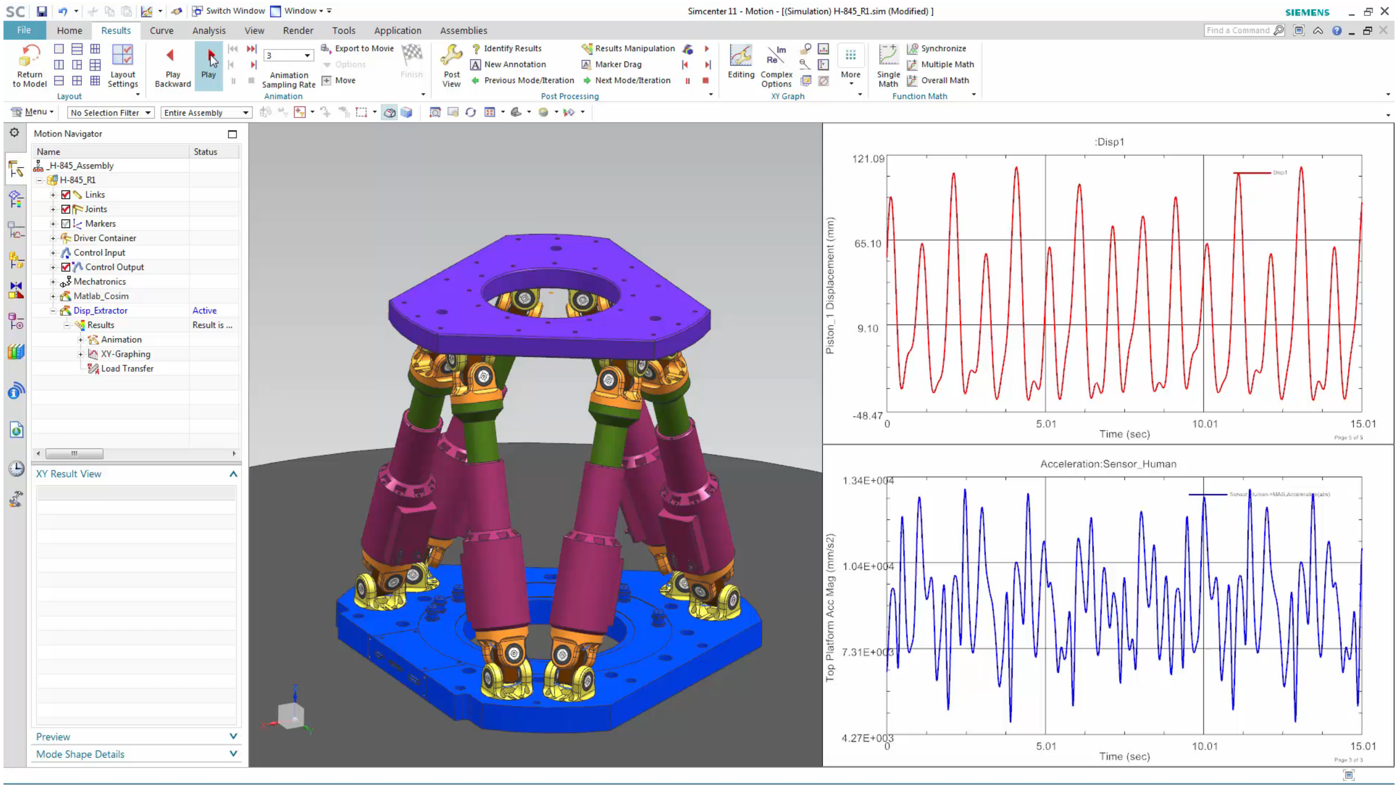

Figure 4. Using Simcenter 3D Motion to evaluate mechanism dynamics.

Motion precision, vibration and acoustics

Irrespective of the high-performing components used for robots, during assembly system integrators might encounter a situation where the end effector's position and the arms motion path curve are not within anticipated tolerance levels for given load conditions. Given the complexity of modern robotics, a simple trial-and-error approach to such problems is inefficient and might not resolve the real issue.

By adopting Simcenter smart testing solutions it is also possible to identify the component causing deviations with real-time measurements. Using a comprehensive testing approach, engineers can characterize unwanted resonances in robot arms using modal analysis, use strain gauges to measure forces and moments and study the dynamic interaction with the robot's foundation.

On an existing setup, increasing production speed is crucial to ramp up productivity with no additional investment. But the production speed and product quality are often inversely related. The Siemens' source-transfer-receiver methodology offers clear visibility of how the vibration of actuators or joints affects the movement of end effectors.

In addition to aligning with vibration requirements, robots used in hospital or laboratory environments should comply with noise requirements. Simcenter testing solutions can also be used to tackle acoustic problems. Using Simcenter Sound Camera™ system for rapid acoustic troubleshooting enables visualization in real-time of the location and frequency of the main sound sources.

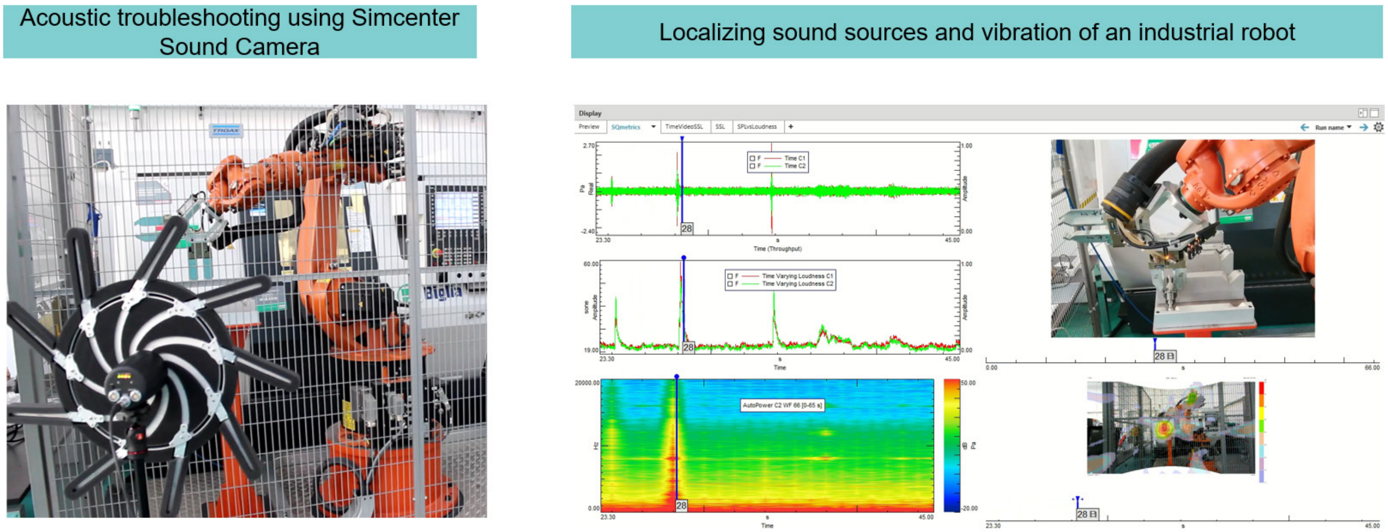

Figure 5. Using Simcenter testing solutions for rapid vibration and acoustic troubleshooting.

Reliability (thermal, structural, cable harness)
Industrial robots once deployed are expected to function seven days a week, 24 hours a day and over a couple of decades or more free from wear with minimum maintenance and zero malfunctions. The continuous operation of actuators and servomotors can increase thermal stress and failure rate. Moreover, the electric motor is prone to produce an electric arc or give off sparks, increasing the risk of fire accidents.

Using Simcenter 3D software, manufacturers can reliably predict thermal, structural and fatigue-related issues of robot arms under realistic load conditions, reducing warranty costs, improving product maintainability and retaining happy customers.

Thermal management of advanced robotics' high-power modules involving motion controllers, alternating current motor drives and switches pose significant reliability problems. Using Simcenter solutions, robotics engineers can eliminate thermal failure and improve the performance quality of power electronics devices with highly efficient and sophisticated measurement and simulation techniques. Low-frequency electromagnetic simulation helps to improve the performance of actuators that involve an electric motor.

Cables surrounding robots enable power and signal transmission. Such cables are constantly subjected to excessive force (bending, stretching and twisting) and can fail prematurely. Developing a faster and safer process for electric cables and wire harness design is crucial to avoiding breakdowns. Using Simcenter, engineers can accurately perform nonlinear simulations of cable to avoid mounting problems and reduce production costs (optimizing the number of connectors, minimizing cable length) and aftersales costs by limiting product recalls.

Moreover, the regulation requires compatibility among the plant equipment and IIoT sensors/actuators. With the Simcenter high-frequency electromagnetic simulation capability, one can efficiently simulate and address the electromagnetic compatibility and interference (EMC/EMI) issues of electrical and electronic systems.

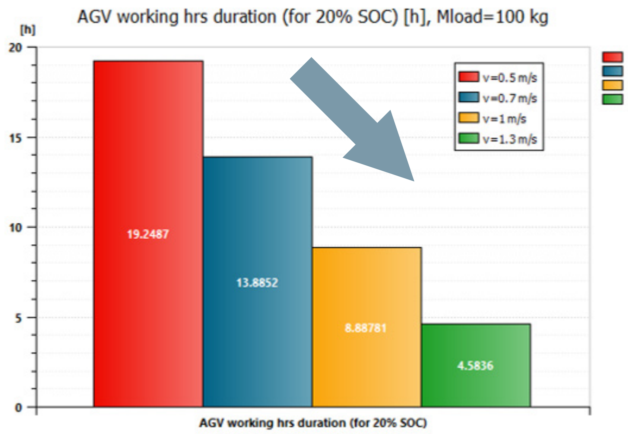

Figure 6. Simulation of mobile robots battery range with varying speed and load.

Energy and operational efficiency

Evaluating the operational performance and energy efficiency of robots before building a prototype eliminates any mismatch in performance expectations. By using simulation and testing solutions to build a realistic and comprehensive digital twin of the advanced robotics system, engineers can perform trade-off studies and evaluate performance and energy consumption for many operational scenarios.

Once robots are deployed on the factory floor, every robot's operational performance can be monitored by syncing its sensor feedback back to the digital twin model. Coupling data enhanced with analytics insights with ML/AI capabilities facilitates optimal maintenance, taking into account the physical state of robots.

Virtual commissioning

Control logic and software algorithms enable the logic, intelligence, communication and networking capabilities of industrial robots. The functioning of autonomous robots relies on the sophisticated control algorithm, sensors and human-machine interface (HMI) software codes.

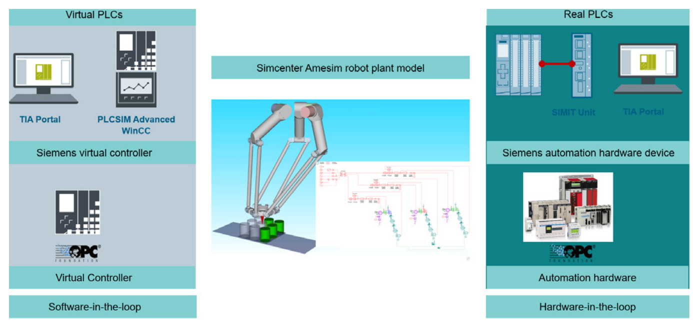

Figure 7. Virtual commissioning – controls development and validation using SiL/HiL.

Using virtual commissioning techniques, automation engineers can create a comprehensive digital twin of the robots – mimic the multiphysics system with its components and connections. Depending on the requirement and hardware availability, a real or virtual controller can be used for this purpose. The digital model linked with the controller commissions the robot virtually and helps analyze several PLC control parameters and associated component behavior (oscillations, pressure loss, temperature, cycle time, energy consumption, what-if scenarios, etc.).

Application cases

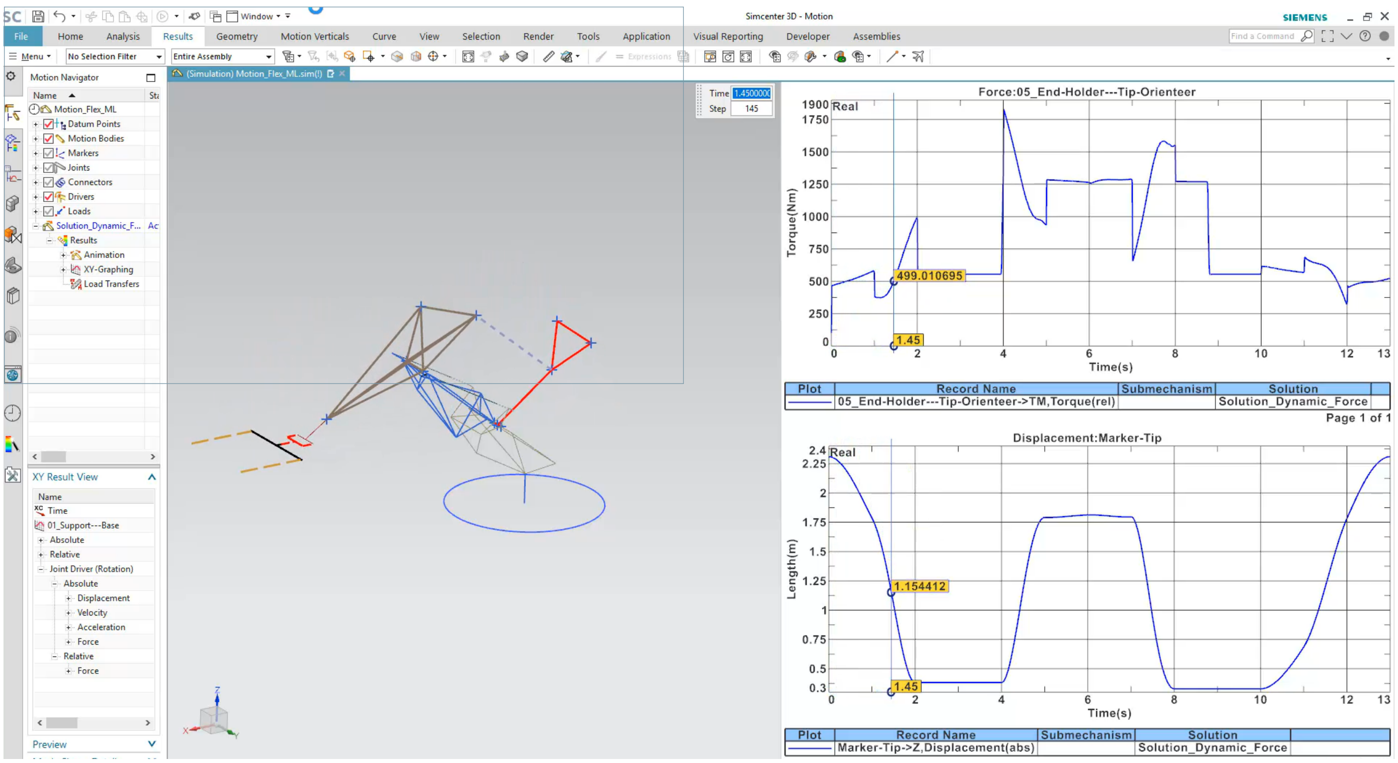

Figure 8. Pick and place robot design – sizing of mechanical components.

Ensuring durable and safe operation of high-speed pick and place robots

The design and deployment of high-speed pick-and-place robots is a capital-intensive task. Every minute saved during its operation on the factory floor directly impacts cost and return-on-investment (ROI) metrics of the factory automation systems. Ensuring high-speed operation of pick-and-place robots depends on decisions made during the design and engineering stage.

Avoiding over- or under design of structural components helps to deliver reliable robots that meet functional requirements with minimum cost. Computer-aided design (CAD), which is associative with Simcenter 3D Motion, enables the user to perform a conceptual study on the kinematics and dynamics analysis of articulated robots, accounting for inertia, joints and constraints.

Integrating multi-body analysis during the preliminary design gives valuable insights into the swept volume, collision detection, loads and forces acting on each component. Such analysis insights help to optimize the structure and save costs while ensuring durability. With an initial assessment of kinematics behavior, engineers have a clear understanding of the mechanical limitations and can sequentially improve this conceptional simulation along with the design process by developing more components until final dimensions have been determined.

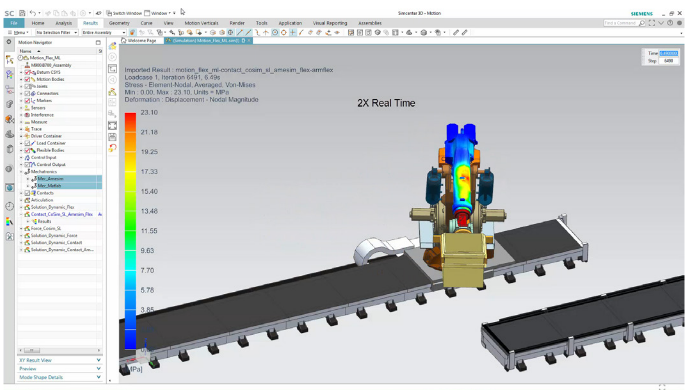

Figure 9. Prediction of dynamic deformation of robot arm during operations.

The vibrations from repetitive operation can induce component fatigue and affect the positional accuracy of the robot as well. Combining MBD with the elasticity of components (based on finite element simulations) can help to predict the dynamic deformations during operation..

The forces on the components depend on how fast the movement is performed. This is defined by the limits of the actuating system and its control logic. Analyzing the operating condition unveils the pitfalls to avoid – effect of actuator, controller and feedback loop mechanism on the dynamic amplification of structural deformation.

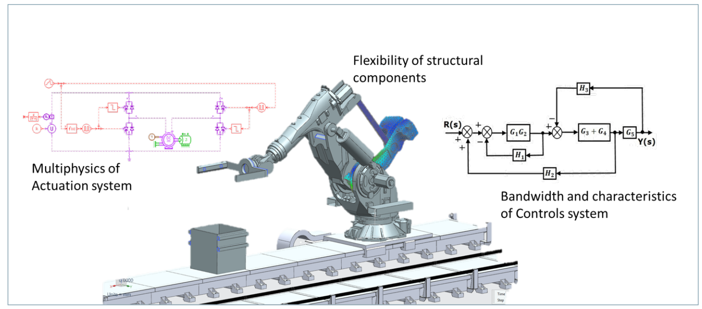

Figure 10. Closed-loop simulation of dynamics, actuation and controls.

Using co-simulation, the MBD solver can exchange information with a controlled multiphysics model of the actuation. The MDB solver gives positions and accelerations to the controller/actuation, while the multiphysics solver responds with corresponding forces acting on the mechanism. Combining kinematics, controls and dynamic flexibility in a holistic simulation exploits the system's potential limits for safely by simulating the real behavior.

Concurrent engineering and virtual commissioning of AGV systems

Automated guided vehicles are the backbone of the digital factory, optimizing the production process and maximizing flexibility. Design, development and deployment of AGVs, used in warehouse and factory environments, have to address several complex challenges :

- Mechanical requirements – The ability to charge and transport the payload accounting for dimension, mass and shape, etc.
- Electronics, integrated circuit and chip characterization – Ensure structural and thermal integrity of delicate internal parts
- Electric drivers requirements – Ensure the required torque and power demand for all working scenarios, without thermal damage
- Battery design and integration – The weight of the battery, charging time and the amount of work performed between recharge
- Controls validation – The potential to transport a charge on predefined routes, avoiding obstacles and responding to potential safety issues

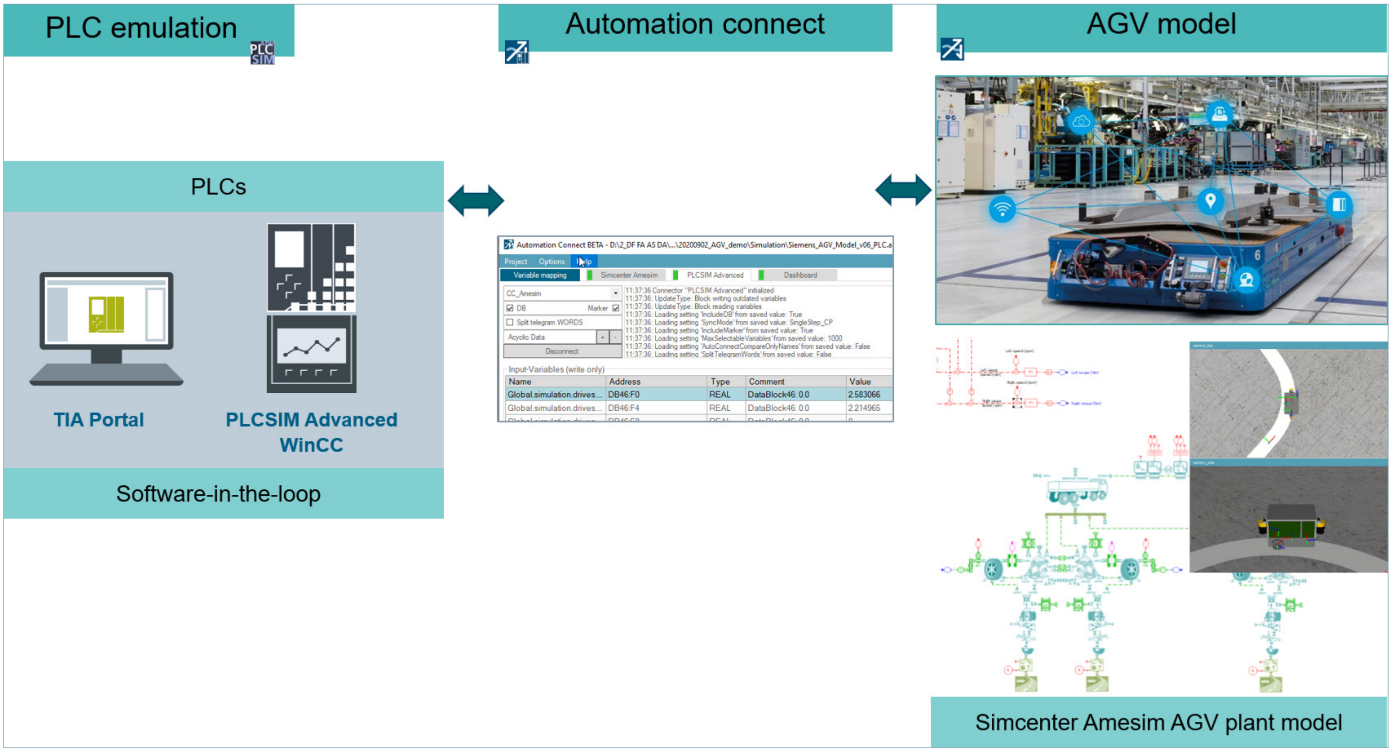

Figure 11. Virtual commissioning of AGV.

Controls validation and commissioning is a critical phase in factory automation projects. Typically, control engineers have to wait for the availability of the prototype to validate the control algorithm and fix software errors. With a shorter time-to-market and diminishing profit margins, robotics manufacturers around the world wrestle with how to best evaluate control algorithms early in the development phase and optimize multiphysics system performance before committing to a prototype.

Using Simcenter Amesim and PLCSim Advanced provides virtual commissioning capabilities that create an environment for the automation control engineers to emulate control logics, size multi-physical systems, validate their PLC ladder logic and HMI files. Virtual commissioning permits a concurrent mechanical, software, electrics and electronics (E/E) hardware design process with early digital evaluation.

To validate AGV control logic, the first step is to mimic the multiphysics system with its components and connections on a digital mockup. Next, parametrize the individual components and define the automation interface. The input/output of the virtual model has to be connected with the PLC program. Depending on the requirement and hardware availability, a real or virtual controller can be used for this purpose. The digital model linked with the controller commissions the real machine virtually and helps analyze any multiphysics and PLC control parameters of the AGV and its performance with different scenarios such as trajectory shape, vehicle loads, height, etc.

The virtual commissioning of a AGV digital mockup helps to increase the know-how in a risk-free environment. The digital model when coupled with inputs from a real sensor can be used for AGV monitoring to perform predictive maintenance tasks. The virtual commissioning technique available in Simcenter solutions permit manufacturers to roll out a concurrent mechanical, software, E/E hardware design process and replace expensive and time-consuming physical tests with early virtual evaluation.

Conclusion

Simcenter solutions provide a unique set of capabilities to size actuators, eliminate vibrations, improve the robot's precision, increase reliable operations of the robotics arm withstanding thermal and mechanical stress and perhaps most importantly, using virtual commissioning to validate control logics before prototyping. By using simulation and testing solutions, several industrially relevant results have been presented and discussed, showing how to efficiently advance robots.

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