NEXUS: A ROS 2 framework for orchestrating industrial robotic lines and cells

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Automation is changing into advanced robotics

Traditional automation (last 70 years)

- High speed (PPM) and no operator
- Predictability & reliability
- Simple logic code with low complexity (e.g. ladder code)
- Well established hardware-based solutions
- Certification & standards
- Ecosystem of key market players

Advanced robotics (last 5 years)

- Program once, repeat forever
- Adaptive perception & manipulation with ML/AI
- Coordination/cooperation, task mgmt. and autonomy

- ML/AI + complex algorithms
- Learning behaviours
- Software-based solutions
- High-level programming languages, high performance computation with GPUs
- Open-source software
- Not many standards, metrics, etc.
Challenges with traditional automation

- Market demand for customization
  Need for advanced automation for high-mix, low-volume use cases

- Lack of agility, flexibility & reusability
  Robotic applications cannot be easily modified or reconfigured

- Long development time
  Need to reduce effort and deployment costs

- Hardware dependency & lack of interoperability
  Technology transfer across geographies is challenging
  Silo solutions, require custom integration for orchestration

- Use of PLC logic
  Control logic is hardcoded in PLCs
  Supporting a “recipe” for a new product requires reprogramming the PLC

- Availability of digital twins
  No easy way to accurately simulate complex custom robotic solutions
We need an architecture for robotic platforms with...

**Seamless orchestration & control**
- At robotic workcell level
- At line level (multiple robotic workcells)

**Modularity**
- Cells can be easily added, exchanged, modified

**Flexibility & agility**
- Easy reconfiguration of process flows

**Scalability**
- Lowers the cost for robotic cell adoption, reconfiguration, upgrade, etc.
NEXUS - architecture & core principles

MES/WMS/ERP node
MES/WMS/ERP plugin

System orchestrator

Workcell orchestrator

Robot Cmd node
Motion Planner node
Perception node
Gripper node
Actuator node

Implementation of abstract interfaces registered as plugins

Level 0
Physical Process

Level 1
Intelligent Devices

Level 2
Control System

Level 3
Operations Management

Level 4
Business Planning

Plugins to interface with hardware
ROS 2 lifecycle nodes

Isolated network DDS domains
DDS over multicast

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NEXUS - architecture & core principles

- Hardware - service providers
  - Orchestrator - coordinates activities among hardware.

- **Modularity** - Behavior trees to specify workflows and trigger hardware
  - BT nodes are capabilities/skills, available at the line or workcell level.

- **Flexibility** - Hardware registration, transmits capability to the orchestrator (e.g. transport, detect, move). Task capability is inferred based on registered hardware.

- **Agility** - Hardware agnostic logic
  - ROS 2 lifecycle (stateful) nodes
  - Runtime loadable plugins for hardware nodes

- **Scalability** - Hardware interfaces are standardized
  - Minimal network traffic by selecting endpoints between workcells and line orchestrator
Intelligent recipe execution

• Recipe = one or more **process steps** in a line (different workcells)

• Recipes and process data stored in WMS/MES/ERP
  – Recipe execution dispatched (job request) to the line orchestrator
  – Enables **intuitive processes to onboard new recipes** (e.g. GUI) vs PLC programming

• Line orchestrator coordinates workcells and transporters to execute recipe (job)
  – Available workcells and transporters bid to execute a process – **self-organization**
  – Automatic queuing and buffering

• If a line and/or workcells reconfigure, the response to a recipe will be **adapted** by the line orchestrator
Behaviour Trees to specify process flows

- **Intuitive** representation of processes
- Enables **sequential and parallel** process execution
- Easy to **reconfigure**
- Applicable at line and workcell levels
- **Composable**
- Can be edited via GUI
Coordination of processes and control in workcells

- Multiple jobs can be executed concurrently – enables high-mix, low volume
- Steps between workcells are synchronized using ROS services
- Data propagates from one workcell to other workcells automatically
- Workcell orchestrators coordinate hardware from different vendors through ROS as a middleware

Job 1
{ step 1: Do process X with ZZ parameters  
  step 2: Do process Y with WW parameters 
}
Simulations to test exhaustively

- Running the orchestrators and nodes (code) with simulated hardware
- Simulation plugins can interface with Gazebo, RViz, etc. or customized hardware models
- Mixes of hardware and simulation are possible for individual component testing
Adopting NEXUS

**Workcell setup**
- Plugins for hardware components
- Algorithms with parametrization for adaptation to recipes
- Build behaviour trees for workcells - codes for each process step

**Line setup**
- Building behaviour trees for line orchestrators

**Recipe preparation**
- DB of recipes to create jobs in WMS/EMS/ERP – lists of processes, steps and parameters
Open challenges

ROS
- Lack of support for open-source **drivers** in ROS 2 (robots, sensors, industrial equipment)
- **ROS 2** capabilities and optimization are work in progress

Other
- Lack of an ecosystem of **system integrators who work with ROS.**
- **Certification** – how to?
- Adoption of new tools & algorithms – frequent **upgrades** might be required
- Cybersecurity – **authentication and data encryption**
Thank you

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