Robotics

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Factory Automation (FA) for Mass Production

Evolution of Manufacturing

- Craftsmanship
- Division of Labor (Team)
- Mass production
  - Assembly Line Work (Workers)
  - Automated Factory Line (Conveyors, Pneumatics, Feeders, Handling Systems)
- Customized Mass Production

Mainly repetitive work, no special skills required ➔ Not Smart!
Customized Mass Production

• Customized Products (e.g. car configuration)
• Small Production Lots
• Space and Production Costs
• Frequent Product Changes (Product Life Time, Time To Market)

Highly flexible systems that can adapt to changes quickly ➔ Smart Machines!
Smart Machines: 'Flexible Manufacturing'

- Assembly machines need to be able to produce different objects / products
- Flexible automated assembly
- Flexible and reconfigurable ‘mechanics’ for handling and assembly
- Highly modular
- In-Process quality control

Smart Machines are flexible, re-configurable, easy-to-use ➔ Robotics!
Flexibility Through Robots

Pros:
- High Accuracy, Speed and Flexibility (Programmable)
- Applicable to virtually any application area

Cons:
- Lack of High Level Programming Environments
- Blind, Lack of Sensitivity

Flexibility is limited through missing perception → Sensors & Vision!
Smart Machines: Sensors

- Robots need to adapt to changes in their environment (dynamic, flexible) – Again!
  → Robots need to feel!

- Measurements
- Tactile Tests
- Limiting force
- Adaptive Motion
- Preventing Damages
- Safety

Sensors increase flexibility, quality, productivity resulting in better products at reduced costs
Smart Machines: Feeders

• Conventional bowl-feeders: Lack of flexibility!
• Flex feeders: Flexibility through vision and robotics
• Controllable through LabVIEW
• In-Process Quality Control
Robot System: Mechatronics System

- Robot + Gripper, Sensor, Pneumatics
- Conveyors
- Programmable Automation Controller
- Vision
- Feeders
- Safety
Smart Machines: Mechatronics Systems

3 Disciplines:
- Mechanical Engineering
- Electrical Engineering
- Software Engineering

→ Software is the glue between automation components

Making the transition from pure mechanical systems to Software Controlled Smart Machines
Challenges for Software Engineering

Glue between FA components

- Proprietary Languages
- Proprietary Protocols
- Proprietary Development Environments
- Proprietary OS
- Scalability
NI LabVIEW

Highly Productive Graphical Development Environment

- Hardware and Communications APIs
- Built-in Libraries
- Custom User Interfaces
- Deployment Targets
- Technology Abstractions
- Programming Approaches
Smart FA Systems with Graphical System Design

LabVIEW as one tool for entire application
• Various Interfaces to FA Components
• Integrating Test & Measurement
• Machine Vision and Sensors
• ImagingLab Robotics
Control

- Increase uptime
- Reduce spare parts and repair time
- Lengthen maintenance cycle
- Stop unscheduled outages
- Prevent catastrophic failure
- Avoid injury and environmental harm
- Optimize machine performance
- Reduce scrap and raw material use
- Increase product quality
- Increase customer confidence
- Increase production output
Advanced Machine Control

- What really makes a machine smart is the ability to tightly integrate multiple specialized subsystems to meet machine requirements.

Motion Control Integration
- High frequency measurements
- Signal processing and filtering
- High speed timing and triggering
- Custom or model based control
- Multi-axis coordinated moves

Motion Control Diagram:
- Controller
  - Motion
  - DAQ
  - Vision
  - HMI
  - ...
Traditional Motion System Architectures

- User Program
- Supervisory Control
- Trajectory Generator
- Interpolation
- Position Loop
- Velocity Loop
- Torque Loop
- Motion I/O

PC
- Plug-In Motion Controller

PLC or PAC
- Smart Drive

PC
- Integrated Motion System

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Fully Reconfigurable Motion Architecture

Motion

- User Program
- Supervisory Control
- Trajectory Generator
- Interpolation
- Position Loop 1-100 kHz
- Velocity Loop 4-100 kHz
- Torque Loop 20-100 kHz
- Motion I/O

PC

Real-Time Controller

User Programmable FPGA

Motion Drive

Other Machine Subsystems and Capabilities

- HMI
- Machine Vision
- Data Acquisition
- Process Control
- Control Design and Simulation
- Filtering and Signal Processing
LabVIEW NI SoftMotion

Fully customizable motion control

- APIs
- Configuration
- Low-level IP

- Embedded Drives
- Drive Interface
- External Drives & Motors
Control Design and Simulation

- LabVIEW Control Design and Simulation Module
- System Identification TK
- PID and Fuzzy Logic Control TK
- Simulation Interface TK
NI Motion Control

- Drive interface modules for stepper and servo motors
- Drive modules for brushed and brushless servo motors as well as stepper motors
- EtherCAT drive support for a wide range of motors
- Easy software development with LabVIEW NI SoftMotion
Vision

• Increase uptime
• Reduce spare parts and repair time
• Lengthen maintenance cycle
• Stop unscheduled outages
• Prevent catastrophic failure
• Avoid injury and environmental harm
• Optimize machine performance
• Reduce scrap and raw material use
• Increase product quality
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• Increase production output
Smart Machines: Machine Vision

- Robots need to adapt to changes in their environment (dynamic, flexible) → Robots need to see!

- In-process vs. end-of-line quality control

Vision increases flexibility, quality, productivity resulting in better products at reduced costs
Advantages of Vision Guided Motion

- Eliminates fixtures and positioning equipment
- Increases adaptability to new products and tasks
- Improves accuracy of a placement task
Vision Guided Motion

- Trajectory Generator
- Control Loop
- Actuator
- Coordinate Transform
- Image Processing
- Camera

Part's Position or Part's Position Error or Trajectory Guidance

Position Setpoint

Position Feedback
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Distributed Processing

NI Vision Development Module

NI Vision Builder AI

Smart Camera

LabVIEW NI SoftMotion

Value or Ultra Rugged NI CompactRIO

Motors and Drives
2D vs. 3D

Shape deformities

2D

3D
Many ways to do 3D vision

- Stereo vision
- Laser triangulation
- Time of flight sensors
- Projected light
- LIDAR
- MRI & CT
Laser Triangulation

Uses a linear laser and a camera at a known offset to produce a 2-D profile, and moves over the object, constructing a 3D profile from acquired profile slices.

- Well-established technology
- High resolution
- Normally attached with motion

![Diagram of Laser Triangulation](image)
Stereovision

Using two cameras that are offset from one another to calculate the distance of specific points or objects (much like mammalian sight).
3D Applications & Recommended Techniques

• Vision-guided industrial automation
  • Location detection
  • Presence detection
  • Robotic bin-picking
  • Robotic depalletization

• Vision-guided autonomous robotics
  • Object detection
  • Object location
  • Path planning

• 3D-based quality control
  • Metrology
  • Volumetric calculations
  • Comparison to CAD
  • Detection of defects (burrs, bumps, etc.)

• Precision 3D scanning
  • Reverse engineering
  • Medical
  • Industrial
Tools for 3D Vision in LabVIEW

AQSense SAL3D Library for LabVIEW (Ported by ImagingLab)

- NI LabVIEW porting of the 3D machine vision library **SAL3D**
- Compatible with all types of image acquisition, including stereovision functions in Vision Development Module stereovision and laser triangulation with SICK IVP Ranger Toolkit
- Tools to obtain complete, true, 3D calibrated data for ultra-fast shape analysis and measurements for in-line inspection and precision scanning
- Comparing dimensions of acquired objects to CAD data
- 2D surface extraction for further 2D analysis using NI Vision Development Module
Common Architectures

Distributed Processing

Centralized Processing
NI 177x Smart Camera

Software and OS
• Real-time operating system
• Includes Vision Builder AI

Internal Features
• Intel Atom processor
• 2 GB flash
• 512 MB DDR2 RAM

M12 to Power and I/O
• Isolated digital I/O (4 inputs, 4 outputs)
• Dedicated trigger
• RS232 serial
• Lighting control (direct-drive lighting)

Lens cover for added reliability and IP67

Industry-standard mounting holes for lighting and camera

M12 to Gigabit Ethernet for enterprise connectivity and Modbus, EtherNet/IP, TCP/P

M12 to USB/VGA
• USB external storage
• VGA video out
Machine Monitoring

- Increase uptime
- Reduce spare parts and repair time
- Lengthen maintenance cycle
- Stop unscheduled outages
- Prevent catastrophic failure
- Avoid injury and environmental harm
- Optimize machine performance
- Reduce scrap and raw material use
- Increase product quality
- Increase customer confidence
- Increase production output
Sources of Failure

- Compliance issues due to reduced stiffness of belt
- Higher energy consumption and heat generation due to wear and tear of gears
- Coupling failure due to fatigue loads
- Inaccuracy due to wear and tear of the lead screw
- Failure to pick up parts due to leakage in pneumatic system
- System runs into EOT due to broken cable of limit switch
- Too much friction because of missing lubrication
- Failure to pick up parts reliably due to dimensional variations in UUTs
- Vibrations due to loose screws and fixtures
## Solution Strategies

<table>
<thead>
<tr>
<th>Solution</th>
<th>Downside</th>
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</thead>
<tbody>
<tr>
<td>Use a Mechanically Stiff Design</td>
<td>Heavy and Expensive</td>
</tr>
<tr>
<td>Over-Engineer Critical Components</td>
<td>Low Efficiency and High Cost</td>
</tr>
<tr>
<td>Use “Maintenance Free” Parts</td>
<td>High Upfront Cost</td>
</tr>
<tr>
<td>Perform Scheduled Maintenance</td>
<td>Less Uptime and Output</td>
</tr>
<tr>
<td>Use Parts With a Long Lifetime</td>
<td>High Upfront Cost</td>
</tr>
<tr>
<td>Replace Parts Early</td>
<td>Expensive, Less Uptime and Output</td>
</tr>
<tr>
<td>Uphold Tight Specifications on Raw Material</td>
<td>Expensive COGS, Quality Control</td>
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<tr>
<td>Limit the Machine Operation Speed</td>
<td>Reduced Throughput</td>
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Add Machine Monitoring
Monitoring System Components

**Input Signals**
- Sensors
  - Automation Components

**Data Acquisition**
- Signal Conditioning
  - A/D
  - D/A
  - DIO
  - TIO

**Analysis**
- Industrial Communication
Sensor Considerations

- Accelerometers
  - IEPE excitation
  - Filtering
  - Simultaneous sampling

- Displacement Probes
  - Probe driver
  - Filtering
  - Voltage range (-30 V to 0 V)

- Tachometers (High Speed)

- Temperature Sensors
  - Amplification
  - Cold-junction compensation
  - Filtering

- Oil Particulate Sensors
  - Voltage, current, or serial communication
What is a Smart Machine

Autonomous Operation
- Modular manufacturing equipment with intelligent controls
- Awareness of environment

Avoid and correct processing errors
- Self-analysis and self-repairing capabilities
- On-the-fly modification of process plans

Learn and Anticipate
- Model-based control, Adaptive control
- Simulation

Interaction with other Machines and Systems
- Interconnected Systems – Smart Factory
- Commonly shared data structures