Advanced Robot Manufacturing
Driving Growth through Increased Production Flexibility

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Explosive Robot Growth through 2025

- 11% CAGR unit growth through 2025


- Cost reductions:
  - Robot HW / SW, perception
  - System engineering
  - Safety systems
Potential for Automation

Growth is Top Priority for Industry

• OEM’s, Tier 1 suppliers, SME’s all see growth as priority
• Increased flexibility: increase capacity for new customers and products
• Major positive economic impact through the entire supply chain
Will Robots Provide Sufficient Flexibility?

How to produce higher product mix demanded by customers?

How to delivery when they want it (and return it too)?
Advanced Robot Manufacturing Priorities

• Increase production rates 30% to 50%
• Mass manufacturing -> mass customization
• Multiple manufacturing processes
• Reduce cost of integration
• Humans and co-robots working in limited floor space
Potential for 30% to 50% Gains

- Consumer goods (in production)
- Automated DC (in production)
- Aerospace (opportunity)
High Impact Emerging Technologies

Topics for today:
• Autonomous mobility
• Fixtureless manufacturing
• Collaborative robots
• Virtual product / process development
Flexible Consumer Goods Production

- New material flow, food processes, controls, robotics
- All products, flavors, sizes on each line
- 50% improvement in asset utilization
- Sales growth through increased product mix
Why Are Mobile Robots Disruptive?

• New levels of performance
  • Transactions per hour
  • Sequencing
  • Storage density

• Easy to re-configure
  • Change in SKU mix or velocity
  • Change in business model

• New algorithm challenges
  • Replace fixed hardware with flexible software
  • Leverage research on autonomous mobile robots
Sequencing with Autonomous Robots

Output sequence 1
5 4 3 2 1

Output sequence 2
5 4 3 2 1

Input sequence 1
1 2 3 4 5

Production order: 395 SKU, 476 cases

Aisle number

1 2 3 4 5 6 7 8
Fully Automated Distribution Centers

- DC’s for retail, grocery, food service, beverage
- 40% gain in storage density, sequenced output for mixed palletizing
- Reduce need for capital expansion, largely pays for automation
- Locate closer to urban centers for same day delivery
- Five to ten leading integrators moving to mobile robot technology
Aerospace Fixed Assets

Composites

Assembly

Increase asset utilization
• More units / month
• Lower fixed costs / unit
• Lower changeover costs

Inspection

Drilling

Painting
Flexibility Options

Collaborative robots  Industrial robots  Mobile robots

Flexible fixtures  No fixtures
Assembly with Shims and Positioners

Composite structure

Aircraft assembly shims

Adjustable assembly positioners

Sources: Aviation Week, April 17, 2015; Duqueine Group, Airbus A350; Assembly Magazine, October 3, 2014..
3D Surface Scanning of Workpiece

- Measurements of mating surfaces
  - Laser tracking
  - Laser scanning
  - Photogrammetry
- Machine excess material to net shape

Fixtureless Aerospace Manufacturing

Technical challenges

- Robot absolute position accuracy
- Robot compliance subject to machining forces
- Resonance excitation during machining
- Variable depth of cut due to workpiece tolerances

Future vision
Flexible Robotic Machining Technology Roadmap

Metrology
- Workpiece and feature location in world, robot coordinates
- 3D surface scanning
- Secondary encoders

Robot compliance
- Robot, workpiece, fixture compliance models
- Redundancy resolution to maximize stiffness
- Real-time robot control

Process knowledge
- Wireless sensing for in-situ process monitoring
- Process modeling
- Sensor and process model integration into robot control
Metrology and Enhanced Accuracy

Electroimpact™ contributions:
• Role of laser tracking of EOAT for absolute accuracy
• Detailed kinematic and stiffness models
• Secondary encoders
• Demonstration of accurate drilling under +/- 0.125 mm

Compliance Optimization

- Detailed measurements of joint and link static stiffness
- Redundancy resolution exploits extra degrees-of-freedom to find optimal stiffness
- Optimization should be task specific, along vector of machining forces

Source: T. Cvitanic, V. Nguyen, L. Sweet, Collaborative and Advanced Robotic Manufacturing Lab, Georgia Tech
Stiffness Optimization for Milling

Fraunhofer Institute (IPA), TU Stuttgart contributions:

- Non-linear joint compliance experiments
- Redundancy resolution for optimal stiffness
- Open loop machining yields significant tolerance variation

Machining Process Sensor Feedback

- Low cost, thin film PVDF wireless sensing for in-situ process monitoring of cutting forces up to 10 MHz
- Machining process modeling
- Sensor and process model integration into robot control yields > 70% error reduction

Dynamics and Chatter Control

Georgia Tech contributions:

- Congruent Convergent Transformation (CCT) based mode coupling chatter avoidance
- Expands range of permissible tool feed orientation or workpiece orientation


Robot mounted milling tool

Chatter avoidance demonstration
Roadmap to Accurate Machining

- Tool force sensing
- Secondary encoders
- Laser tracking
- Process models
- Redundancy resolution
- Kinematic and compliance models
- 3D surface scanning
- Chatter avoidance
- Closed loop control
Future of Collaborative Manufacturing

Aerospace industry example
Standards for Safe Human Interaction

- ISO/TS 15066 Technical Specification
  - Safety-rated monitored stop
  - Hand guiding
  - Speed and separation monitoring
  - Power and force limiting
- Still requires full risk assessment
  - Includes all equipment and processes in cell
  - following industry best practices (FMECA)

Power and force limiting approaches
- Current / encoder based torque estimates (Universal)
- Series elastic actuators (ReThink)
- Pressure sensitive skin (Kuka)
- Load cell in base (Fanuc)
Collaborative Operations

- Collaborative operations
  - Robot and human perform tasks simultaneously during task execution
- Sequential process flow
  - Most common implementation today
  - Human and CoBot have separate tasks
  - Buffers in between to prevent starving / blocking
- Task sharing
  - Human and CoBot work at team
  - Requires higher level of coordination, communication, flexibility
Extending CoBot Perception to 3D

2D vision pick limited to parts on flat surface

Part flat on table

Part tilted

3D vision tracking on flexible conveyor
3D Vision Tracking for Moving Targets

Collaborative Robots for Automotive Assembly Lines
3D Vision Tracking using Low Cost 2D Camera with GPU Accelerator
Robot Operating System (ROS) Enabled Integration

Collaborative and Advanced Robotic Manufacturing Lab (Georgia Tech)

- Universal Robot
- Kuka KR 500
- ReThink Robot
- Kuka KR 210 (3)

- Laser tracker / scanner
- Tool force sensor
- Milling head
- 3D vision tracker

Liquid cooled GPU-based controller
Hardware Robot Operating System (H-ROS)

Multi-Level Human Collaboration

Planning and control levels

Task level
- Planning, scheduling, flow
- Re-planning

Control level
- Robot path / process planning
- Mobile robot route planning
- Adaptive control

Machine level
- Machines, processes, fixtures
- Machine, process, perception

Human interaction
Contact

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