How To Create The Right Collaborative System For Your Application

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Definitions

• **Cobot**: for this presentation a robot specifically designed for people in a shared work space. i.e. KUKA iiwa, Rethink Baxter, ABB Yumi, Gomtec Roberta, etc.

• **Collaboration**: determined by application and workspace, NOT the robot itself
Benefits of Human-Robot Collaboration (HRC)

• Robot strength: Repetition of simple handling tasks and precision
• Human strength: Unique cognitive skills, i.e. understanding task.
• Rationalize tasks by combining strengths and dividing the work optimally between robot and human.
• Human-robot collaboration enables variable automation.
• Tasks for which complete automation is too expensive or too complex can thus be partially rationalized.
• Non-ergonomic workstations can be improved by robots.
Forms of Human Robot Collaboration

- **No fixed guard, virtual safety fence**
  - Contact not desired, unlikely (e.g., photo-electric barrier)

- **Fixed safety fence**
  - Contact not possible

- **Shared workspace**
  - Contact not desired, but possible

- **Shared workspace, but exclusive motion**
  - Contact possible, but only with stationary robot (e.g., in the case of industrial robot as handling assistant)

- **Shared workspace**
  - Contact desired, simultaneous motion (e.g., manual guidance)

- **Shared workspace**
  - Contact not desired, but possible

*Increase in Human-Robot Collaboration*
Forms of Human Robot Collaboration

Focus has been on fully collaborative applications

We will discuss options throughout the collaborative spectrum
Forms of Human Robot Collaboration

We’ll cover options throughout the collaborative spectrum
Human Robot Collaboration

Types of collaboration we can use:

• Safety rated, monitored stop
• Hand guiding
• Speed and separation monitoring
• Power and force limiting
Starting Point

• Good news!

• The basic cell development process hasn’t changed in this era of collaborative robots.

• Presentation will focus on the additional considerations.
Creating a Robotic System

1. Understand process goals
2. Create specification
3. Evaluate technologies
4. Design System
5. Optimize solution
1- Understand Process Goals
Process Goals

• S.M.A.R.T.
• Specific
• Measurable
• Achievable
• Realistic
• Timely
Is Collaboration in the Plan?

• Has the end user created Specific collaboration goals? If not, why?
• What does collaboration add to the process?
• What is the highest level of collaboration? Safety systems must address highest level of collaboration.
Is Collaboration in the Plan?

- **All** points of human robot interaction identified for each step? *(Measurable)*
- Are they really required? Or just desired?
2- Create Specification
Define Cell Conditions

- Inputs/outputs (physical & electronic)
- Power available
- Cell access/repair strategies
- Noise
- Visibility
- Area restrictions (Includes non-process related items in the workspace)
- Environmental
- Budget
- Additional??
How Conditions Impact Collaboration?

- **Cell Access** – access needs to be safe DURING MOTION, not only for repairs when robot typically off
- **Noise** - noisy environments mean people can’t hear the robot moving & may have to wear ear protection
- **Visibility** – mists/dust/smoke can impair people’s ability to see robot motion in the workspace
How Conditions Impact Collaboration?

- **Area restrictions** (Includes non-process related items in the workspace) – anything in the workspace between the human and robot has to be considered a crush/pinch hazard. Cables/items on the floor are trip hazards.

- **Environmental** (High humidity, high voltage, etc) – slip hazard, shock hazard
How Conditions Impact Collaboration?

• **Budget** – Collaborative cells may have lower or higher costs depending on the level of collaboration desired.
  – Simple cobots: lower cost, may not require guarding.
  – Advanced cobots: more expensive, add’l features.
  – Standard robots: add’l safety hardware required

• **Additional??**
  – Example: are there moving parts around the robot where injury could occur
Basics of Robot Selection

• Reach
• Payload
• Cycle time
• Tool Requirement
Basics of Robot Selection

• **Reach**

• Performance impact: allows handling of larger parts, greater working range.

• Safety Impact: Longer arm means more momentum at tool tip. Risk assessment will need to include the weight of the arm (excluding Axis 1).

• Typical Cobot reach limited to approx 1.1m
Basics of Robot Selection

• **Payload**

• **Performance Impact:** High payload robots offer add’l tooling flexibility, future expansion

• **Safety Impact:** Moving high payloads creates a lot of inertia, very difficult to separate inertia from external forces

• **Typical Cobot payload 14kg or less**
Basics of Robot Selection

- **Cycle time**

  - Performance Impact: Low cycle time = high production throughput
  
  - Safety Impact: Low cycle time = high speed motion. Collaborative speeds limited by TS:15066
Basics of Robot Selection

• Tool Requirements

• Safety Impact:
  – No pinch points
  – No sharp edges
  – Rounded corners
  – No hot spots

• Performance Impact: Tooling can end up heavier/slower & more expensive due to covers and add’l safety equipment.
3- Evaluate Technologies
How to Find the Right Collaborative Robot

- Start with Payload, Speed & Reach (as always)

- Do you require higher payloads?
- Do you require higher speeds?
- Do you require higher/variable arm stiffness?
- Do you require force sensing along the arm? At the flange?
- Do you require virtual walls?
- Do you require advanced software programming?
- Do you require user activation buttons on the robot/flange?
- Do you require extra power & i/o at the robot flange?

Yes = higher cost
Cobot vs. Robot

- Two different products with separate feature sets.
- Cobot has integrated safety, but speed payload may be very limited.
- Standard Robot handles high payload and/or high speed applications with restricted collaboration. Longer lifecycle. Add’l safety hardware is required.
Collaborative Robot Segmentation

- High level force control arms
- Lightweight construction
- Heavier payloads
- Industrial speeds when workspace is free
- Risk managed via force control and Advanced software features

Two main "collaborative" markets

- Low cost, smaller arms
- Lightweight construction
- Reduced risk of injury due to low payload and limited speeds
Safety Implementation - PLd, Cat. 3

**Standards**
- Category 3 means a cross monitoring, dual-channel system.
- The performance level determines the required failure probability / reliability.

**Redundant Sensors**
- For Position & Torque

**Safe Communication**
- Using Failsafe over EtherCAT(FSoE)

**Redundant Processing**
- Two independent cores
- Different compilers

**Safe Reaction**
- E-Stop
- Safe Signal
KUKA iiwa Robot

- 7 Axis
- 7kg & 14kg Payload
- Senses Force on DRIVEN side of the motor
- Meets ISO 10218-1 & ISO 10218-2
- Redundant force & position sensors, software
- Independent Safety software layer
- Advanced software options
- JAVA API
- Medical version soon to be released!
Vision

• Pro: Great as a redundant level of safety for robot position and speed
• Con: People are unpredictable and can regularly block line of sight
• Consider not just the body, but hands around the tooling
Area Scanners

• **Pro:** Allow easy detection of people in working range so robot can move faster when not in collaborative mode.

• **Con:** Entire working range of robot must be monitored. Can shut down a lot of floor space when people in working range (whether or not collaboration is intended).
Evaluate Collaboration

• Given the Cell Restrictions, Robot Requirements (Payload, Reach, Cycle Time, Tooling), Available Technologies, etc. is collaboration achievable safely?
4- Design System
System Design

• Standard design practices still apply.
• Need add’l safety based on level of expected collaboration.
• RISK ASSESSMENT is more important than ever. Risk of injury must be fully evaluated during all collaboration.
• Follow the standards for collaboration
Standards

Standards harmonized with the Machinery Directive: safety standards

Describes hazards arising from industrial robots:
- Electrical hazards
- Mechanical hazards
- ...

Prescribes measures for design engineering,
- Stability, strength, energy sources, ...

Safety equipment,
- Safe control functions (E-STOP, enabling, etc.) in PL d Cat. 3, covers ...

and user documentation.

Presumption of conformity with the Machinery Directive

Specific

C standards

B standards

A standards

General

e.g. ISO 10218
Safety requirements for industrial robots

e.g. ISO 13849
Safety of machinery – Safety-related parts of control systems

ISO 12100
Safety of machinery – Basic concepts, general principles of design
ISO 13849-1: Performance Level

- Risk parameters
  - S Severity of injury
    - S1 - Light (usually reversible)
    - S2 - Severe (usually irreversible/death)
  - F Frequency and/or duration of exposure to hazard
    - F1 - Rare to infrequent and/or short duration of exposure
    - F2 - Frequent to continuous and/or long duration of exposure
  - P Possibility of avoiding the hazard or limiting the damage
    - P1 - Possible under certain conditions
    - P2 - Scarcely possible

Industrial robots:
S2 – F2 – P1 = Performance Level d

PL d
Probability of failure:
Standards – ISO 10218 (2011)

• Performance requirements
  – “Safety-related parts of control systems must be designed to meet the requirements of PL “d” with structure category 3 as described in ISO 13849-1:2006”

Architectures

Category B and Category 1

Sensor → Logic → Actuator

Category 2

Sensor → Logic → Actuator
  Test unit → Shutdown method

Category 3 and Category 4

Sensor → Logic → Actuator

“Dual-channel”
Excerpt From Force Limitation Standard

ISO 10218-1:2011 (Part 1: for the robot)

– 5.10 Collaborative operation requirements

– 5.10.5 Power and force limiting by inherent design or control

“The power or force limiting function of the robot shall be in compliance with 5.4. If any parameter limit is exceeded, a protective stop shall be issued.”

– 5.4 Safety-related control system performance (hardware/software)

– 5.4.2 Performance requirement

“Safety-related parts of control systems shall be designed so that they comply with PL=d with structure category 3 as described in ISO 13849-1:2006, or so that they comply with SIL 2 with a hardware fault tolerance of 1 with a proof test interval of not less than 20 years, as described in IEC 62061:2005.”
5.11.5 Operation in the collaborative workspace

5.11.5.5 Power and force limiting by design or control

“Robot systems designed to control hazards by power or force limiting shall use robots which comply with ISO 10218-1.

Parameters of power, force, and ergonomics shall be determined by risk assessment.”

ISO 10218-2:2011 (Part 2: Robot systems and integration)
Design Considerations

• Standard EN ISO 10218-1:2011 states that the robot is only a component in a robot system and that it is in itself insufficient for safe collaborative operation.

• The application involving collaborative operation must be investigated as a whole and analyzed in a risk assessment.

• Additional information can be found in ISO/TS 15066.
  – Weaker than a standard, but might become a standard in the future

• Conclusion:
  – Human-robot collaboration not possible without a risk assessment.
  – Consider overall cell, not just the robot (application, clamps, gripper system, robot).
5- Optimize Solution
Optimize Solution

• Cost Reduction:
  – Possible to remove fencing/guarding?
  – Can cobot ‘touch’ features allow for removal of vision?
  – Can I reduce floor space requirements using cobot safety features?
Optimize Solution

• Improve Effectiveness
  – Can I monitor presence of people and increase throughput when nobody in working range?
  – Can collaboration be managed in length of time or function, to minimize time when robot speed limited?
  – Can a cobot be used without any special safety equipment?
  – Does the collaboration make the overall process more effective?
Collaborative Examples
Medical Collaborative Application
Medical Collaborative Application
Medical Collaborative Application
Industrial Collaborative Application
Examples of Two Approaches to Machine Tending
Scanner Makes Machine Tending Collaborative

Advantages -
• Higher Payload Capacities
• Faster Robot Motion, Results in Higher Machine Spindle Utilization
• Shorter Door Open/Close Time

Disadvantages -
• Large Scan Area Can Result in Robot Slowing Down Due to Scan Area Personnel Intrusion
Collaborative Robot Alternative For Machine Tending

Advantages -
• Can Be Flexible/Portable To Move From Machine To Machine
• Could Be A More Effective Way To Address Wide Part Variety

Disadvantages -
• Lower Machine Utilization
• Still Need To Address Controls Integration To Machine For End Of Cycle, Chuck Open/Close
Next Level Collaboration
New Technologies = Market Evolution

Innovation hubs

Industrial robotics
- PC
- Off-line programming

Compliant, safe robotics
- Mechatronics
- Safety
- Simple programming & operation

Mobile manipulators
3rd Robotic revolution
- Combined mobility & manipulation
- Intelligence
- Intuitive operation

2nd Robotic revolution

1st Robotic revolution

1st Robotic revolution
- PC
- Off-line programming

2nd Robotic revolution
- Mechatronics
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Mobile Robotics

- Logistics / Laboratory automation
- Pick and place
- Fetch and carry
- Handling tasks
- Inspection / surveillance
- Mobile assembly
- R&D platform
Mobile Collaboration

- transportable
- no fences
- can be docked to different working places
- specific trolleys for workpiece storage
- integrated vision
- flexible gripper(s)
Closing Remarks
Closing Remarks

• It’s not magic, experience will be the best teacher.

• Use the standards!

• When in doubt, check with an expert.
KUKA is Hiring

• Sales

• Engineering

• Customer Service

• Let me know if you are interested!
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