Modularity in industrial automation - How modules are used at industrial Human Robot Collaboration Applications

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***Abstract*— In this paper the author shows how modules are used to realize Human Robot Collaboration Applications using TS15066. Here modules play an important role. This is why the work of ISO/TC299/WG6 on modularity is supporting not only service robot applications in the public domain but also industrial robot applications where the robot services workers in their work stations.**

I. INTRODUCTION

ISO/TC299/WG6s work on the document: ”Modularity for service robots – General requirements” comes in a time where the request for easy to combine modules has become an industry requirement not only at robots but also for all Industrie 4.0 scenarios. The internet of things also requires the agile re-configurability of production lines in order to meet the customers demands on customized products. This request for “lot size one” brings a challenge to conventional manufacturing paradigms, where economy of scale played an important role. The challenge today is to manufacture individual products as efficient as mass products. Here modularity is of the essence! Modularity promises ease of re-configuration and agile response to changing customer demands.

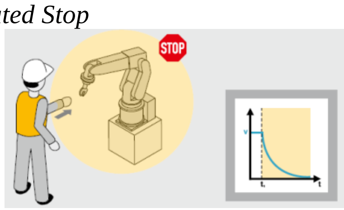
In industry safety for man and machine is of the essence. This is why ISO10218-1 gives guidance to the robot manufacturer on the safety functions a robot. ISO10218-2 gives guidance for the integrator when putting a robot system together. Up until the publication of ISO/TS15066 there was no guidance on how safe Human Robot Collaboration (HRC) can be achieved. In the following the forms of HRC according to TS15066 and its implications according to specification are introduced. Thereafter the mechatronic approach towards modularity in industrial controls and sensors is presented. All this is done with an example HRC application in mind.

II. TS15066

A. Methods according to TS15066

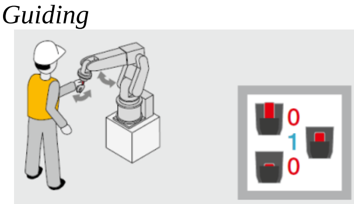
Condensing the TS 15066 to its essence, there are 4 methods' of HRC:

1) Safe rated Stop



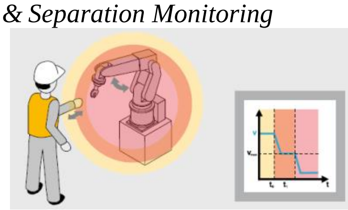
- according EN ISO 10218-2 5.2.
→ Robot in STO (Safe Torque Off) when Person in Collaborative Workspace
→ No Collision possible

2) Hand Guiding



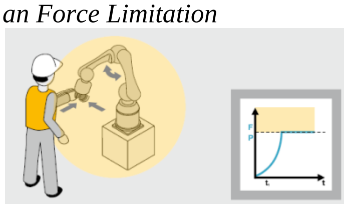
- according EN ISO 10218-2 5.2.
- Safe rated Stop included
  + Safe rated monitored Speed (SLS)
  + Guiding device near TCP
    → Robot in STO when Person enters Collaborative Workspace
    → Manually actuating the Robot in SLS
    → No Collision possible

3) Speed & Separation Monitoring



- according EN ISO 10218-2 5.2.
- Safe rated Stop included
  + external Sensor to detect Person & Robot
  option - Safe rated monitored speed (SLS)
  - Safe rated soft Axis
    → Robot in SLS when Person in Col.WS.
    → Robot in STO when Person too close
    → No Collision possible

4) Power an Force Limitation



- according EN ISO 10218-2 5.2.
- Safe rated Stop included

+ Safe rated collision sensors inside the Robot
option - Safe rated monitored speed (SLS)
- Safe rated soft Axis
→ Robot in STO when collision occurs in Col.WS.
→ Collision possible - <u>“under certain conditions”</u>

Among these four methods, method 4, power and force limiting is the one that really is new to industry. Methods 1 through 3 have traditionally been installed using conventional guarding methods. New to method one to three is, that camera technology has allowed to replace hard guarding when realizing collaborative applications.

B. *Forms of HRC*

With the four methods at hand in industry the following forms of HRC have materialized in industry.

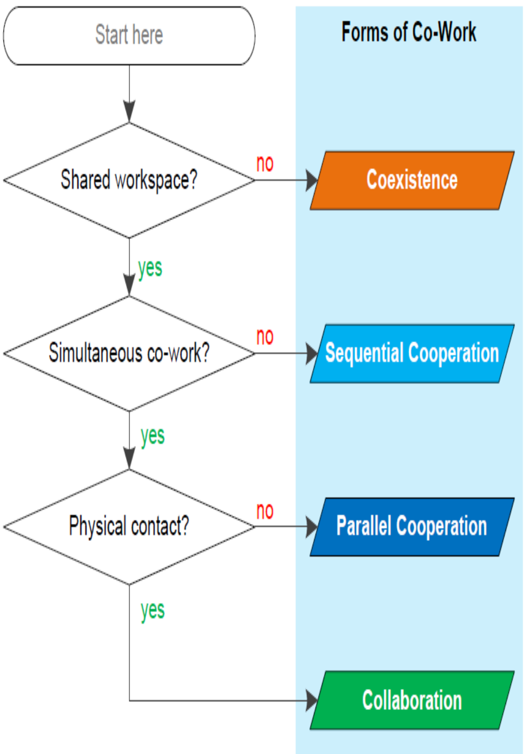


Figure 1. Forms of HRC (Source Frauenhofer IFF Magdeburg)

As figure 2 shows, true collaboration is achieved when either method 2 or 4 are applied. However a combination of method 3 and 4 has become an industry trend for reasons to be explained later.

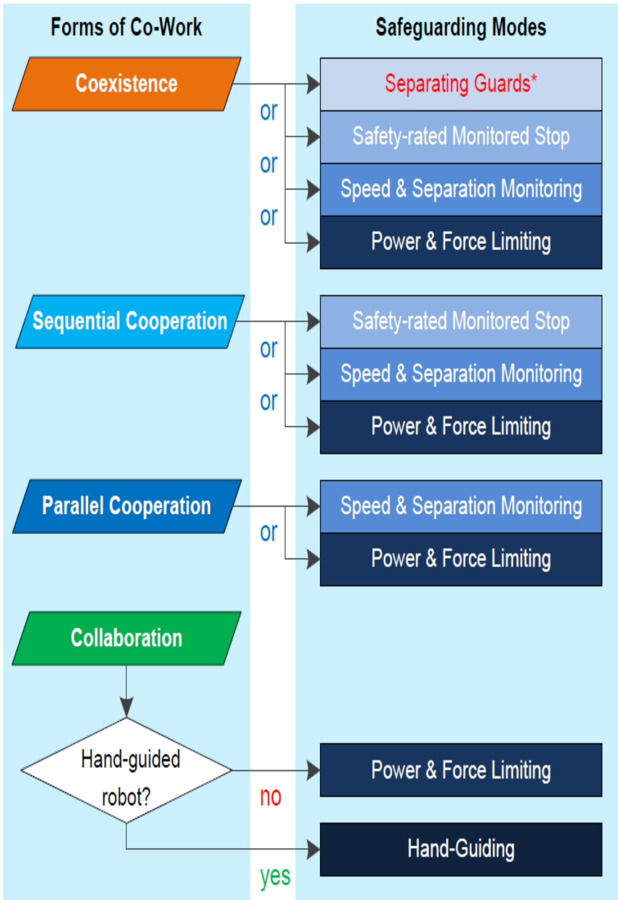


Figure 2. Forms of Co work and its associated safeguarding modes

C. *Riskassessment*

When it comes to designing industry applications of service robots, a risk assessment is required. When it comes to Safety Performance TS15066 refers to EN ISO 10218-2. In EN ISO 10218-2 is written:

5.2.2 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 hardware fault tolerance of 1 with a proof test interval of not less than 20 years as described in IEC 62061:2005.

This means in particular:

a) a single fault in any of these parts does not lead to the loss of the safety function,

b) whenever reasonably practicable, the single fault shall be detected at or before the next demand upon the safety function,

c) when the single fault occurs, the safety function is always performed and a safe state shall be maintained until the detected fault is corrected,

d) all reasonably foreseeable faults shall be detected.

The requirements a) to d) are considered to be equivalent to structure category 3 as described in ISO 13849-1:2006.

NOTE The requirement of single-fault detection does not mean that all faults will be detected. Consequently, the accumulation of undetected faults can lead to an unintended output and a hazardous situation at the machine.

5.2.3 Other control system performance criteria

The results of a comprehensive risk assessment performed on the robot system and its intended application may determine that a safety-related control system performance other than that stated in 5.2.2 is warranted for the application.

Selection of one of these other safety-related performance criteria shall be specifically identified, and appropriate limitations and cautions shall be included in the information for use provided with the affected equipment.

With this information, the designer can choose to follow the typ C standard requirement of PLd Cat3 for all cobot modules or choose to prove with a risk assessment, that a different safety performance suffices for a particular module of the cobot application.

Selecting/ designing the right modules therefore is the essence when designing a HRC application.

III. Mechatronic Approach to Modularity in Controls

A. Mechatronics, another word for Modularity in Controls Design

In machine design "mechatronics" was the buzzword long before industrie4.0 or internet of things. As figure 3 describes mechatronics combines the three disciplines IT, Mechanics and Electronics. The full use of this modularization however comes with Industrie 4.0 and the internet of things, where mechatronic modules build the core around which modular machine concepts are centered in order to provide the consumer a individualized product at the cost of a mass product.

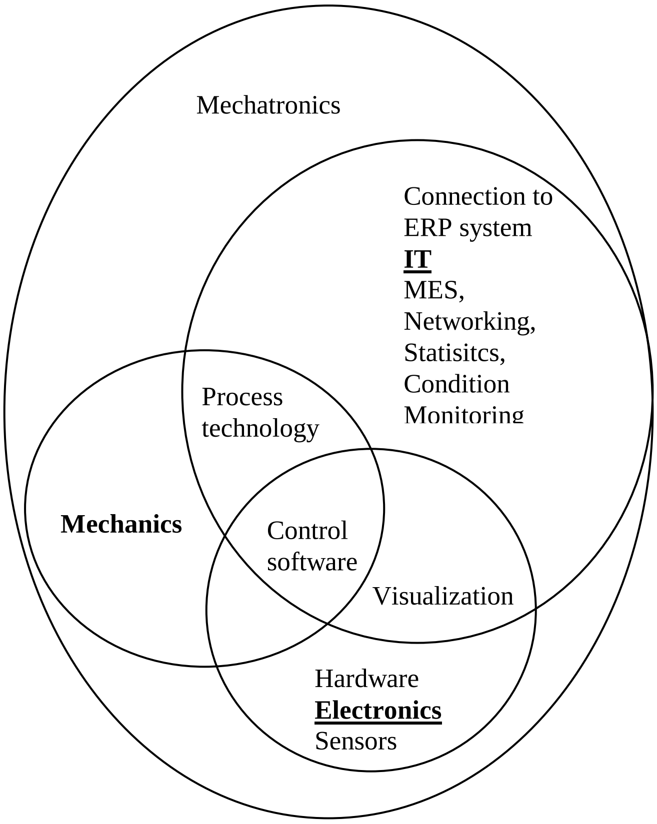


Figure 3. Mechatronic Circles

As Figure 4 shows this requires that Mechanical Engineers, Electrical Engineers and Application Engineers start to think in modules that are synchronized with each other. In order to do so modularity, also in the controls design and its programming software as well as distributed control architecture, is needed.

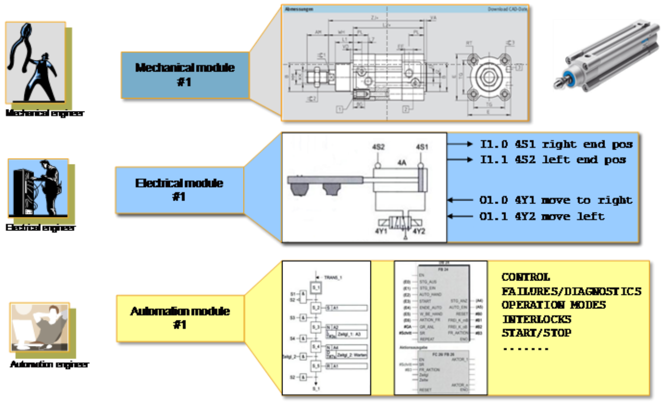


Figure 4. 3 Engineering disciplines working together via Modular design.

When the principles of modularization of machines are applied, control programs can be split up into modules accordingly.

The relevant criteria are:

- Uniform interfaces
- The impact on the remaining software modules. Reaction in the event of a failure
- Reusability of modules

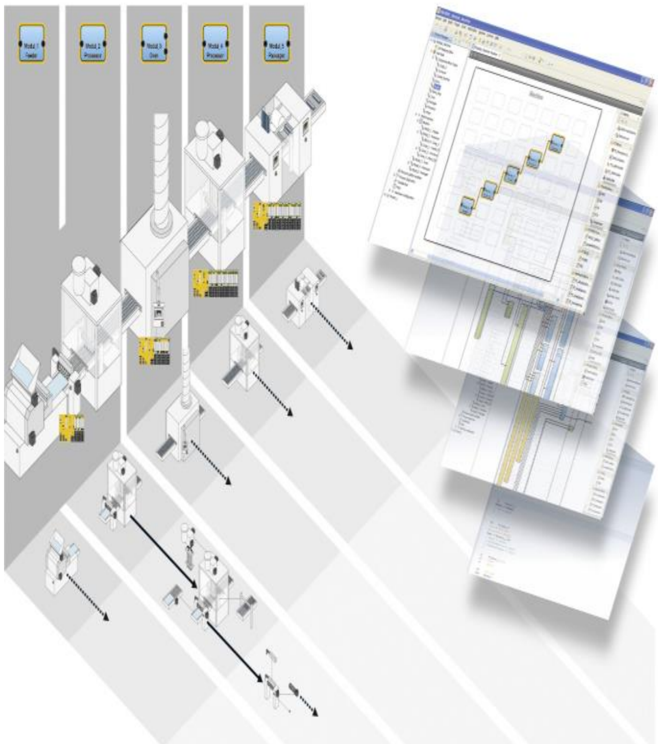


Figure 5. Machine modules become software modules.

B. PSS4000 Modular Control Architecture

The modular logic has been implemented in the design of the PSS4000 Automation Controller.

As Figure 6 shows, the path towards modularity in programmable logic controls was an evolutionary one starting in the 70s with I/O modules directly attached at the CPU of a PLC. In the 80s decentralized I/O periphery was achieved. In the 90s the combination of PLC systems with their respective decentralized periphery became possible.

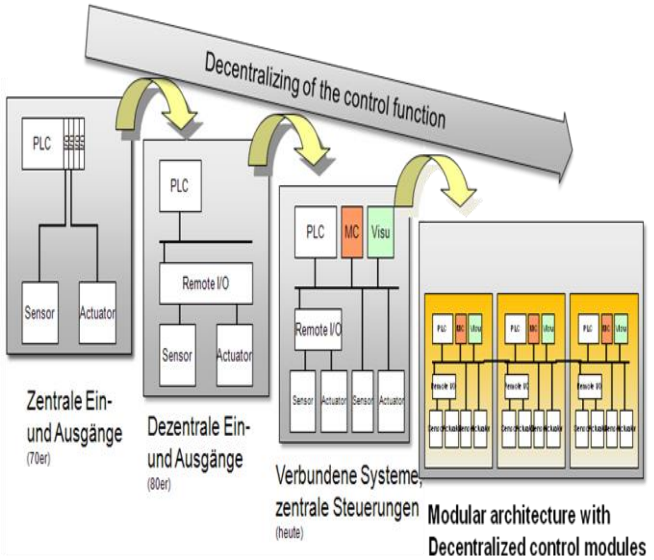


Figure 6. Different types of control architecture.

Today Modular architecture is possible as shown in Figure 7 at the example of the PSS4000 automation system, which is the only industrial platform to date that offers true modular design capability to the application engineer.

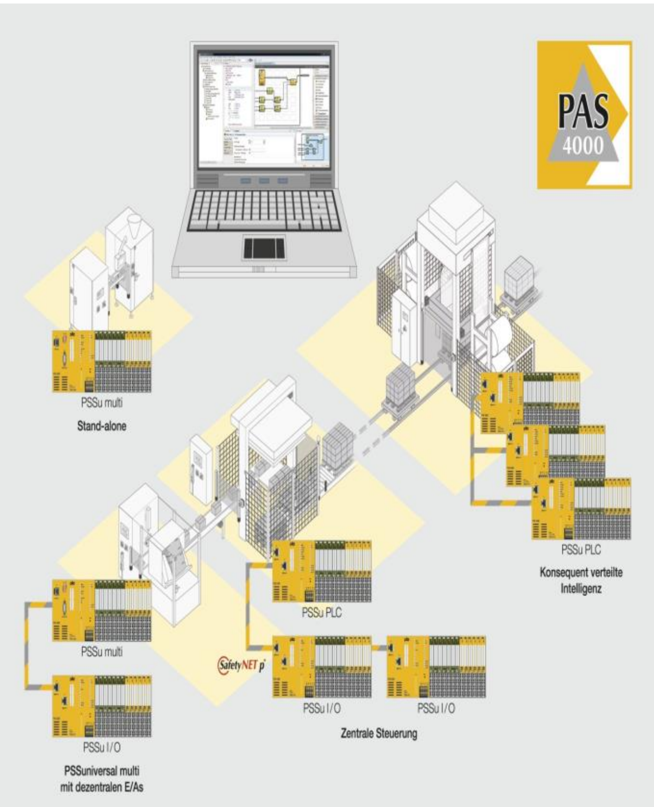


Figure 7. PSS4000 Modular Control System

IV. Modular Build of an Compliant TS15066 HRC Work Station

In order to build a HRC application in compliance with TS15066 one first needs to decide on the HRC method for the application. In our example we have chosen a combination of method 4 and 3 since the desired form is collaboration as shown in Figure 2. We chose the combination of method three and four because experience has shown, that tact time is significantly reduced when a human is present. In the absence of the worker however the benefit of a robot and its speed and accuracy can be used to its optimum, when speed and separation monitoring safely switches to collaborative mode when a worker is entering the work station, where the method 4 safety functions then take over to protect the worker in its interaction with the robot. As a reminder here are the requirements on the robot system.

- Speed and separation monitoring
  - Robot has to have a defined distance to the worker, which is depending on the safe speed
  - Robot is only one module in a collaborative system. A safe robot by itself can not guarantee a safe human robot collaboration.
  - The relative speed of robot and worker towards each other have to be taken in consideration when calculating the safety distances according to ISO13855
- Power and force limiting by design or control
  - The robot is limited in regards of dynamic power and static force or energy
  - If one parameter (Power, force or energy) is exceeded an emergency stop is initiated.

Next modules to be chosen are the robot and its sensors.

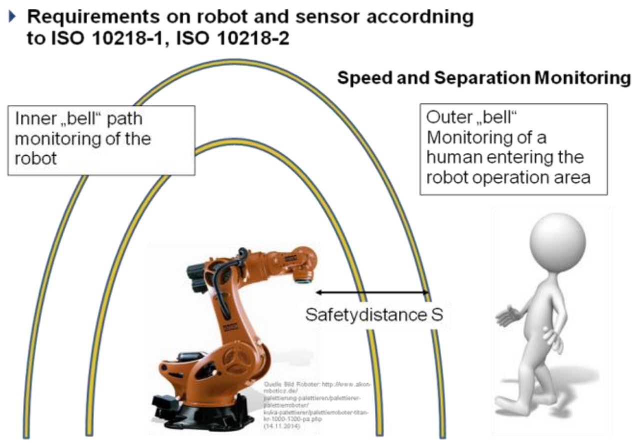


Figure 8. Requirements in general

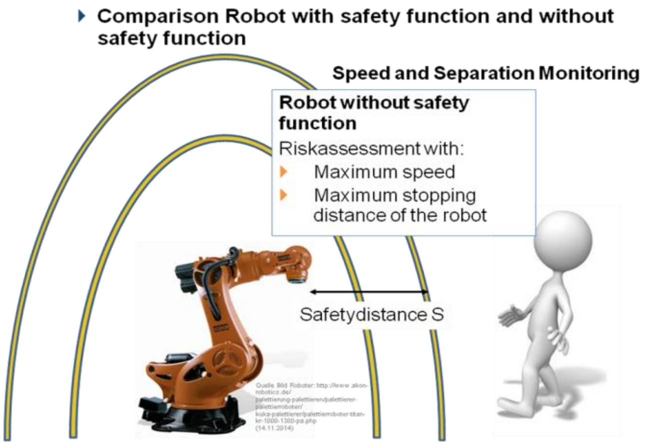


Figure 9. Requirements on the sensor when the robot controler has no safety functions.

Figure 10. Requirements on the sensor when the robot has safety functions.

With this information at hand we chose as sensor the Safety Eye and as Robot the LBR iiwa.

In figure 11 we show the view of the safety eye on a HLR application similar to the one in figure 12.

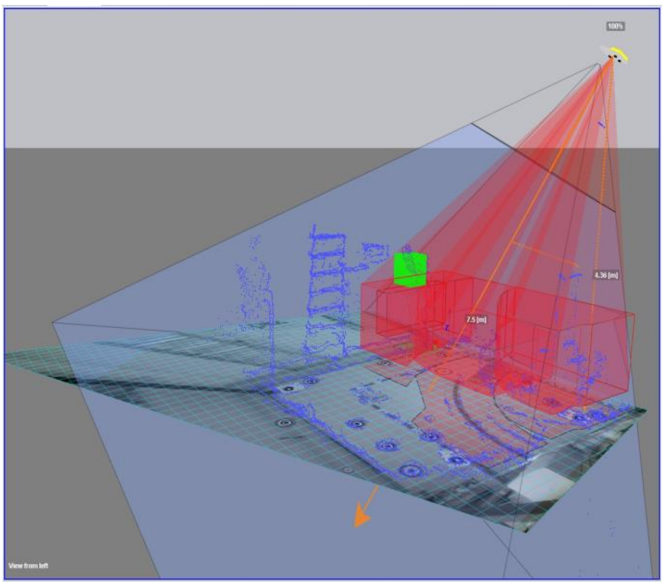


Figure 11. Safety Eye creating an outer bell for a safe robot.

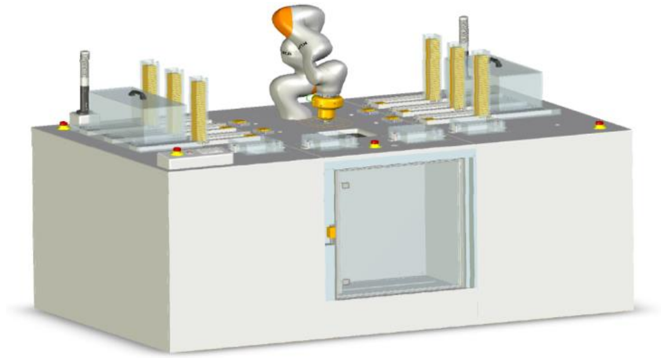


Figure 12. HRC application Automatica 2016

In order to integrate the cobot into the automation around the robot application we choose the PSS4000.

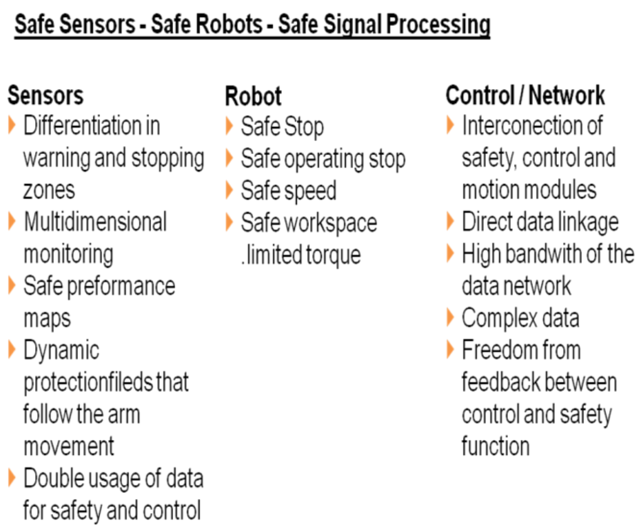
With this we have 3 main modules for the application.

- Module 1: Robot
- Module 2: Sensor
- Module 3: Automation.

In order to get the application CE marked we followed TS15066 by first selecting the method, then the modules and then we did perform a risk assessment on the design. This allowed the safe display of this robot application at the Automatica 2016 in Munich, where the robot handed out chocolates after a quality inspection to interested visitors.

V. Conclusion

In conclusion of this paper the work of ISO/TC299 WG6 on modularity is important not only to service robots but also to industrial robots and the success of Industrie 4.0 applications. Safety is a vital part and needs to provide easy to configure interfaces to allow safe re-configuration of work stations. In summary these are the challenges when it comes to service robot applications in industry:



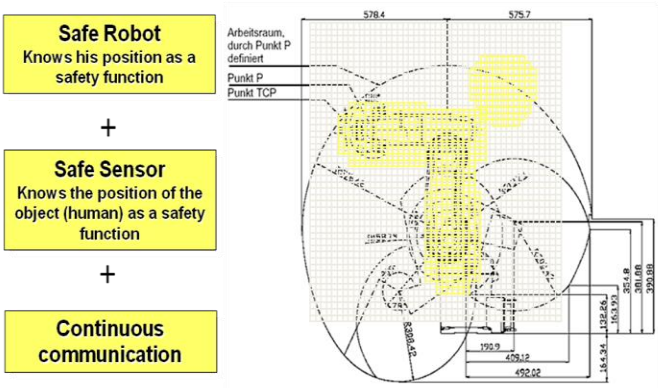


Figure 13. Modular approach at HRC

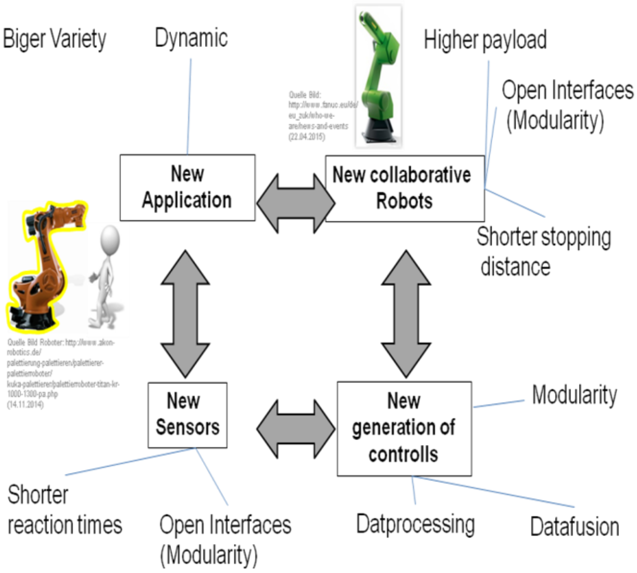


Figure 14. Potential for research and development in the field of HRC