SEINÄJOEN AMMATTIKORKEAKOULU
SEINÄJOKI UNIVERSITY OF APPLIED SCIENCES

COLLABORATIVE ROBOTICS

Human-robot collaboration in heavy manufacturing tasks

Timo Koukkari
Project Engineer
2.12.2016

CONTENT

FINNISH ABSTRACT

Yhteistyörobotiikka on puhuttu aihe jossa monet toimijat haluavat olla mukana joko toimittajina tai teknologian hyödyntäjinä. Standardoinnin kehittyminen antaa mahdollisuuksia soveltaa robotiikkaa uusilla tavoilla tilanteissa, joissa ihminen toimii samassa tilassa robotin kanssa. Alle 15 kg käsittelykyvyn luokassa yhteistyörobotteja on jo tarjolla moneen tarpeeseen ja sovellutukseen, raskaammissa sovellutuksissa sovellukset ovat kuitenkin vielä harvinaisempia. Molemmissa tilanteissa yhteistyörobotiikan toteuttamista ohjaavat kuitenkin samat säädökset. Yhteistyörobotti on yhteistyörobotiikan tunnetuin muoto, mutta säädökset antavat mahdollisuuden toteuttaa yhteistyörobotiikkaa myös muilla keinoilla.

Study ”Human-robot collaboration in heavy manufacturing tasks” kartoittaa yhteistyörobotiikkaan liittyviä standardeja, sovellutuksia ja aiheeseen liittyviä tutkimuksia. Näkökulma on ”raskaissa” sovellutuksissa mutta monet käsitellyt teemat pätevät myös ”kevyempään” yhteistyörobotiikkaan. Loppukateettina yrityksiä haastetaan miettimään, miten he voisivat soveltaa yhteistyörobotiikkaa heidän alallaan. Studyn lähdeluetteloon on koottu mielenkiintoista lisämateriaalia aiheeseen liittyen.

Terveisin,
Timo Koukkari
Projekti-insinööri
Seinäjoen ammattikorkeakoulu

1. INTRODUCTION

Human-robot collaboration is an application which potentially improves productivity and comfort in different kind of manufacturing tasks. Traditionally robots and humans are worked in separated environments which doesn't allow them to do the same task at same time. Now "new" standards and devices make co-operative applications easier and legally possible to implement. This makes it possible to implement atomatization in to new areas of production and assembly tasks, which are requiring concurrent flexibility and creativity of humans.

Generally speaking, robotization improves productivity and quality of products. A lot of assembly tasks can be made with industrial robots if requirements of automation are taken into account during product development (design for automated assembly/manufacturing). Still there is tasks like hose and harness assembly which are really hard to automate, thus people is needed for these tasks. Also mass customization can be implemented with a human-robot collaborative workcell, where humans are doing "customization" tasks. The mass customization means utilization of mass production paradigms to production of a modular product with customization flexibility.

In this study human-robot collaboration in heavy assembly tasks is discussed. More information from topics can be found from the bibliography. In this study "heavy" means tasks where handling capacity over 15 kg is needed. This threshold value is selected because of collaborative robot availability. There is a lot of collaborative robots from different manufacturers but most of them does have less than 15kg handling capacity. The list under covers few manufacturers which does have or will have models in 15 kg class. Many of these does have multiple collaborative robot models.

- Universal Robots: UR-series
- KUKA: LBR iiwa models
- ABB: YuMi
- Rethink Robotics: Sawyer and Baxter
- Yaskawa: HC10 (incoming)
- Fanuc: CR-7iA (incoming)
- MABI: Speedy-series (incoming)

2. TOPIC RELATED SAFETY PRINCIPLES

In this chapter collaborative-robotics related regulations are introduced at general manner. From our point of view ISO/TS 15066 is the most interesting one, but it can't be mentioned without others.

Industrial robot safety functionality is defined in SFS-EN ISO 10218-1 (Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots) [18]. Whole robotized workcell has to be implemented according to SFS-EN ISO 10218-2 (Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration) [9]. Safety of the robot cell have to be verified according to SFS-EN ISO 12100 (Safety of machinery - General principles for design – Risk assessment and risk reduction) risk assessment [17]. Electrical control systems are to be implemented according to SFS-EN ISO 13849-1 (Safety of machinery. Safety-related parts of control systems. Part 1: General principles for design), which is referred in 12100 and so on.

According to ISO/TS 15066 (Robots and robotic devices — Collaborative robots) ("extension" of 10218-1) collaborative workspace is: "space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation". It is possible that collaborative workspace doesn't cover the whole workspace of the robot [9]. Take a notice that all mentioned standards are updated recently (after 2010), and thus there is much partially outdated written material available.

In a collaborative workspace safety is ensured with four possible methods [9]:

a) safety-rated monitored stop
b) hand guiding
c) speed and separation monitoring
d) power and force limiting

a) safety-rated monitored stop. The simplest method to allow an operator to enter into the collaborative workspace without releasing an emergency stop. When an operator enters into the collaborative workspace and a robot is in the workspace the robot will be stopped with the safety-rated monitored stop (feature of the robot controller). After the operator leaves from the workspace robot can resume its work. Presence of the operator shall be detected with safety-rated control system. [9] An example of this kind of functionality is provided in TUT demo: "Human robot co-operation welding workcell case study" [8].

b) hand guiding. Operator can guide a robot with a hand-operated devise which includes an emergency stop function. Therefore, an operator can use the robot to lighten his/her tasks. Safety have to be ensured in transitions between different kind of operating modes. [9] The real life example from Ford manufacturing line can be viewed from the YouTube [3]. More examples are presented in the chapter five.

c) speed and separation monitoring. In case a) the robot has to be stopped when operator is in the collaborative workspace. With the method c) concurrent movements of the robot and the operator are permitted in the collaborative workspace. System maintains protective separation between hazardous parts and operator. [9] An example can be seen from the chapter five [15].

d) power and force limiting. In cases a) and c) separation between a moving robot and an operator is ensured. In the case d) physical contact between an operator and a moving robot (including gripper and workpiece) can occur either intentionally or unintentionally. Contact can be static (clamping or crushing) or dynamic (impact). A robot has to include either passive and/or active measures to ensure safety. Passive can mean as example rounded and soft edges (no sharp or pointy objects) of the robot and gripper. Active means as example that forces and torques of the robot are actively limited. Power and force limits for different body parts are presented in the ISO/TS 15066. [9] Collaborative robot models mentioned in the chapter one (list) are expressing this (case d)) functionality. Collaborative robots for heavy tasks are presented in the chapter tree.

3. AVAILABLE COMMERCIAL SOLUTIONS

In this chapter different kind of available solutions for collaborative robotics in heavy assembly tasks are covered. This study doesn't cover all possibilities (available safety-rated solutions and products).

Collaborative robots for heavy manufacturing tasks (ISO/TS 15066 case d)). As told in the chapter one, there is a lot of manufacturers and robot models for light collaborative robot tasks. However, situation in heavy tasks is different and at the moment there is only one commercially available industrial collaborative robot in "heavy" class, the Fanuc CR-35iA [2]. Fanuc does have 35 kg handling capacity, it is covered with passive soft cover and equipped with active collision stop and push pack function [2]. Also hand guiding functionality is possible to implement with a separate guiding devise.

Comau released its AURA-robots in June 2016 [1]. Probably there will be two models with handling capacities 60 kg and 110 kg, but these are not commercially available yet [5]. Comau presents that its robots will have functionality related to 15066 case d) (power and force limiting), but also case c) (speed and separation monitoring) [1].

Equipment to realize collaborative robotics with "standard" industrial robots (ISO/TS 15066 case a), potentially others). According to SFS-EN ISO 13849-1 safety-related part of a control system means: "part of a control system that responds to safety-related input signals and generates safety-related output signals" [19]. According to SFS-EN ISO 10218-1 safety-rated means: "characterized by having a prescribed safety function with a specified safety-related performance" [18]. Required safety-related performance level depends from severity of possible injury (risk) scenarios in the system and is described in the SFS-EN ISO 13849-1.

Therefore, collaborative robotic systems can be implemented with "safety-related" control system which consist "safety-rated" components. Here few proven and available solutions for safety functionality (operator presence observation) are described. These can also be used with "power and force limited" robots to unleash safety related speed limitations when an operator isn't in the collaborative workspace.

Safety light curtain. A light curtain is simple way to optically detect objects between a sender unit and a receiver unit. Typically position of light curtains is fixed and operation is not reconfigurable (whole area between devices is typically observed). Multiple use examples can be found from Sick Product Catalog: Opto-Electronic Protective Devices [11].

Safety laser scanner. With laser scanners 2D-area can be supervised with one device (no need for a sender and a receiver). Scanners are also often programmable and therefore it is possible to handle different field geometries. Laser scanners are probably replacing safety pressure mats in many cases because of easier reconfiguration and flexibility. Multiple use examples can be found from Sick Product Catalog: Opto-Electronic Protective Devices [11].

Camera based 3D space monitoring system. Pilz SafetyEYE is safety-rated camera based 3D space monitoring system. System includes a camera-unit, an analysis unit and software to configure safety functions. [14] An example can be seen from the TUT demo: "Human robot co-operation welding workcell case study". SafetyEYE is based to camera imaging and thus some applications like welding can be troublesome to implement. [8]

Safe gripping solutions. There are some manufacturers for collaborative-robot grippers (Robotiq, On Robot ApS, Schunk). Often these grippers have rounded edges and force limiting features. So far only Schunk does have gripper with active separation monitoring. Schunk Co-act JL1 does have "Capacitive Sensor Systems" for separation monitoring [16].

4. IMPLEMENTED REAL LIFE APPLICATIONS

There is already a lot of documented applications and examples related to co-operative robotics in industrial applications. Ideas can be explored as an example from the Universal Robots YouTube channel [22]. In some countries (China…) companies are happily implementing “co-operative robotics” with standard robots [4]. With that freedom they are probably gaining competitivity benefits over western countries.

In collaborative applications a co-operative or a “naturally safe” (robot’s maximum forces are limited) robot is often placed to tasks which are normally handled with a “normal” industrial robots and traditional safety systems. Usually tasks are different kind of material handling and machine tending operations. Difference is that with a co-operative robot the application doesn’t need safety equipment which makes realization of robotisation easier. Also space can be saved because of lack of fences and other safety structures. One example from this kind of implementation is the electric motor production in the Siemens production line, where the KUKA LBR iiwa is serving a lathe [20].

As mentioned collaborative robots are often used in traditional tasks of robots and tasks where robots are continuously co-operating with humans are not that common in manufacturing industry. It is also possible that implementations of real co-operative robotics are held as “strategic” benefits and thus not publicly documented.

Subject of this study is collaborative robotics in “heavy” manufacturing tasks. As mentioned, at the moment there is only one commercially available “collaborative” robot available with handling capability over 15 kg. That means that only possible way to realize a heavy co-operative robot system is to use a commercially available Fanuc robot or a “standard” industrial robot with separated safety functionality described in chapters two and tree.

Fanuc have shown us demos related to car-industry [2]. However, there is no available documentation from real life implementations (found within this study). Only (found within in this study) real life implementation related to co-operative robotics in (possible) “heavy” assembly tasks is published by Volkswagen/Audi [10]. In the “classroom” it is stated that collaborative robotics (hand guiding) are used in car windshield assembly tasks on car manufacturing lines. However, only fully automated windshield assembly related publications were found within this study.

5. TOPIC RELATED STUDIES

There is a lot of robotics related projects going on in Europe [12]. A lot of material is published in these projects but majority of these publications are not concerning solutions related to collaborative robotics in industrial environments and heavy tasks (or study outcome is "highly conceptual" or application specific). Probably most mature "public" studies related to collaborative robotics in heavy tasks are published in Franhofer related projects/studies.

Especially studies STROBAS [21] (Stationary Robotic Assistance System for Die Making) and SAPARO [15] (Safe Human-Robot Cooperation with High Payload Robots in Industrial Applications) are interesting. Studies are including pretty much all ways (see chapter two) to implement a human-robot co-operative environment in heavy tasks with industrial robots.

In the STROBAS an industrial robot is hand guided (case b)) in a workbench environment. Safety in transitions between operation modes is handled with a safety-rated monitored stop. Also optical workplace monitoring is used. That is developed in the study EXECELL [23] (Experimental Evaluation of Advanced Sensor-Based Supervision and Work Cell Integration Strategies). System offers SafetyEYE-like functionality with projectors and cameras, but in addition clear visual feedback for operators is also provided. In the SAPARO speed and separation monitored (case c)) workspace is developed. In the workspace also visual feedback and controls for operators are created with projectors. Also hand guiding is implemented.

In general, project Robo-Partner is also worth to explore [13]. There is a lot of different kind of material provided through project's web-page. White paper "ROBO-PARTNER: Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future" opens up many concepts and topics related to collaborative robotics [6]. White paper "Design Considerations for Safe Human-robot Collaborative Workplaces" introduces safety-principles and different kind of methods to implement collaborative robotics [7].

6. BENEFITS AND SUMMARY

Benefits of co-operative robotics are generally introduced in the chapter one and four. Still majority of benefits are still "yours to found". That means that machine tool builders and integrators have to be creative when they figure out possible applications where human-robot collaboration can fetch benefits. Of course there are general benefits like easiness off commissioning, room savings related to the safety equipment, reduction of employee fatigue and so on. Therefore, technology is challenging us to find out feasible applications in Finnish project-filled industry.

This study topic was selected because it would be interesting to find out more things related to co-operative robotics in heavy manufacturing tasks. However, it turned out that topic was a bit hard to bite. That was because there wasn't really available information from real-life implementations related to the subject. Still subject related studies were found, examined and found to be interesting. Also ISO/TS 15066 were explored and found to be quite clear to interpret. Collaborative robotics in the light class (under 15 kg) is a technologically matured opportunity, however in the heavy class there is still room for development.

BIBLIOGRAPHY

[1] A REAL SENSITIVE ROBOT PRESS RELEASE, Comau, Referred 2.11.2016, Available: https://edit.comau.com/SiteCollectionDocuments/media/press-release/2016/en/PR_06_21_Automatica_Aura.pdf

[2] Brochure CR-35iA, FANUC Europe Corporation, Referred 2.11.2016, Available: http://www.fanuc.eu/~/media/files/pdf/products/robots/brochures/brochure%20cr-35ia.pdf?la=en

[3] Car Workers and Robots Work Hand-in-Hand, Ford Europe 14.7.2016, Referred 2.11.2016, Available: https://www.youtube.com/watch?v=I8nMKH3y_1I

[4] Chinese factory workers being replaced by robots – 2015, AP Archive 8.10.2015, Referred 2.11.2016, Available: https://www.youtube.com/watch?v=Rx83B8z2ANg

[5] Comau introduces two new Racer robots and the SCARA robot family along with a preview of their high payload collaborative robots, Comau, Referred 2.11.2016, Available: http://www.comau.com/EN/media/news/2016/06/comau-at-automatica-2016

[6] G. Michalos, S. Makris, J. Spiliotopoulos, etc., ROBO-PARTNER: Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future, Elsevier B.V., 2015, Referred 2.11.2016, Available: doi:10.1016/j.procir.2014.10.079

[7] G. Michalos, S. Makris, P. Tsarouchi, etc., Design Considerations for Safe Human-robot Collaborative Workplaces, Elsevier B.V., 2015, Referred 2.11.2016, Available: doi:10.1016/j.procir.2015.08.014

[8] Human robot co-operation welding workcell case study, TUT Mechanical Engineering and Industrial Systems 29.3.2010, Referred 2.11.2016, Available: https://www.youtube.com/watch?v=Kxw-SJd-j-o

[9] ISO/TS 15066 Robots and robotic devices — Collaborative robots, First edition 2016-02-15, ISO

[10] New human-robot cooperation in Audi's production processes (2015-02-12), Volkswagen, Referred 2.11.2016, Available: http://www.volkswagenag.com/content/vwcorp/info_center/en/news/2015/02/cooperation.html

[11] Opto Electronic Protective Devices, Sick 30.7.2015, Referred 2.11.2016, Available: https://sick-virgin-ia.data.continum.net/media/dox/9/99/199/Product_catalog_Opto_Electronic_Protective_Devices_en_IM0064199.PDF

[12] Related activities and collaboration, Lean automation project (LIAA)/ Fraunhofer-Gesellschaft, Referred 2.11.2016, Available: http://www.project-leanautomation.eu/index.php?id=relatedactivities

[13] ROBO-PARTNER Project - Seamless Human-Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future, Referred 2.11.2016, Available: http://www.robo-partner.eu/

[14] Safe Camera System SafetyEYE, Pilz, Referred 2.11.2016, Available: https://www.pilz.com/download/open/Leaf_SafetyEYE_1003954-ENU-01.pdf

[15] Safe Human-Robot Cooperation with High Payload Robots, Fraunhofer-Gesellschaft 2016, Referred 2.11.2016, Available: http://www.iff.fraunhofer.de/en/business-units/robotic-systems/saparo.html

[16] Schunk Co-ackt Meets Cobots, SCHUNK GmbH & Co. KG, Referred 2.11.2016, Available: https://fi.schunk.com/fileadmin/user_upload/Live_ab_2016/00_Startseite/HERO/MRK/neu/SCS_16_0112_MRK-Uebersicht_Broschuere_EN_RGB_144dpi.pdf

[17] SFS-EN ISO 12100, Safety of machinery - General principles for design – Risk assessment and risk reduction (ISO 12100:2010), ISO

[18] SFS-EN ISO 10218-1, Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots (ISO 10218-1:2011), ISO

[19] SFS-EN ISO 13849-1, Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots (ISO 10218-1:2011), ISO

[20] Siemens is relying on a flexible KUKA cell for human-robot collaboration in electric motor production, KUKA Roboter GmbH, Referred 2.11.2016, Available: http://www.kuka-robotics.com/res/robotics/Solutions/PDF/EN/KUKA_SIEMENS_EN.pdf

[21] Stationary Robotic Assistance System for Die Making, Fraunhofer-Gesellschaft 2016, Referred 2.11.2016, Available: http://www.iff.fraunhofer.de/en/business-units/robotic-systems/strobas.html

[22] Universal Robots YouTube channel, Referred 2.11.2016, Available: https://www.youtube.com/user/UniversalRobotsVideo

[23] Workplace Monitoring Sensors, Fraunhofer-Gesellschaft 2016, Referred 2.11.2016, Available: http://www.iff.fraunhofer.de/en/business-units/robotic-systems/technologies/workplace-monitoring-sensors.html