ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 2 [May]

1. Dávid KÓCZI, 2. József SÁROSI

THE SAFETY OF COLLABORATIVE ROBOTICS – A REVIEW

1. Faculty of Engineering, University of Szeged, Mars tér 7. 6724, Szeged, HUNGARY

Abstract: There is a growing demand for humans and machines to collaborate. Many examples can be found of this in our daily lives; simple devices in our household or semi-automatic machines in factories where some level of collaboration has been realized. The field of robotics also has a chance to make workplaces safer, more collaborative, and more productive for the operators. One of these forms of this collaboration is when a human and a robot can work together without any physical barriers. The aim of this review is to collect the available and applicable technology in the field of collaborative robotics safety based on "Collaborative robots - ISO/TS 15066:2016" standard. The safety aspects of collaboration are to comparing the implications of standards with the direction in which research are conducted in science. In this review the requirements are compared starting from the risk assessment through the theoretical methods to the implemented case studies. Finally, the paper provides insights to the possible directions in the field of human machine collaboration.
Keywords: robot safety, human–robot collaboration, cobot safety, cobot review, standard

1. INTRODUCTION

Collaborative robots (cobot) are industrial robotic arms that are capable of reaching some level of collaboration with humans [1]. This collaboration can be useful and dangerous to humans in many ways. Statistics as Figure 1 shows that the robotization of factories is increasing year by year, which is reflected in the number of collaborative robots in recent years, which reached 6% in 2020 [2].

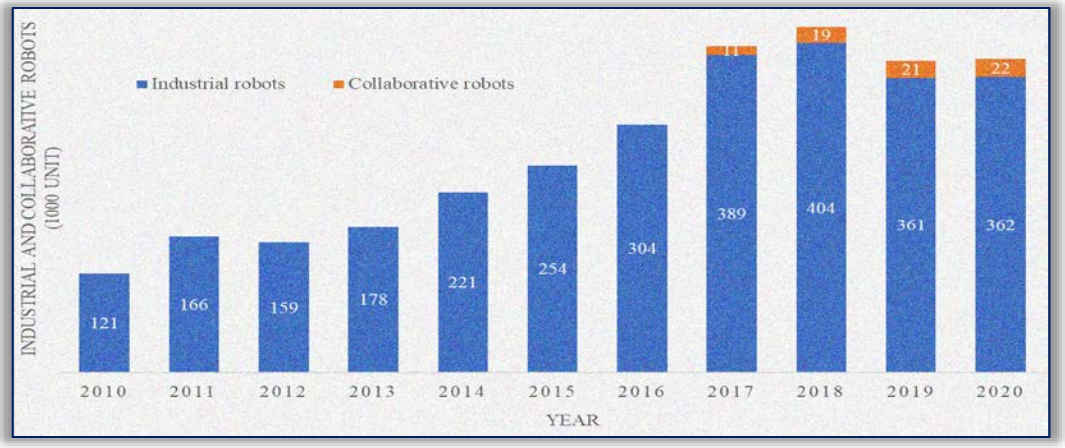

Figure 1. Collaborative and industrial robot trends [2]

Several types of collaboration are distinguished, depending on the level of human-machine collaboration. This can be coexistence, cooperation, and collaboration [3]. Coexistence is when the work area of a person and a machine is separated, contact is possible but unpredictable. [4] In the case of cooperation, part of all the workspace could be the same, but human and robot are separated in time, with one working in the collaborative workspace and the other not [5]. Can be done by complete collaboration when human and robot work together in a workspace at the same time. The collaborative workspace (Figure 2) could be all of part of the robot cell workspace [6].

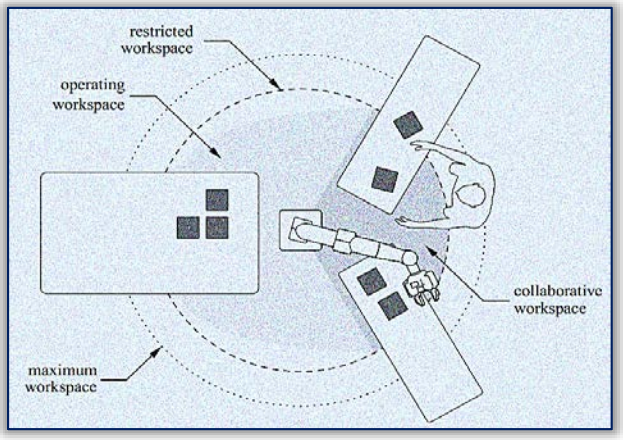

Figure 2. Collaborative workspace [6]

Whole of this workspace needs to be evaluated and considered for risk analysis when the goal is to safely design a manufacturing system which is supported by a collaborative robot.

This paper begins with an examination of the regulations and standards applicable to European conformity assessment for machinery. What makes a collaborative robot and a manufacturing cell using a collaborative robot specialty and what does not. It examines the type of "Type A", "Type B" and "Type C" standards can be apply the use of collaborative robots and examines the technical solutions available to meet the safety requirements of the standards. It highlights the conformity assessment process through the "Collaborative robots - ISO / TS 15066: 2016" standard, from risk assessment to individual technology solutions.

Followed by a review of the literature, which means evaluating articles for the following terms. Numerous articles between 2010 and 2022 years were found during the search. However, in the search for examples, articles were selected that were created in the past 2-3 years.

2. THE SAFETY OF COLLABORATIVE ROBOTICS

Conformity assessment of machinery in Europe is guided by the Machinery Directive 2006/42 / EC [7]. As the robot is a partially finished machine, its suitability is not usually evaluated on its own [8]. Connected to other technologies, machines, gripping devices, etc. thus, only the safety assessment of the whole system makes sense, and the risk assessment should consider the full scope of the system [9]. Considering the hierarchy of standards as Figure 3 shows, "Type A" , "Type B" and "Type C" standard can be considered when creating a collaborative application [10].

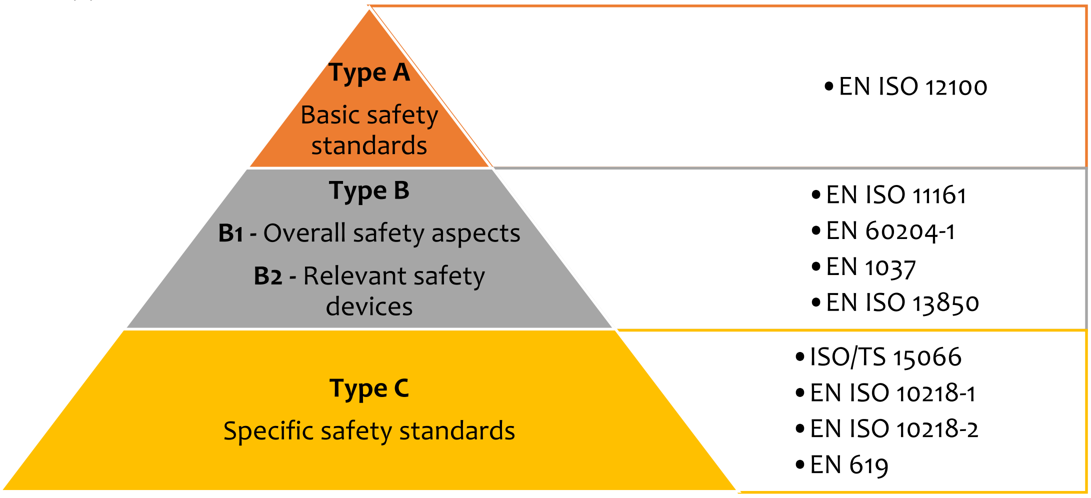

Figure 3. Standards hierarchy [10]

"Safety of machinery. General principles for design. Risk assessment and risk reduction - ISO 12100:2010" contains general safety requirements and provides guidance on how to perform a risk assessment [11].

The "Type B" standards the "Safety of machinery. Integrated manufacturing systems. Basic requirements - ISO 11161: 2007" for a group of machines [12]. Applicable to "Safety of machinery. Electrical equipment of machines. Part 1: General requirements - EN ISO 60204-1: 2005" which covers safety requirements for electrical equipment [13]. As regards the safety of machinery, the "Safety of machinery. Prevention of unexpected start-up - EN 1037" [14], Safety of machinery. Safety distances to prevent hazard zones being reached by upper and lower limbs - ISO 13857: 2008" [15], "Safety of machinery. Emergency stop function. Principles for design - ISO 13850: 2015" [16]. In addition, numerous standards can be applied to collaborative robot systems depending on the application where robot is used.

There are specific "C" type standards for collaborative robot applications. The two most important are "Robots and robotic devices. Safety requirements for industrial robots. Part 1: Robots - ISO 10218-1: 2011" which contains specifications for robot builders and "Robots and robotic devices. Safety requirements for industrial robots. Part 2: Robot systems and integration - ISO 10218-2: 2011" which applies to robot integrators themselves [17], [18]. The former has been supplemented by a technical specification which is "Collaborative robots - ISO / TS 15066: 2016" a technical specification dedicated to the use of collaborative robots which contains several references to the standards mentioned earlier.

In addition to the general machine and robot requirements of the standards, where contact between the operator and the robot is not permitted, it is necessary to specify what contact is allowed. The technical specification distinguishes between two types of human-robot contact. One is the "Quasi-static contact", and the other is the "Transient contact" [19]. The force of the contacts is maximized by dividing the human body into zones, and force and pressure values acting on the surface were determined. The strictest thresholds are imposed around allowed around the eyes and the head [20].

Methods of collaboration can be: "Safety-rated monitored stop" is one of the most common collaborative applications where the appearance of a person results in a controlled stop in the workspace (stop category 2) [21.] Secondly, the "Hand guiding" function is widespread not only for cobots but also for many industrial robots, this type of training method can be used when the robot can be moved by hand to position [22]. There is also "Speed & separation monitoring" and "Power & force limiting", where the collaboration is realized in real time [23], [24].

3. APPLICATIONS OF COLLABORATIVE ROBOTS

Initially, the introduction of collaborative robots into production began with simple tasks, as before with industrial robots. Collaborative robots are used for various tasks where dull, dangerous, dirty work must be done. The simplest of these is the pick & place applications that can be implemented with less space when using a cobot, with laser scanner area monitoring can avoid the fence construction [25]. This type of system can be used, for example, for assembly [26]. However, there are many commercially available welding applications where it is difficult to reduce their safety risk to the appropriate level in a collaborative use [27]. Cobots are used not only in industry but also in agriculture [28]. Experiments are also underway for the medical use of cobots, as Figure 4 shows including COVID-19 test sampling [29], [30].

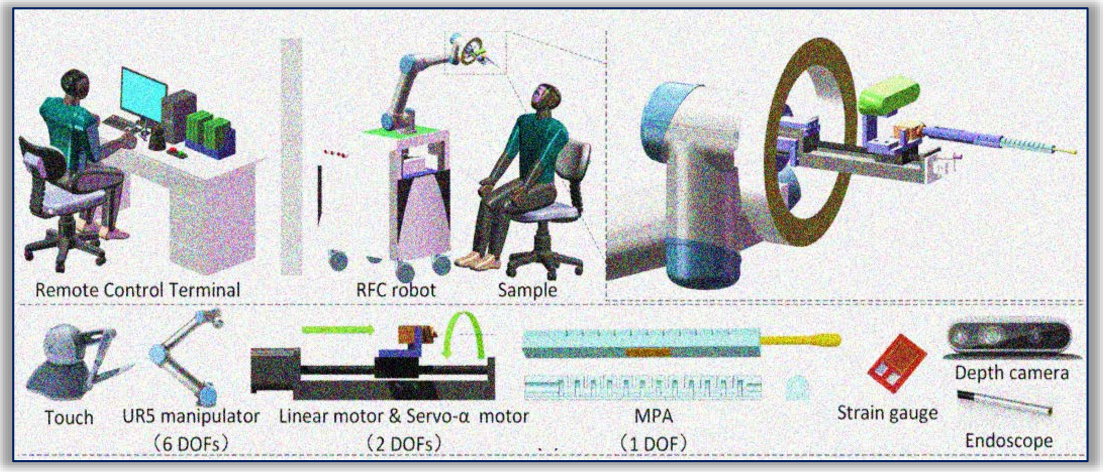

Figure 4. Collaborative robot for COVID-19 oropharyngeal swabbing [30]

Considering security papers, speed and separation monitoring is growing and such applications are emerging [31]. Furthermore, due to the use of deep learning cameras, the optical observation and evaluation of the collaborative field is also constantly growing [32].

Looking to the future, robotic sensing is constantly evolving, both in terms of electro-mechanical systems [33] and in terms of camera applications [34]. On the software side, examples can be found of the application of artificial intelligence and the development of error detection systems [35].

4. CONCLUSION

This article overviews what key standards and rules apply to collaborative robots. Overall, the conformity assessment of collaborative robots is based on the same foundations as non-collaborative robots. The biggest difference is that contacts are allowed between human and robot but it is well regulated and subject to strict limits. In terms of applications and safety solutions, it can be said that they are experimenting with a solution for any application that can be solved with an industrial robot, and further, collaborative robots have appeared in various industries where they have never been used before.

Note: This paper was presented at ICOSTEE 2022 – International Conference on Science, Technology, Engineering and Economy, organized by University of Szeged, Faculty of Engineering (HUNGARY) and Hungarian Academy of Sciencies – Regional Commettee in Szeged (HUNGARY), in Szeged, HUNGARY, in 24th of March, 2022

References

[1] Haddadin S. ; Croft E., Physical human-robot interaction. Springer Handbook of Robotics. Oussama Khatib. 2nd. ed. Berlin Germany: Springer, 2016. pp. 1835-1874
[2] IFR presentation, World Robotics 2021, online https://ifr.org/
[3] Emanuele M., Federica F., Andrea J., Fabio P., Alessandro D. L., Francesco L., Human-robot coexistence and interaction in open industrial cells, Robotics and Computer Integrated Manufacturing 61 (2020)
[4] Hungarian Chamber of Engineers, Collaborative robots , online https://www.mmk.hu/informaciok/hirek/kollaborativ-robotok (25.01.2022)
[5] Pedrocchi, N., Vicentini, F., Matteo, M., & Tosatti, L. M. (2013). Safe Human-Robot Cooperation in an Industrial Environment. International Journal of Advanced Robotic Systems
[6] Mihelj M. et al. (2019) Collaborative Robots. In: Robotics. Springer, Cham
[7] EU-parliament, Directive 2006/42/EC of the European Parliament and of the Coucil of 17, May 2006 Official Journal of the European Union, 2006 (May 2006), p. 63
[8] Max D., Rolf S., Doris L., Harald S., Hans-Jörg S., Guide for Safe Machinery. 2015 online https://cdn.sick.com/media/
[9] B. Matthias, S. Kock, H. Jerregard, M. Kallman, I. Lundberg and R. Mellander, "Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept," 2011 IEEE International Symposium on Assembly and Manufacturing (ISAM), 2011, pp. 1-6

[10] H. Pacaiova, "Machinery Safety Requirements as an Effective Tools for Operational Safety Management", in Risk Assessment. London, United Kingdom: IntechOpen, 2017 [Online].
[11] International Organisation of Standardisation. ISO, 2010, Safety of machinery. General principles for design. Risk assessment and risk reduction (ISO 12100:2010)
[12] International Organisation of Standardisation. ISO, 2007, Safety of machinery. Integrated manufacturing systems. Basic requirements (ISO 11161:2007)
[13] International Organisation of Standardisation. ISO, 2010, Safety of machinery. Electrical equipment of machines. Part 1: General requirements (IEC 60204-1:2005, modified)
[14] International Organisation of Standardisation. ISO, 1997, Safety of machinery. Prevention of unexpected start-up
[15] International Organisation of Standardisation. ISO, 2008, Safety of machinery. Safety distances to prevent hazard zones being reached by upper and lower limbs (ISO 13857:2008)
[16] International Organisation of Standardisation. ISO, 2015, Safety of machinery. Emergency stop function. Principles for design (ISO 13850:2015)
[17] International Organisation of Standardisation. ISO, 2011, Robots and robotic devices. Safety requirements for industrial robots. Part 1: Robots (ISO 10218-1:2011)
[18] International Organisation of Standardisation. ISO, 2011, Robots and robotic devices. Safety requirements for industrial robots. Part 2: Robot systems and integration (ISO 10218-2:2011)
[19] International Organisation of Standardisation. ISO, 2011, Robots and robotic devices — Collaborative robots (ISO/TS 15066:2016)
[20] F. Ferraguti, M. Bertuletti, C. T. Landi, M. Bonfè, C. Fantuzzi and C. Secchi, "A Control Barrier Function Approach for Maximizing Performance While Fulfilling to ISO/TS 15066 Regulations," in IEEE Robotics and Automation Letters, vol. 5, no. 4, pp. 5921-5928, Oct. 2020
[21] Mohamad B., Marko P., Andreas S., A new strategy for ensuring human safety during various levels of interaction with industrial robots, CIRP Annals, Volume 66, Issue 1, 2017, Pages 453-456
[22] Fuji M., Murakami H., Sonehara M., Study on Application of a Human-Robot Collaborative System Using Hand-Guiding in a Production Line, IHI Engineering Review Vol. 49 No. 2016
[23] Jeremy A. Marvel, Rick Norcross, Implementing speed and separation monitoring in collaborative robot workcells, Robotics and Computer-Integrated Manufacturing, Volume 44, 2017, Pages 144-155
[24] P. Aivaliotis, S. Aivaliotis, C. Gkournelos, K. Kokkalis, G. Michalos, S. Makris, Power and force limiting on industrial robots for human-robot collaboration, Robotics and Computer-Integrated Manufacturing, Volume 59, 2019, Pages 346-360
[25] S. K. Lennart Andersson, J. Bruch, M. Hedelind and A. Granlund, "Critical Factors Supporting the Implementation of Collaborative Robot Applications," 2021 26th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), 2021, pp. 01-07
[26] Staffan K., Anna G., Jessica B., Mikael H., Experienced Challenges When Implementing Collaborative Robot Applications in Assembly Operations, International Journal of Automation Technology, 2021, Volume 15, Issue 5, Pages 678-688, Released September 05, 2021
[27] Arvola M., Ek S., Jokinen K., Welding Door Frames with Collaborative Robot, Telulainen, 2(4), 39-40.
[28] M. Polic, M. Car, F. Petric and M. Orsag, "Compliant Plant Exploration for Agricultural Procedures With a Collaborative Robot," in IEEE Robotics and Automation Letters, vol. 6, no. 2, pp. 2768-2774, 2021
[29] Neidhardt, M., Gerlach, S., Laves, M., Latus, S., Stapper, C., Gromniak, M. & Schlaefer, A. (2021). Collaborative robot assisted smart needle placement. Current Directions in Biomedical Engineering, 7(2), 472-475
[30] Yongquan C., Qiwen W., Chuliang C., Chengjiang W., Qing G., Heng Z., Zheng L., Zonggao M., Ruihuan X., Zhenglong S., Huihuan Q., A collaborative robot for COVID-19 oropharyngeal swabbing, Robotics and Autonomous Systems, Volume 148, 2022, 103917, ISSN 0921-8890
[31] Eugene K., Yoji Y., Shogo O., Mikihiro S., Hiroki K., Considerations of potential runaway motion and physical interaction for speed and separation monitoring, Robotics and Computer-Integrated Manufacturing, Volume 67, 2021, 102034, ISSN 0736-5845
[32] O. D. Miguel Lázaro, W. M. Mohammed, B. R. Ferrer, R. Bejarano and J. L. Martinez Lastra, "An Approach for adapting a Cobot Workstation to Human Operator within a Deep Learning Camera," 2019 IEEE 17th International Conference on Industrial Informatics (INDIN), 2019, pp. 789-794
[33] Davinson C., Mathieu ., Arnaud H., Resonant sensors for multi-axis force and torque estimation in collaborative robotics, Mechatronics, Volume 82, 2022, 102703
[34] Pagani, R.; Nuzzi, C.; Ghidelli, M.; Borboni, A.; Lancini, M.; Legnani, G. Cobot User Frame Calibration: Evaluation and Comparison between Positioning Repeatability Performances Achieved by Traditional and Vision-Based Methods. Robotics 2021, 10, 45
[35] Graabæk, S. G., Ancker, E. V., Christensen, A. L., & Fugl, A. R.. (2022). An Experimental Comparison of Anomaly Detection Methods for Collaborative Robot Manipulators (Version 1). TechRxiv

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665