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COVR Toolkit – Supporting safety of interactive robotics applications

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Abstract—Collaborative robots (cobots) are increasingly finding use beyond the traditional domain of manufacturing, in areas such as healthcare, rehabilitation, agriculture and logistics. This development greatly increases the size and variations in the level of expertise of cobot stakeholders. This becomes particularly critical considering the role of human safety for collaborative robotics applications. In order to support the wide range of cobot stakeholders, the EU-funded project COVR “Being safe around collaborative and versatile robots in shared spaces” has developed a freely available, web-based Toolkit that offers support to understand how to consider the safety of cobot applications. This paper describes the state of the art for ensuring safety across various life cycle phases in the development and implementation of collaborative robotics applications and highlights how the Toolkit provides practical support during these tasks. The Toolkit aims to be the most comprehensive resource for supporting cobot stakeholders in ensuring the safety of their applications.

Keywords—physical human-robot interaction, safety, collaborative robotics, standardization

I. INTRODUCTION

The concept of human-robot interaction (HRI), based on a synergistic combination of collaborative robots (cobots) and humans’ skills and capabilities in a working environment, has made large headways in recent years and has been a subject of large research efforts. Increasing levels of HRI have become possible thanks to the integration of safety-related features in robot control systems and advances in multi-modal interfaces for more intuitive HRI [1]. The current focus in the robotics community on applying artificial intelligence (AI) and machine learning (ML) techniques, with the goal of enabling robots to adapt their behavior in unstructured environments and allowing better interaction with humans will lead to an increase in the markets and domains that collaborative robotics are used in. Indeed, statistics from recent years show

how robots are penetrating new markets beyond industrial production, from logistics, to inspection and maintenance, construction, and medical applications [2]. The authors in [3] highlight how the boundaries between industrial and service robot are increasingly being blurred. This trend increases the number of stakeholders, while also lowering the overall level of expertise of these stakeholders, especially with respect to safety of such collaborative applications.

The cross-domain nature of robotics is positive from the point of view of robotics users and manufacturers. The same robotic hardware can be used for industrial and healthcare applications, creating larger markets. From the perspective of safety and standardization, this cross-domain nature is however increasingly a challenge. End-users and system integrators often rely in international standardization as a representation of the state of the art. While adherence to standards is voluntary, the use of harmonized standards in Europe confers the presumption of conformity to essential health and safety requirements and gives robotics end-users and system integrators a high degree of certainty that their systems are safe. In contrast to the flexibility regarding how a robot can be used, standards are by design domain specific. In particular, there are different standards for medical, industrial, agricultural, and service robotics applications that are unfortunately not completely synchronized. This leads to uncertainty, especially in situations where the same robotic system can be used for multiple domains (e.g. using an exoskeleton in the factory or for rehabilitation purposes).

Regardless of the domain of applications featuring HRI, there are always residual mechanical risks, unavoidable and often necessary for the implementation of the specific task or activity. This introduces a common perspective between service and industrial robots. Additionally, some mechanical hazards related to the operation of medical robots can be analogue to ones characterizing personal care service robots

or collaborative robots, considering both patient and therapist perspectives. This approach is supported to a small extent by cross-references between standards belonging to different domains (e.g. ISO/TR 23482-1 [4] references ISO/TS 15066 [5]). The EU funded project COVR “Being safe around collaborative and versatile robots in shared spaces” has developed a safety skills concept, proposed in [6] and detailed in [7]. This concept is designed to help users when executing system-level validation measurements (SLVM) of their HRI application. The idea of a SLVM provides users and integrators with a tool for the analysis of specific application conditions and considers the implementation, the modalities of the HRI, and the actual hazards as defined in the individual risk analysis.

This paper will provide an overview on the state of the art for ensuring safety of HRI applications and introduce the COVR lifecycle model to specify the various tasks involved when developing and implementing HRI applications. The COVR Toolkit, developed as a freely available website to support all COVR stakeholders along various phases of the COVR lifecycle model will then be described. The Toolkit aims to be the most comprehensive resource for supporting cobot stakeholders (coboteers) in ensuring the safety of their individual applications. The paper will end with an outlook on future developments of the COVR Toolkit and project.

II. STATE OF THE ART

A. Ensuring safety of physical human-robot interaction

The EC Machinery Directive MD/2006/42 defines the essential health and safety requirements that all machines brought onto the European market must observe, and is therefore a useful starting point for achieving self-conformity as indicated by the CE mark [8]. The directive also lists so-called harmonized standards that provide further guidance and requirements with respect to the essential health and safety of humans working with the said machines. It is not mandatory to follow these standards. However, their application confers the presumption of conformity to the essential requirements on the users, giving manufacturers a higher degree of certainty that their systems are safe. For this reason, this method is often used by robotics system integrators. Collaborative robots used for healthcare or rehabilitation purposes also require the CE mark to be made commercially available in the European Union (EU).

In addition to the Machinery Directive, the EU regulation 2017/745 (European Parliament and Council of the European Union, 2017), also known as the Medical Device Regulation (MDR) [9] is also required for robots used in healthcare and rehabilitation. The MDR emphasizes safety and performance during the entire lifetime of the HRI application.

Previous work [10] has highlighted the dilemmas raised by the cross-domain nature of robotics. Standards are currently by design domain-specific, i.e. their scope is intentionally limited to manufacturing or medical applications, and it is not always clear to a roboticist which standards are applicable to their system. Currently these standards covering different domains are not completely synchronized and can have conflicting requirements or recommendations. This can lead to uncertainty, especially when existing robots are adapted to be used in new domains or for multiple domains (i.e., an exoskeleton used for medical purposes is later used to support workers in manufacturing).

This work has been carried out within the framework of the European Project COVR, receiving funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 779966.

Standards that set specific requirements, e.g. on the safety of a cobot application, often also provide guidance on how to validate that these requirements have been achieved. It is however only in recent versions of robotics safety standards that such guidance for how to perform validation measurements has been provided. In the recent draft international standard (DIS) version of the ISO/DIS 10218-2 [11], published in late 2020 and currently in evaluation, greater attention to the issue of how to execute a validation measurement for power and force limiting (PFL) robots is given. Other standards which also provide testing procedures include the ISO 3691-4 [12], the ISO/TR 23482-1 and the ISO 18646 series. The ISO 3691-4 applies to driverless industrial trucks and automatically guided vehicles and provided guidance on testing procedures for the detection of persons and for stability tests. The ISO/TR 23482-1 provides “test methods ...to verify compliance to the requirements of 13482”, which is in turn related to personal care robots. The ISO 18646 series looks at measuring robot performance. The ISO 18646-1 [13] provides guidance for measuring stopping characteristics and rated speeds, and the ISO 18646-2 [14] provides guidance on testing obstacle detection and obstacle avoidance functionalities. This fragmentation of guidelines according to application area can be challenging for novice coboteers to navigate, especially given the cross-domain nature of robots, where a single robot system can be used for a wide variety of applications.

B. Lifecycle model for cobot application development

Based upon discussions with various coboteers, the COVR consortium adapted the generic life cycle model to highlight six particular lifecycle phases for the conception, design and implementation of collaborative robotics applications (Fig. 1). This was done with the aim of developing new COVR offerings tailored to each of these phases.

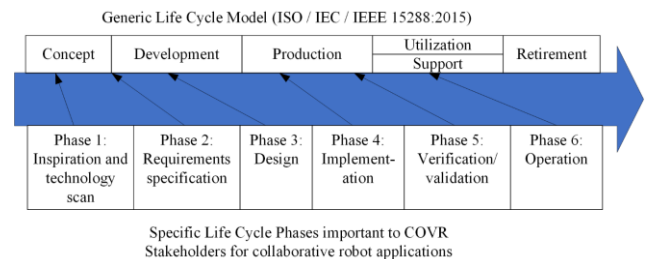


Fig. 1. Life cycle phases for cobot application development identified by COVR stakeholders and their relationship to the generic life cycle model

In the first phase, stakeholders are typically looking for inspiration from other available solutions. Typical questions that a stakeholder in this phase asks include “What has already been done? How was the issue of safety handled? Which safeguarding modes were used and what special issues needed to be considered?” In general, a stakeholder in this phase requires sufficient information to make an informed decision whether an available experience is applicable to their particular situation. The level of background knowledge of the stakeholders in this phase is widely varied, meaning the level of detail should be sufficient to give a robotics novice a clear understanding of the use-case, while also satisfying the curiosity of expert-level safety and robotics engineers.

An important part of the second phase is identifying essential health and safety requirements arising from

regulatory or standards conformity. A typical question faced by a planning engineer is, “What standards and laws are applicable to my system? Am I missing anything?” Again, stakeholders in this phase can have a wide variety of background knowledge.

In the third lifecycle phase, design, a team of engineers typically work together to design various aspects of the application, from a variety of perspectives such as mechanical, electrical, and software. A typical task in this phase is the risk analysis, which identifies relevant hazards, calculates the risk for each one, and then determines suitable risk reduction measures (RRM). While many engineers are familiar with the concepts of a risk analysis for a typical machine, HRI introduces additional hazards that can initially be difficult to estimate.

The implementation phase includes building up the system and testing all software. Before normal operation begins, the system performance with respect to adherence to safety requirements is typically checked through a validation measurement. As HRI applications are quite new, typical questions include, “How do I test? Can I test safety performance with a human worker or are there more suitable methods?”

Stakeholders are often surprised to learn that once their HRI application is in normal operation (phase six of the lifecycle model from Figure 1), that any change to the robotic system requires them to revisit the risk analysis and eventually perform new validation measurements.

The authors are not aware of any online services or guides that support coboteers along all these development phases. This lifecycle model was used to systematically develop the COVR Toolkit according to stakeholder needs along the various lifecycle phases.

C. Safety skills approach

In addition to the lifecycle model, the COVR project has defined six cross-domain safety skills. Safety skills were identified through two-pronged approach described in [6]. First, existing standards were investigated to determine existing operating/safeguarding modes. A second, bottom-up method included defining a wide variety of robotics applications, considering relevant hazards for these, and postulating mitigation methods. Safety skills are defined as an abstract representation of the ability of the robot system to reduce some risk. These can be executed in a variety of means and are indeed independent on how the protection against a specific hazard is delivered. A safety skill therefore simply describes the desired type of protection. An important characteristic of safety skills is that they can be validated for specific applications at a system level. This allows their use together with SLVM. The COVR consortium has identified six safety skills:

- Maintain safe distance (MSD)
- Maintain dynamic stability (DYS)
- Limit physical interaction energy (LIE)
- Limit range of movement (LRM)
- Maintain proper alignment (MPA)
- Limit restraining energy (LRE)

The authors would like to emphasize that these safety skills are not meant to replace existing definitions or supercede available standards. An overview of the correlation between operating modes as listed in various standards and the six safety skills can be seen in [7].

The concept of safety skills is important to understand when using the COVR Toolkit, especially as they are used for filtering various databases.

III. THE COVR TOOLKIT

The COVR Toolkit (www.safearoundrobots.com) was developed to be a freely accessible website that serves as a knowledge base for cobot stakeholders interested in safety (Fig. 2). The initial version consisted of a simple database which helps users to identify which standards and regulations are applicable for a specific robot type within a specific application domain. The Toolkit also included a database of protocols, which offered cobot stakeholders filtering tools to find relevant SLVM for their specific domain, type of robotic device and safety skill.

Based on feedback from COVR stakeholders, the Toolkit was expanded to include a wider set of offerings, focusing on the specific challenges faced by HRI application designers along the phases of the lifecycle.

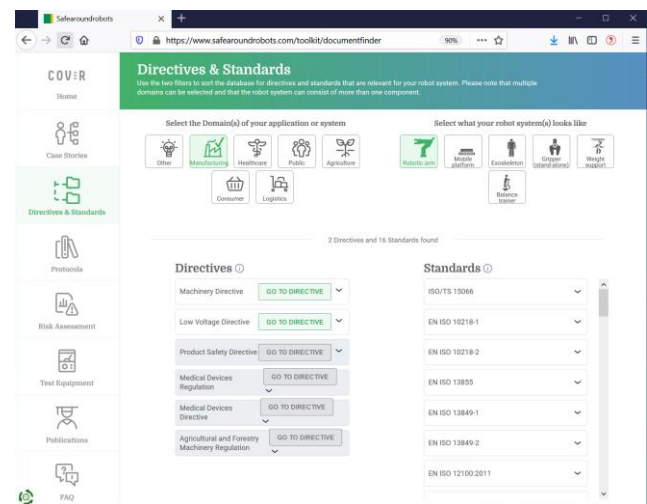


Fig. 2. Screenshot of COVR Toolkit, Directives & Standards sub-section

In the following sub-sections, the COVR Toolkit offerings and their relation to the lifecycle phases from the previous section will be described.

A. Case Stories

Case stories in COVR are meant to support coboteers during Phase 1 “Inspiration and technology scan” of the lifecycle for cobot development. The Toolkit currently contains over 20 case stories in the form of PDF documents of typically 3 pages, describing challenges, solutions and reflections from the projects funded by the COVR consortium. These so-called COVR Awards are short experiments with a run-time of 9 months, a budget of between 60.000-150.000€, and in a consortium of between 1-4 partners. Besides serving as inspiration for other coboteers, they are a way for us to share the experience built up by either COVR awards or experiences from the COVR community. Since these experiments are funded by COVR, we are able to demand a

higher level of transparency regarding safety challenges and considerations. While the typical length of a case story is intentionally short, they sometimes contain links to larger documents such as detailed project deliverables with experimental data and additional insights. Case stories are designed to be accessible and understandable by people with a low level of expertise, and the additional documents linked therein are targeted towards stakeholders with higher levels of expertise.

B. Directives and Standards

The Toolkit subsection “Directives and Standards” allows users to find the directives and standards relevant to a specific cobot installation/product, as is often the case in Phase 2 of the lifecycle. The tool works as a filter, with two parameters: the domain(s) that the cobot will operate in and the basic components of the system. The filter currently offers six different options for cobot type. This level of granularity was deemed sufficient to match the level of detail in the realm of directives and standards, where many different cobot types will be subject to the same regulation, while also being simple enough to understand by non-expert robotics users. The filtering allows for combinations of cobot types to be chosen.

C. Risk Assessment

A risk assessment is fundamental to any collaborative robotics application, and many stakeholders expressed interest in practical support with specific relation to cobots. This work corresponds to Phase 3 of the lifecycle. The first page of the Risk Assessment tool summarizes the relevant part of ISO 10218-2 [15] related to risk assessment. The page “Typical Hazards” is a video library containing short videos explaining how to identify and avoid/mitigate some of the most typical hazards with cobots. The “Step by step” page within this subsection is interactive and guides the user through the different steps in a risk assessment.

At the outset of the COVR project, the consortium believed this information was general knowledge and well-understood within the cobot community. We learned that while many companies did indeed have safety experts who were well versed in the execution of a risk assessment, their confidence for novel cobot applications was much lower and some guidance was requested, specifically including practical examples of what kinds of hazards are typically considered, and which are explicitly excluded. A future release will also contain a risk assessment template with some examples from various COVR Awards. However, there really is not a one-size-fits-all template, especially in consideration of the many available methodologies for assessing the risk and the effectiveness of risk mitigation measures. This sub-section is also designed to be able to be used by stakeholders with varying levels of background knowledge. Expert users will likely profit most from examples from other applications, and novice users will appreciate the videos and overall explanation for the process.

D. Protocols

As mentioned previously, the overall safety skills approach introduced by the COVR project supports users to perform SLVM. The consortium developed so-called protocols, which are step-by-step guides for how to execute these SLVM. The tool for finding relevant protocols works on the same principle as the previous one and draws data from the same database. There are twenty protocols in the current

version of the Toolkit, which are valid for following types of robot device:

- Robotic arm,
- Mobile platform
- Exoskeleton
- Gripper
- Weight support
- Balance trainer

The filter function allows the user to select device types and the safety skill, and then highlights which protocols are applicable for that system. The user can then download the protocols and use these when planning and executing their SLVM during Phase 5 of the lifecycle. The authors would like to note that there is no filter for domain, such as healthcare, manufacturing, or logistics. COVR protocols have been designed to be valid across domains and contain all the factors that users must consider related to certain situations/environments within the protocol itself.

E. Test Equipment, Publications, other

The subsection “Test Equipment” is a library of measurement equipment is that can be used in the execution of SLVM and is closely related to the protocols. The library is designed to help users find suitable equipment for measuring specific dimensions of interest such as force, pressure, distance, angle, etc. The COVR consortium has performed a market research to find equipment that is usable for safety validation measurement. The library is not meant to endorse any specific manufacturer and there is a feedback form for COVR stakeholders (including measuring equipment manufacturers) to offer suggestions for new devices not yet listed.

The Publications section of the Toolkit currently contains a library of 93 publications, all relevant to cobot safety. The library is continuously updated and offers functionalities for filtering and also for external users to make suggestions for additions. We have not been able to find any similar collection of publications on this topic on the internet, making this the first of its kind.

There are a number of questions about cobot safety that various stakeholders have posed to the COVR consortium. For these typical questions, the COVR Toolkit has a frequently asked questions (FAQ) section. This section is generally for stakeholders with a lower level of cobot safety expertise.

F. Feedback mechanisms

Custom-made online questionnaires were developed to systematically collect feedback from COVR Awardees and any users of the Toolkit. The Toolkit user survey has three main sections:

- Relevant information on the respondent and his or her use of the COVR Toolkit
- An abbreviated version of the Usability, Satisfaction and Ease of Use (USE) questionnaire [16]
- Suggestions for improvement

The Toolkit survey is anonymous and there is only one question regarding whether the respondent was involved in a COVR Award project. The questionnaires have proven to be

suitable for collecting in-depth information about the usage and user experience of the various COVR elements in the previous evaluation cycle.

We received 25 responses through the online Toolkit user survey, 20 of which are or were involved in the COVR project. Most of the participants reported they used the Toolkit several times or even regularly and they looked at several section contents or searched for specific information (Fig. 3). The sections that were most frequently browsed or used to search for information (Figure 3) were the sections Protocols (n=20), Directives and Standards (n=19), Risk Assessment (n=16) and Case Stories (n=14).

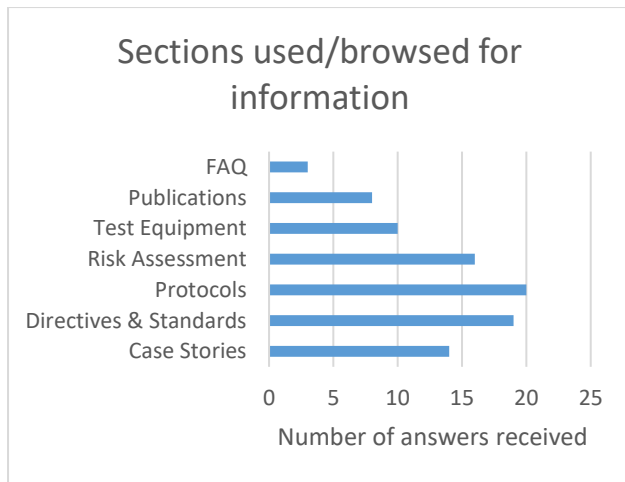


Fig. 3. Toolkit sections used or browsed for information by the respondents

All but one of the respondents indicated that the Toolkit can save time, mostly for people new to the subject of robot safety (n=11). The person who indicated that no, the information given in the Toolkit is not precise enough or not adapted to their case, suggested that the relevant information could instead be found by consulting a safety expert. When asked for an estimation of time saved, most respondents selected a few days (Fig. 4).

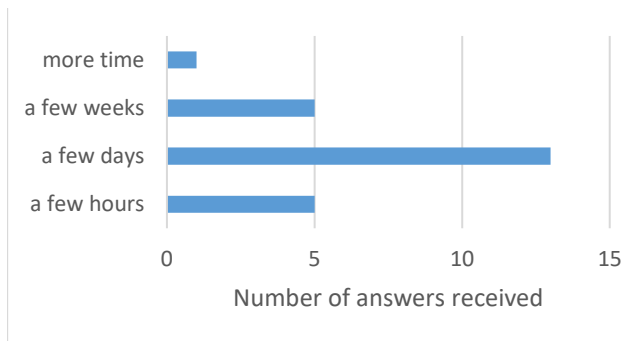


Fig. 4. Responses regarding estimated time saved due to Toolkit usage

The short version of the USE questionnaire resulted in a generally positive appreciation of the COVR Toolkit, with an overall average score of 5.6 out of 7 possible points (Fig. 5).

In addition to the Toolkit survey, we received also 20 responses through the protocol feedback form. This feedback was provided by 16 Award beneficiaries from 13 different COVR Awards. Most respondents mainly looked at the protocol to give feedback to COVR as an expert (n=7). Others

wanted to compare it with their current testing practice in safety validation (n=5), adapt it to test performance of a safety device (n=4) or of a safety function (n=3), or look how they could validate safety skills for a future application (n=1). The overall need and appreciation for the protocols was high (4.2 and 4.1 points out of 5 on average respectively). Most of the respondents found that the protocol they referred to in their evaluation is precise enough (n=14). Some found it a bit too complex (n=2) or not completely precise enough (n=4), but none of them selected the options unnecessarily complex or not precise enough.

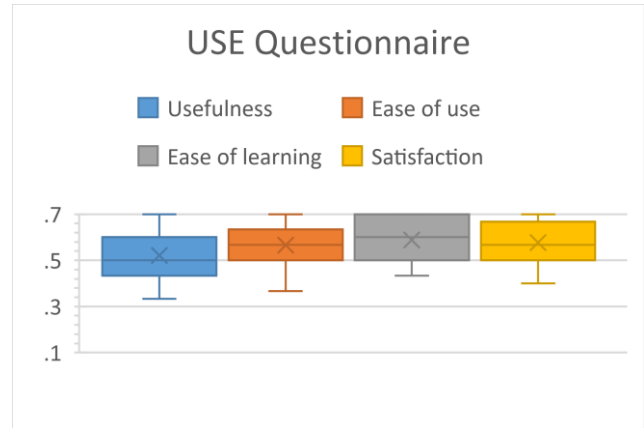


Fig. 5. Boxplots of USE questionnaire results (based on the mean per section and participant) as rated on a 7-point Likert scale (1: strongly disagree, 7: strongly agree)

Besides the use of online surveys, a number of other means for soliciting feedback on the Toolkit and protocols have been used. These include discussions in various workshops and through official interactions with various international standardization bodies. COVR organized yearly workshops at the European Robotics Forum (ERF) from 2018-2021, which typically had around 100 participants from research and industry and which offered at least one-third of the workshop time for discussions. Additionally, individual consortium members hosted over 10 specialized COVR workshops in 2020 and 2021. These workshops had between 20-90 participants from research and industry and also featured significant amounts of time for discussion and feedback. In terms of standardization activities, COVR initiated two separate activities in late 2020. At the European level, COVR initiated a CEN-CWA focusing on the overall structure of protocols and featuring two examples. Furthermore, the COVR consortium initiated an ISO-PAS focusing on the protocol for measurement of power and force limited robots. These activities have resulted in hundreds of individual comments to concepts of the protocols and safety skills, as well as on the contents of specific protocols. Both are expected to be published by late 2021 or early 2022.

IV. CONCLUSION

This paper deals with the topic of ensuring safety for new robotics applications featuring HRI. The cross-domain nature of robotics increasingly makes it difficult for robotics end-users and system integrators to identify relevant requirements, standards, and regulation.

The EU-funded project COVR has developed a web-based Toolkit designed to offer stakeholders with a wide range of background knowledge and expertise support along various

phases of the lifecycle. The Toolkit builds on the concept of safety skills to offer users a high degree of certainty regarding the relevant health and safety requirements, as well as practical guides for how to execute a risk analysis and how to perform system level validation measurements with various types of measuring equipment.

A major goal of COVR is building consensus with all relevant stakeholders, across Europe and the world. We look forward to continuing the discussion with relevant stakeholders from standardization, occupational and health insurance, safety verification bodies, and national regulation agencies, and the robotics community.

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