# The anthropometric basis for the designing of collaborative workplaces

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***Abstract*—The present paper deals with collaborative robotics and proposes to enable collaborative workstations by means of the critical study of the in-force standards on Human Robot Cooperation. The paper introduces the anthropocentric paradigm and presents a new basis for designing workstation composed by two key concepts: (i) human and robot spaces are elementary spaces able to generate all other spaces; (ii) dynamic variations of the elementary spaces in terms of shape, size and position occur. Moreover, dynamic positions of human and robot spaces enable collaborative operations in case of mobile robots.**

***Keywords—human-robot interaction, anthropocentric design, safety, dynamic workspace.***

## I. INTRODUCTION

Modern manufacturing plants are based on multi-stage processes [1] by alternating humans and robotic systems. Industry 4.0 pushes forward fully automated processes and it makes manufactures to implement more and more automated systems [2-4]; in such a context, humans contribute to participative designing [5, 6] but there are a lot of assembling processes which cannot be performed without human contributions. Several researches [7, 8] have assumed humans as central actors because they cannot be easily replaced by advanced technologies [7], but they should mutually reinforcing interactions [8].

Researchers [9, 10] claim that workstations could be more productive by combining: (i) human intelligence, (ii) flexibility and adaptability of the manufacturing line, (iii) strength, endurance and accuracy of robots. The combination of human beneficial characteristics with modern robots opens huge possibilities to simultaneously increase productivity, reduce ergonomically bad work postures [11] and increase the perceived well-being on shift [12]. The fusion of human-robot skills seems to be the key approach for manufacturing plant improvement.

Within this trend, the designing of manufacturing plants has to be based on three kind of workstations: (1) human workstation, station's tasks are performed only by humans; (2) robotic workstation, station's tasks are performed only by robotic systems; (3) human-robot workstation, hybrid workstation where station's tasks are performed by means of human-robot collaboration (HRC). Workstation types (1) and (2) are common use stations while workstation (3) is still not fully implemented due to safety reasons. In fact, moving among the in-force standards for collaborative workstation, in order to assure safety, could be very tiring. Besides, several rules and prescriptions are made by the organizations for standardization but sometimes they are only few guidelines [13-15].

An attempt to solve this *maze of rules* was done by using engineering design methods and identifying the specific applications for each standard [16].

In many cases, standards could be limiting (only static robot, no mention of mobile robot) or incomplete ("techno-centric" design). For example, the definition of operational space [13] does not mention: (i) the presence of the human as part of the process; (ii) human space required to carry out the task. Indeed, the current trend is to design a robotic workstation following a safety-based approach, starting from the task assessment, defining the allowed interactions between humans and robot systems (collaborative operations) and the workstation spaces such as the operative space and collaborative space. Finally, the human is added to perform the tasks where it is necessary to overcome the lack of robot. This is a "techno-centric" design, i.e. all aspects are focused on robots. Moreover, standards give no mention of a space that could be defined as "human workspace", where only the presence of the human is allowed and how this space should be identified.

Moreover, standards for collaborative workstation face only static robots that is clearly not enough in the modern smart manufacturing plant where more and more mobile systems are involved. Mobile robots (on rails or carried by autonomous systems) continuously moves the reference frame and therefore all the spaces are time-changing. The definition of dynamic space is a very challenging topic [17, 18]. Few researchers are focusing on mobile robots and AGVs [7]. They considered the cognitive stress that the mobile robots lead to the humans and proposed a "human-centred design for shop floor".

Several works [18, 19] have developed approaches for designing human-robot workstations; the main contributions

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are: (i) introduction of interaction modalities; (ii) definition of workspaces with accessibility properties. In [18], authors focus more on the definition of access spaces, identifying three dynamic areas (safe, warning and unsafe area) and analysing how the robot system should react to the human presence. More details of the interaction levels are provided in [19] where authors introduce the static and dynamic space concept. They move from a safety-based approach to one based on human-robot interactions assessing task's aim.

Therefore, by following the standards, human presence is usually recognised as an intrusion while workstation designing is safety-based and techno-centric through a static workspace. All the safety efforts push forward the limitation of the human presence as much as possible, and control hazard by protective stop, speed reducing and control system performance, in order to limit potential damage for human. Safety-wise, these aspects are a mandatory goal, but they do not allow (strictly limit) a synergetic HRC. To overcome this limitation, a "Huma Centred Design" should be adopted [20]. Thence, a new design prospective is required; we believe that design practices should follow an "anthropocentric design" approach: human should be at the heart of the whole design process.

The present paper highlights the basis for anthropocentric design focusing on two main topics: (i) elementary spaces for collaborative workstation; (ii) dynamic variations of the elementary spaces.

In the following, Section 2 introduces standards and literature definitions; Section 3 presents the Human-Robot Interaction (HRI); Section 4 explains the collaborative operations; finally, conclusions are depicted in Section 5.

## II. BACKGROUND DEFINITIONS

Standards [13-15] provide a first definition for workstation's spaces:

- *Collaborative workspace* – is the space, within the operating space, where the robot system (including the workpiece) and a human can concurrently perform tasks during production operation. Interaction operations are provided by ISO/TS 15066 [13].
- *Operational space* – is the portion of the restricted space that is actually used while performing all motions commanded by the task programme.
- *Restricted space* – is the portion of the maximum space restricted by limiting devices that establish limits which will not be exceeded.
- *Maximum space* – is the space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end-effector and the workpiece.
- *Safeguarded space* – is the space defined by the safeguarding perimeter.

Besides, the collaborative operations [13] can be summarized as follow:

- *Safety-rated monitored stop (SRMS)*: there is no collaborative workspace, the operational workspace is totally occupied by the robot that can work independently, and the human cannot stand by the robot while it is working;
- *Hand-guiding (HG)*: the human can stand by the robot in direct contact and control of it;
- *Speed and separation monitoring (SSM)*: a collaborative workspace exists and it depends on a combination of the relative distance and velocity of the robot system and human; below a certain distance, the robot system goes in a protective stop;
- *Power and force limiting (PFL)*: there is no minimum protective distance; the contact between robot system and human is allowed.

A different approach [18-19] for workstation design is based on two kind of collaborative interactions:

- *Workspace-sharing* - robot and human sequentially perform their tasks sharing the same workspace in different times;
- *Time-sharing*: robot and human concurrently perform their tasks without sharing workspace.

Time-sharing and workspace-sharing interactions can only exist within collaborative space. Relation between standards and collaborative interactions are represented in Table I.

TABLE I. COLLABORATIVE OPERATIONS FOR TIME AND WORKSPACE SHARING

| Operations<br>Interactions | SRMS | SSM | HG | PFL |
|---|---|---|---|---|
| **Shared workspace without shared task** | x | x | | |
| **Shared workspace and shared task**<br>NO PHYSICAL INTERACTION | | x | | |
| **Shared workspace and shared task**<br>PHYSICAL INTERACTION | | | x | x |
| **Shared workspace and shared task**<br>POSSIBLE PHYSICAL INTERACTION | | | | x |

## III. HUMAN-ROBOT INTERACTION

If we consider the anthropocentric basis for the designing of the collaborative approach, two elementary spaces can be proposed to classify the interaction between human and robot during the productive process:

- *human space* – is the locus of all human movements required to fully perform his tasks.
- *robot space* – is the locus of all robot movements required to fully perform his tasks.

According to the ISO standards and combining the proposed elementary spaces, different composed spaces could be defined (Fig. 1); furthermore, a detailed description of the features of such spaces could be accomplished as in the following.

### *A. Composed spaces*

- *Collaborative space* – is the intersection of robot and human space. The collaborative space is a dynamic combination of the elementary spaces characterized by different control rules. Human can interact with the robot system in safety mode.
- *Operational space* – is the union of human and robot space. It represents the space strictly necessary to carry out the operation considering the

presence of the robot and the human, the needed tools and journey.

- *Restricted perimeter* – is the perimeter that cannot be violated by a human not involved in the task.
- *Safeguarded space* – is the space out of the safeguarded devices, generated as offset from them.

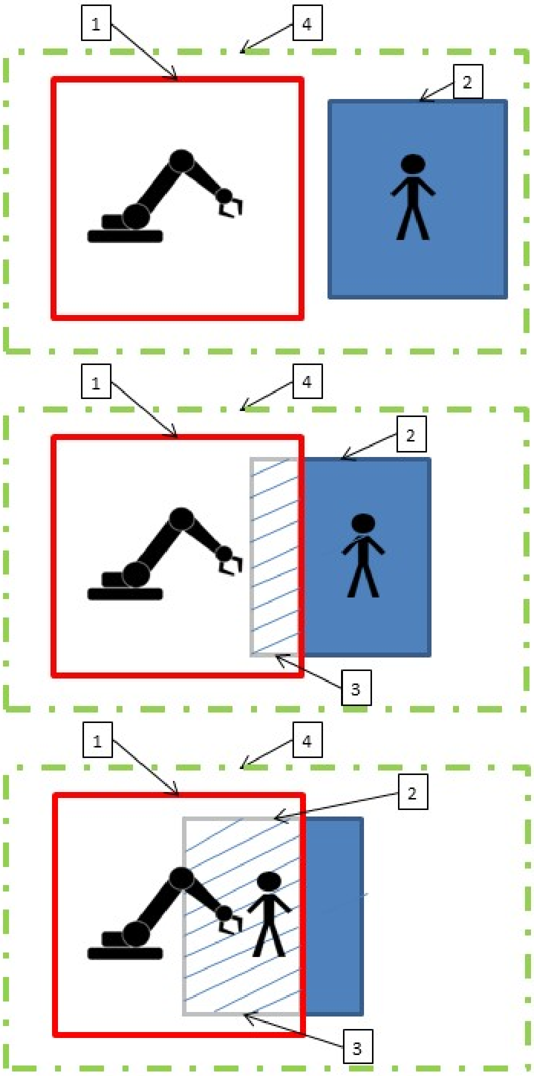

Fig. 1 Representation of the significant spaces: 1) Robot Space, 2) Human Space, 3) Collaborative Space, 4) Restricted Perimeters.

### B. *Features of existing spaces*

Elementary spaces can dynamically change their shape, size and position. As consequence, the spaces are no longer static, but can be dynamically adapt to the task. The control system can modify them following the task sequences or reacting to an unintended situation.

Space position, obviously, is strictly related to human or robot position during task execution. Space size is affected by both separation distance and relative speed magnitude between human and robot time-by-time. Space shape is affected by relative moving direction between human and robot time-by-time. Besides, shape is affected by specific task too.

As human and robot space can change during task, the collaborative space can also change; therefore, the operational space is dynamic too. In according to the definition, when human and robot space change in shape, dimension and position, the operational space follows those variations.

Starting from space definitions and their properties, it can be defined the collaborative operations and rules for enabling HRI.

## IV. DESCRIPTION OF COLLABORATIVE OPERATIONS

### A. *Safety-rated monitored stop*

Human and robot spaces are disjointed and intersection is forbidden while robot is working (Fig. 1). There is no collaboration space as well as collaborative operations. Human can approach workstation only with robot setting on stand-by mode. The robot space violation generally causes a protective stop of the robot system.

In this case, there is no real interactions between human and robot.

In such a scenario, human safety is guaranteed by limiting a proper collaboration. To enable HRC, a different conception of interaction should be adopted. During task execution, human and robot spaces are ideally overlapped and alternatively activated. Therefore, no time-sharing tasks are allowed. A protective stop occurs whenever human is enabled to enter by switching the activated space from robot to human space. Consequently, workspace-sharing is enabled.

### B. *Hand-guiding*

In hand-guiding operation, robot is a tool in human's hands. The operational space is all the space necessary to carry out the task. There is no a proper "robot space" because it does not execute own task. The workspace meets human requirements to handle the robot and carry out the tasks.

This case is not a collaborative operation, since human carries out tasks by handling the robot's end-effector.

Working spaces, with different access properties, should be defined, in order to guarantee human safety and enable the interaction.

Such operation identifies a collaborative workspace, which is characterised by time-sharing and workspace-sharing interactions. Within collaborative workspace, robot has no own and autonomous motion but it is guided by human.

Therefore, a robot space, defined as the motion domain of robot during the collaboration, is characterised by two sub-domains: (i) autonomous motion domain (outside collaborative workspace); (ii) guided motion domain which corresponds to collaborative workspace.

### C. *Speed and separation monitoring*

Human and robot can perform their task independently. Separation distance between human and robot has to be monitored in real-time in order to adjust robot's speed according to safety rules. Direct and indirect contacts are forbidden; moreover, violation of robot nearest perimeter causes a protective stop of the robot system.

Such a collaborative operation confines human and robot motion within a fixed and static areas (or domains depending only on relative speed and distance), as presented in the standards.

Using dynamic elementary spaces, it is possible to improve the interaction between human and robot by adapting position, size and shape.

Human and robot have their own space where they can perform their tasks. During the interaction, such spaces can intersect and overlap, generating different configurations.

The design of the workstation has to take into account the human comfort and the cognitive stress caused by the motion of the robot system. The prescriptions about speed limiting and minimum separation distance given in the standards are still valid. A time-sharing and workspace-sharing operation can be assumed between human and robot, and a kind of collaboration can occur, even if direct interaction is still forbidden.

### D. *Power and force limiting*

Direct and indirect contacts between human and robot are allowed, active and passive safety features are applied and human and robot can perform their task side by side. This is the higher level of interaction and, potentially, the most dangerous.

Although this operation represents a complete HRC, it is not widely used due to high cognitive stress (i.e. not predictable robot path) and the difficult to guarantee an appropriate safety level.

Human has to feel comfortable physically and mentally; he should have the whole control of the workstation knowing what happens surrounding him.

In order to improve power and force limiting, it is necessary to efficiently accommodate human and robot not limiting their capability by a severe safety-based design but combining them through interaction of the elementary spaces.

In this operation, the collaborative space is highly dynamic due to the concurrently motion of robot and human.

This operational mode can be used in combination with the other collaborative operations in order to improve the safety during the execution of the tasks and perform a larger set of operation.

## V. CONCLUSIONS

The present paper illustrates the contents of international standards related to collaborative workspace and it highlights the basis for anthropocentric design. The paper tackles two main topics: (i) human and robot spaces as elementary spaces; (ii) dynamic variations of the elementary spaces in terms of shape, size and position. Besides, it assumes human as a key subject for the collaborative operations success.

The human-robot collaboration is the new trend of the industry process characterized by low production volume. In the next years, HRC will likely be a more role of significance and could be widely used even in private and public fields. For this reason, it is very important to identify an innovative approach based on the anthropocentric paradigm. Moreover, workstation design requirements have to switch from an only safety-based design to a collaboration-based aspect too. The human presence shall be recognised as productivity element and no more as intruder but an active element of the workstation. These are keys aspects to really enable a useful HRC.

The future perspectives of the present work concern the validation of collaborative workspaces dynamically updated by taking into account a highly human-robot interaction.

## ACKNOWLEDGMENT

The present work was developed with the economic support of MIUR (Italian Ministry of University and Research) performing the activities of the project ARS01_00861 “Integrated collaborative systems for smart factory - ICOSAF”.

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