

Workspace Sharing with Proximity-Aware Robots: a Pilot on User Perspective*

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Abstract— This paper presents a study on key Human Factors considered in a Human-Robot Interaction (HRI) manufacturing scenario. We investigate user-perceived trust in collaborative robots, targeting crucial aspects such as acceptance, interaction fluency, cognitive workload, and usability. The experimental study is focused on a car door inspection and assembly task, where a human operator and a cobot operate side by side within a small shared workspace. The second link of the robot platform is equipped with 30 distributed proximity sensors that map the surrounding environment and detect nearby obstacles. Two distinct control strategies are evaluated for generating collision avoidance motions. The first strategy, Sensor Mounting (SM), leverages the sensors' mounting locations as control inputs to generate reactive avoidance motions, as described in [1]. The second approach, Whole-Body (WB), utilizes any point within the robot's geometric model, enabling both sensorized and non-sensorized links to respond to unpredictable events, as detailed in [2]. 24 subjects were involved in the experimental trials, performing assembly actions alongside a UR10e robot. Without prior knowledge of the control strategies employed, participants completed an online survey to rate their overall experience in both robot operating conditions (SM and WB). Results suggested that the WB proximity-aware controller did not compromise the system's perceived usability, trustworthiness, or efficiency. No statistically significant differences were observed among key subjective metrics ($p > 0.05$). Acceptance, usefulness, and satisfaction scores remained consistently high across both conditions. Finally, qualitative insights suggested users' preference for the WB control strategy, often described as more adaptive and responsive.

Keywords— Human-Robot Interaction, Proximity Sensing, Large-area sensors, Perceived safety, System Usability.

I. INTRODUCTION

With the advent of Industry 4.0 and its natural evolution into Industry 5.0, Human-Robot Collaboration (HRC) has emerged as a fundamental paradigm in modern manufacturing. As industries shift towards intelligent automation, HRC enables seamless cooperation between humans and robots, combining human adaptability and problem-solving skills with robotic precision and efficiency. This approach not only enhances productivity but also improves the ergonomics and the overall system flexibility, opening new scenarios for next-generation manufacturing systems.

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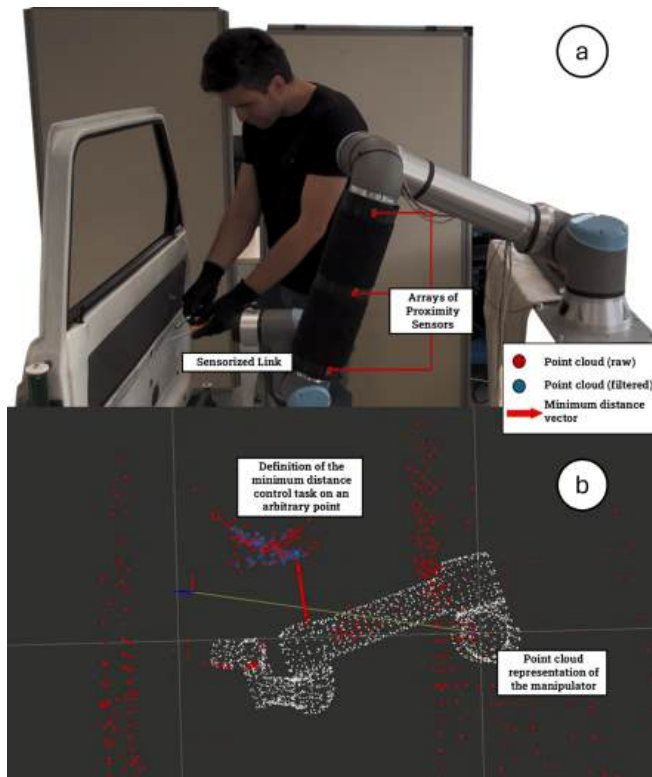


Fig. 1: (a) A close-up view of the experimental setup, showing the only UR10e sensorized link (the second one) equipped with ProxySKIN technology, which includes arrays of proximity sensors (indicated by red arrows).

(b) A top-down view of the RViz2 software is presented, showing in red the unfiltered point cloud of the robot, in blue the filtered one with mesh removal, and the vector representing the distance between the closest pair of points from the robot model and the environment point cloud, respectively.

To ensure safety in human-robot collaborative applications and address the uncertainties introduced by human presence in the shared workspace, robots are typically equipped with multi-modal sensing architectures. A well-established strategy involves the use of vision-based technologies, such as 3D cameras, LiDARs, and motion capture systems, to monitor the collaborative environment. These technologies are preferred for their ability to provide enhanced environmental awareness and detailed situational information, as demonstrated in [3]–[7]. Specifically, authors in [8]–[12] propose different vision-based solutions for tracking humans within the collaborative workspace and introduce different control architectures to ensure a safe robot operation. However,

vision-based interfaces can be prone to failure in cluttered or unstructured environments due to limitations in the sensors field of view, light sensitivity and environmental occlusions.

To address these challenges, researchers have explored alternative approaches based on different perceptual technologies. Distributed tactile sensors, as described in [13]–[16], stand out for their ability to precisely detect contact in physical Human-Robot Interaction applications [17] and clutter exploration [18]–[21]. In particular, distributed networks of tactile sensors can cover large areas of the robot’s body, enabling real-time obstacle detection, efficient contact force management, and enhanced interaction safety in unknown environments. However, tactile sensing technologies have inherent limitations in complex and dynamic scenarios, as they can only detect collisions after they occur rather than proactively preventing them. To overcome this limitation, proximity sensors have been investigated as a complementary or alternative solution, enabling robots to perceive obstacles before physical contact occurs [1].

The integration of distributed proximity sensor networks on the robot surface allows for robust and comprehensive environment perception. As shown in [1], [22], distance measurements collected by multi-zone Time of Flight (ToF) sensors can be used to generate a point cloud representation of the robot surroundings, detecting obstacles in close proximity to the robot body. However, Whole-Body (WB) sensor integration presents significant engineering challenges and demands substantial time, materials, and implementation effort. Hence, most studies, including [1], [23], [24], focus on deploying proximity sensors in specific areas of the robot body — typically those most prone to collisions and environmental interaction. To address this problem, in a previous work [2] we proposed a novel control strategy enabling WB avoidance motions through the use of localized proximity sensors. Building upon that approach, the WB algorithm fuses ToF sensors feedback with the robot’s geometric model through computational geometric methods. The robot’s model accounts for both sensorized and non-sensorized links, enabling reactive behavior in response to unpredictable events such as moving obstacles and humans. By comparing this control strategy with a baseline method described in [1], quantitative results suggest that our approach shows improvements in the safety distance margin between the robot and the detected obstacles up to 100 mm, due to the rendering of virtual avoidance tasks on non-sensorized links. However, to align with the Industry 5.0 paradigm and foster human-centricity in industrial settings while promoting socially sustainable workplaces, it is critical to address user-perceived trust towards cobots, along with acceptance, fluency, cognitive workload, and usability when designing human-centered robotic systems. Assessing users’ trust allows to determine whether operators feel comfortable and confident working alongside robots, directly impacting adoption and collaboration [25]. Similarly, acceptance reflects the willingness of users to integrate cobots into their workflows, which is essential for successful adoption [26]. Fluency in interaction ensures that human-robot collabora-

tion is efficient and intuitive, making shared tasks smoother [27]. Cognitive workload must be carefully managed to prevent mental overload or underload, enabling operators to focus on their primary responsibilities without excessive strain [28]. Usability determines how intuitive and accessible the system is [29], shaping the overall user experience and the long-term effectiveness of cobot implementation.

In this context, this paper presents a qualitative and quantitative analysis of safety perception in a Human-Robot Interaction manufacturing scenario. The user study involved 24 participants performing a car door inspection and assembly task while sharing the workspace with a collaborative robot. Participants carried out predefined actions while the robot operated under two distinct control architectures, as described in [2]. The specific control strategies were not disclosed to the participants to ensure unbiased evaluation. After each experimental trial, user-perceived trust in the collaborative robot was evaluated using an online survey.

The structure of the paper is outlined as follows: Section 2 details the methodology, highlights the differences between the control strategies employed, and analyzes the metrics evaluated on the questionnaire. Section 3 describes the experimental setup, whereas Section 4 reports quantitative and qualitative results. Lastly, Section 5 summarizes the research findings and suggests possible directions for future advancements.

II. METHODOLOGY

The control architectures used in this study to assess user-perceived trust in collaborative robots are based on the task-priority control framework presented in [18], which defines two priority levels: the highest is assigned to collision avoidance, while goal-reaching is managed at a lower level. As detailed in [2], the Sensor Mounting (SM) and WB controllers leverage a KD-tree representation [30] of the robot’s geometric model to perform a k-nearest neighbor search, identifying the pair of points with the minimum distance between the robot and the environment’s point cloud, as illustrated in Figure 1-b. Specifically, the closest point on the robot is used, through the definition and application of **task-induced Jacobian** and **rigid-body Jacobian** described in [2], to trigger the collision avoidance motion task. The only distinction between the controllers lies in the robot model employed, and, consequently, in the control point on the robot used to perform reactive collision avoidance. In the SM controller, this point is computed based on a geometric model of the robot that is limited to the sensor-equipped link, as illustrated in Figure 1-a. In contrast, the WB controller uses the entire geometric model, including non-sensorized links.

To investigate user impressions when interacting with the robot under the SM and WB control strategies, key aspects such as acceptance, interaction fluency, cognitive workload, and usability were examined. A dedicated questionnaire was designed to include the following metrics, assessed using validated psychometric scales:

- **Trust Toward Robots** [25]: a 10-item Likert scale (1–5) measuring participants’ trust in robotic systems.
- **System Usability Scale** [29]: a 10-item Likert scale (1–5) evaluating perceived usability.
- **NASA Task Load Index** [31]: a multidimensional workload assessment tool consisting of six items, each rated on a 100-point scale.
- **Fluency in Human-Robot Interaction Scale** [27]: a 6-item Likert scale (1–7) assessing perceived fluency and efficiency in human-robot collaboration.
- **Van der Laan Acceptance Scale** [32]: a standardized measure that assesses perceived usefulness and satisfaction, rated on a 5-point bipolar semantic differential scale.

These metrics were selected to comprehensively assess human-robot interaction quality across multiple dimensions critical for collaborative robotics acceptance [33]. Trust evaluates users’ confidence in robot reliability and safety, essential for effective collaboration and preventing under-reliance or over-reliance issues in industrial environments. Usability measures system ease-of-use and learnability, determining practical adoption potential and user satisfaction in collaborative workspaces. Cognitive workload assesses mental effort required during interaction, crucial for maintaining operator performance and preventing fatigue in industrial settings. Fluency captures interaction smoothness and efficiency, directly reflecting collaboration quality and team coordination effectiveness.

The questionnaire was administered using an online platform and structured in three phases: (1) demographic information and robotics familiarity collected before the first trial, (2) post-trial assessment after the first experimental condition, and (3) post-trial assessment after the second experimental condition, including a comparative question about perceived differences between conditions. Each assessment phase included all five validated scales to ensure comprehensive evaluation of user experience across both experimental conditions.

In addition to the structured assessments, participants responded to three open-ended questions designed to gather qualitative insights into their experience and perception of the interaction with both the SM and WB controllers. The first question asked whether they noticed any differences in the robot’s behavior between the two experimental conditions and, if so, to describe them. The second question explored the user’s overall experience when collaborating with the robot, allowing to reflect on aspects such as ease of interaction and adaptability. Finally, the third question focused on safety, prompting participants to identify specific interaction elements that influenced their perception of security. All subjective recorded data were analyzed alongside objective measures of the minimum human-robot distance to comprehensively evaluate the system performance in both SM and WB configurations.

III. EXPERIMENTAL VALIDATION

This section details the experimental setup and the tests performed to validate the implemented algorithms and assess user-perceived trust in collaborative robots using the SM and WB control architectures. Furthermore, a brief overview of the system architecture is provided. In our experimental setup, we used a UR10e robot from Universal Robots, partially equipped with distributed time-of-flight sensors. Specifically, 30 VL53L8CX proximity sensors by ST Microelectronics [34] were integrated into custom-designed, 3D-printed covers, enclosing the second link of the UR10e manipulator, as shown in Figure 1-a. Each ToF sensor offered a multi-zone depth sensing capability, generating up to 64 distance measurements organized in a squared grid and providing a coarse representation of the environment, as shown in Figure 1-b. Furthermore, these proximity sensors featured a maximum operational range of 4 m, a field of view (FoV) of 45° and a maximum data acquisition frequency of 15 Hz. During the experimental trials, to prevent cognitive biases among the participants, covers were also applied to the first robot link, but their sensors were kept idle and did not contribute to the construction of the environment point cloud. Geometric information about the robot surroundings was sampled only through the sensors located on the second link, as shown in Figure 1-a.

The system architecture is based on the ROS 2 Humble distribution, running on a standard Linux (Ubuntu 22.04) kernel without real-time extensions. Therefore the existing configuration does not provide hard real-time guarantees and is used primarily as a proof-of-concept to evaluate the proposed control strategies.

A. Shared workspace HRI experiments

The experimental task consists of a sequence of simulated assembly actions that the human must perform on a car door, while the robot autonomously moves in the shared workspace. In this coexistence scenario, both the robot and the human are assigned specific targets shown in Figure 2:

- The blue waypoints **H1**, **H2**, **H3** indicate the locations on the car door where the human operator must perform his assembly operations (e.g. screwing, clamping).
- The red waypoints **R1** and **R2** indicate the goal positions that the robot must sequentially reach.
- The four regions **P0**, **P1**, **P2** and **P3** marked on the ground, indicate the working positions where the human operator must stand to perform his tasks.
- **T1** and **T2** indicate the tool changing positions, located respectively to the left and right of the robot base.

The experimental trials involved 24 participants (8 females, 16 males) aged 24 to 40, all of whom were university researchers with diverse professional backgrounds in robotics, biomedical engineering, and electronics. Recruitment was conducted through flyers posted on the bulletin board of our university pavilion. Each participant performed two different assembly cycles within the shared workspace. Each experiment was repeated twice, once with the robot

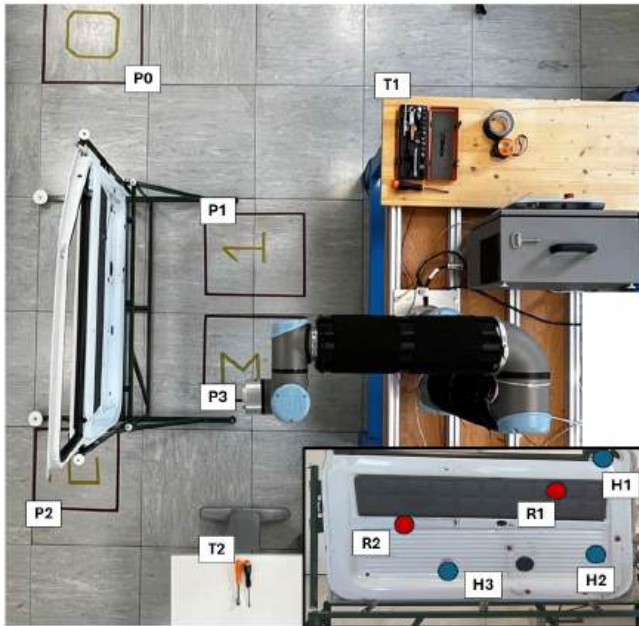


Fig. 2: Experimental setup configuration for the shared workspace scenario. Robot motion waypoints R1 and R2 are marked with red dots, while blue dots represent the assembly locations for the subjects (H1, H2 and H3). The bird-eye view shows the locations used as markers for the assembly cycles progression, as well as the two toolbox locations represented as T1 and T2.

controlled by the SM controller and once by the WB controller.

- 1) In the first trial, participants started the assembly task from position **P0** and moved towards the toolbox **T1**, located to the left of the robot base, standing in **P1**. After 10 seconds, they were instructed to move toward the **H1** target on the car door, perform the assembly operation with a screwdriver for about 15 seconds. Once finished, participants were asked to return to **T1**, change the tool for a ratchet wrench and, after 10 seconds, move towards the target **H2** to assemble another component for 15 seconds. Finally, users had to return to **T1**, drop the tool, and leave the shared workspace. The overall task lasted approximately one minute;
- 2) The second trial had a very similar structure to first one, but in this case participants were asked to perform both the screwing and ratcheting operations on the same target **H3**. Participants joined the shared workspace starting from position **P2** and approached the tool position **T2**. The area designated for performing the screwing and ratcheting operations was indicated by **P3**. The duration of this trial was comparable to the previous one.

Figure 3 depicts the assembly procedures executed by two participants during the first (top) and second (bottom) assembly trials over time.

Throughout the duration of both trials, the robot only moves between the red goals R1 and R2 and does not perform any actual operation, as the tool has been omitted.

This configuration was intentionally implemented to focus exclusively on the effects of proximity-based sensing and evaluate user-perceived trust and safety under controlled conditions.

B. HRI Performance Evaluation

To evaluate the performance of the proposed WB and SM robot controllers and assess users' perceived trust in collaborative robots, we utilized both objective and subjective metrics. In particular, to obtain an objective perspective on the robot's behavior using the SM and WB control architectures, we analyzed the minimum distance computed between the robot and the human operator during each phase of the experiment. A detailed analysis of the experimental objective metrics considered in this study can be found in [2]. In addition, participants were asked to complete an online questionnaire after the **SM** and **WB** experiments to investigate their impressions. The questionnaire completion process was divided into three phases:

- **General Information:** The first part of the survey gathered data on participants' confidence and familiarity with robotics. This form was completed before the first experimental trial.
- **Perceived Safety and Reliability in trial 1:** The second part, completed immediately after the first trial, assessed participants' perceived safety during task execution and the robot's reliability in performing its task correctly.
- **Perceived Safety and Reliability in trial 2:** The third part of the survey, identical to the previous one, focused on the second experiment. It included an additional question asking participants if they noticed any differences in the robot's behavior between the first and second trials.

To avoid systematic patterns that could influence the outcomes of the survey, the order of WB and SM experiments was randomly shuffled and not disclosed to participants. As a result, 12 subjects completed the WB experiment first, while the remaining 12 completed the SM experiment first.

IV. RESULTS AND DISCUSSION

This section analyses the subjective results collected from the HRI trials survey and compares them to the objective experimental metrics reported in [2]. The survey results indicate that participants generally perceived the system as trustworthy, usable, and effective in both configurations. Prior to statistical analysis, data normality was assessed using Shapiro-Wilk tests. All variables satisfied normality assumptions (Trust: $W = 0.93-0.94$, $p > 0.10$; Usability: $W = 0.94-0.94$, $p > 0.22$; Cognitive Workload: $W = 0.93-0.95$, $p > 0.24$; Fluency: $W = 0.94-0.95$, $p > 0.19$), enabling the use of paired t-tests. No statistically significant differences were observed between conditions (all $p > 0.05$), suggesting that the controller based on the WB approach did not negatively impact the perceived quality of interaction. Instead, it maintained a high standard of user experience while enabling advanced proximity-aware behaviors.

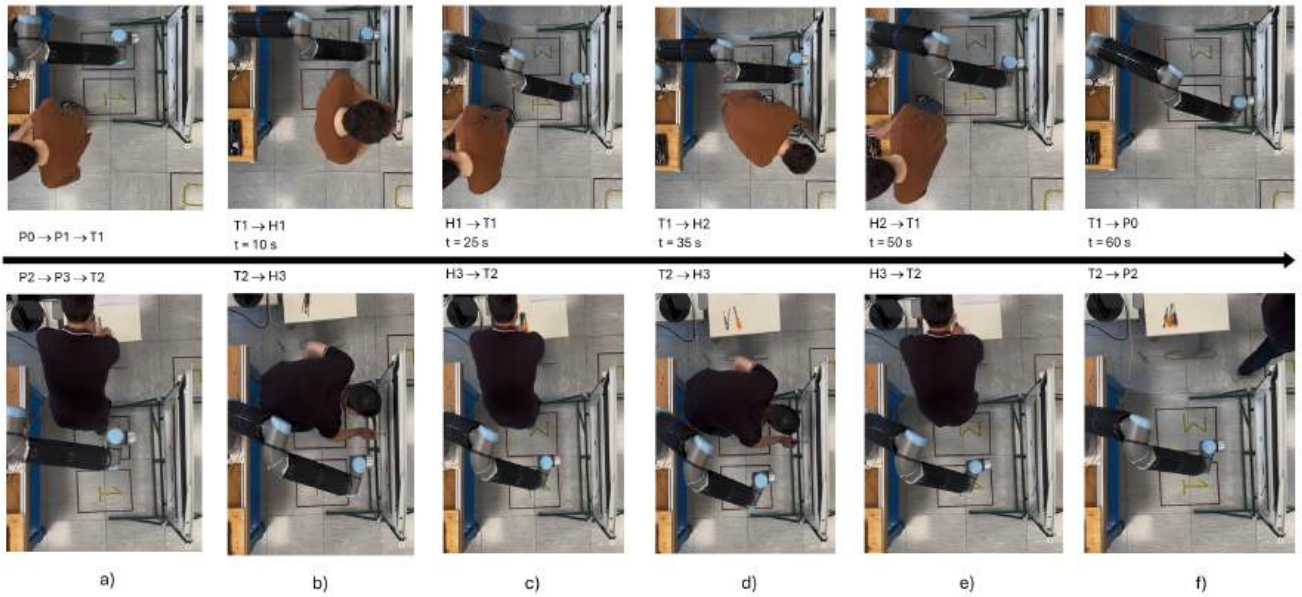


Fig. 3: Timeline of the assembly cycle. (a) The subject enters the shared workspace and reaches the target toolbox location. (b) When the first acoustic signal is given, the subject moves to the first assembly target, while the robot attempts to reach its assigned waypoints. (c) The subject is signaled to move back to the tool location to simulate a tool change. (d) After 35 seconds in the cycle, the subject moves towards the second assembly location and performs the mockup task for 15 seconds more. (e) At the 50 seconds mark the subject is prompted to reach the toolbox one last time to leave the tools, then is asked to leave the workspace and to go back to the initial location (**P0/P2**) as shown in (f).

TABLE I: Comparison of the mean (\bar{X}) and standard deviation (σ) for SM and WB approaches across the four evaluation metrics.

Metric	SM		WB	
	\bar{X} (Mean)	σ (SD)	\bar{X} (Mean)	σ (SD)
Trust	4.27	0.536	4.25	0.471
Usability	4.29	0.430	4.22	0.395
Cognitive Workload	25.69	10.65	25.73	9.509
Fluency	6.30	0.620	6.16	0.664

As highlighted in Table I, participants reported high levels of trust in the robot across both conditions (SM: $\bar{X} = 4.27$, $\sigma = 0.536$; WB: $\bar{X} = 4.25$, $\sigma = 0.471$). Similarly, perceived usability remained comparable (SM: $\bar{X} = 4.29$, $\sigma = 0.430$; WB: $\bar{X} = 4.22$, $\sigma = 0.395$). Cognitive workload showed minimal variation between configurations (SM: $\bar{X} = 25.69$, $\sigma = 10.65$; WB: $\bar{X} = 25.73$, $\sigma = 9.509$). Fluency in interaction was consistently highly rated (SM: $\bar{X} = 6.30$, $\sigma = 0.620$; WB: $\bar{X} = 6.16$, $\sigma = 0.664$).

TABLE II: Mean (\bar{X}) and standard deviation (σ) for SM and WB across subscale metrics.

Metric	SM		WB	
	\bar{X} (Mean)	σ (SD)	\bar{X} (Mean)	σ (SD)
Acceptance score	4.20	0.346	4.18	0.386
Usefulness	4.47	0.356	4.33	0.310
Satisfaction	4.10	0.596	3.94	0.603

Participants' acceptance of the system remained consistently high across conditions. As indicated in Table II the total acceptance score was similar between the SM approach ($\bar{X} = 4.20$, $\sigma = 0.346$) and the WB approach ($\bar{X} = 4.18$,

$\sigma = 0.386$). When considering the usefulness subscale, the WB approach received slightly higher ratings ($\bar{X} = 4.47$, $\sigma = 0.356$) compared to the SM approach ($\bar{X} = 4.33$, $\sigma = 0.310$). Conversely, for the satisfaction subscale, ratings were slightly higher in the SM case ($\bar{X} = 4.10$, $\sigma = 0.596$) compared to the WB case ($\bar{X} = 3.94$, $\sigma = 0.603$).

The qualitative feedback provided additional insights into participants' experiences, based on responses to three open-ended questions. First, participants were asked whether they noticed differences in the robot's behavior between the two experimental conditions. While some ($n = 8$) did not perceive substantial differences, others ($n = 11$) described the WB controller as more responsive and better adapted to human movements. A few ($n = 3$) also reported feeling safer, attributing this to the robot's ability to adjust dynamically to their proximity. One participant remarked that in the WB experiment, the robot seemed to perceive their presence better, preventing accidental collisions: *[In the WB experiment], the robot seemed to perceive my presence better, and I didn't accidentally collide with it like I did in the other test.* Another noted how the improved responsiveness contributed to a smoother interaction: *I felt that the robot [with the WB controller] moved in a more fluid way and responded better to my movements, which gave me a stronger sense of control.* However, some ($n = 2$) found the WB controller movements slightly more abrupt or less precise. One participant pointed out: *The robot [with WB controller] felt slightly less precise compared to the other one, with more small, unnecessary movements.* Similarly, another described difficulties in predicting the robot's next action: *Sometimes, the adjustments [in WB experiment] felt slightly unpredictable, making it*

harder to anticipate its next movement. These responses suggest that the WB approach generally enhanced interaction and safety, and only minor inconsistencies in movement smoothness were noted.

This is consistent with the statistical analysis on the minimum absolute human-robot distance reported in [2]. In particular, results show that on average the minimum distance along the whole experimental trials using the SM and WB controllers are comparable when users approach the workcell from **P0** (SM: $\bar{X} = 0.331$ [m], $\sigma_{max} = 0.129$ [m]; WB: $\bar{X} = 0.339$ [m], $\sigma_{max} = 0.126$ [m]). In contrast, when the assembly task starts from **P2** the WB algorithm exhibits slight performance improvements with respect to SM (SM: $\bar{X} = 0.285$ [m], $\sigma_{max} = 0.189$ [m]; WB: $\bar{X} = 0.310$ [m], $\sigma_{max} = 0.167$ [m]), since the avoidance tasks are generated on the non-sensorized robot wrist, which gets closer to the subject when using the SM algorithm. Further details can be found in [2].

Secondly, participants described their overall experience of collaborating with the robot. Most responses indicated that the interaction was smooth and efficient across both conditions, with a preference for the WB controller among some ($n = 14$) who perceived it as more adaptive to their actions. As one participant expressed: *When I interacted with the robot [with the WB controller], I noticed it moved in coordination with me, which felt very natural.* Another appreciated how the robot's responsiveness contributed to a more intuitive interaction: *I felt confident working near the robot [with the WB controller]. The fact that it seemed to recognize my presence made it feel more like a collaborative partner rather than just a machine.* For some ($n = 3$), however, the experience remained largely the same across conditions. One participant stated: *Both conditions felt similar. The robot moved in predictable ways, and I didn't notice any major changes.* Another shared a similar impression: *Regardless of the configuration, the robot's behavior remained consistent.*

Finally, participants reflected on the aspects of interaction that influenced their sense of safety. Many ($n = 9$) emphasized the importance of movement speed and proximity awareness, with several ($n = 7$) stating that the WB approach increased their confidence in the system. One participant described feeling reassured by the robot's ability to actively adjust to their presence: *I felt safer when I interacted with the [WB controlled] robot because it adjusted its position to avoid me, rather than just following a pre-set path.* Another highlighted the significance of real-time adaptation: *Knowing that the robot could detect me and react accordingly made me feel more at ease compared to the first test.* Only a few ($n = 3$) raised concerns about movement consistency. One participant noted: *Although I felt safe in both cases, the slight jerkiness [in the WB experiment] was something I noticed.* Similarly, another observed occasional delays: *The robot's reactions [in WB experiment] sometimes felt slightly delayed, making me question how accurately it sensed my presence.*

The results suggest that the WB controller did not adversely affect the perceived usability, trust, or efficiency of the system. Psychometric evaluations consistently produced

high ratings in both scenarios, indicating that the system effectively maintains a reliable and favorable user experience.

V. CONCLUSIONS

In this paper, we presented a user study exploring participants' perceived safety in a human-robot interaction assembly scenario. In particular, subjects were instructed to perform predefined tasks while sharing the workspace with a UR10e robot, which was partially equipped with multi-zone proximity sensors and operated under different control strategies (SM and WB). Subjective responses were collected from 24 participants using a custom-designed questionnaire, which evaluated key human factors metrics to analyze the interaction experience in both robot operating conditions. The psychometric measures consistently showed high ratings across both the SM and WB experimental trials, showing that our system effectively maintains a stable and positive user experience. The absence of significant differences in trust, usability, interaction fluency, acceptance, and workload ratings indicates that the enhanced proximity-awareness features did not disrupt users' perception of the robot's reliability and effectiveness. Although the quantitative results across the four human factors metrics showed only small differences between the two controllers, the qualitative feedback revealed a more nuanced perception of the system. Participants generally expressed a positive impression of the WB control system, often describing it as more adaptive and responsive. While some noted minor inconsistencies in motion accuracy, the prevailing sentiment reflected an appreciation for the robot's ability to recognize and react to human presence dynamically. These findings are consistent with the objective absolute minimum distance results reported in [2], showing improvements in the safety margin distance between the operator and the robot operating under the WB control strategy. These results highlight the potential advantages of whole-body proximity-based adaptation in industrial robotics. By maintaining a high standard of user experience while incorporating advanced sensing capabilities — and in the absence of any negative effects on trust, usability, or workload — such systems may facilitate smoother and safer human-robot interaction in shared workspaces.

Future research will involve a larger and more diverse participant population, enabling a more robust statistical analysis of key human factors such as acceptance, interaction fluency, cognitive workload, and usability. The HRI assembly task will be extended to a more complex scenario, featuring a heavy-duty industrial robot and a cobot actively collaborating with a human operator inside a car chassis to install the rooftop.

Therefore, operating in such a scenario—focused on more realistic industrial assembly tasks—requires shifting the focus from a conceptual safety perspective to a certified safety approach, in accordance with the safety regulations defined in ISO 13849 and ISO 10218, including the specification of Performance Levels (PL), minimum separation distances, and permissible robot velocities [35].

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