# "*They're not going to do all the tasks we do*": Understanding Trust and Reassurance towards a UV-C Disinfection Robot

Maria J. Galvez Trigo*, Gisela Reyes-Cruz†, Horia A. Maior†, Cecily Pepper†, Dominic Price†, Pauline Leonard‡, Chira Tochia‡, Richard Hyde§, Nicholas Watson¶, and Joel E. Fischer†

***Abstract*—Increasingly, robots are adopted for routine tasks such as cleaning and disinfection of public spaces, raising questions about attitudes and trust of professional cleaners who might in future have robots as teammates, and whether the general public feels reassured when disinfection is carried out by robots. In this paper, we present the results of a mixed-methods user study exploring how trust and reassurance by both professional cleaners and members of the public is affected by the use of a UV-C disinfection robot and information about its performance after disinfecting a simulated classroom. The results show a range of insights for those designing and wishing to deploy UV-C robots: we found that trust and reassurance are affected by information about the UV-C robot's task performance, with more information coinciding with significantly more agreement to be able to judge that the robot is doing a good job. However, care should be taken when designing information about task performance to avoid misinterpretation. Overall, the results suggest a generally positive picture regarding the use of UV-C disinfecting robots and that cleaning professionals would be happy to have them as their teammates; however, there were also some concerns regarding the effect on less-skilled jobs. Taken together, our results provide considerations to make UV-C robots welcomed by cleaning teams as well as to provide reassurance to space users.**

***Index Terms*—human-robot interaction, UV-C light, disinfection, trust, reassurance**

## I. Introduction

Mobile robots that use short wavelength ultraviolet light (UV-C) to inactivate or kill microorganisms and pathogens for disinfection (including effectively inactivating viruses such as COVID-19 [13]) have the potential to complement the work of cleaning teams (e.g. in hospitals [23]); and they may reassure people that the space is safe to use. Past research has explored how mobile cleaning robots are used in domestic settings [11], and there are a range of publications on robotic topics such as path-planning related to UV-C robots (e.g., [1], [5]). However, to the best of our knowledge there is currently a lack of Human-Robot Interaction (HRI) studies on the trust towards mobile UV-C robots and whether people feel reassured to enter and make use of a disinfected space as a result. Furthermore, prior work has argued that as UV-C robots do not replace (manual) cleaning, they need to be integrated in existing cleaning and disinfecting practices [23]; and while we would assume that it is productive to think about these robots as tools or 'teammates' for the cleaning teams—not as replacements—we wanted to explore the views of professional cleaners.

Thus, we designed a "mixed-methods" study to investigate trust and reassurance towards a mobile UV-C disinfecting robot both by a) professional cleaners, to explore their views towards potentially integrating the robot into their cleaning team, and b) the general public, to explore how reassured they feel as a result of the UV-C robot disinfecting a public space (i.e., a classroom) that they would enter and use. As direct interaction with these robots while they are in operation is unsafe without protective clothing due to UV-C light being harmful to people, we focus on the effects that safe observation of a live-feed from a distance has on people's trust and reassurance. The study presented here aims to answer the following research questions:

- RQ1 What are the expectations of both professional cleaners and the general public towards UV-C disinfecting robots?
- RQ2 How do different approaches to inform and educate people about the UV-C robot's task performance affect self-reported reassurance to use the space?
- RQ3 How do both professional cleaners and the general public feel about the use of UV-C robots after having experienced the UV-C robot in the study?

## II. Related Work

### A. Trust and reassurance towards robots

Trust is a complex and multidimensional concept that has been extensively investigated in the domains of HRI and automation [12], [14], being recognised as a major factor influencing effective collaboration in human-robot teams [12], and increasing acceptance of robots as collaborators or service providers [16]. Trusting a robot is strongly dependent on the robot's performance and attributes such as type, size, proximity, and robot behaviour [14]. Further, robot reliability directly impacts trust building; that is, positive

This work has been supported by the UKRI Trustworthy Autonomous Systems Hub and Horizon: Trusted Data-Driven Products, Engineering and Physical Sciences Research Council [grant numbers EP/V00784X/1, EP/T022493/1].

*School of Computer Science and Informatics, Cardiff University, †School of Computer Science, University of Nottingham, ‡Faculty of Social Sciences, University of Southampton, §School of Law, University of Nottingham, ¶Faculty of Engineering, University of Nottingham.

Corresponding author's email: galveztrigom@cardiff.ac.uk

perceptions that a robot can perform its function properly provoke higher trust in it [14], whereas robot errors decrease said trust [9], [21]. Research has argued that trust in robots has recently increased as a result of the COVID-19 pandemic [28], and that trust is at the core of the (non-)use of robots in healthcare [2]. Although investigating trust towards robots is not new, the concept of *reassurance* in relation to trust development has not been explored in HRI. Reassurance has been considered as a feeling humans seek to counter dis-trust [17], [19], it has been associated with decreasing stress and anxiety, and usually consists of educating people [20]. In our study, this "education" takes the form of different levels of information available to the user about the UV-C robot's task performance.

### *B. UV-C robots for disinfection*

Systems using UV-C light for sanitising healthcare environments (e.g., patient rooms, hospital theatres) have been long developed and implemented [5], [15], [23], evolving from stationary machines to mobile robotic systems. Design and deployment of UV-C robots for disinfecting other public settings have proliferated since the COVID-19 pandemic began [1] having reached an estimated inflexion point in mid-2020 [6]. Despite a plethora of UV-C robotic systems both in the market and under research and development [15], research on UV-C robots mostly focuses on technical matters such as improving efficiency, reliability, and cost [5], and only a few studies have focused on understanding people's perceptions of them [10], [24]. Little is known about human interaction with UV-C robots and about feelings of trust and acceptance towards them, especially as UV-C light can be harmful to people, potentially leading to vision damage, burns, or the development of skin conditions such as allergies or melanoma [26]. Although general positive attitudes to adopt these systems have been reported, people have little knowledge of their functionality. Moreover, there are inconclusive understandings of their fears of being replaced [10], [24]. Cleaners could see the UV-C robot as something threatening to take over their job [3], or as just a tool to support their cleaning work which due to its 'non-routine manual' nature may be less prone to automation [7].

## III. The Study

The study presented in this paper followed a mixed-methods approach, and was run at the University of Nottingham. The robot used during the study is a Helios UV-C disinfection robot [1], a mobile robot that uses shortwave ultraviolet light for the disinfection of spaces. This robot is designed to not operate when a human is present, having sensors that trigger shut off if nearby movement is detected. The study was approved by the university's ethics committee. Health and safety concerns were mitigated by assurances to never switch on the UV-C robot at any point during the study—unbeknown to the participants.

[1]https://www.uvclight.co.uk/helios-uvc-robot/

### *A. Design*

Our study had three main stages, as follows.

*1) Stage 1 - Pre-study questionnaire:* Questions on demographics, prior experience or exposure to robots and expectations about the UV-C disinfecting robot used in our study (prior to having seen it).

*2) Stage 2 - Experimental user-study:* We designed a user-study to understand how various approaches to informing and educating space users about the disinfection tasks carried out by the robot may affect the trust towards the robot and its disinfection, and how reassured they feel to use the space as a result. Participants were asked to imagine they would take part in an activity in a classroom setting. Practically, we asked them to enter our lab (laid out in a classroom setting, see Fig. 1) after having been disinfected by our UV-C robot, and then choose a seat where they would sit, following three conditions:

- C1 Participants can see a plain-text sign reading "This space has been disinfected by our UV-C disinfecting robot" before entering the room;
- C2 Participants can see the same sign as before, and additionally, they are shown a "live feed" of the robot disinfecting the space prior to them entering the room (a still image of this can be seen in Fig. 1);
- C3 Participants are shown a visualisation mock-up with detailed information on the disinfection carried out by the robot, as can be seen in Fig. 2.

In each condition participants are given more information about the task performance of the robot. We designed the mock-up shown in Fig. 2 for the purposes of engaging the participants in reflecting whether this type of information could be reassuring or not, not as an accurate visualisation of radiation. Our working hypothesis was that, for each condition, with the addition of new data or information about how the robot performs the disinfection task, participants would feel more reassured to enter the space than in the previous one, and make better informed decisions about where they would sit. Note that "seat choice" here is a proxy for a behavioural measure, i.e., it would show whether people would change their behaviour as a result of the information. After each of the conditions participants were asked to fill out a post-condition questionnaire with Likert-scale statements on a 5-point scale to explore their feelings of safety and reassurance.

*3) Stage 3 - Post-study questionnaire:* Questions on expectations about the UV-C disinfecting robot used in our study (after having participated in the user-study), and questions on their opinions and feelings about having a robot like the one used in our study as part of their team at work. This later questionnaire, administered to participants involved in professional cleaning services, was designed following the principles of the Technology Acceptance Model (TAM) [25], which explores the perceived usefulness and usage intentions for a new technology participants are presented with, to evaluate their acceptance of said new technology. The questionnaires had 5-point Likert responses (strongly disagree to strongly agree). The whole process followed a semi-structured interview style, adding to participants' responses to the paper-based questionnaires, to seek clarifications, contextualise their answers and overall experience during the different stages of the study.

Fig. 1: "Live feed" shown to participants in C2.

### B. Participants

Twenty three participants from different age-groups (over 18) were recruited (ten male, thirteen female). Thirteen participants indicated that they were professionals in the cleaning industry or that their job, fully or partially, related to cleaning services. Participants belonged to different groups: students and employees of the institution organising the study, some working in professional cleaning services; professional cleaners from other sectors; and members of the general public.

### C. Procedure

After ethical approval was obtained, respondents to a call for participants were invited in pairs to meet a member of the research team in person at at a previously agreed time to encourage conversation between participants about their experience during the study. Upon arrival, participants could ask questions and their informed consent was obtained. From this moment, their conversation with the researcher leading the sessions was audio-recorded. They were encouraged to share their thoughts with each other and the researcher, following the think-aloud protocol.

Stage 1 and Stage 3 were completed in a separate room. For Stage 2, participants were led to the lab space set-up as a small classroom or seminar room (Fig. 1). Before entering, they were presented with the information relevant to each condition (i.e., plain-text sign, "live feed" of the disinfection, or visualisation). Upon entering the room, participants could see the robot after it finished disinfecting the room and were asked to choose a seat as if they were attending a seminar or lecture there. Afterwards, participants were led back to the initial room, where a post-condition questionnaire was administered. This process was repeated for the three conditions described.

All participants were taken through the three conditions in the same order: C1 - C2 - C3, as our working hypothesis posits order effects (i.e., information given in each condition affects stronger agreement with feelings of reassurance).

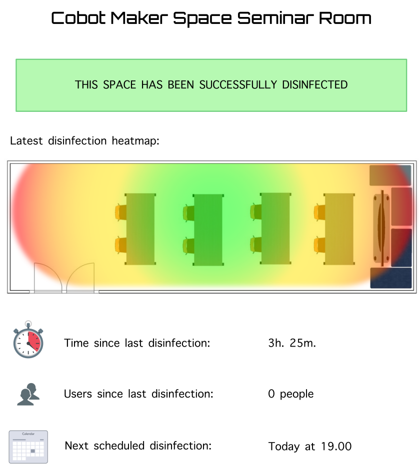


Fig. 2: Visualisation mock-up of the room disinfection shown to participants in C3.

### D. Analysis

*1) Quantitative analysis:* Two of the authors conducted an analysis of the quantitative questionnaire responses using IBM SPSS Statistics. Where this quantitative analysis provided non-conclusive results, clarifications were sought from the qualitative data to complement and to provide context to participants' responses following a "mixed-methods" approach.

*2) Qualitative analysis:* Two of the authors with no previous experience with robots and with no personal experience of professional cleaning services conducted a thematic analysis [4] of the audio-recorded data, which were transcribed by a professional service. An experiential perspective was employed, as the focus was on capturing the participants' understandings and views. The authors familiarised themselves with the data by listening to all the recordings and correcting the study transcriptions. Then, these were inductively coded, capturing semantic and latent meaning. After revision of the initial codes and discussions with the whole team, codes were grouped in two ways: within each stage (1-3) and conditions (C1-C3) to provide explanations of participants' questionnaire responses, and seat choices; and as themes across the whole study. Therefore, this paper provides qualitative data as descriptive responses for each study stage and as overarching themes. The authors maintained ongoing reflective discussions for taking into account biases in relation to the topic.

## IV. Results

We present a the results of a "mixed-methods" analysis of the three stages of the study.

### A. Pre-study questionnaire

To explore differences on expectations about the UV-C robot prior and post study, we present a comparison in section IV-C. The medians shown in table I suggest that, before the study, participants believed that the robot would do a good job and they would be able to interact with it somehow. They were also generally willing to consider using a robot like the one used in the study. This was further backed by the qualitative analysis. Whilst some participants assumed the robot would be simplistic in appearance, function, and interaction modality, others assumed more complex functionality such as voice interaction and recognition of human patterns or movements. Further, participants were mostly hesitant or unsure about the robot's capabilities due to a lack of knowledge and experience with it, and trusting or making judgements about it was difficult. Previous experiences with other tech and robots, and media representation of robots, were mentioned as shaping participants' expectations of the UV-C robot. Among participants, there was a rough balance between expected UV-C robot capabilities and limitations.

### B. *User study*

*1) Quantitative results: experimental conditions C1-C3:* We conducted non-parametric tests for non-normally distributed data to determine if there were significant differences between the responses to the post-condition questionnaire for the 3 study conditions.

A Friedman test was run to determine if participants felt reassured/safe when using the space after this had been disinfected by the robot. Participants reassurance decreased from C1 (M = 2.04), to C2 (M = 1.83), and then increased in C3 (M=2.13), but the differences were not statistically significant, $\chi^2$ = 3.36, p = .19.

A Friedman test was also run to determine if participants' trust in the robot was impacted in the three study conditions. As expected, with more information about how the disinfection was performed by the robot, participants' trust in the robot doing a good job increased (C1 M = 1.87, C2 M = 1.96, C3 M = 2.17 respectively), but the differences were not statistically significant, $\chi^2$ = 3.36, p = .19.

Finally, a Friedman test was run to determine whether participants felt they had enough information about the robot for them to trust that it is doing a good job at disinfecting the space. A statistically significantly difference was found, $\chi^2$ = 7.625, $p < .022$ (C1 M = 1.72, C2 M = 1.98, C3 M = 2.3). Post-hoc Wilcoxon test found a significant difference between C1 and C3 ($p < .022$), indicating that participants agreed that they had enough information to trust the robot had done a good job when having both seen the robot in action (C2) and the visualisation (C3) as compared to when they had only seen a sign saying that the space had been disinfected (C1). There was no statistically significant difference for C1-C2 and C2-C3 pairwise comparisons.

Participants were asked if they felt less safe, equally safe or safer using the space, as compared to the previous condition, using as "condition 0" not knowing that the robot had disinfected the space. Fig. 3 shows that the number of participants feeling safer than before increased with each condition, suggesting that they felt safer after having seen both the "live feed" of the robot and the visualisation.

*2) Qualitative responses:*

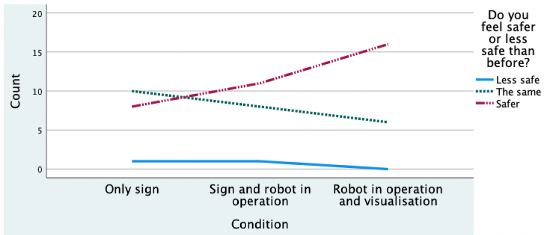


Fig. 3: Graph showing the changes in participants' self-reported feeling of safety across the three conditions.

*a) C1:* Most participants reported that seat choice during the initial condition was either random or based on personal preference. The majority expected the UV-C robot to be smaller or more compact in design. Three participants felt that basic signage was sufficient to inspire trust, while another three participants trusted the UV-C robot only after seeing it. Moreover, another group of participants explained that their trust stemmed from the institution doing the research, and their responsibility to ensure efficiency. Four participants had previous experience working with UV-C light and several more had existing knowledge of UV-C light technology, which similarly increased trust in the robot. Three participants were cautious in that they wanted to wait until they had seen the UV-C robot disinfecting a space before trusting it.

*b) C2:* Ten participants changed their seat choice to the side of the classroom nearest to the route of the UV-C robot after seeing the "live feed" in C2, with five other participants' choices remaining unchanged but only because they were already close to the disinfection route. Four other participants expressed their seat choice was based solely on the range of the UV-C light, which they were uncertain of at this stage, and another four did not change their choice at all after seeing the robot. Five participants also reported that seeing the UV-C robot in action increased feelings of safety and trust.

*c) C3:* Eight participants were positive about the visualisation and the specific information it provided. Thirteen participants stated that more specific and visible information about the UV-C robot's performance reassured them of its effectiveness. For many of them, the visualisation provoked feelings of safety. However, the heatmap was perceived by six participants as a potential site for generating negative feelings in room users, such as stress and worries about seat choice (e.g., when the "good seats" are not available), and leading them to feel less safe. In that regard, there was a general consensus among participants that the heatmap colours were confusing or misleading. For that reason, several participants required an explanation of the heatmap meaning, whereas only two participants accurately understood it as representing radiation intensity. As a result, some participants expressed that it would be more useful to convey disinfection status or safety areas rather than radiation levels. Interestingly, seven participants found that the heatmap challenged their expectations of the UV-C robot; that is, they overestimated its

TABLE I: Medians for the six questions on expectations about the UV-C disinfecting robot before and after the study (5-point Likert items).

| Question | Median before | Median after | Difference |
|---|---|---|---|
| 1. The robot will do a good job at disinfecting the space | 4 | 4 | 0 |
| 2. The robot will be able to perceive what you are going to do before you do it | 3 | 2 | -1 |
| 3. I think that I will be able to interact with the robot | 4 | 4 | 0 |
| 4. I think that the robot will be able to recognise when I look at it or when I look at something else | 3 | 2 | -1 |
| 5. I think the robot will be able to understand me | 4 | 3 | -1 |
| 6. I would consider using a robot like the robot used in this study | 4 | 4 | 0 |

effectiveness, and they encountered a mismatch between the expected disinfection coverage of the room and the different coloured zones shown in the heatmap (e.g., not every corner was covered, blind spots not shown). Therefore, participants suggested that the information provided should be clear, simple, and careful in using certain terminology to avoid misleading, confusing, and overwhelming people. Regarding seat choice, most of the participants explicitly changed their previous seat, kept their seat (given that it was located under perceived safe areas i.e., green seats), or expressed they would be influenced to change it, based on the heatmap. Only six participants reported not being influenced to change or keep their seats based on the heatmap. For them, other factors were involved in choosing a seat, such as personal preferences and a perception that, although not perfect, the UV-C robot did an acceptable job disinfecting the room.

### C. Post-study questionnaire

We ran a Wilcoxon signed-rank test for the six questions asked before and after the study as seen in Table I to test whether participants changed their mind significantly. We found a statistically significant decrease between the Likert response provided for question 2. This indicates that participants had higher expectations about the robot being able to perceive humans when they had not seen the robot, as compared to after the study, when they had experienced the robot, $z = -2.765, p < .006$. We did not find any other statistically significant differences.

The qualitative data revealed that some participants now felt the UV-C robot would not be able to perceive any surroundings, with a few more participants noting that the UV-C robot was simpler than first imagined. Some reported that their perceptions had changed simply due to seeing the UV-C robot in action and by its appearance, with the general change demonstrating that participants had originally overestimated the robot's ability.

After examining the Median, Mode and Standard Deviation corresponding to the responses obtained in the post-study questionnaire administered to the thirteen participants that were involved in professional cleaning services, in Table II we can observe that the acceptance of the UV-C disinfecting robot was generally high across all participants, and that the fear that robots might replace them in their jobs was low. Both the questionnaire responses and the qualitative data indicate that there was a general openness to adopt a UV-C robot for their work tasks, assuming training and information is given to them. Many participants stated that the UV-C robot would be seen as a tool rather than a team member, not replacing human cleaners given its limited functionality. Participants believed that a UV-C robot would reassure people using the spaces they clean, especially due to the COVID-19 pandemic. Nonetheless, a few participants mentioned some barriers to adoption of a UV-C robot, such as generating more tasks for them and its lack of suitability to specific settings.

### D. Interview themes across study stages

#### 1) Trust in the UV-C robot:

*a) More information and knowledge of UV-C science and technology results in more reassurance in using the UV-C robot:* Participants repeatedly conveyed this theme, e.g., *"making the information about how it actually operates accessible to people would...kind of put them more at ease" (P207)*[2]. This was strengthened by participants reporting that a lack of information resulted in limited trust. Similarly, participants who had existing knowledge of UV-C technology were more trusting of the UV-C robot. Some participants also noted that a level of understanding of UV-C technology was important for public acceptance.

*b) Tangible evidence of disinfection, such as a 'before and after', would increase trust, whereas having no evidence is a barrier to trust:* Participants reported, for instance *"I'm sure they kill viruses and everything, but I don't know. I haven't seen the viruses" (P203)* Some participants suggested that having a "before and after" of disinfection, comparable to television cleaning adverts, would help them trust the UV-C robot because they felt that visual proof was necessary to trust the robot's capability.

*c) Concerns over the UV-C robot include worries over radiation exposure and occlusion resulting in an incomplete job:* Multiple concerns over the UV-C robot were brought up by participants. Worries around radiation exposure were present for many, with suggestions for extra measures to ensure safety. Aspects like training with the UV-C robot were thought to be a must due to these concerns. Alternatively, others reported that just the word "radiation" *"can send alarm bells ringing" (P108)*, being associated with danger and that even with safety measures some people would still be concerned about exposure. A further issue is that of occlusion with the UV-C robot, in which some areas that blocked the UV-C light with obstacles would not be disinfected, and thus

[2]Participant IDs P2xx denote professional cleaners. IDs P1xx denote general public.

TABLE II: Median, Mode and Standard Deviation for the 8 post-study questions based on the TAM (5-point Likert items).

| Question | Median | Mode | Std. Deviation |
|---|---|---|---|
| 1. I would be happy to have the UV-C disinfecting robot as part of my team at work | 4 | 4 | 0.622 |
| 2. I think the robot will help me do my job | 4 | 4 | 0.577 |
| 3. I fear robots like this might replace me in my job | 2 | 2 | 0.603 |
| 4. I would feel confident in learning to use the robot | 4 | 4 | 0.492 |
| 5. I would rather have somebody else using or operating the robot | 2 | 2 | 0.669 |
| 6. I would be open to adapt my way of working to work with the robot | 4 | 4 | 0.577 |
| 7. I would feel safer in my job working with the robot | 4 | 4 | 0.985 |
| 8. I feel the robot will help me with my workload | 4 | 5 | 0.996 |

the UV-C robot would not complete the full disinfection: *"I would not be filled with a lot of confidence that it hit the right... there'd be areas that would have been blocked" (P111)*.

*d) Limitation of the UV-C robot in physically cleaning untidy spaces:* Participants voiced concerns, e.g. *"it definitely needs to be clean and tidy... If you see a messy table, you think it's dirty. If you see a table, it looks clean, it could have God knows on it, but you just assume it's clean" (P104)*. As well as being a barrier to trust, the UV-C robot's inability to cope with untidy spaces was also an issue because it would not help with cleaner workload if the cleaners would still need to come in and tidy the space themselves.

*2) Ideal functionality and places to use the UV-C robot:*

*a) Desired functionality of the UV-C robot:* Many participants described features such as a touchscreen to control the robot, voice recognition, and face recognition: *"it'd be good if it recognises us –all the cleaners" (P102)*. Moreover, some participants felt the robot should not be anthropomorphised because it would blur the line between human and robot capability: *"You don't need all the robots to look like humans because they're not going to do all the tasks we do" (P203)*.

*b) The UV-C robot would be useful in large, open spaces where disinfection is crucial, such as health settings; but is limited by its size and radiation implications:* Participants believed that the best places for the robot was in hospitals and care homes, *"where people are vulnerable" (P205)*. Conversely, there was consensus among participants that the UV-C robot would not be useful for home use, due to radiation and suitability: *"my house is full of plants, it will kill them all anyway. And I've got my cat and... it's healthy to have some bacteria at home" (P209)*. The different settings for which the UV-C robot could be used is limited due to the radiation implications, with many participants discussing issues with timing the radiation cycles being difficult in busy places and the issue of obstacles and equipment blocking the light. Participants also discussed the usefulness of the UV-C robot during COVID-19 times, as disinfection has become a priority in many places.

*3) Views on robots in society and the workplace:*

*a) A combined team of robots and humans are preferable due to their different skill sets, to minimise error, and to increase the safety of humans during dangerous tasks:* This was a significant topic throughout the three stages of the study. All participants believed that a combined team would be best, e.g.,: *"it's almost like a team of one doing the disinfecting and the other doing the actual cleaning" (P211)*. Other reasons mentioned were increasing efficiency, minimising error, valuing human interaction, and to ensure the safety of human cleaners during dangerous tasks. The UV-C robot was recognised as being efficient and cleaners especially noted that it would save them time when cleaning at work or release them to do other tasks: *"you could go off and do something else and come back when you know that's in time to finish" (P102)*. However, the need for a human cleaner was still an important factor for many participants, as humans would still be needed to physically clean spaces and a human presence is important for adaptability and decision-making.

*b) On robots in society and replacing human jobs, some think humans will still be needed which offers comfort, while others worry about economic imbalance.:* Robots were seen by some participants as collaborators and a teammate rather than a replacement, whereas others felt concerned that, even though robots could not currently replace jobs, using robots in the workplace was making way for robots to replace humans in the future. Many participants noticed the dichotomy themselves, in that robots can help with dangerous tasks or make tasks more efficient overall, versus the threat humans feel against their jobs and other opportunities. Some participants mentioned newly needed jobs in society: *"with more robots, there are going to be more high-level jobs in obviously software engineering, coding..." (P204)*. However, this also resulted in the concern over an economical and societal imbalance being created: *"robots are taking jobs for the less-skilled people... it just needs to be balanced out" (P109)*. Nevertheless, despite these mixed views, most participants felt that robots could not completely take over human jobs, which offered a level of comfort.

## V. Discussion

This paper presented the results of a mixed-methods study aiming to elucidate the general public and cleaners' trust and reassurance towards a UV-C robot for disinfection. In the following, we discuss the implications for HRI research.

### A. Contributors and barriers to trusting the UV-C robot

Both our quantitative and qualitative results reveal that participants overestimated the capabilities of the UV-C robot before seeing it. In the case of UV-C light, this can be troublesome, as inappropriately high levels of trust in robots can cause overreliance or misuse [14]. Whilst training can mitigate such issues [12], expectations of the general public should also be taken into consideration as users of the spaces to be disinfected. Seeing the robot in action and having its functionality explained through the conditions helped participants to adjust their understanding of its capabilities and limitations. Interestingly, questionnaire responses show that participants believed that the robot would do a good job, whilst the qualitative analysis reflects that opinions were divided; some trusted it due to their knowledge of UV-C light or the science behind it, whereas others were more reluctant to provide judgments without seeing it. Trust in institutions or manufacturers and known information about UV-C robots also play an important role in trusting its effectiveness. Lastly, a major barrier to trust is not being able to directly assess the performance of the robot; thus, design should account for how to provide people with adequate proof of UV-C disinfection.

### B. More information can reassure but also raise concerns

Robot design often emphasises social features that are known to aid trust with users; for instance, human-like characteristics such as eye gaze and emotive facial expressions [22]. However, deployments of non-social robots ought to approach the issue of trust differently. In this study, information was provided to participants in three different modalities aiming to understand how it affected their reported reassurance to use the space. Our study shows that more information provided in every condition affected some participants' seat choice. Both seeing the robot in action (C2) and the visualisation of its performance (C3) provided either reassurance of their previous choice or prompted them to change it. Nevertheless, the visualisation provoked some confusion and some even stated that it might be anxiety-inducing due to perceiving areas as unsafe (e.g., corners, red areas). This suggests that more information can also raise concerns, especially if robot capabilities and limitations are unclear. The fact that UV-C light can be both harmful to humans while also being able to kill viruses and bacteria adds further complexity to the potential trust dilemmas raised by the deployment of UV-C robots [27]. Whilst most participants felt safe using the space disinfected by the robot, a few mentioned worries concerning "radiation" terminology and its visual representation.

### C. Are people worried that robots will take over their jobs?

Our mixed-method analyses show that participants from both groups (i.e., general public and cleaners) are generally willing to consider using a robot like the one used in this study. This result reflects a general openness and acceptance of UV-C robots [18], despite low levels of knowledge and user experience [24]. Although there have been claims that digitalisation and automation will imminently overtake human jobs [3], evidence in the context of industrial robots show that jobs have not been replaced; yet there have been disruptive effects on employment due to the impact on task demand [7]. Our participants had mixed views: while they believed humans' skill sets are not likely to be completely automated (cf. [3]), there were also concerns about potential consequences of robotic developments. These findings echo past research wherein people have stated they are fearful of being replaced in their jobs but have provided neutral or inconclusive explanations [24]. Moreover, adjustment of participants' expectations and understanding of robot capability could have helped them to assess that the UV-C robot would not be able to perform the tasks of a human cleaner. Given that participants preferred human-robot teams due to the perceived benefits of complementary skill sets, UV-C robot design could benefit from integrating human elements in the flow instead of aiming to replace the cleaners [8].

### D. Limitations

Whilst our approach has helped us gain an initial understanding of the relationship between trust and reassurance in HRI, it should be noted that the context of UV-C robots is very specific, with interactions designed to be limited due to safety reasons [10]. Therefore, the results of this study might not be generalisable to other types of robots or cultural settings, as the factors that affect trust and reassurance in these could differ. Nonetheless, it is difficult to know which factors, if any, will be common across settings, thus future work is needed to establish if our findings regarding the relationship of trust and reassurance apply to HRI more generally.

## VI. Conclusions

This paper presented results from a user study investigating trust and reassurance of both the general public and professional cleaners towards a UV-C disinfection robot. Our main findings begin to answer our three research questions stated in the introduction:

Regarding RQ1, the analysis of pre- and post-study questionnaires on the expectations about the UV-C disinfecting robot shows a decrease in three (one of them a statistically significant change), and no change in the other three statements; indicating that people overestimated the interaction, recognition and understanding capabilities of the robot. This is also supported by the analysis of the interview responses. There were no statistically significant differences between the expectations of professional cleaners and those of the general public, neither pre- nor post-study.

Regarding RQ2, after experiencing more approaches to be informed and educated about the UV-C robots' task performance, participants showed more agreement that they trusted the robot did a good job at disinfecting the space, but this was not significant. There was however a significant effect on the agreement that they had enough information that the robot is doing a good job; after having experienced all three approaches (C1-C3) they agreed significantly more that they had enough information compared with just seeing a sign that the space was disinfected by a robot (C1). The thematic analysis added further insight and nuance to this. While more information was generally seen to benefit feelings of reassurance, just providing more information is no panacea; instead, the visualisation mock-up was by some found to raise concerns about the robot's task performance, thereby calling into question the safety of the space. Others raised questions about how readily interpretable the visualised information was. Overall, the findings suggest that designers thinking about including visual representations of data pertaining to a given robot's performance ought to carefully consider and test their designs with a diverse set of participants.

Regarding RQ3, both the generally increasing trend in responses after each condition C1-C3 as well as the post-study questionnaire suggests a generally positive picture regarding the use of UV-C disinfecting robots after having seen one in action. The analysis of interview responses suggests that cleaning professionals would be happy to have the robot as part of their team and help them to do their job. The positive views frequently included traits such as the complementary nature of the robot, and its potential to save time. However, while the cleaners broadly disagreed with negative statements such as that the robot might replace their jobs in future, they did express caveats about potential economic imbalance and how less-skilled jobs were at risk. Overall then, this mixed picture suggests a range of concerns and insights that those designing and wishing to deploy UV-C robots should take into account in order to make them welcome by cleaning teams as well as to provide reassurance to space users.

## REFERENCES


[1] L Banjanovic-Mehmedovic, I Karabegovic, J Jahic, and M Omercic. Optimal path planning of a disinfection mobile robot against covid-19 in a ros-based research platform. In *Conference on Automation Science and Engineering (CASE)*, volume 2147, page 2152, 2021.

[2] Aladin Begić. Application of service robots for disinfection in medical institutions. In *International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies*, pages 1056–1065. Springer, 2017.

[3] Jeff Borland and Michael Coelli. Are robots taking our jobs? *Australian Economic Review*, 50(4):377–397, 2017.

[4] Virginia Braun. *Thematic analysis : a practical guide / Virginia Braun and Victoria Clarke.* SAGE, 2022.

[5] Jonathan Conroy, Christopher Thierauf, Parker Rule, Evan Krause, Hugo Akitaya, Andrei Gonczi, Matias Korman, and Matthias Scheutz. Robot development and path planning for indoor ultraviolet light disinfection. In *2021 IEEE International Conference on Robotics and Automation (ICRA)*, pages 7795–7801, 2021.

[6] Angel Contreras Cruz, Ashwaq Al Khalil, Aynur Kirbac, Kelly Cowan, and Ozgul Ayyildiz. Forecasting the use of decontamination robots in the covid era. In *2022 Portland International Conference on Management of Engineering and Technology (PICMET)*, pages 1–9, 2022.

[7] Gaaitzen J. de Vries, Elisabetta Gentile, Sébastien Miroudot, and Konstantin M. Wacker. The rise of robots and the fall of routine jobs. *Labour Economics*, 66:101885, 2020.

[8] Michael Decker, Martin Fischer, and Ingrid Ott. Service robotics and human labor: A first technology assessment of substitution and cooperation. *Robotics and Autonomous Systems*, 87:348–354, 2017.

[9] Munjal Desai, Poornima Kaniarasu, Mikhail Medvedev, Aaron Steinfeld, and Holly Yanco. Impact of robot failures and feedback on real-time trust. In *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pages 251–258, 2013.

[10] Laura Fiorini, Erika Rovini, Sergio Russo, Lara Toccafondi, Grazia D'Onofrio, Federica Gabriella Cornacchia Loizzo, Manuele Bonaccorsi, Francesco Giuliani, Gianna Vignani, Daniele Sancarlo, Antonio Greco, and Filippo Cavallo. On the use of assistive technology during the covid-19 outbreak: Results and lessons learned from pilot studies. *Sensors*, 22(17), 2022.

[11] Jodi Forlizzi and Carl DiSalvo. Service robots in the domestic environment: a study of the roomba vacuum in the home. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, pages 258–265, 2006.

[12] Amos Freedy, Ewart DeVisser, Gershon Weltman, and Nicole Coeyman. Measurement of trust in human-robot collaboration. In *2007 International Symposium on Collaborative Technologies and Systems*, pages 106–114, 2007.

[13] Moez Guettari, Ines Gharbi, and Samir Hamza. Uvc disinfection robot. *Environmental Science and Pollution Research*, 28(30):40394–40399, 2021.

[14] Peter A. Hancock, Deborah R. Billings, Kristin E. Schaefer, Jessie Y. C. Chen, Ewart J. de Visser, and Raja Parasuraman. A meta-analysis of factors affecting trust in human-robot interaction. *Human Factors*, 53(5):517–527, 2011. PMID: 22046724.

[15] Jane Holland, Liz Kingston, Conor McCarthy, Eddie Armstrong, Peter O'Dwyer, Fionn Merz, and Mark McConnell. Service robots in the healthcare sector. *Robotics*, 10(1), 2021.

[16] Hilary McDermott, Nazmin Choudhury, Molly Lewin-Runacres, Ismail Aemn, and Esther Moss. Gender differences in understanding and acceptance of robot-assisted surgery. *Journal of robotic surgery*, 14(1):227–232, 2020.

[17] Daniel Ohana. Trust, distrust and reassurance: Diversion and preventive orders through the prism of feindstrafrecht. *Modern Law Review*, 73(5):721 – 751, 2010.

[18] Laura Pedersen, Nadia Masroor, Kaila Cooper, Amie Patrick, Faezeh Razjouyan, Michelle Doll, Michael P Stevens, and Gonzalo Bearman. Barriers and perceptions of environmental cleaning: An environmental services perspective. *American Journal of Infection Control*, 46(12):1406–1407, 2018.

[19] Mäkelä Pekka and Townley Cynthia. *Trust : Analytic and Applied Perspectives.* Number vol. 263 in Nordic Value Studies, NVS. Brill, 2013.

[20] Ben B. Pradhan, Jens Ivar Brox, and Aage Indahl. Chapter 6 - watchful waiting and brief education. In Simon Dagenais and Scott Haldeman, editors, *Evidence-Based Management of Low Back Pain*, pages 55–72. Mosby, Saint Louis, 2012.

[21] Paul Robinette, Ayanna M. Howard, and Alan R. Wagner. Effect of robot performance on human-robot trust in time-critical situations. *IEEE Transactions on Human-Machine Systems*, 47(4):425–436, August 2017. Publisher Copyright: © 2013 IEEE.

[22] Shane Saunderson and Goldie Nejat. How robots influence humans: A survey of nonverbal communication in social human–robot interaction. *International Journal of Social Robotics*, 11(4):575–608, 2019.

[23] Diab-El Schahawi, Walter Zingg, Margreet Vos, Hilary Humphreys, Lorena Lopez-Cerero, Astrid Fueszl, Jean Ralph Zahar, Elisabeth Presterl, et al. Ultraviolet disinfection robots to improve hospital cleaning: Real promise or just a gimmick? *Antimicrobial Resistance & Infection Control*, 10(1):1–3, 2021.

[24] Sergio D Sierra Marín, Daniel Gomez-Vargas, Nathalia Céspedes, Marcela Múnera, Flavio Roberti, Patricio Barria, Subramanian Ramamoorthy, Marcelo Becker, Ricardo Carelli, and Carlos A Cifuentes. Expectations and perceptions of healthcare professionals for robot deployment in hospital environments during the covid-19 pandemic. *Frontiers in Robotics and AI*, 8:612746, 2021.

[25] Viswanath Venkatesh and Fred D. Davis. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, 46(2):186–204, 2000.

[26] Salvatore Zaffina, Vincenzo Camisa, Marco Lembo, Maria Rosaria Vinci, Mario Graziano Tucci, Massimo Borra, Antonio Napolitano, and Vittorio Cannatà. Accidental exposure to uv radiation produced by germicidal lamp: Case report and risk assessment. *Photochemistry and Photobiology*, 88(4):1001–1004, 2012.

[27] Akib Zaman, Mohammad Shahjahan Majib, Shoeb Ahmed Tanjim, Shah Md Ahasan Siddique, Shafayetul Islam, Md Shadman Aadeeb, Nafiz Imtiaz Khan, Riasat Haque, Md Rashid Ul Islam, M Rayhan Ferdous Faisal, et al. Uvc-purge: A novel cost-effective disinfection robot for combating covid-19 pandemic. *Ieee Access*, 10:37613–37634, 2022.

[28] Zhanjing Zeng, Po-Ju Chen, and Alan A. Lew. From high-touch to high-tech: Covid-19 drives robotics adoption. *Tourism Geographies*, 22(3):724–734, 2020.