Towards Understanding Trust and Reassurance in Human-Robot Teams: A User Study with a UV-C Disinfection Robot

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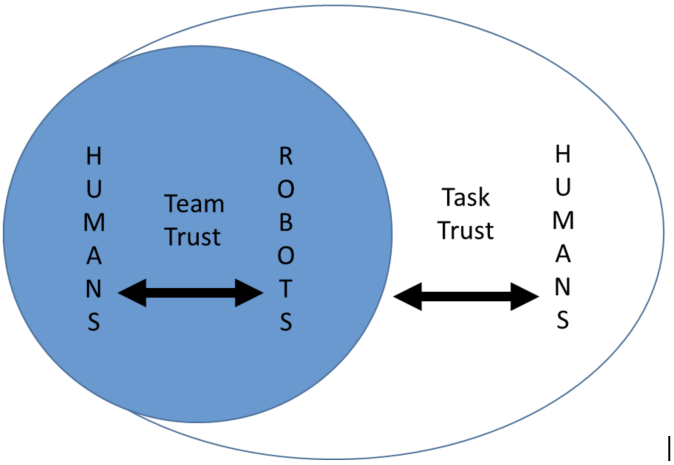

Fig. 1. Trust within and towards human robot teams.

The global COVID-19 pandemic has presented novel challenges for routine tasks such as cleaning and disinfection of public spaces. These tasks are normally completed by human teams, but personal distancing requirements make humans working in close proximity difficult, accompanied by additional pressures of workforce capacity due to employee sickness and austerity measures. These challenges present increased opportunities for human-robot collaborative teams but questions still remain relating to trust towards the robot within the team and, more broadly, the trust of affected groups (e.g., cleaning professionals and the general public) towards tasks carried out by robot-assisted teams. In this paper we present an overview of the preliminary results of a study aiming to explore different aspects related to trust within and towards human robot teams focusing on the task of the cleaning and disinfection of public spaces.

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CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

Additional Key Words and Phrases: human-robot interaction, UV-C light, disinfection, trust

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1 INTRODUCTION

The use of 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 [9]) has not only the potential to complement the work of cleaning teams such as in hospitals [13], but also the potential to reassure people that the space is safe to use. Research has argued that trust in robots has recently increased as a result of the pandemic [15], and that trust is at the core of the (non-)use of robots in healthcare [2]. In this workshop paper we present preliminary results from a study investigating how reassured space users feel by a UV-C robot disinfecting a public space. The concept of 'reassurance' has been considered as a feeling humans seek to counter dis-trust [10, 11], it has been associated with decreasing stress and anxiety, and usually consists of educating people [12], however, the concept has not been explored in the field of Human-Computer Interaction (HCI). In our study, this 'education' takes the form of different levels of information available to the user about the task performance of the UV-C robot.

Furthermore, we were interested in exploring the views and attitudes of professional cleaners towards UV-C robots; prior work has argued that as UV-C robots do not replace (manual) cleaning it will need to be integrated in existing cleaning and disinfecting practices [13]; and we would take the ethical standpoint that it is better to think about these robots as tools or 'teammates' for the cleaning teams, not as replacements. However, we wanted to explore how professional cleaners would see it; would they see the UV-C robot as something threatening to take over their job [3], or perhaps as just a tool to support their cleaning work which due to its 'non-routine manual' nature may be less prone to automation [6], for instance?

There are a number of prior studies in Human-Computer Interaction (HCI) and Human-Robot Interaction (HRI) that explored how mobile cleaning robots are used in domestic settings (e.g., [7, 8]), and there are a range of publications on robotic topics such as path-planning related to UV-C robots [1, 4]. However, to the best of our knowledge there is currently a lack of HRI studies on the use of and trust towards mobile UV-C robots, or how humans and robots may work together to complete a cleaning task.

Thus, we have designed an experiment to study views and attitudes 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 that they would use. The fact that UV-C light can be both harmful to humans while also being able to kill microorganisms such as viruses and bacteria if applied at the appropriate dosage adds further complexity to the potential trust-dilemmas raised by the deployment of UV-C robots.

The broader aims of the project that the experiment we report here is part of are to explore and consolidate the various factors that hinder or benefit trust in human-robot teams. The aims to develop this deeper understanding are twofold: 1. trust within human-robot teams; and 2. trust towards human-robot teams (see Figure 1). This research

aims to contribute to the development of mechanisms that safeguard trust in order to facilitate effective human-robot collaboration. Against this background, the experiment presented here aims to answer the following research questions:

- RQ1 What expectations and views do both professional cleaners and the general public hold towards robots and autonomous systems in general and UV-C disinfecting robots in particular?
- RQ2 How does experiencing different approaches to inform and educate people about the robot's UV-C disinfection task performance (e.g., by data visualisation) affect their 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 action during the study?

In the remainder of this paper, we present our work in progress and the early results from our experimental user study with the UV-C robot.

2 THE STUDY

The study presented in this paper followed a mixed-methods approach, and was run at the Cobot Maker Space of the University of Nottingham.

2.1 Design

Our study had three main stages:

2.1.1 Stage 1 - Pre-study questionnaire. This contained questions on demographics, prior experience or exposure to specific Autonomous Systems, general attitudes towards robots, and expectations about the UV-C disinfecting robot used in our study (prior to having seeing it).

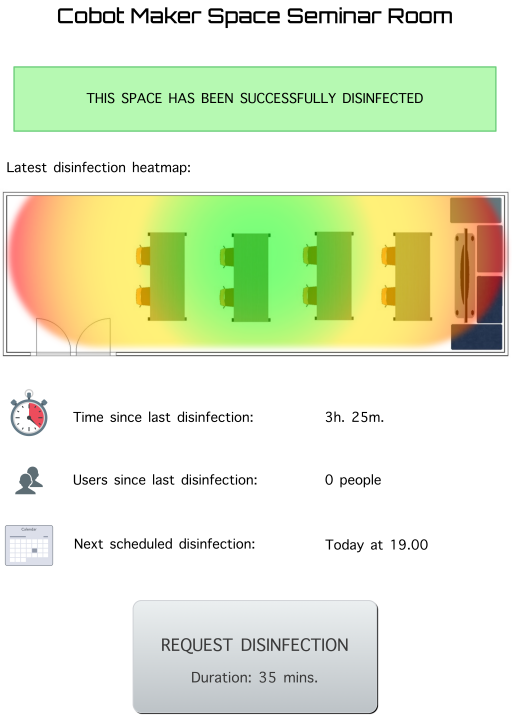
2.1.2 Stage 2 - Experimental user-study. We designed a user-study to understand how various approaches to informing and educating space users about the disinfection tasks carried out by the robot may affect the trust towards the robot and its disinfection, and how reassured they feel to use the space 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 Figure 2a) after having been disinfected by our UV-C robot, and then choose a seat where they would sit, following three different 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 Figure 2a;
- C3 Participants are shown a visualisation with detailed information on the disinfection carried out by the robot, as can be seen in Figure 2b.

After each of the conditions participants were asked to fill out a post-condition questionnaire with Likert-scale statements on a 5-point scale. In this paper we focus on the analysis of the level of agreement with three of these statements: that they feel reassured/safe as a result of the robot disinfecting the space (Q1); that they trust the robot does a good job at disinfecting the space (Q2); and that they feel they had enough information to trust that the robot is doing a good job at disinfecting the space (Q3).

2.1.3 Stage 3 - Post-study questionnaire. This questionnaire was comprised of questions on expectations about the UV-C disinfecting robot used in our study (after having participated in the user-study), as well as, for those participants that were involved in professional cleaning services, questions on their opinions and feelings when presented with the possibility of 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) by Venkatesh and Davis [5, 14], which explores the perceived usefulness and usage intentions for a new technology participants are presented with, to evaluate their acceptance of said new technology.

(a) Still image of the live feed of the UV-C robot shown to participants in C2.



(b) Visualisation with information about the disinfection of the room carried out by the robot as shown to participants in C3.

Fig. 2

Besides participants being asked to fill-out paper-based questionnaires, the whole process, including the administration of the questionnaires, followed a semi-structured interview style to help contextualise participants' answers to the questionnaires and overall experience during the different stages of the study.

2.2 Participants

Participants had to be at least 18 years of age to be able to take part in the study. At least half of the participants were recruited from groups of professionals involved in cleaning services at work.

A total of 23 participants from different age-groups were recruited, of which 10 self-identified as male and 14 self-identified as female. 13 participants indicated that they were professionals in the cleaning industry or that their job or part of their job related to cleaning services. Participants belonged to different groups: students at the institution organising the study; employees of the same institution in areas of research, administrative and professional services, and estates and cleaning services; professional cleaners in other local businesses/institutions in different sectors; members of the general public not belonging to the institution organising the study.

2.3 Procedure

Before the study commenced, Ethical Approval was obtained from the Ethics Committee of the University of Nottingham.

A call for participants containing information about the study was distributed and a suitable date and time was agreed with those interested.

During the study, pairs of participants were invited to meet a member of the research team in person at the University of Nottingham at the previously agreed time convenient to them. Pairs were needed to encourage conversation between participants about their experience during the study, with recordings of these interactions becoming a source of qualitative data analysis.

Upon arrival, participants were welcomed to the building and were offered the chance to ask questions and, once questions were answered, informed consent was taken for their participation in the study. From this moment, their conversation with the researcher leading the sessions was audio recorded for further analysis, and participants were encouraged to share their thoughts with each other and the researcher following the think-aloud protocol throughout their time there. They were then taken to a suitable room to receive more information on the dynamics of the session and to proceed with the different stages of the study.

Stage 1 and 3 were completed in the room where the initial information about the session was provided to participants.

For Stage 2, participants were led by the researcher to a separate room set-up as a small classroom or seminar room, as can be seen in Figure 2a. The room would be closed, and before entering they would be presented with the information relevant to each condition (i.e., plain-text sign, 'live feed' of the disinfection, visualisation). Upon entering the room, participants were asked to choose a seat as if they were attending a seminar or lecture in that room based on the information that they were presented with before entering the room. Afterwards, participants were led back to the initial room, where the post-condition questionnaire was administered. This process was repeated for the three conditions described.

All participants were taken through the three different conditions in the same order: C1 - C2 - C3, as 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.

A think-aloud protocol was used throughout the different conditions to capture participants' thoughts.

3 PRELIMINARY RESULTS

In this paper we present our initial results mostly focused around an initial quantitative evaluation of the questionnaire data collected during the user study. The questionnaires subject of this preliminary analysis had possible responses as 5-point Likert items (strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree).

3.1 Post-condition questionnaire

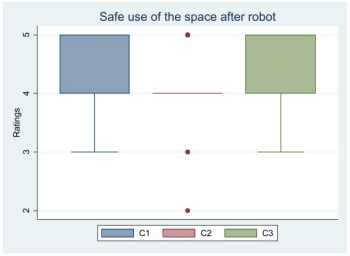
We conducted non-parametric tests for non-normally distributed data in order to determine if there were significant differences between the 3 study conditions in:

Q1 participants' feeling of reassurance/safety when using the space post-cleaning;
Q2 trust on the robot doing a good job at disinfecting the space;
Q3 and whether they believed that the amount of information received was enough for them to trust that the robot is doing a good job at disinfecting the space or not.

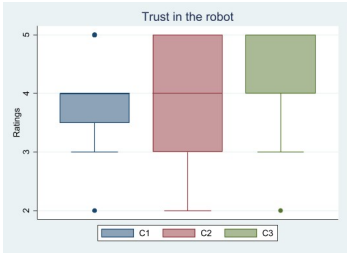
A Friedman test was run to determine if participants felt reassured/safe when using the space after this had been disinfected by the UV-C disinfecting robot. Participants reassurance decreased from C1 (M = 2.04), to C2 (M = 1.83), and then increased in C3 (M=2.13), but the differences were not statistically significant, χ^2 = 3.36, p = .19 see Figure 3a.

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, χ^2 = 3.36, p = .19 see Figure 3b.

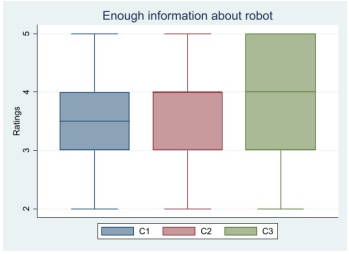
A Friedman test was run to determine whether participants felt they had enough information about the robot for them to trust that the robot is doing a good job at disinfecting the space (see Figure 3c). A statistically significantly difference was found, χ^2 = 7.625, p < .022 (C1 M = 1.72, C2 M = 1.98, C3 M = 2.3). Post-hoc Wilcoxon test found a statistically significant difference between C1 and C3 (p < .022), indicating that participants agreed significantly more 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 has been disinfected. There was no statistically significant difference for C1-C2 and C2-C3 pairwise comparisons.



(a) *"I feel reassured/safe to use the space knowing that the robot disinfects it"*



(b) *"I trust that the robot does a good job at disinfecting the space"*



(c) *I feel I had enough information to trust that the robot is doing a good job at disinfecting the space*

Fig. 3

3.2 Pre-study and post-study questionnaire: questions on expectations about the UV-C disinfecting robot used in our study

To explore if there were significant differences between the responses provided by participants regarding their expectations about the UV-C disinfecting robot before and after taking part in the study, we run a Wilcoxon signed-rank test for the six questions asked before and after the study as seen in Table 1. We found a statistically significant decrease

Table 1. 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

Table 2. 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

between the Likert response provided before and after the study in question 2. This indicates that participants had higher expectations about the robot being able to perceive what they were going to do before they would do it when they had not seen the robot, as compared to after the study, when they had already seen the robot, $z = -2.765, p < .006$. Although we did not find statistically significant differences between the responses to the other questions before and after the study, the medians for each of them can be seen in Table 1. From these data we can see that even before the study, participants in general believed that the robot would do a good job and that they would be able to interact with the robot somehow. They were also generally willing to consider using a robot like the one used in the study before and after having taken part in the study.

3.3 Post-study questionnaire for cleaning professionals

After examining the Median, Mode and Standard Deviation corresponding to the responses obtained in the post-study questionnaire administered to the 12 participants that were involved in professional cleaning services as part of their job, a preliminary analysis indicated that the acceptance of the UV-C disinfecting robot was generally high across all participants, as can be seen in Table 2.

3.4 Qualitative data from think aloud protocol and semi-structured interviews

Qualitative data obtained during the study is currently undergoing transcription and analysis. Throughout the study, participants were prompted to voice their thoughts about the UV-C robot and the situation they were in. We also sought in this manner clarification and context on their responses to the questionnaires, carrying out this in the way of a semi-structured interview following their completion of each questionnaire.

An initial look to the data suggests that the responses to the questionnaires alone are indeed not enough to understand participants' feeling of trust and reassurance on the UV-C robot, with some participants highlighting aspects such as

trust on the institution deploying the robot as one of the main factors affecting their trust on the robot itself. It was highlighted that the way in which information is presented, in particular the use of colours, should be carefully decided, as the same colour combination may have different meanings, especially when it came to participants from different cultures or backgrounds. We also observed that there was a consensus among participants when it came to deciding if a team with only robots, a team with only humans or a team with both human and robots would be preferable for the task on hand (i.e., cleaning and disinfection of public spaces). Some of the justifications used made reference to the feeling that, whilst a robot could possibly do a more throughout job, there was the need for humans in the team to supervise that there are no failures; others believed that the current capabilities of this type of robots were too limited to be able to have a robot-only team, but that this might be possible in the future; some other participants referred to robots and humans complementing each other, and that a human-robot team would be preferred in order to get the best of both sides.

4 NEXT STEPS

As we presented in Section 2, for our study we took a mixed-methods approach, having collected both quantitative and qualitative data to balance out the potential limitations of each method. However, we are yet to formally finalise the analysis of these data.

This paper reports on the preliminary findings of analysing part of the quantitative data alone, without incorporating the analysis of the sessions' recordings, as well as some initial extracts from them without associating them to the quantitative data. These recordings contained not only comments and thoughts expressed by the participants during the sessions, but also their justification or reasoning behind their responses to the various questionnaires, which may provide clarifications when the quantitative data alone is not sufficient to draw conclusions. An initial look at these recordings hints for instance at the complexity behind the factors enabling or inhibiting trust in social and service robots, not just in the context of UV-C disinfection: does this trust depend on the information received about the robot, on how the robot interacts with its surroundings, or maybe on who is its manufacturer or the institution deploying it?

Our next steps will include finalising an in-depth analysis of the quantitative data, consolidating the results of this with the justifications given by participants in the recordings, as well as a thematic analysis of these recordings to gain a better understanding on: the expectations towards robots and autonomous systems both in general and in the contexts of UV-C disinfection; on how receiving different information may affect the reassurance, feeling of safety and the trust on our UV-C robot doing a good job; as well as on the attitudes towards the adoption of this technology.

5 CONCLUSIONS

In this paper we presented initial results from a user study investigating the trust and reassurance both the general public and professional cleaners have towards a UV-C disinfection robot. To recap, our main findings to begin to answer our three research question stated in the introduction:

Regarding RQ1, the preliminary analysis of pre- and post-study questionnaire statements 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.

Regarding RQ2, after having experienced 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, however this was not significant. There was 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.

Regarding RQ3, both the generally increasing trend in responses during 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 experienced one in action. Preliminary inspection of responses suggest that cleaning professionals are in agreement with positive statement about the robot, such as that they would be happy to have the robot as part of their team and help them to do their job, and in disagreement with negative statements such as that the robot might replace them in future.

In summary, while more analysis is needed as outlined above, our preliminary results present some initial insights into the complex nature of trust and reassurance towards UV-C disinfecting robots, such as the importance of strategies to provide information about the performance of the robot's disinfection task. Our findings point out that, on the whole, both the general public and professional cleaners were in favour of the UV-C robot, and their responses suggested an increase in trust and reassurance when more information about the disinfection task performance is provided, such as through visualisations.

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