Perspectives on Mediated Reality for an Enhanced Automation Experience

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Abstract
Contemporary automated systems rely mainly on conventional audiovisual feedback technologies based on 2D displays and audio. Rapid technology advances — especially but not restricted to edge computing, augmented and virtual reality, and adaptive interfaces — can enable mediated reality systems that will revolutionize interactions between humans and automated systems. In this position paper, we outline the potential of mediated reality to create a "good" automation experience. Specifically, we outline two potential scenarios facilitating mediated reality during human-automation collaboration. Guided by these examples, we highlight the potential benefits of using mediated reality, outline future research directions to achieve them, and specify the open challenges that are likely to be encountered. The paper argues for the viability of mediated reality and raises the need to align community efforts in realizing the full benefits of human-automation interactions.

Keywords
Mediated reality, human-automation experience, human-automation interaction, augmented reality, diminished reality,

1. Introduction

Rapid developments and deployment of ubiquitous computing technologies — such as edge computing, machine learning, artificial intelligence, and augmented and virtual reality — have acquainted both novices and experts with automated systems in their everyday lives. Arguably, the main design challenge faced is in creating systems that can be used by experts and non-experts alike without compromising on user experience and expectations across different domains such as automated vehicles [1], robots [2, 3], home automation [4, 5], but also ChatGPT [6]. With (semi-)automated vehicles, for example, how can we provide safe and efficient interactions with non-experts, handle and manage takeovers and handovers in the human-automation team, manage trust/authority/responsibility between actors, deal with conflicts without robbing users of their sense of autonomy. It has been shown that efficient communication between humans and automation systems is required to tackle these challenges [7, 8, 9, 10]. Nonetheless, many systems today continue to rely on conventional 2D displays or audio feedback that cannot adapt to the changing requirements of the user, context, or environment. In most cases, only research prototypes rely on augmented reality (AR) to seamlessly enhance the environment with virtual content (e.g. AR head-up displays [11] or in shared human-robot workspaces [12]).

This position paper seeks to go beyond such conventional systems. We explore mediated reality as an adaptive tool that can enhance the automation experience for experts and novices. Mediated reality describes a perceived reality that is augmented, enhanced, deliberately diminished, or otherwise altered in real-time [13, 14]. With that, it goes beyond AR, which "only" adds virtual content to the user's perceived reality. While a convincing and plausible alteration of the environment by mediated reality still seems visionary, approaches comprising augmented reality, diminished reality (DR), and a combination of both already provide a glimpse of what might be possible in the future. For example, AR applications are already used to add digital content to the real world using head-mounted displays [15], and smartphones [16, 17]. Diminished reality prototypes can remove objects in real-time by reconstructing the background [18].

When combined, we believe that such technologies can enhance the automation experience by providing a form of human engagement in human-automation interaction that is yet to be explored. In the following, we outline two examples of how mediated reality can contribute to this domain and describe essential research directions necessary to fulfil this vision.

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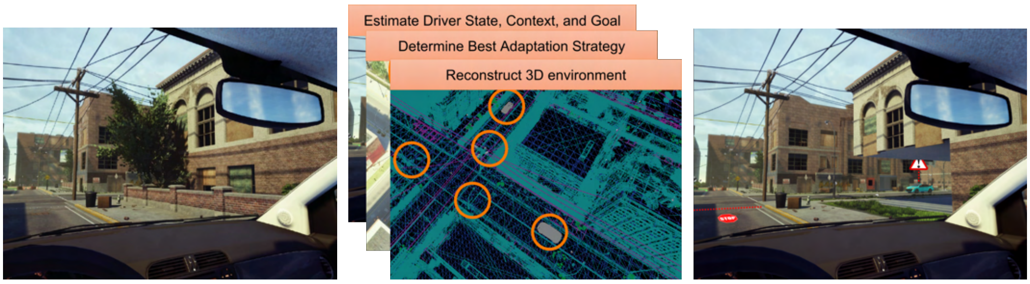
2. Motivating Examples

In this section, we present two examples to highlight the benefits of mediated reality. We outline one example in the private context for non-professionals (Section 2.1) and one in an industrial setting for specialists (Section 2.2).



(a) User's view of an obstructed crossing

(b) Processing steps of the system

(c) Mediated view with removed parts of a building (DR) and extra UI elements (AR)

Figure 1: When a (semi-)automated vehicle approaches an obstructed crossing, a mediated reality can provide the user with extra information (stop-line, signs) and mediate the view (clear view of crossing by removing part of a building).

2.1. Automated Vehicles

Driving automation has received much attention in recent years, especially with the release of consumer vehicles equipped with automated driving features. This domain highlights the importance of a good (driving) automation experience, as the human has to work closely with the automation system (and the car) to use the system safely. For example, in SAE Level 3 [19], the automation system can request the driver to take over. This is no longer the case in higher levels, such as SAE Level 4 [19]. Regardless, a good experience with the automation system requires the driver to trust the system, which can be done by communicating information about internal and external states (e.g., Oliveira et al. [20]).

A mediated reality system offers potential solutions to this challenge. In 1a, a vehicle approaches an obstructed crossing. This could be dangerous in case of a take-over request or make the driver uneasy because they must trust the automation system. A mediated reality system could use techniques such as environment reconstruction, tracking, and registration — all parts of Augmented and Diminished Reality — to provide a mediated view of reality. The system could also estimate the user's state, the overall context, and the (shared) goals to provide the best level of information. Such a view could be similar to the one in 1c where the crossing is not obstructed anymore, and UI elements such as stop signs, lines, and warning signs support the driver in building situation awareness or communicate the system's understanding.

2.2. Human Robot Interaction

Conventional human-robot cooperation and collaboration have already been envisioned with AR, for example, to provide information about the robot's state or its upcoming actions (e.g., Bambussek et al. [21]) or to make *in situ* recommendations [22]). These can be extended by applying a real-time mediated reality approach to enhance collaboration in human-robot teams further. Primarily where robots and operators work together on a task, having a shared goal, and contact is possible (or even desired), a mediated view can enhance team performance. For example, if both work together on the same part during an assembly or maintenance task.

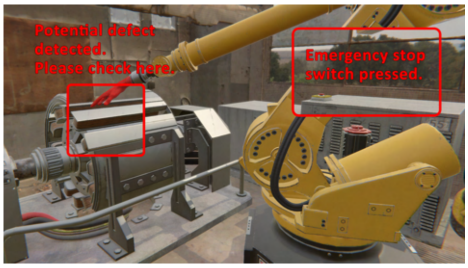


Figure 2: Mediated view of a human that works together with an "intelligent" robot. The robot is in motion, and a virtual hand points at the problem. Parts of the robot and the machine are automatically hidden for a clear view (highlighted with red borders), and important information is provided (e.g., the vital turned-off safety switch).

In such a task and environment, AR has been shown to support human-robot teams by, for example, adding contextual information such as task instructions, future robot trajectories, visual cues for essential components, and more [3]. Going beyond that, a mediated reality approach could, for example, partially hide parts of the robot to provide the human with a clearer view (e.g., by visually removing obstructing parts of the robot's arm) or remove components of the work-piece to support the human operator (e.g., during assembly or maintenance). A mediated reality approach could also diminish distracting factors in the surroundings, such as factory noise or irrelevant equipment, to support the human operator to focus on the actual task. As an example, this scenario is shown in Figure 2.

3. How can mediated reality contribute?

In both of the described examples Section 2, a comprehensive processing pipeline is necessary to reap the benefits of mediated reality. Fundamental are three core aspects:
1. An accurate model of the environment.
2. A deep understanding of the human operator.
3. A thorough knowledge of the (shared) context.

An accurate model of the environment must include information about geometry, lighting, and materials for a realistic modification of reality. Without it, the modified reality would be perceived as unconvincing, aesthetically unpleasant, implausible, or eerie — similar to an augmented reality where an object is not correctly embedded into the scene. In addition, the system must understand the human operator — their preferences and requirements — so that the automation system can collaborate with the user by mediating reality without being intrusive or annoying. For this, it needs to know the state of the human operator to make assumptions about his current skill level, mental load, situational awareness, and more. It could achieve this by making inferences from the human operator's explicit behaviour (e.g., speech requests) and implicit behaviour (e.g., gaze, posture). Automated systems might even have access to information that fellow human operators do not (e.g., psychophysiological activity, statistics of competence levels), which could support its inference of whether or not support is required. Finally, an automation system needs to know about the (shared) goals, tasks, and intermediate steps to truly support the human operator during a task, be it driving or a workflow within the industrial context. To reiterate, this is necessary to make the mediation of reality as natural, effective, helpful, and non-disturbing as possible. This can be achieved by preemptively providing necessary information or removing parts of reality to make the following tasks easier to perform. While many of these variables can be predetermined for some particular scenarios, a mediated reality system benefits most from real-time assessment of the environment, the operator, the goals, and tasks. This way, a real-time modification that is situation-dependent and respects the given environment and human states can happen.

Following the workshop's theme, we now outline how mediated reality can improve human engagement and the experience of interaction with an automation system in the following paragraphs on particular challenges. In particular, we highlight the potential of mediated reality and motivate future research challenges.

How to create takeover requests that encourage operators to intervene and emphasize possible outcomes? With mediated reality, automation systems can modify perceived reality so that the operators can anticipate takeovers early and are prepared for them. Mediated reality can also guide the intervention, provide necessary information for situational awareness, and highlight possible outcomes. It can also alter reality so that the human operator can safely, effectively, and efficiently perform the takeover and any upcoming actions by guiding him and giving him cues that allow him to focus on the essential aspects while unnecessary or intrusive content fades into the background (or even vanishes altogether; similar to the example in Section 2.1).

How can we encourage sustained interaction with automated systems? An automation system that communicates with a human operator via a mediated reality has not only the means to prompt explicit requests from the user but also to nudge the user towards collaborative interactions. For example, this can happen by modifying perceived reality to choose a preferable action over a viable but worse alternative. In addition, it can also highlight the benefits of usage by mediating reality. For example, in a home automation system paired with an AR-HMD, the automation system could mediate reality so that it is the most natural thing for a human operator to interact with the system and, by that, sustain interaction beyond the initial excitement phase. This could be done, for example, by representing a reality that anticipates the positive consequences of interacting with the automation system. Here, the system can adapt if the interaction patterns become natural and habitual.

How to design for the overall reliability of human-automation teams? In addition to traditional 2D displays and plain augmented reality, mediated reality has other means to support reliable cooperation in teams of human(s) and automation system(s). Here, mediated reality can work towards a consistent team performance by its unique means of adding information and making usually hidden structures and entities visible to the human operator. Humans can then integrate this knowledge into their planning and action processes and perform better in the human-automation team. This means, if designed carefully, a mediated reality approach promises to make the interaction between the human and the automation experience more transparent and, at best, leads to communication between the two that is at least as effective as the one between two human team members.

How to support the development of trust in these assemblies? Especially complex automation systems can use mediated reality to support the development of trust and manage and maintain it. For example, a home automation system can use an "x-ray" view to display the result of its actions in reality in real-time, even when hidden, to the human operator. Such an automation system that facilitates mediated reality techniques can also implicitly communicate its understanding of the world (as seen in Figure 1) and potentially its insecurities in a collaborative task. In addition, such a system can also add and highlight audiovisual content in real-time. For example, in a technical context, this could mean that the system shows the human operator how an internal mechanism of a complex workpiece works ("x-ray") or is influenced by an action of the team and asks the human operator if this understanding is correct. Given that this information on what the automation system knows and what it doesn't know helps when building trust [23, 24], a mediated reality approach offers additional channels for this, compared to traditional AR or 2D displays.

How to ensure and support the well-being of human operators? For this specific challenge, mediated reality has the potential to hint towards dangers or dangerous situations by a) highlighting them and b) making them visible or c) a combination of both. Such a procedure is shown in Section 2.1 where the automation system makes the danger visible, annotates it, and by that, ensures the well-being of the human operator. Mediated reality, in general, can be used in human-automation teams to communicate intention, short-/medium-/ and long-term goals, processing steps, and available information about the automation systems' state and context.

4. Research challenges

The contributions of mediated reality to an enhanced automation experience naturally revolve around the technological means to augment or deliberately diminish reality. That is, modifying perceived reality for a human operator to ensure that shared goals are achieved effectively, efficiently, safely, and satisfactorily. To realize this vision, the following core challenges need to be addressed:
1. For a beneficial mediated reality, further advancements in software (real-time tracking, registration, reconstruction) and hardware (tracking and semi-transparent display) for (audio-)visual displays are necessary.
2. One of the more ethical challenges is not simply to design a mediated environment that presents an altered reality as realistically and plausibly as possible but to consider that it can also lead to "reality confusion" in which the human user is no longer able to determine what is real and what is not - even if he tries.
3. Appropriate design patterns and strategies for dynamically mediating reality are needed so that (potentially dynamic) modifications are not annoying, distracting, eerie, or ineffective.
4. Systems for context tracking and estimation are necessary so that the mediated reality can adapt according to the human state, the shared goals, and the environment.
5. Toolkits/frameworks need to be developed that allow for an easy design and development of mediated reality prototypes (e.g., similar to ARCore[25] and ARKit[26]).
6. Qualitative and quantitative studies that assess users' reactions to mediated reality in a human-automation team need to be performed.
7. In this paper, we mainly discussed visual mediated reality. However, work on spatial audio [27], auditory illusions [28] and also haptics [29], and smell [30] promise future extensions of this genuinely multi-sensory vision.

Of course, any mediated reality-based approach involves significant ethical issues. This includes long-term consequences and aspects like how the human reacts to or after sustained interaction with a modified reality and if there is any effect on the experience of "real reality" after such a sustained interaction. It is also essential to ensure that *no user* in a human-automation team that relies on mediated reality *is unaware* that they are facing a mediated environment. While this is not a problem with today's displays, it is relevant to consider these aspects early on. An overview is provided by [31, p. 239].

5. Conclusion & Outlook

In this position paper, we outlined the potential of mediated reality for increasing the experience in human-automation teams. Focusing on visual alterations, including augmenting and diminishing reality, our examples illustrate how mediated reality can improve the human automation experience. Following this, we described several areas where mediated reality can contribute and present these contributions (takeover requests, sustained interaction, overall reliability, trust, and operator's well-being). While mediated reality technology is arguably still in its infancy, we showed that the potential benefits for human-automation teams of this output modality are plentiful. Thus, in the future, researchers must work on soft- and hardware, UI/design patterns, management strategies for a shared context, lab and field studies, and multimodal mediated reality to truly benefit from mediated reality in human-automation teams. Still, with today's technology stack, it is already possible to implement and test prototypes of mediated reality user interfaces, for example, by simulating them in virtual reality. We highly encourage doing precisely that, e.g. by testing the above-mentioned use cases and contributions.

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A. Online Resources

The virtual scene in Figure 2 is generated in Unity with assets of:

- Alarm button,
- Building,
- Electric engine,
- Environment map,
- Machine + Rotor,
- Hand, and
- Robot.