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Design and Development of an XR Assistance System for Industrial Workers

vorgelegt von
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Saarbrücken, Tag. Monat Jahr

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Zusammenfassung

Kurze Zusammenfassung des Inhaltes in deutscher Sprache, der Umfang beträgt zwischen einer halben und einer ganzen DIN A4-Seite.

Orientieren Sie sich bei der Aufteilung bzw. dem Inhalt Ihrer Zusammenfassung an Kent Becks Artikel: `http://plg.uwaterloo.ca/~migod/research/beckOOPSLA.html`.

We have seen that computer programming is an art,
because it applies accumulated knowledge to the world,
because it requires skill and ingenuity, and especially
because it produces objects of beauty.

— Donald E. Knuth [1]

Danksagung

Hier können Sie Personen danken, die zum Erfolg der Arbeit beigetragen haben, beispielsweise Ihren Betreuern in der Firma, Ihren Professoren/Dozenten an der htw saar, Freunden, Familie usw.

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1 Introduction

In modern industrial environments, ensuring the safety and well-being of workers is an increasingly complex challenge. This is due to the rise in automation of factories, which has led to workers being exposed to a range of risks from moving parts to robots. Traditional safety measures like warning signs, floor markings, and standard training provide a necessary foundation, but they are not always sufficient. In many cases, these static systems fail to reach workers at the right moment, especially when attention is focused elsewhere or hazards change rapidly. These systems require real-time adaptation and individualization.

To protect workers more effectively, safety solutions must become adaptive, personalized, and accessible. They must understand the individual context of the worker: how they move, where they are in the environment, and when they may be at risk, whether from poor posture, fatigue, or close proximity to danger zones.

Advances in extended reality (XR) and wearable technology, such as full-body haptic suits and immersive head-mounted displays, are opening new avenues for real-time assistance and feedback systems. These technologies are no longer confined to research labs or entertainment industries but are being increasingly considered for applications in healthcare, rehabilitation, training, and industrial safety. In this context, integrating real-time physiological and spatial data with immersive and haptic feedback presents a promising opportunity to enhance worker safety in hazardous zones.

This thesis explores how such a system could be designed and deployed. Specifically, it proposes an XR-based assistance framework that helps workers stay safe by making risk visible, posture perceptible, and hazards tangible. By integrating real-time motion, biometric, and positional data, the system aims to provide immediate, personalized support without disrupting the workflow or overwhelming the user. Rather than replacing human judgment, it enhances situational awareness and supports safer, more ergonomic behavior in industrial settings.

2 Theoretical Background

This chapter outlines the conceptual and scientific foundations relevant to the development of an XR-based assistance system for industrial workers. It introduces key technologies, principles of ergonomics, human-machine interaction modalities, and architectural tools that enable real-time support in complex environments.

2.1 Extended Reality in Industrial Contexts

Extended Reality (XR) technologies—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are increasingly being explored beyond their origins in gaming and entertainment. In recent years, they have shown significant promise for applications in healthcare, education, training, and particularly in industrial environments. These immersive systems offer novel ways to visualize information, monitor surroundings, and interact with complex machinery or digital twins in real time.

In industrial settings, XR can bridge the gap between human workers and automated systems by enhancing spatial awareness, reducing cognitive load, and supporting ergonomically sound behavior. By embedding visualizations directly into the user's perceptual field and supplementing them with spatially anchored cues or haptic feedback, XR opens new pathways for context-sensitive assistance. This is especially relevant in environments that involve repetitive tasks, heavy machinery, or dynamic hazards—scenarios in which traditional safety protocols may fall short.

This section introduces the conceptual foundations of XR, outlines its most common industrial applications, and discusses the key challenges and opportunities associated with deploying XR systems in real-world industrial settings.

2.1.1 Definition and Taxonomy

Extended Reality (XR) is an umbrella term encompassing a spectrum of technologies that combine or replace real-world perception with computer-generated input. The conceptual foundation for this spectrum was introduced by Milgram and Kishino in their seminal work on Mixed Reality visual displays [2].

At the core of their model lies the *Reality–Virtuality Continuum*, which represents a scale between the completely real environment and the fully virtual environment. Technologies within this continuum can be classified as follows:

- **Real Environment (RE):** The physical world, unmediated by digital augmentation.
- **Augmented Reality (AR):** Systems that overlay virtual elements onto the real world while maintaining real-time interaction and correct spatial registration. Examples include visual annotations or digital twins of industrial machinery displayed through XR headsets.
- **Mixed Reality (MR):** A broader concept encompassing AR, but also allowing for deeper integration where virtual and real elements interact and are spatially and temporally consistent. In MR, digital and physical objects can influence each other.

- **Augmented Virtuality (AV):** Mostly virtual environments that incorporate some real-world data—such as sensor streams or camera feeds.
- **Virtual Reality (VR):** Fully immersive digital environments with little or no real-world input.

XR, as used in this thesis, refers to the entire continuum and highlights systems that combine immersive visualization (e.g., via head-mounted displays) with real-world input data (e.g., motion capture, spatial localization, physiological sensors). This definition is especially relevant in safety-critical industrial contexts, where virtual feedback must accurately reflect physical risks and user behavior in real time.

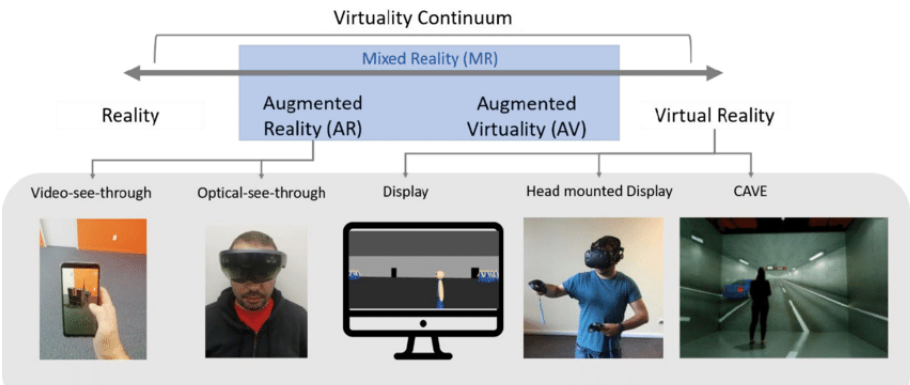

Figure 2.1: The Reality–Virtuality Continuum, adapted from Milgram and Kishino [2].

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Bibliography

[1] Donald E. Knuth. "Computer Programming as an Art". In: *Communications of the ACM* 17.12 (1974), pp. 667–673.

[2] Paul Milgram and Fumio Kishino. "A taxonomy of mixed reality visual displays". In: *IEICE TRANSACTIONS on Information and Systems*. Vol. 77. 12. IEICE, 1994, pp. 1321–1329.

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Kolophon

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