Comparing AR Interaction Techniques and User Interfaces for Worker Guidance Systems for Industrial Applications

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Abstract

We present an empirical evaluation of interaction techniques used in Augmented Reality (AR) for worker guidance systems. Recent advancements in AR technology have shown promise in improving worker assembly efficiency, yet few empirical studies directly compare the performance and usability of different AR Graphical User Interfaces (GUI) and Natural User Interfaces (NUI). We compare task completion times and usability between voice commands, gestures and virtual buttons, across anchored and floating GUI. Thirty-six participants completed an AR-based worker training task as part of a 2×3 between-subjects design. Taking into account the small sample size, our results showed no differences between GUI and NUI in task completion times or usability scores. Learning rates were better in anchored interfaces in comparison to floating ones. We discuss these results in the frame of Mental Models theory and discuss their limitations, providing insights for optimizing AR interaction design in industrial training applications.

CCS Concepts

• ; • **Human-centered computing** → *Empirical studies in interaction design*;

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Design Methods, User Experience Design, Virtual/Augmented Reality

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1 Introduction and Background Work

Augmented Reality (AR) has gained recognition as a cost-efficient and flexible training tool, as it reduces reliance on static instructional materials, offering real-time, interactive guidance [2, 8, 21]. AR superimposes holographic instructions onto the physical workspace via see-through lenses, allowing workers to interact with digital overlays. It can be found in different forms such as Head-Mounted Displays (HMD) and handheld devices (tablets and mobile phones). Equipped with multiple sensors, it supports different interaction methods and Natural User Interfaces (NUI), such as gestures and voice commands [10, 24].

HMD AR-based training is particularly interesting for complex manual assembly tasks as it offers visualization in context [7]. To ensure its advantages and effectiveness, user interaction methods must be adaptive, frictionless, and user-friendly[10, 24]. User-based studies can shape AR design practices and create universally accepted standards to align them with user needs and environmental variables [1, 12]. Moreover, according to [1] addressing ergonomic issues in AR design minimizes risks of occupational hazards. Yet, limited research has been done into standardized design guidelines and interaction techniques for AR guidance applications, especially in industrial settings, and different NUI [1].

Mental Models theory highlights the importance of internal representations and user expectations in interface design [14]. Users rely on prior knowledge and experience when interacting with new systems [6]. Inconsistencies in Graphical User Interface (GUI) can divert user expectations and hinder usability [3, 22]. Additionally, factors such as memory, attention capacity, and information placement must be considered to optimize learning [17].

Previous research has shown that different AR NUI can have different learning rates. For example, [16] showed that naive AR users initially preferred voice commands over gestures, due to problems with accidental gestures. However, users who are more familiar with AR hand gestures prefer them. The authors note that both interaction techniques had a learning curve [16]. Additionally, voice command use in AR is constrained by ambient noise, privacy, and confidentiality concerns [20]. A combination of different modalities is sometimes required for optimal operation [1, 15].

The present study provides empirical data on user performance in an AR-guided assembly task with LEGO-like bricks in an industrial setting. With an exploratory approach, we compare voice commands, gestures, and virtual button interactions across two different GUI, with anchored or floating panels to pinpoint the most feasible interface for task guidance systems based on user performance metrics. Behavioural measures such as task completion times, subjective system usability evaluation, and learning rates were measured. Our results will inform future AR GUI and NUI design, stepping towards the development of more intuitive and efficient training systems in industrial settings.

2 Methods

2.1 Participants

Thirty-six participants (12 female, Mage=27.3 years) took part in the study. They all had normal or corrected-to-normal vision. Participants had no diagnosis of psychological or neurological disorders according to self-reports. They all gave their informed written consent before participating. The experiment was approved by the ethics committee of the Faculty of Social Sciences at the University of Kaiserslautern, according to the ethical standards of the institution as well as aligning with the German Research Center for Artificial Intelligence guideline and in compliance with the 1964 Helsinki Declaration. Additionally, as the recruitment took place in an academic setting, participants were students, researchers and employees of educational bodies. None of the participants were experts in AR experiences, having their experiences varying between interacting for the first time with AR and merely trying them.

2.2 Apparatus and Materials

The study was conducted using a Microsoft HoloLens 2 (HL2) head-mounted display (HMD), which provides see-through holographic lenses with a 42° horizontal field of view (HFoV) and a 29° vertical field of view (VFoV). The device features a per-eye resolution of 1440x936 and a refresh rate of 60 Hz. An assembly workstation, measuring 0.83 m in height, was positioned in front of an Industry 4.0 production island where participants assembled the model as shown in figure 1.

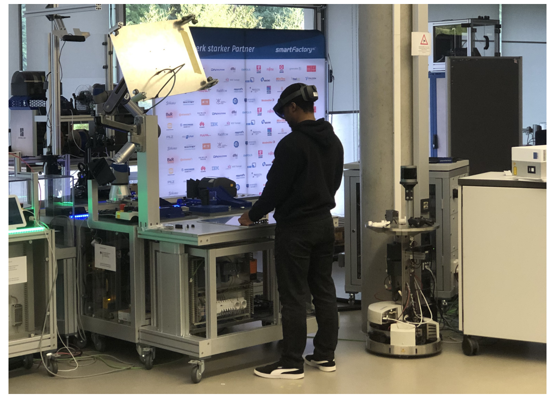


Figure 1: Experimental setup, showing a participant during the study, the production island, and the laboratory setup.

The AR application was developed using the Unity game engine 2021.3.40f1 [23] and the Mixed Reality Toolkit 3.2.1 [18]. Figma (2024, February) [11] was utilized for interface prototyping, ensuring a clean and intuitive design. Blender 4.1 [4] was employed to create animations, allowing modular integration into Unity for enhanced flexibility.

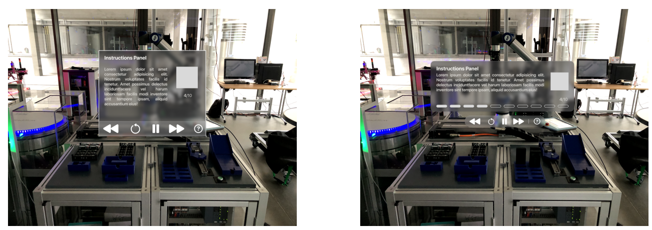


Figure 2: Figma prototypes for anchored (Left) and floating (Right) panels.

2.3 Questionnaires

To assess usability participants completed the System Usability Scale[5] (SUS): Consists of 10 alternating positive and negative statements rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

2.4 Experimental Design

Participants started the experiment with a set of instructions to familiarize themselves with the AR system. They then assembled a miniature truck model, shown in figure 3, using LEGO-like bricks and 3D-printed parts in 32-steps, divided into two symmetrical subassemblies (cab and trailer). For each step, they received text-based assembly instructions, a rotating 3D preview of the required part and an animated demonstration of the assembly process. After the preview, animations faded out and a corresponding image was displayed in the top-right corner of the tutorial panel. The control panel provided navigation indicators for progressing through steps, pausing, resuming, and repeating animations. Step times were defined as the time between the end of the preview and the activation

Figure 3: Assembled truck, placed on an A4 paper for reference.

of the “next-step” button. Completion times were calculated as the sum of all step times. The interface also included a progress bar for completed steps, and a control panel with a help button (see [9] for interaction design elements). Click sound played upon successful interaction with the different UI elements as feedback. Following the assembly, participants completed the SUS questionnaire and were debriefed about the intention of the experiment. Additionally, they were asked to report any inconveniences, relevant to the interactions, during the task.

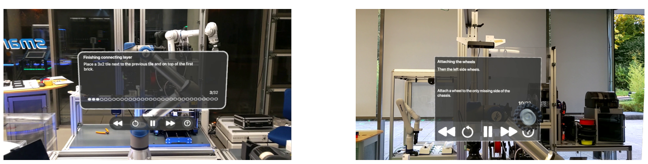
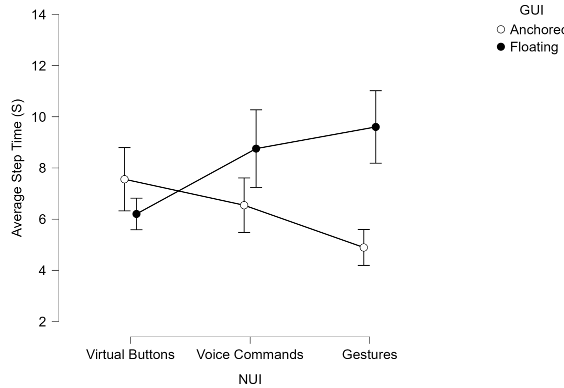
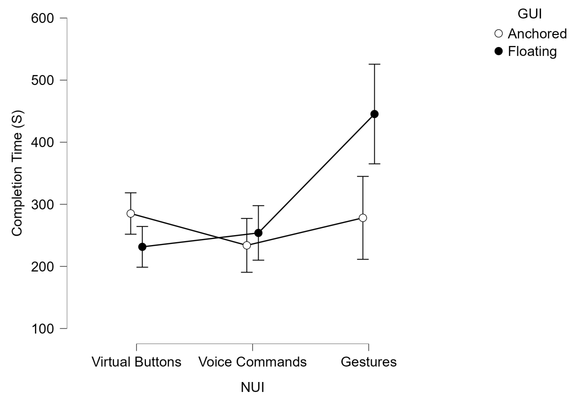


Figure 4: Designs rendered in HoloLens 2, Floating SI design(Left) and Anchored SI Design(Right).

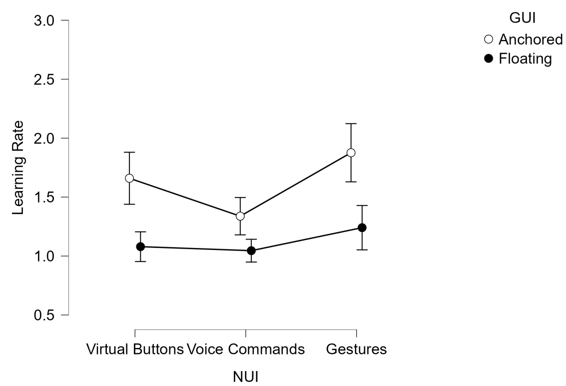
2.4.1 Analysis. To evaluate time-based performance metrics (completion times, mean step times, learning rates), and usability ratings, we conducted a 2×3 between-subjects ANOVA for each metric, with factors GUI (anchored, floating) and NUI (Virtual buttons, Voice commands, Gestures). Steps 1, 16, and 32 were excluded from the analysis, which comprise the first and last steps, as well as the step after the end of the first assembly unit. Statistical analyses were performed using JASP (0.19.3).



(a) Completion times.



(b) Mean step times.



(c) Learning rates.

Figure 5: Experimental results across different interfaces. (a) Mean step times, (b) Task completion times, and (c) Learning rates.

3 Results

3.1 Completion Times

Results of completion times are shown in Figure 5a. No significant main effect of GUI ($F(1, 30) = 1.06$, $p = .312$, $\eta^2 = .025$), NUI ($F(2, 30) = 2.94$, $p = .068$, $\eta^2 = .142$) and no significant interaction ($F(2, 30) = 2.25$, $p = .123$, $\eta^2 = .109$).

3.2 Average Step Time

Results of Average Step Times are shown in Figure 5b. No significant main effect of GUI ($F(1, 30) = 3.95$, $p = .056$, $\eta^2 = .095$) nor NUI ($F(2, 30) = 0.23$, $p = .799$, $\eta^2 = .011$) were found. A significant interaction between GUI and NUI was observed ($F(2, 30) = 3.56$, $p = .041$, $\eta^2 = .171$). Post hoc tests for the interaction however revealed no significant differences (all p Tukey $\geq .076$).

3.3 Learning Rates

Results for learning rates are shown in Figure 5c. A significant main effect of GUI was found ($F(1, 30) = 11.65$, $p = .002$, $\eta^2 = .249$), where learning rates for Anchored GUIs were consistently higher than Floating ones across all NUI conditions. No significant main effect of NUI ($F(2, 30) = 2.07$, $p = .144$, $\eta^2 = .088$) and no interaction ($F(2, 30) = 0.52$, $p = .599$, $\eta^2 = .022$) were found.

3.4 System Usability Scale (SUS) Score

No significant differences in SUS scores across conditions ($p > .05$).

4 Discussion

This study investigated the effectiveness of different AR GUI and NUI in worker guidance systems by analysing their impact on completion time, learning rates, and usability scores in a manual assembly task. The results showed no significant main effects or interactions on task completion times or usability scores. All participants demonstrated positive learning rates, which varied significantly depending on the GUI. Anchored panels were associated with higher rates than floating ones, and no effects of NUI or interaction were observed.

Previous studies comparing AR to traditional worker guidance systems suggest that prior user experience and interface complexity influence task learning rates [13, 19]. Anchored GUI appears to leverage users' familiarity with conventional interfaces, enabling more intuitive interaction and minimising learning effort. In contrast, floating GUI may disrupt users' established mental models and demand greater cognitive adaptation, reducing learning efficiency.

While anchored GUI demonstrated a learning advantage, the absence of effects related to NUI may reflect limitations in statistical power due to the small sample size. Additionally, the task might have been generally too easy, likely introducing ceiling effects, as all participants completed it with minimal reliance on in-UI help functions. These may also have concealed potential differences in completion times, usability, and interaction effects. Furthermore, participants reported unintended activation of gesture-based controls, particularly in floating GUI conditions, which may have negatively impacted the performance. Environmental distractions in the open lab setting, such as ambient noise, may also have affected the measures, especially those relying on voice commands.

To strengthen the generalisability of these findings, future research should replicate them with larger samples, and task difficulty should be increased to resemble manual assembly tasks on the shop floor. In conclusion, increasing user exposure to AR hardware in industrial contexts may improve usability, learning outcomes, and technology adoption, leading to broader adoption of AR-based guidance systems and more effective AR training solutions.

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[1]https://cordis.europa.eu/project/id/101138782

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