SBB HoloGuide: An Intuitive Augmented Reality Application for Improving the Industrial Maintenance of Train Doors

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Abstract

Industrial maintenance in dynamic environments often involves complex workflows and demands tailored operator support. To address these challenges, we present SBB HoloGuide, an augmented reality (AR) application developed for Swiss Federal Railways (SBB) to simplify train door maintenance. Designed for HoloLens 2, the system overlays virtual information onto physical components, enabling operators—especially novices—to complete tasks efficiently using intuitive interfaces. Key features include 3D virtual-physical door alignment, step-by-step instructions with annotated visuals and component highlighting, and a miniature view for detailed tasks. The application integrates SBB's maintenance data from manuals and logs, achieving a 2.85x average speedup in task completion compared to traditional methods, as validated through a user study involving participants with diverse AR experience levels. This work highlights AR's potential to optimize industrial workflows and lays the groundwork for AR-based maintenance technologies.

1. Introduction

Industry 4.0 represents the fourth industrial revolution, characterized by the integration of digital technologies, automation, and data-driven systems into industrial processes. Within this context, the concept of Operator 4.0 emerges, highlighting a new generation of skilled operators equipped with human-machine interaction technologies to collaboratively address complex challenges [10]. As production processes become increasingly complex, there is a growing need to support operators with assistance systems that can provide tailored, contextualized, and actionable information [11].

In recent years, the railway industry has adopted several Industry 4.0 principles to enhance maintenance procedures. Contextualized maintenance technologies, such as Augmented Reality (AR), overlay virtual information onto physical objects, improving decision-making and task execution processes. AR enables real-time information delivery, standardizes workflows, and personalizes content to the operator's expertise and experience [11]. This is particularly relevant for dynamic working environments where operators must adapt quickly and leverage expert knowledge [6]. By assisting operators in visualizing critical information and simplifying workflows, AR can transform maintenance operations, enhancing efficiency, safety, and effectiveness [3]. This will not only contribute to the development of novel AR adaptive tools but also encourage users to abandon traditional methods in favor of AR-assisted solutions [11].

The application of AR for industrial maintenance offer significant potential, particularly in assisting novice operators who can benefit greatly from intuitive guidance and support. Despite these advantages, challenges persist in fully leveraging AR's potential. Existing AR systems often lack the necessary usability to accommodate operators with varying skill levels and learning capabilities [5]. For Swiss Federal Railways (SBB), these challenges are amplified by difficulties with complex workflows, including the need for three manuals of approximately 170 pages each, two spreadsheets for maintenance logs, and managing train doors with more than 300 individual components.

To address these limitations, our project introduces an innovative and user-friendly AR application specifically designed to support railway maintenance operators in performing train door maintenance tasks for SBB. The primary goal of our system is to provide the right information at the right time through an intuitive interface, particularly tailored for novice operators. Our solution allows operators to visualize and interact with virtual overlays aligned seamlessly with physical components. The system incorporates features such as a customized maintenance interface informed by SBB operator feedback, virtual-physical alignment for door placement, and step-by-step instructions with annotated visuals and optional 3D views for examining intricate and small elements. An interactive tutorial is also included to minimize training requirements.

The main contributions of this work are:

- We present a novel end-to-end application for train door maintenance at SBB, integrating interaction with menus and 3D objects. The application is linked to SBB's data pool, encompassing three detailed manuals and log files, processed through a backend for data extraction and transformation.
- We implemented the interface as an app for the HoloLens 2, featuring interactive tutorials, movable virtual objects, and advanced visualization features such as component highlighting and miniature 3D models.
- We conducted real-world tests and a comprehensive user study, showcasing the system's intuitiveness and its ability to empower novice operators to efficiently perform maintenance tasks with minimal training, achieving an average **2.85x** speedup in maintenance completion time compared to traditional methods.

2. Related Works

2.1. Maintenance via Augmented Reality Interfaces

In [12], AR interfaces are analyzed for industrial maintenance tasks, highlighting their ability to overlay digital content onto the physical world using devices like smartphones, tablets, and AR glasses. These overlays, ranging from data displays to interactive 3D models, enhance training by merging theoretical knowledge with practical skills. AR interfaces provide instant feedback, offering corrective guidance by tracking user actions and response times, thus improving efficiency and effectiveness in maintenance operations. In the industrial domain, AR interfaces improve comprehension of complex processes, as shown in [7]. In their work, AR was employed during heavy machinery maintenance to overlay critical information and step-by-step instructions directly onto equipment, guiding technicians through repairs without relying on bulky manuals or frequent consultations with supervisors. However, operators must be trained to effectively use specific AR environments. This requires well-structured procedures, such as integrated tutorials on interacting with MR applications and using hardware gestures effectively [1].

Hardware selection plays a critical role in the successful delivery of AR interfaces for industrial maintenance [12]. Devices like Head-Mounted Displays (HMDs), mobile phones, and tablets enhance user interaction and provide immersive visualization experiences [4]. Transparent-lens HMDs, such as Microsoft HoloLens and Magic Leap 2, enable users to view real-world scenes with overlaid virtual objects, making them particularly suitable for industrial maintenance tasks. Despite their potential, the adoption of HMD see-through devices in real industrial settings remains underexplored [12]. Research indicates that further user testing of AR interfaces on factory floors is essential. Such tests would refine interface design through feedback loops from real users and better address operator requirements, thereby improving system implementation readiness [1].

2.2. AR System Design for Industrial Maintenance

Despite advancements in AR technology, effectively managing and presenting maintenance information in AR interfaces remains a challenge. A model proposed in [1] addresses this by integrating three key data domains: virtual data, maintenance data, and CAD data. Virtual data explains how tasks or procedures should be performed using textual, graphical, or 3D models. Maintenance data provides insights into when maintenance should occur based on system health. CAD data identifies the location of specific components by overlaying 3D models onto real-world equipment.

Combining these domains enables the creation of specialized diagnostics interfaces, which helps identifying and resolve equipment issues by offering repair suggestions. Effective AR systems prioritize usability by incorporating simple, intuitive menus that minimize training time and enhance user satisfaction. Critical features include navigation elements like next/previous/confirm buttons and context-aware visualizations, such as overlaid CAD models and 3D system health representations. Adhering to these design principles, AR systems have shown significant advantages over traditional methods, including reduced operating times, improved navigation and content quality, and enhanced usability, making AR an indispensable tool for modern industrial maintenance operations [1, 2].

3. Method

In this section, we outline the main components and techniques utilized in the system, as illustrated in Fig. 1. We then provide a detailed explanation of each part of our proposed method.

3.1. Login Interface

Upon opening the application, the user is presented with a login prompt. This screen serves two primary functions: (a) authentication and authorization, and (b) the display of only relevant tasks for the specific worker, based on their profile (see Sec. 3.2).

3.2. Maintenance Tasks Interface

After logging in, the worker is presented with a list of maintenance tasks that need to be completed. This list is displayed as a table, with each row providing essential information to help the worker locate the door requiring maintenance. Specifically, the train number, carriage, and door

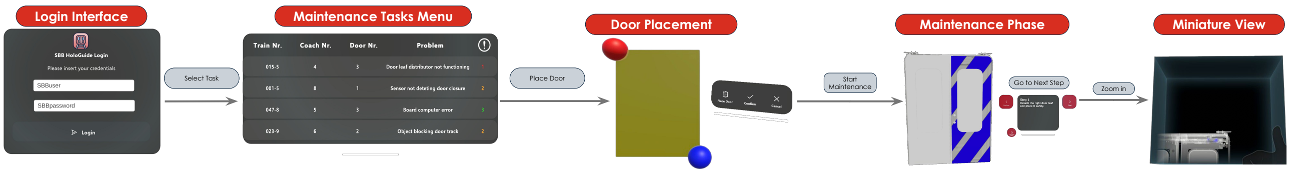

Figure 1. Application Flow.

number are presented, which together allow for the unique identification of each door within the repair facility. Each row also indicates the priority level of the maintenance task, with tasks sorted from highest to lowest priority. The priority is represented by a numerical value ranging from 3 (lowest priority) to 1 (highest priority), accompanied by a color gradient from green (low priority) to red (high priority). We used colored numbers to indicate priority levels to assist users with color impairments, allowing them to rely on the numbers if they cannot distinguish colors. The user can then select a task to proceed with, which leads to the door placement step (see Section 3.3).

3.3. Door Placement Interface

Before starting maintenance, the application must overlay the door model onto the faulty door. To achieve this, the real-world coordinates of the door frame are required. Although recent work has explored the use of 6D pose estimation methods for automatic door placement [9], current results are still insufficient, as precise alignment between the 3D door model and the physical door is essential to avoid misalignment of small components during maintenance. As a result, we rely on the user to provide the application with the necessary coordinates for door placement.

This process is performed interactively, where the worker moves two spheres to the bottom-right and top-left corners of the door. A yellow plane is displayed between the two spheres, providing visual feedback on where the door will be overlaid, as illustrated in Fig. 7. During this phase, a small menu appears, allowing the user to confirm the placement, redo it, or cancel the operation and return to the maintenance tasks interface.

Once the plane is aligned satisfactorily with the door, the worker can confirm the placement. The application will then scale, rotate, and transform the door model accordingly, positioning it in the designated spot. To ensure proper overlay, precise plane placement is necessary. To facilitate this, the application allows the worker to make quick adjustments to the placement with a single interaction after confirmation. When satisfied with the overlay, the worker can proceed with the maintenance steps (see Sec. 3.4).

3.4. Maintenance Steps Interface

The main interface is designed to guide the worker through maintenance steps and consists of several key components:

Steps Menu: this component displays the current step along with a description of the required action, directly adapted from the paper user manuals. Workers can easily navigate between steps with a single interaction, advancing or going back as needed.

Highlighting Door: the overlaid door model highlights the relevant component to work on using a black-and-blue color scheme, allowing workers to clearly see the highlighted component while slightly revealing the hidden internal components. This scheme was chosen based on user preference from A/B testing (see Sec. 4.2) and feedback from senior SBB operators (see Sec. 4.1). Additionally, when a small component is highlighted, a bright red circle appears around it to help the worker pinpoint its location. The door model disappears when the worker moves close to perform maintenance, ensuring a clear view of the component. A special blue-striped highlighting is also applied based on findings from the visual impairment section of the user study.

Miniature View: for small components or when close to the door, the worker can use a miniature hand gesture to trigger a zoomed-in view of the component in the palm of their hand. This view centers on the highlighted component but also shows nearby small components in semi-transparent colors. This feature helps workers with intricate components and assists in locating components when the overlay is hidden.

4. Ablation Study

4.1. Application Development Protocol

To develop our application, we began by classifying participants into three user types:

- `Type 1`: Users with no prior experience, either in AR or in industrial maintenance.
- `Type 2`: Users with AR experience but no industrial maintenance experience.

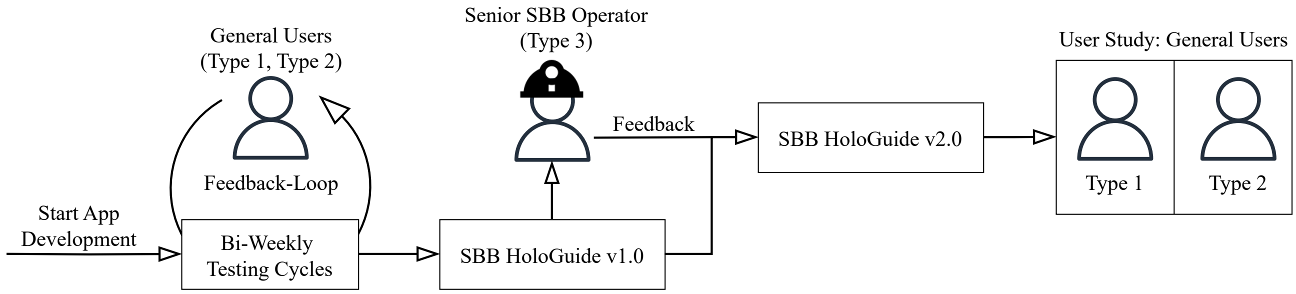

Figure 2. Application Development Protocol.

- `Type 3`: Users with experience in both AR and industrial maintenance.

We employed a feedback-in-the-loop model [8], conducting biweekly testing cycles with both `type 1` and `type 2` users. These iterative sessions allowed us to identify, refine, or remove features, improving the application's overall flow and interactions. After the application reached a robust level of usability, appearance, and navigation, we conducted a test at the SBB maintenance facility, gathering feedback from a `type 3` user—a senior SBB maintenance operator. This input guided us in enhancing the application's content quality, ensuring the information displayed at each step was precisely tailored to the operator's needs.
To focus on the primary objective of developing an application to assist novice operators, we conducted a comprehensive user study with both `type 1` and `type 2` users. Fig. 2 illustrates the application development protocol adopted.
All experiments utilized the Microsoft HoloLens 2 [1] for the MR interface, with Unity as the development engine. A lightweight Python backend was used for processing maintenance data, while C# scripts facilitated automation across Unity scenes. The source code is publicly available at: `https://github.com/lucat1/mixed-reality`.

4.2. User Study

We conducted a user study to evaluate the intuitiveness and usability of our interface. The study included 18 participants divided into two groups: `type 1` and `type 2` users. `Type 1` participants were aged 23 to 28 years, with a mean age of 24.6 years (SD = 2.4). `Type 2` participants ranged from 22 to 53 years, with a mean age of 27.2 years (SD = 9.8). Overall, participants ranged from 22 to 53 years, with a mean age of 25.8 years (SD = 7.1). To ensure controlled experimental conditions, the study was carried out in a simulated environment, as illustrated in Fig. 6.
In the first phase, participants completed a preliminary questionnaire assessing their current levels of frustration and mental fatigue, along with preferences for app design elements through a 5-second testing method. Demographic data, such as age and prior experience in maintenance and/or augmented reality devices, were collected to classify users into `type 1` or `type 2` groups.
Following the questionnaire, participants performed a maintenance task using a traditional SBB maintenance manual. For simplicity and convenience, a condensed version of the manual was used: instead of the original three manuals (approximately 170 pages each), a 20-page version was provided. Despite this simplification, the AR application was expected to outperform the traditional method in terms of task completion time. Participants were tasked with identifying and performing the correct steps to achieve a predefined maintenance goal without external assistance. We recorded the time taken for both locating instructions in the manual and performing the physical actions on a mock door within the controlled lab environment.
In the next phase, participants tested our AR application. They first completed a tutorial to familiarize themselves with the interface controls and understand the information displayed in the menus. Subsequently, they performed a usability test involving a maintenance task of similar complexity to that in the traditional method. During the test, the application automatically recorded timing data for various Unity scenes via the HoloLens, saving them as CSV files for each participant for later analysis.
After completing the tutorial and usability test, participants filled out a survey to provide feedback on the application. This included questions about overall usability and specific features or scenes of the application. We also measured users' mental fatigue, frustration level, and satisfaction. Participants also provided preferences across several A/B design choices, such as component highlighting mechanisms, visual impairment simulations, and interaction methods for virtual elements. The full survey form is available at the following link: Google Form.
For the application test with the senior SBB operator, a sim-

[1] https://learn.microsoft.com/en-us/hololens/

ilar questionnaire was used, with additional questions about the content quality of the application. This included evaluating the prioritization of information in the maintenance task menu and the sufficiency of details provided in the maintenance interface—feedback that general users, without any industrial maintenance experience, could not adequately provide.
Our study primarily employed evaluative research techniques, as outlined in Tab. 1. Generative research methods were leveraged earlier during the feedback loop with general users and the senior SBB operator's input during the application development.

Research Technique	Approach
5-seconds testing	Attitudinal
Usability testing	Behavioural
User survey	Qualitative, Quantitative, Attitudinal
A/B testing	Quantitative

Table 1. Evaluative Research Techniques and Approaches.

The following sections present an analysis of the user study results, including time as a key performance indicator (KPI) and insights gathered from user evaluations of the application through the study form.

a) Tutorial Effectiveness Analysis: We evaluate whether the tutorial provided in the application effectively helped users understand the AR mechanisms and improved their performance in the subsequent challenge phase, where they carried out maintenance tasks. Fig. 3 demonstrates the tutorial's impact, showing a consistent reduction in time spent across all three application interfaces: Tasks Menu, Place Door, and Steps Menu. For each interface, the median time during the challenge phase is significantly lower than in the tutorial, indicating that users learned to perform the same tasks more efficiently. Furthermore, the narrower inter-quartile range and whiskers in the challenge phase reflect reduced variability and greater consistency among users. The Place Door interface shows the most pronounced improvement, with a substantial reduction in median time and a narrower spread, suggesting that this initially challenging task was mastered through the tutorial. These results underscore the tutorial's effectiveness in facilitating user learning and enabling faster, more consistent performance during the subsequent challenge maintenance task.

b) User-Friendliness Analysis for AR Novices: We evaluate the usability of the application's interfaces by comparing the time spent by `type 1` and `type 2` users. Fig. 4 shows that for the `Tasks Menu` and `Place Door` interfaces, the median times for both user types are closely aligned, and the inter-quartile ranges show substantial overlap, indicating that these interfaces are equally user-friendly for novices and experienced users alike. However, in the `Steps Menu` interface, `type 1` users exhibit longer completion times and greater variability compared to `type 2` users. We believe this discrepancy arises because progressing through the `Steps Menu` requires users to perform a hand gesture, using the palm of the hand, to access the 3D miniature for visualizing small and intricate components. For users with no prior AR experience, mastering this gesture was less intuitive and smooth compared to those with AR experience. Despite this, the discrepancy is not that significant, and overall, across all three interfaces, we can conclude that the application is user-friendly for users with no prior AR experience.

c) Performance Comparison: SBB HoloGuide vs. Traditional Maintenance Method: We evaluate the performance of SBB HoloGuide against the traditional maintenance method using task completion time as the KPI. Fig. 5 illustrates individual user times for both methods, with average times represented by dashed lines. The results clearly demonstrate that SBB HoloGuide consistently outperforms the use of the manual.

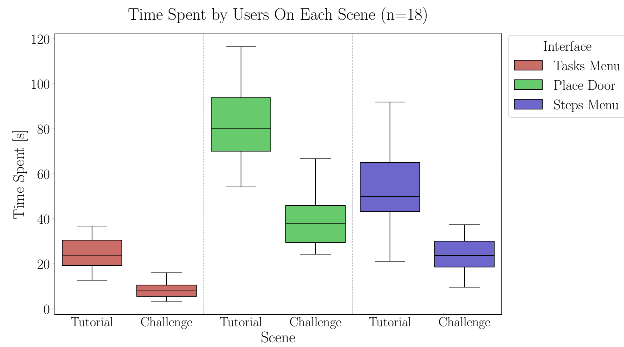

Figure 3. Tutorial Effectiveness.

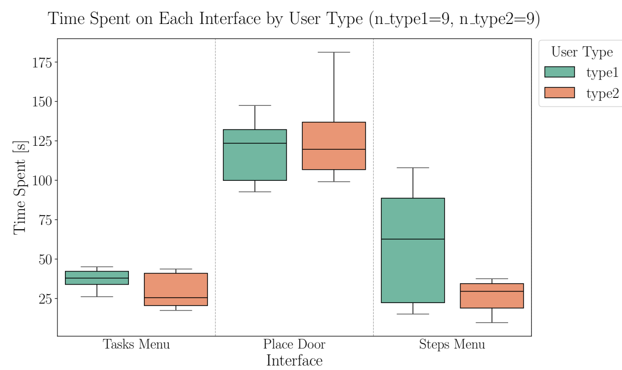

Figure 4. Application User-Friendliness.

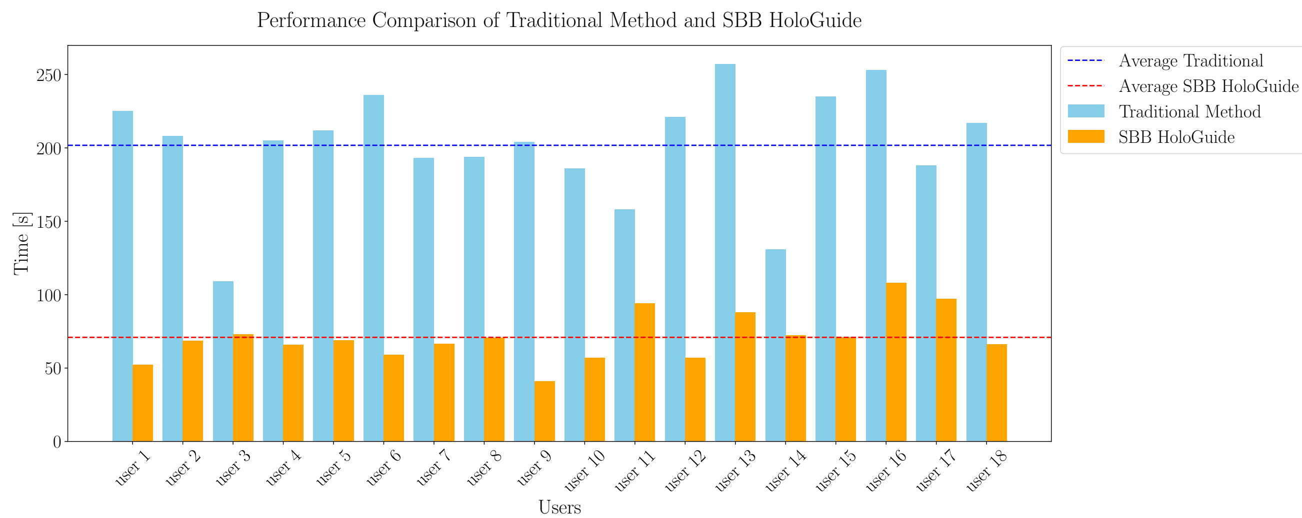

Figure 5. SBB HoloGuide vs. Traditional Method Performance Comparison.

For all users, the time required to complete the maintenance task with the AR application is significantly lower than with the traditional method. The average time for the traditional method is 201.78 seconds, compared to 70.92 seconds for SBB HoloGuide, achieving a **2.85x** speedup on average. This substantial reduction in task completion time empirically supports the conclusion that the AR application offers a faster, more efficient, and streamlined alternative for train door maintenance.

d) User Evaluation Insights: We summarize some key findings from the user study form completed by participants in Tab. 2.

Measure	**Mean**	**STD**
Perceived Frustration [1-5]	2	0.82
Perceived Fatigue [1-5]	2.38	0.87
Navigation	4.85	0.38
Usability	4.62	0.51
Appearance	4.70	0.48
Content Quality	4.62	0.65

Table 2. Some key insights from the user study form.

Nearly 90% of users reported no increased frustration or mental fatigue after using the AR application, and 100% found the tutorial helpful in understanding the AR mechanisms. The Steps Menu and Tasks Menu were the most appreciated interfaces, favored by 61.5% and 30.8% of users, respectively, while the Place Door received the lowest preference, with 84.6% ranking it the least favorable. The application received an average rating above 4.5 across all the interface operability categories outlined in [1], i.e. navigation, usability, appearance, and content quality. Furthermore, all users preferred the AR application over the traditional manual for performing the maintenance task.

5. Conclusion and Future Work

In this work, we introduced SBB HoloGuide, an innovative AR application designed for intuitive and efficient maintenance of SBB train doors.

Our user study shows that users with no AR experience perform maintenance tasks as quickly as those with AR expertise, demonstrating the application's user-friendliness. Furthermore, the study revealed that the AR application achieves a remarkable 2.85x reduction in task completion time compared to traditional manual methods.

Future work could focus on optimizing the `Place Door` interface, identified as a bottleneck in both design and performance. Implementing an automatic door placement mechanism using 6D-pose estimation could further enhance efficiency by eliminating the need for manual placement. Additionally, integrating an Extract, Transform, and Load (ETL) layer could automate and streamline the organization of SBB's extensive and heterogeneous maintenance data, improving usability and expanding the application's potential capabilities.

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Appendix

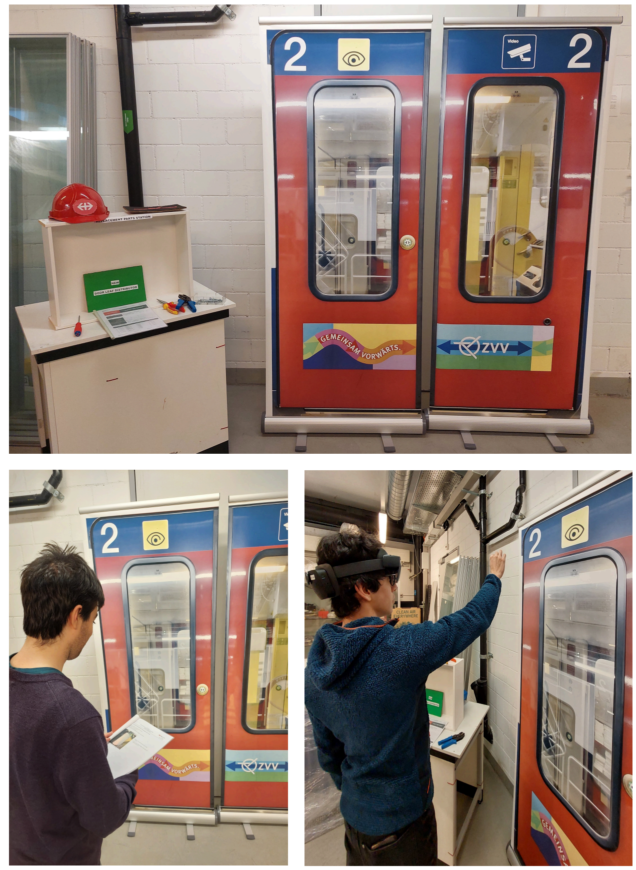

Figure 6. Top: Experimental setup featuring two movable mock door leaves printed to scale and a mock maintenance station equipped with tools and the user manual. Bottom-left: A user performing the maintenance challenge using the user manual. Bottom-right: A user performing the maintenance task using the SBB HoloGuide application with the HoloLens 2.

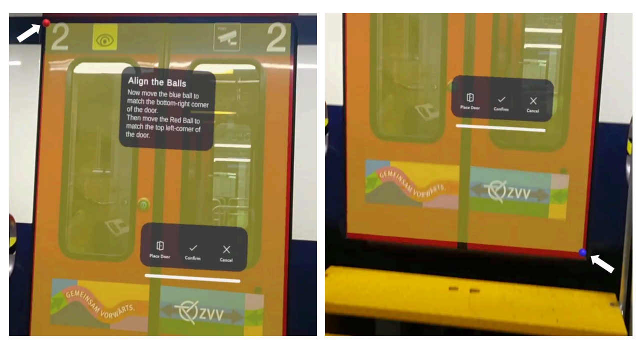

Figure 7. Operator's view during the door placement phase. The red ball (left, indicated by a white arrow) is in the top-left corner, and the blue ball (right, indicated by white arrow) is in the bottom-right. Both are dragged to their correct positions by the operator.