Augmenting Welding Training: An XR Platform to Foster Muscle Memory and Mindfulness for Skills Development

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Figure 1: Integrated XR welding helmet and torch system.

ABSTRACT

Metal welding is a craft manufacturing skill that can be unusually difficult to externalize and represent to novices. Building competency requires an apprentice to iteratively practice embodied skills and sensitize themselves to a sensorially complex practice. To explore these challenges, we identified opportunities for mixed reality and meditation processes to augment welding training and practice. Our demo showcases an extended reality (XR) welding helmet and torch that enhances the embodied learning of welding. We do this in two key ways: biometric sensing that enhances mindfulness and stress management in sensorially challenging environments, and combined motion-sensing and visual XR feedback that helps improve proprioceptive and embodied learning.

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CCS CONCEPTS

• **Human-centered computing** → *User interface toolkits*; User interface programming; **Mixed / augmented reality**;

KEYWORDS

Augmented Reality, 3D Interaction, Prototyping, Craft, Toolkits, Embodied Interaction, Ubiquitous Computing, Smart Objects and Environments

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1 INTRODUCTION

Many industries rely on skilled welders to produce the products we use daily. Attracting and retaining novice welders within training opportunities has, however, become increasingly challenging. The American Welding Society predicts a deficit of 375,000 welders in the United States by 2024 [11]. The shortage of welding operators can be attributed to two main factors: negative perceptions surrounding the profession and the challenge of replacing retirees with younger generations [11]. This suggests a need for increased creativity in training young welders. Training welders requires developing complex embodied knowledge across hand-eye coordination, movement, proprioception, and sound. This embodied knowledge is acquired through in-situ apprenticeship and hands-on interactions with tools and materials [4]. These attributes can be complex to understand and hard to replicate in training scenarios. As such, systems are needed that can support the development of this embodied knowledge in a more experientially efficient and rich way than by simply 'welding more'. Prior research and commercial products have explored XR (extended reality) and VR (virtual reality) in possible welding augmentation [12, 18–21], but these systems are generally designed for classrooms or settings without active welding.

Our demonstration responds to this need by creating a functional XR- and ML-enabled welding system that supports augmented welding training. The primary contribution of this work is the system and approach of augmenting embodied understanding — eye-hand coordination, active listening, and mindfulness — to help novice learners manage and navigate a challenging craft practice. A secondary contribution is the development of open-source software for the Quest platform that makes our interactive design available to other researchers as a resource to examine XR-driven craft augmentation.

2 RELATED WORK

Mixed reality systems have enabled research on immersive experiences in education, embodiment, handcraft, and welding. Prior work explores the approaches of these experiences in entertainment and education [10], as well as guidelines on the relationship between the virtual world and physical embodiment [2, 7, 9]. There have been some approaches leveraging XR simulations to accelerate crafts training [3] and to enable students to enter the workforce more rapidly [5]. For MIG welding, previous research has created AR, VR, and specialized peripherals for welding simulators that allow users to experience an immersive environment for setting up, executing, and validating welding processes [12, 18, 19, 21]. Publicly available products such as the Miller AugmentedArc system, Lincoln Electric VRTEX 360, Soldamatic, and guideWELD® VR welding simulator help beginners develop muscle memory in a safe and effective manner, but use costly and abstracted systems. Muscle memory and the performance of skilled activities can be greatly enhanced by mindfulness routines. For example, existing research found that mindful breath patterns can improve academic performance [6], change emotional state [15], and improve performance when operating vehicles [1, 13, 14]. Projects have also leveraged technology to create systems that support the awareness of breathing [16] and further explore enhancing mindfulness design through breathing in a mixed reality environment [17]. To our knowledge, no work to date has investigated computer-supported mindfulness in welding activities.

3 EXPERIENCE OVERVIEW

Figure 2: User experience of using XR Welding

Although our system is designed and primarily intended for in-situ (live welding) use (see Figure 2), it can also be used to practice welding through augmented reality when not in-situ. In this case, the XR welding helmet and gun will simulate the experience of the welding arc by adding sounds and animations (e.g. welding sparks.) This enables participants to practice welding and experience the real-time meditation and embodied XR feedback of our system when not engaged in active welding tasks.

Our experience begins with participants getting accustomed to the augmented helmet and gun devices. They also participate in the guided breathing meditation exercise to improve their focus before welding (Figure 2.a). Next, to calibrate the XR representation of the weld to a real work surface, the start and endpoints of the weld line can be set by the user (Figure 2.b). As the participant begins to 'weld', the system provides real-time visual feedback on the different speeds, angles, and variances from ideal welding behaviors (Figure 2.c). If an actual arc is present, the pass-through display automatically dims to maintain the graphical user feedback throughout the weld (Figure 2.d). After a weld (virtual or real) is finished, the participant can review their weld line performance in 3D space, reflecting on their performance and variance (Figure 2.e).

Finally, an 'instructor' or demonstration onlooker can see the real-time point-of-view experience of the welding participant, as well as review the experience asynchronously with the other participant (Figure 2.f).

4 TECHNICAL APPROACH

4.1 XR Visual Feedback

We created a series of visual feedback mechanisms for the XR headset display. We used two separate XR indicators for work and the weld gun travel angle in order to make slight changes and adjustments visible (see Figure 3). The indicators, along with status icons presented near the top of the viewport, allow users to see feedback without taking focus away from an active weld. The status icons, by contrast, can give a much clearer overview of performance for instructors or users viewing live playback, particularly when focusing on the tip of the welding gun is not as important.

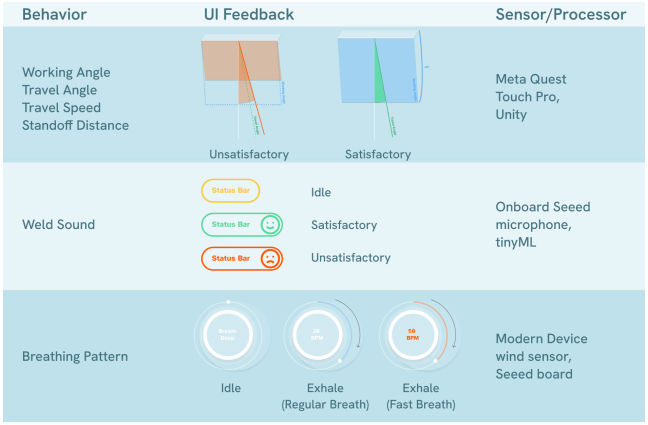

Figure 3: Visual XR UI

4.2 Device Design

To provide support for and to evaluate these experiences, we created a functional device system that integrates sound and breath sensing with a Meta Quest Pro headset and a standard MIG welding helmet and gun. We interfaced the Seeed ESP32S3 board with a Unity program running the XR display, using the Quest Pro's USB-C port and the Serial Port Utility Pro plugin [1]. A 3D-printed enclosure interfaces a Quest Touch Pro controller with a welding stick, aligning the independent systems together as well as protecting the controller from weld spatter and heat. Using the existing buttons on the Touch Pro controllers allows users to control different settings such as POV recordings, spatial calibration, and navigating the Quest UI.

4.3 Pre-welding Meditation

Novices to welding can be overwhelmed and stressed by the overpowering sensory cues, such as sparks, heat, and scents. While there has been research into helping welders become accustomed to a sensorially demanding task through XR simulation, this work has

[1] https://assetstore.unity.com/packages/tools/utilities/serial-port-utility-pro-125863

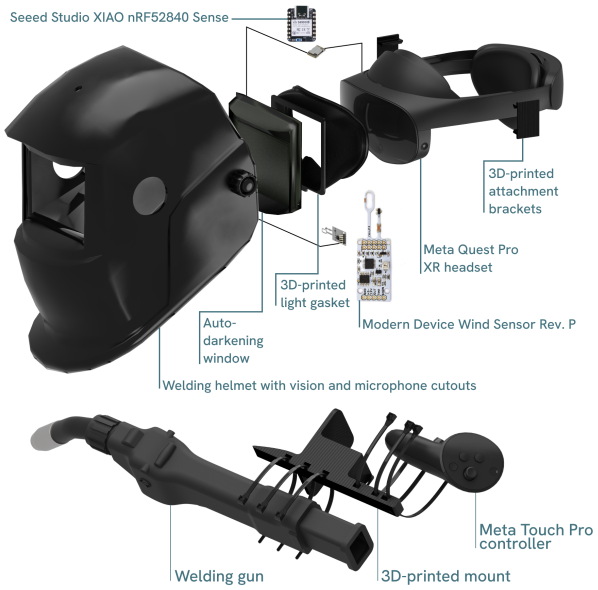

Figure 4: Device assemblies

been limited to welding practice in non-in-situ environments and to building a learner's exposure to the sonic and visual experience of welding [8]. While at our partner welding site, the Industrial Arts Workshop, we observed that when learners engage in breathing exercises and meditation it can help induce relaxation, foster a sense of focus on the task and materials, and build proprioceptive awareness. As such, we saw an opportunity to explore how such mindfulness practices can be scaffolded and augmented with technology-mediated support.

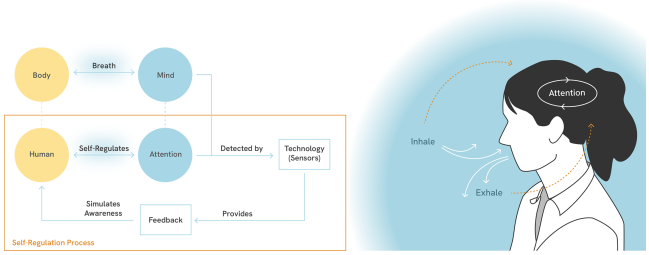

Figure 5: Meditation and attention

We leverage the welders' breath as an input for our AR system (see Figure 5). We use an off-the-shelf anemometer to track breathing. As an indicator of stress and well-being during welding tasks, we gather real-time data on the user's breathing rates through this sensor and present the readings within the XR UI (see Figure 3.) When the platform is initialized, each trainee is encouraged to engage in breathing exercises before the welding session. This action also serves to calibrate the sensor to the individual. We expect that such interactive strategies will help learners practice

and adopt mindfulness techniques that will ultimately benefit task performance and eye-hand coordination.

5 CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

We demonstrate a multimodal XR system for training of the welding process. Our system explores the incorporation of mindfulness and multisensory awareness into skill building through breath meditation, as well as improving the embodied skill-based practice of welding by leveraging augmented reality. The system used in our demo consists of two main components: an augmented welding torch for hand-tracking and a welding helmet with an integrated XR headset and a breath sensor. The system provides real-time visual feedback on welding torch movements and enables the learner to practice mindfulness with breathing exercises to improve focus and craft-building. There are some limitations to our approach. In-helmet XR further restricts the already limited field of view within the protective helmet by adding a significant amount of visual interface elements. Additionally, ergonomics remain a challenge. The headset is heavy for prolonged use and the visual pass-through of the XR can offer less than optimal quality for some welding tasks. Future work will explore ways to improve the ergonomics of our XR setup, refine the implementation of breath monitoring and feedback, and examine the potential haptic feedback to reduce the need for on-screen displays. In addition, we plan to assess how our XR training affects welding skill acquisition for novices.

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