Integrating AR Technology Into CBM Laboratory Experiments

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Integrating Augmented Reality Technology into Condition Based Monitoring Laboratory Experiments (Practice)

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ABSTRACT

This paper examines the pilot phase integration of Augmented Reality (AR) technology into a Condition Based Monitoring (CBM) engineering taught module. Students participate in a laboratory cycle within the CBM module, engaging in multiple experiments on a weekly basis, including Shaft Alignment, which provides meaningful, industry-relevant experience in an engineering environment. During the laboratory sessions, multiple pairs of students complete the experiment simultaneously on multiple custom engineering rigs. The Shaft Alignment procedure, although very relevant to industry needs, is also complex and time consuming, with students often struggling to complete the task within the designated laboratory time. AR technology has been introduced into this module to improve the experimental instructional design, improve the learning experiences for the students and reduce unavoidable practical delays during the experimental cycle. Existing experimental procedures have been implemented as AR content including re-crafted instructional content, multimedia content (videos and images), and custom CAD data overlaid on the engineering rigs as AR reference geometry.

The newly-introduced AR-based experiments were completed by multiple students over the course of a number of weeks in April and May 2023. Students provided participant feedback via survey before and after engagement with the AR technology. Test groups were aligned within the class as comparators in terms of using existing non-AR procedures and new AR-enhanced procedures.

The outcomes from this pilot phase are presented in this paper, with particular focus on student and lecturer experience, knowledge gained in the context of content creation pathways for future AR integration and increased productivity within the laboratory.

1 INTRODUCTION

1.1 Background to Pilot Project

The Condition Based Monitoring (CBM) module is a Year 2 module in the Engineering Reliability Management Bachelor of Technology programme in School of Mechanical Engineering in Technological University Dublin Bolton Street Campus. Within the laboratory cycle for this CBM module, students complete multiple practical engineering experiments of varying levels of complexity.

A pilot project began in December 2022 with the aim of developing and integrating Augmented Reality (AR) content to enhance existing experimental completion processes.

1.2 Benefits of AR Integration

AR-enhanced learning and training scenarios provide an interactive learning experience by allowing students to engage with virtual objects in a hands-on manner. They can manipulate and interact with virtual machine parts, observe their functionality, and perform simulated tasks. This interactivity fosters active learning, improves retention, and helps students develop practical skills in a safe and controlled environment.

When dealing with complex machinery, safety is paramount. AR-enhanced training enables students to practice and gain familiarity with equipment without the associated physical risks. They can learn to identify potential hazards, understand safety protocols, and practice correct procedures. This helps reduce accidents, prevent damage to expensive machinery, and build confidence before working with real equipment.

AR-enhanced content can provide real-time guidance and feedback to students during training. Virtual overlays can display step-by-step instructions, highlight specific components, or provide contextual information about the machinery. This guidance helps students navigate complex procedures more effectively, troubleshoot issues, and perform tasks accurately, enhancing their learning and performance, providing detailed context and information in situ, creating a situated learning environment in which students can feel comfortable.

The immersive and interactive nature of AR-enhanced training captivates students' attention and enhances their engagement. By blending the virtual and real-world elements, AR creates an exciting and motivating learning environment. Students are more likely to stay focused, enjoy the training process, and feel motivated to explore and master complex machinery concepts.

1.3 Experimental Selection

A specific shaft alignment experiment was chosen from the CBM module which gave sufficient scope for AR-enhancement, AR geometry integration and instructional design capacity, whilst being also of appropriate duration to allow a suitable student experience using AR hardware.

The complete experiment involves several discrete processes including:

- mounting and calibrating laser alignment units
- measuring misalignment
- physical re-aligning of shafts

The experiment also includes multiple, pre-requisite setup tasks including preparing coupling jaws and mounting shaft units. To provide a suitable completion time for the shaft alignment experiment, the overall process was sub-divided into multiple, discrete experimental steps.

Figure 1 shows the assembled apparatus for the experiment, including (a) fixed motor housing, (b) shaft coupling housing, (c) movable bearing mountings and (d) laser alignment equipment.

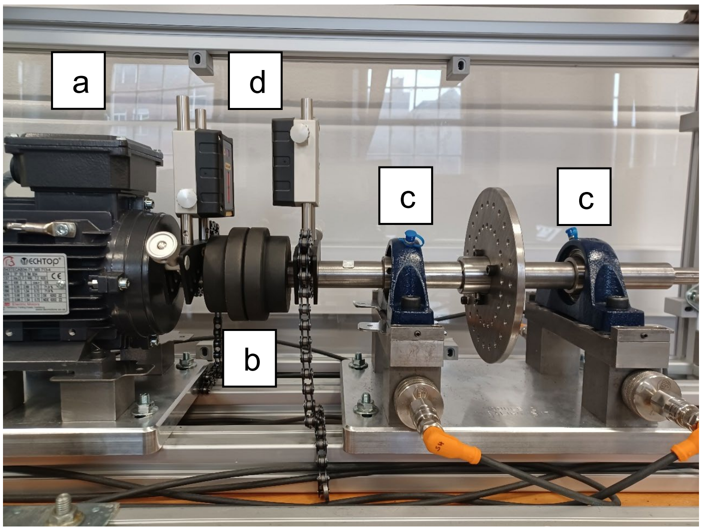

Figure 1 Experimental Rig

This sub-division of experimental process allowed the AR content authors to decide on the specific entry point at which students would engage with the AR-enhanced stage of the experiment. As the tasks are composed of discrete steps that lead students through each process, this enabled a degree of flexibility in the deployment of the AR-enhanced learning scenarios as tasks can be reorganised and re-arranged based on feedback and changes to module requirements etc.

This sub-division of experimental process also provided the AR content authors with a useful testing opportunity in AR content authoring, whereby the pre-requisite setup tasks were also enhanced with AR content. The usefulness and instructional design capacity of these enhanced setup tasks was evaluated before considering the larger core elements of the experimental process. These initial setup tasks were not included in the live engagement sessions by the students.

2 PRACTICE

2.1 AR Hardware

The Microsoft HoloLens 2 device is a head-mounted AR-enabled device, or 'headset'. The device operates in an untethered state, not connected physically to additional hardware, and it accesses data solely via Wi-Fi. The inbuilt headset hardware includes head-tracking gyroscopic sensors, inward-facing eye-tracking sensors and outward-facing cameras for hand- and gesture-tracking.

AR data is projected onto the visor at the front of the headset to provide the AR immersion effect to the wearer. AR content is developed for this headset using a variety of software development platforms, including Microsoft Dynamics 365 Guides, Unity and Unreal Engine.

Both device battery life and re-charging time are important concerns with respect to future perpetual rollout of HoloLens 2 devices. During the engagement phases of this pilot project, the battery status of devices was monitored carefully throughout all experimental engagement. In a future live implementation, a bottleneck or disruption to access of a set of laboratory-specific HoloLens 2 devices, due to re-charging time, would be a critical usage factor.

2.2 AR Content Authoring

Microsoft develop an AR content-authoring application, Microsoft Dynamics 365 Guides ('Guides'). All 'Guides' content is stored in the cloud and streamed 'on-demand' to the headset while in use. The specific cloud storage mechanism is specific and nuanced; it can only be developed within a Microsoft Dataverse cloud storage implementation. This implementation has perpetual maintenance cost implication, which is not insignificant in the academic realm. Guides has been specifically designed by Microsoft as a 'no-code' development platform to ease the authoring process and includes two separate development environments: a 'desktop-authoring' application and a 'headset-authoring' application.

AR content is initially created on the Guides desktop-authoring application, where the narrative for explicit instructional content is crafted and subdivided into parent 'tasks' and child 'steps', and where bespoke multimedia and CAD content is added. When sufficient content has been developed on the desktop-authoring application, additional custom, contextual AR integration is developed specifically on the headset-authoring application. This allows the author to specifically overlay, or integrate, the AR geometry onto the real-life base context.

The Guides desktop-authoring application provides a collection of pre-built AR data commonly incorporated within AR-enhanced scenarios. The provision of this data has the potential to reduce the amount of custom CAD data required from the AR author.

The workflows of placing, overlaying and aligning AR data onto the real-life base context using the AR headset is a relatively simple task but is not ideal. It requires the manual intervention from the content author, where the time spent coordinating content can be significant, and the precision available in placing and aligning content is variable at best.

2.3 CAD Data Development

The chosen shaft alignment experiment uses a variety of mechanical equipment elements, including the mechanical rig itself, laser alignment equipment, and additional adjustment tools and equipment. Equivalent CAD data, or CAD models, of this equipment are required from an appropriate 3D modelling application and are subsequently exported or translated to appropriate AR-specific content. The level-of-detail required for AR model display is significantly less than that required for general manufacturing purposes of that same specific equipment.

The choice of CAD application is not constrained exclusively to one specific application brand. In the specific context of Guides workflow, Microsoft recommend the use of Blender, a free 3D modelling, sculpting, and rendering application. Blender is available on free-to-use, open-source licensing model and is very commonly used within the visualisation and rendering industry. However, Blender modelling workflows are not optimal compared to other applications within the engineering realm.

SolidWorks is a commercially-licensed, closed-source, parametric CAD application which is more commonplace in the engineering realm. Functionality within SolidWorks allows geometry to be created and edited more appropriately than in Blender. The creation of appropriate CAD models in SolidWorks also provides the ability for the author to simultaneously retain a manufacturing-specific level-of-detail for the CAD model data as well as a simplified AR-specific level-of-detail. SolidWorks provides AR data export functionality which allows the export of geometry directly from SolidWorks to a format which can be imported directly into Guides. This SolidWorks functionality negated any requirement to use Blender and provided a much shorter completion time in the development of the relevant CAD geometry and AR data for this pilot project.

2.4 Polygon Count Considerations

The level-of-detail of CAD geometry displayed by the headset has an effect on the performance of the headset whereby geometry of high polygon count can be unnecessarily processor-intensive whilst not yielding, or providing, equivalent representative gains for that high level of detail. Microsoft provide appropriate guidelines and polygon count recommendations for use within the Guides environment displayed on a HoloLens 2 device. These guidelines also provide certain workflows for specific software, with the aim of reducing the overall polygon count. The proposed guidelines are provided for Blender and SolidWorks.

An alternative ‘configuration-based’ polygon reduction workflow was implemented in SolidWorks by the authors which was more appropriate in terms of manipulating native SolidWorks CAD geometry.

2.5 AR Learning Scenario Development

Microsoft provide suggested strategies of instructional content design specifically tailored to Guides, including direct actions in language use and the specific nature/psychology of instruction. Some of the strategies also combat against some of the in-built software limitations of Guides itself. The design strategies were considered and purposefully used in the development of the content for this pilot project.

The AR-enhanced version of the shaft alignment experiment was divided into two primary Guides learning scenarios, and each learning scenario was further sub-divided into multiple parent tasks and child steps, mimicking the existing physical experimental instructions.
The required laser alignment equipment interacts with a tablet device and a related tablet application, from which multiple screenshots were extracted. Experimental actions using the mechanical rig which were intricate and/or difficulted to verbally describe, were captured via video-recording of live demonstration. The resulting image and video content were integrated into the relevant points of each Guides learning scenario.
Branching strategies were also implemented within the instructional design to provide opportunities for task review, and also for repetition of iterative experimental steps, which presented as authentic engineering learning within the experiment.

2.6 CAD equivalent of Experimental Equipment

The CAD geometry of the mechanical rig used in the shaft alignment experiment was originally developed natively in SolidWorks for manufacturing purposes in the design phase of the lab equipment. However, the data was relatively polygon-intense as a result of its manufacturing level of detail. A process was implemented in SolidWorks to reduce polygon count by 'configuring de-featured, simplified CAD components' while still retaining sufficient levels of detail appropriate for AR integration overlay. This defeaturing process presented only minor workflow obstacles or constraints, as the original geometry had been created very appropriately in its original form.
The CAD geometry of the laser alignment equipment was sourced from the equipment OEM provider. Whilst this CAD geometry was very well defined and accurate, it was provided in a neutral CAD file format, which did not provide, or allow for, an opportunity to apply the same SolidWorks defeaturing process. As a result, it was required to remodel the laser alignment units in SolidWorks in a simplified form, using the original CAD data as a baseline reference. The fine grain level-of-detail was not required in this new CAD model, and an appropriately-simplified model was developed.

2.7 Authoring and Testing of AR-enhanced experiments

The authoring and development of initial AR-enhanced instructional content involved multiple iterations and revisions to the instructional narrative, CAD data and multimedia content. A series of engagement testing sessions were proposed to trial the initial learning scenarios, and gain insights on the quality of these initial revisions.
The current, standard, long-standing student experience for the shaft alignment experiment involves:

- an initial live instructor demonstration of the experiment on a specific demonstration rig
- the division of the student cohort into teams of four students per available experimental rig
- the subsequent completion of the experiment by each team using traditional paper-based instructions

The first phase of engagement testing sessions was carried out in multiple sessions, each session comprising two students and each student completing the experiment individually on a separate rig using individual HoloLens 2 headsets. All queries, interactions, comments and insights from each student were recorded individually; this initial overall set of comments and insights were captured from three separate sessions comprising a total of six students. All Guides content was revised, informed accordingly by the recorded comments and insights.

A second phase of engagement testing was carried out, again in multiple sessions, using eight students from a different, but related, programme. The rationale was to investigate if students from a related field could still engage with a technical engineering experiment, guided with AR enhancements. Subsequent to this phase, all Guides content was revised again, informed by the new comments and insights taken.

Finally, a third phase of engagement testing was carried out using eight staff members from the School of Mechanical Engineering, each having varied technical expertise in the engineering realm and in the software/technology realm. Upon completion of this third testing phase with a subsequent appropriate revision process, we concluded that the development and delivery of the AR-enhancement experience for the chosen experiment was sufficiently close to optimal.

2.8 Revision of AR-enhanced content

The revision strategies applied to the Guides content included:

- update of narrative content
- clarification of instructional text
- amendment of screenshots, photographs and related imagery
- clarification of specific experimental process
- addition and removal of specific parent tasks and/or child steps

It was clear from the phased approach of revision management that whilst the AR content authors had sufficient expertise to develop the content from an instructional and technical perspective, certain instructional elements would regularly, and incorrectly, infer existing knowledge or meaning which was not explicitly or clearly explained.

The insights gained from the iterative design and testing will form the basis of future authoring of AR enhancements of existing experimental processes within the programme.

3 RESULTS

3.1 Findings

3.1.1 Reduced Volume of Student Queries

In all engagement testing sessions, the AR-enhanced mode of experimental completion yielded a substantially lower volume of mid-experiment student queries, in terms of experimental issues. Students using the AR-enhanced data were able to engage with, and navigate across, the provided instructional data, without requiring the previously-encountered high levels of lecture intervention.
This also consequently reduced the required mid-experiment activity of the supervising instructor.
This allowed the supervising instructor to engage in more meaningful discussions with the students in terms of the relevancy of experimental process, in essence the ‘why’ rather than the ‘how’.
This presents as the obvious advantage in implementation of AR-enhanced learning scenarios, providing:

- maintaining the quality of experimental output
- the student with a more appropriate learning experience
- the instructor with a means to reduce repetitive, time-consuming fundamental or basic level queries regarding the experimental process.

3.1.2 Lack of Concurrent Multi-user Interaction

In the non-AR-enhanced mode of experimental completion, multiple students would work together in teams to complete the experiment on a single rig.
Currently, the Guides application does not provide functionality to allow multi-user access to a concurrent AR session. This lack of concurrency requires a single user to complete the AR-enhanced equivalent in isolation on a single rig.
As the AR interactions cannot be shared between users, and due to a resulting lack of team collaboration between students, certain experimental issues and mistakes made in the experimental process were amplified; in many cases, a simple reduction in available physical hands contributed to multiple equipment malfunctions.
This lack of concurrency can be considered a major flaw in the overall testing experience and also can be considered a major compromise in the experimental process. This is one of the biggest disadvantages in that is reduces what is a collaborative task between students to a solo task, albeit one enhanced by AR.

3.1.3 Bottleneck in Content Reading

Currently, the Guides application only provides functionality to output text-, image- and video-based data as accessible formats of instruction as part of any AR enhancement.
However, the Guides application does not explicitly provide functionality to output audio-only instruction as part of the AR-enhancement.
An audio alternative would reduce the requirement of the students to read every AR experimental step. This was perceived as a stumbling block, or bottleneck, to certain students in their completion of multiple experimental steps. The bottleneck did not

manifest in interpretation but simply in time spent considering the narrative; a more appropriate instructional environment for certain students would allow them to simply listen to the instructions.

3.1.4 AR Hardware Induction

In the first phase of engagement testing sessions, students were not given a 'pre-flight' induction with regard to operation of the HoloLens 2 device. They were introduced to the device at the start of the experiment, which purposefully presented feedback in terms of the most obvious interaction bottlenecks with the device.
A short video introduction was crafted in advance on the second phase of engagement testing sessions which was subsequently provided to students well in advance of their first experiences of the headset. This pre-emptive video content provided the students with more awareness of the AR-enhanced environment and experience. The initial headset setup time and general student interaction with the headset during the completion of the shaft alignment experiment were positively impacted in the subsequent phases of engagement testing sessions.

3.2 Recommendations

Whilst the current status of the pilot project can be considered a resounding success, impactful constraints in this format of AR-enhanced learning are evident; a lack of concurrent user interactions and standalone audio support.
Alternate AR content-authoring platforms, Unity and Unreal Engine, do provide audio support. A future intention of this pilot project is to develop similar AR-enhanced experimental processes within the existing laboratory space using these alternate development platforms. This will allow further student engagement testing to compare user interactions and user experience between the content authored in different platforms.
Resources exist within alternate development platforms to develop concurrent, multi-user interactions. This is a critical research element within the pilot project, but the technical details in developing the required AR-enhanced content are significant.

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