UNDERGRADUATE RESEARCH FELLOWSHIP FINAL REPORT

Year of Award: 2021

Project Title: Augmented Reality (AR) in Steel Fabrication

Research Organization: University of Wisconsin-Madison

Undergraduate Student Fellowship Awardee: Edmund Elder

Faculty Sponsor: Hannah Blum

DISCLAIMER

PREFACE

The AISC Undergraduate Research Fellowship Program funds undergraduate students under the direction of faculty sponsors to study structural steel design and construction topics for one term (semester or quarter). This research can be done as a standalone project or part of a larger research project.

For students, this is an opportunity to work independently and actively participate in research to develop a better understanding of steel design and construction. This experience may open opportunities for Master's or PhD work or enhance a resume for post-graduate industry positions.

For faculty sponsors, a fellowship supports an undergraduate student to assist in their research and may attract an outstanding undergraduate student to attend graduate school to continue with related research.

More information on the program can be found on the AISC website at:
https://www.aisc.org/technical-resources/research/undergraduate-research-fellowships/

Introduction

Steel fabrication requires good spatial visualization of 2D shop drawings for fabricators to construct parts properly. Quality checks of fabricated steel parts also require proper spatial visualization to ensure all welds and measurements are exact. Even with experience, interpreting shop drawings takes time and is necessary to prevent errors. Augmented reality (AR) brings information into the real world in 3D making it easier to understand. The implementation of AR in steel fabrication would decrease the time needed to interpret shop drawings and can serve as an additional quality control check. This report summarizes the work conducted in the Fall 2021 semester at UW-Madison, which built upon work conducted in the Spring 2021 semester.

Background

AR is the implementation of a virtual world into the real world, different from Virtual Reality (VR) which only shows a virtual world. AR allows the user to see information (like shop drawings, building plans, dimensions) in their view without needing a physical paper copy of the information. AR is commonly used with handheld devices such as smartphones and tablets since the software can be created quicker and used on devices the person or company already has and are multi-functional. Companies like Ford, Hyundai, and Volkswagen have used AR with handheld devices for customer service and quicker repairs by labeling the parts of the vehicle in the AR app. Projection-based AR has also been used to create a hands-free experience. GM performed a pilot study on projection-based AR for welding during manufacturing and found a 15% accuracy improvement using the program [1]. AR headsets also allow for hands-free operation while also placing virtual information into the real world with depth, making it appear real and 3D.

There have been multiple studies on implementing AR into the construction and fabrication industries. One such study had subjects construct a piping assembly using paper-based isometric drawings and another assembly using an AR headset with assembly directions and animations. The study found that the AR program led to a 50% assembly time improvement along with a 50% accuracy improvement compared to the 2D drawings [2]. The potential for improved work efficiency and accuracy also provides financial benefits as the same study performed a cost estimation of the two methods based on results, and found the AR program saved two-thirds of the cost from fewer errors [2]. Another study incorporated BIM with AR to produce a training software for precast wood-framed walls. The study found that using an AR headset was advantageous to using an AR app on a phone as its hands-free nature did not slow down work [3]. Participants in the precast wall study mentioned that the step-by-step instructions and dimensions included in the AR program were beneficial while the similarity between the colors of the real-world objects and virtual models made it hard to distinguish between the two [3]. AR has also been used for training new workers in installation, fabrication, and inspection as information from CAD or BIM models can create overlays and/or animations to show the order of work, specific work tasks, dimensions, and other useful information [3],[4].

Research Work

This part of the project aims to test out the HoloLens 2 headset, which was used to create a working AR program that gives steel fabricators a 3D model of shop drawings. In the future, the project will aim to provide the steel fabricators with measurements and step-by-step assembly instructions for a better workflow. This will reduce the time which would otherwise be spent looking through shop drawings to find the measurements of parts and interpreting the overall assembly. The use of AR in steel fabrication is meant to reduce fabrication time, create a better environment for the fabricator, and reduce costly errors.

For this project, the Microsoft HoloLens 2 was used since it is currently the most-advanced AR headset on the market. The UW-Madison Division of Information Technology (DoIT) Web and Mobile Solutions (WaMS) team developed the AR program for the HoloLens headset. The program works by recognizing a QR code with an app on the HoloLens which then displays the corresponding steel model on the headset lined up with the corner of the QR code as shown in Figure 1.

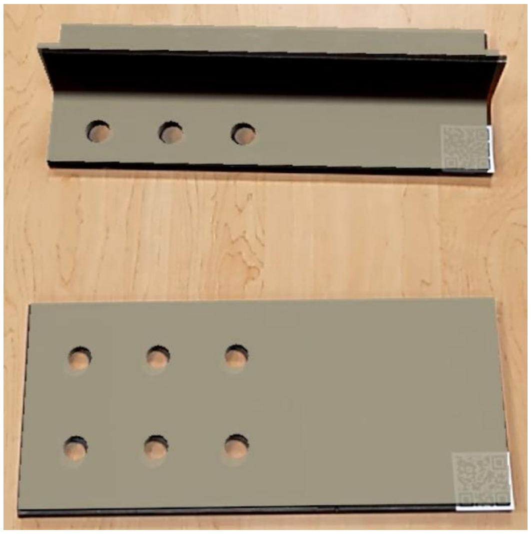

Figure 1: View of the AR models overlaying a steel plate (bottom) and tee (top) in the HoloLens program. The models are displayed using the QR codes seen on the bottom right corner of each piece.

Each steel model has a unique QR code so that the correct model is displayed by the HoloLens. Along with the original plate and tee models, there are 8 additional plate models and 6 additional tee models which have different errors compared to the actual steel pieces, all of which will be discussed in the error models section.

<u>Part 1 - QR code recognition</u>

It is crucial to ensure that the QR code is readable for the model, especially under various fabrication environments in a manufacturing facility. This is because the HoloLens needs to be able to recognize the QR code to enhance spatial visualization. If the QR code orientation is incorrect, the model will not display properly and instead it will be rotated, following the QR code orientation, and will not align with the steel member. See Figure 2 for the consequences of misplacing and misorienting the QR code.

Figure 2a-c: *Fig. a (Top Left)* - Misaligned QR code, not flush with the corner of the steel tee
Fig. b (Top Right) - Resulting model from Figure 2a orientation with QR code slightly misaligned
Fig. c (Bottom) - Model with QR code placed on the incorrect side of the steel tee and rotated

While QR code alignment on the steel piece is important, the QR code itself is still recognizable after slight damage. Figure 3 shows an example of a wrinkled QR code that was tested and still recognizable by the HoloLens program.

Figure 3: A wrinkled QR code that the HoloLens program could still recognize

Multiple factors can affect how well the HoloLens recognizes the QR code. Testing found that the HoloLens should be approximately 2 feet away and at least 60 degrees from the QR code plane for the HoloLens to recognize it and load the model. The HoloLens was tested under three lighting conditions: Bright, Dim, and Dark, and also under two different QR code conditions: with or without tape covering the QR code to determine how well the program performs in different scenarios. The quicker the HoloLens loads the hologram, the better it recognizes the QR code. See Table 1 for the time the HoloLens takes to load the hologram model under these different conditions:

Table 1: The time (in seconds) the HoloLens takes to load the AR model under different conditions

		Lighting Condition		
		Dark	Dim	Light
QR Code Condition	Tape	N/A	4.2	4.2
	No Tape	19	4.2	4.2

The result indicated that the HoloLens has no difficulty in recognizing the QR code under bright and dim lighting conditions, with or without tape covering the QR code. However, the HoloLens takes almost 5 times longer to load the QR code under dark conditions without tape on, and it also was not able to load the QR code under dark conditions with tape on. The dark conditions would not be realistic to simulate fabrication shop conditions, but it shows the limits of the HoloLens program.

In a fabrication shop, fabricators move around their workspace to properly construct steel components and connections, and quality control supervisors inspect the fabricated parts to ensure proper fabrication was completed per drawings and specifications. Because of this, it is important that the HoloLens is able to keep the AR model in place when walking around with the headset on. Tests were performed on the program by walking backward from the model to check how well it stays in place and walking back toward the model to see if the placement of the model was still correct on the steel piece. When walking 15 feet backward and then back to the steel piece, the model stayed in place on the steel parts. Next, the program was tested by walking backward and in a 30-foot circle around the model. With this test, the model stayed in place on the steel parts as the researcher walked around the testing area, but upon returning to the steel piece, the model had moved ¾” to the side. Once close enough, the HoloLens corrected the placement of the model when it recognized the QR code on the model again. Testing also found that when the researcher got 15 feet or further away from the steel piece, the model started to float around in the HoloLens; it did not look anchored to the steel but instead bounced up and down slightly as the researcher moved around. This slight movement of the model from the distance between the HoloLens and the QR code on the steel piece most likely caused the ¾” movement of the model. Movement around the steel piece and model was also tested up close where the researcher walked in a circle around the steel piece from 5 feet away. While moving, the model would move slightly as it adjusted itself to the new view in the HoloLens, but it corrected itself immediately and was in the correct position whenever the researcher stopped to check.

The movement tests were also used to test how well the HoloLens program kept the model in place when the QR code was taken off the steel piece following initial recognition. The same observations were made during all the tests and followed the observations from tests when the QR code was left on the steel model. The model would move slightly as the researcher moved around the room with the HoloLens, but it would correct itself immediately and be in the correct position up close. After walking in a 30-foot circle, the model was again misaligned with the steel piece, but since the QR code was no longer on the steel, the misalignment remained since the HoloLens could not realign the model using the QR code.

In real practice, steel pieces may not be at waist height where a QR code can be placed on top, the QR code may need to be sideways or placed upside down on the steel at different heights. The HoloLens QR code program was tested to make sure that QR codes could still be recognized when they are higher up and sideways or upside down. Figure 4 shows a picture of the tee in both of these positions.

Figure 4: Setup of the steel tee to test when the QR code is sideways (left) and upside down (right) both at approximately eye level

In each position, the HoloLens was able to recognize the QR code and properly display the models as shown in Figure 5.

Figure 5: AR model overlaid on the sideways (left) and upside down (right) steel tee

Slight variance was observed in the sideways model, but that was attributed to the setup of the test which had a researcher holding the steel tee in place and allowed for movement of the tee. Recognition of the upside down model took approximately 30 seconds, which was longer than expected. The small steel tee did not leave much room for the researcher to fit their head with the HoloLens headset into the correct position for detection of the QR code and also less light under the steel tee could have also been a factor in the longer recognition time.

Part 2 - Error models recognition

A total of 9 plate models and 7 tee models were made to test the HoloLens program. There was a correct model for both the plate and tee along with 8 plate models with errors and 6 tee models with errors. The errors include incorrect bolt hole sizes, bolt holes slightly misaligned, and different plate widths. These errors were modeled to simulate fabrication errors that could take place in a fabrication shop. These error models were made to overlay the same steel plate and tee to test how easily the errors can be seen using the AR program. Making multiple error models was seen as most practical for this project instead of using one correct model for each steel piece and fabricating steel pieces with errors. Figure 6 shows the bolt hole numbering system for the plate and tee along with the directions used for testing.

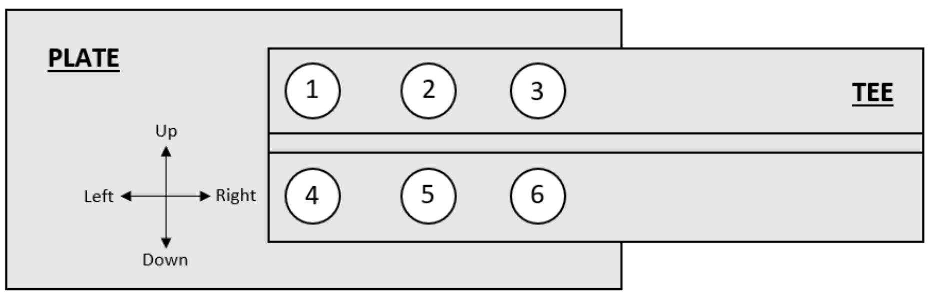

Figure 6: Descriptive directions and bolt hole numbering system used for the steel plate and tee

Figures 7 and 8 show the dimensions of the steel plate and tee.

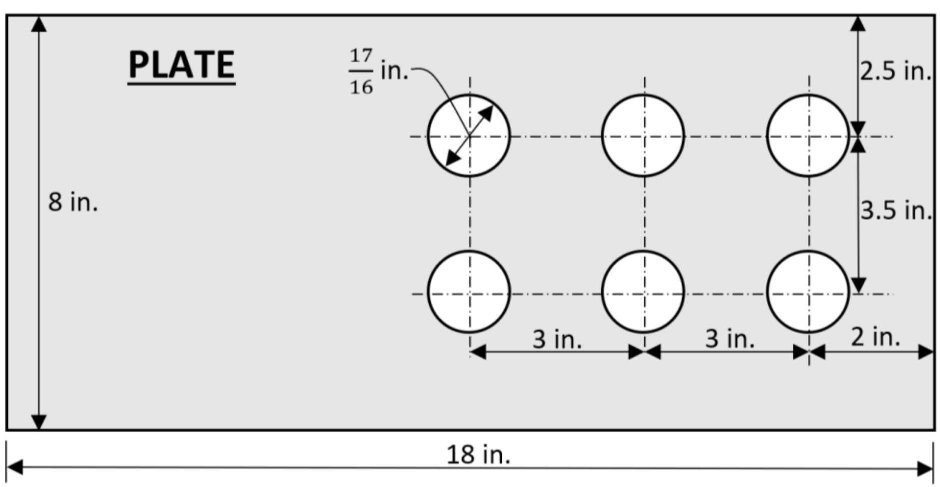

Figure 7: Dimensions of the steel plate

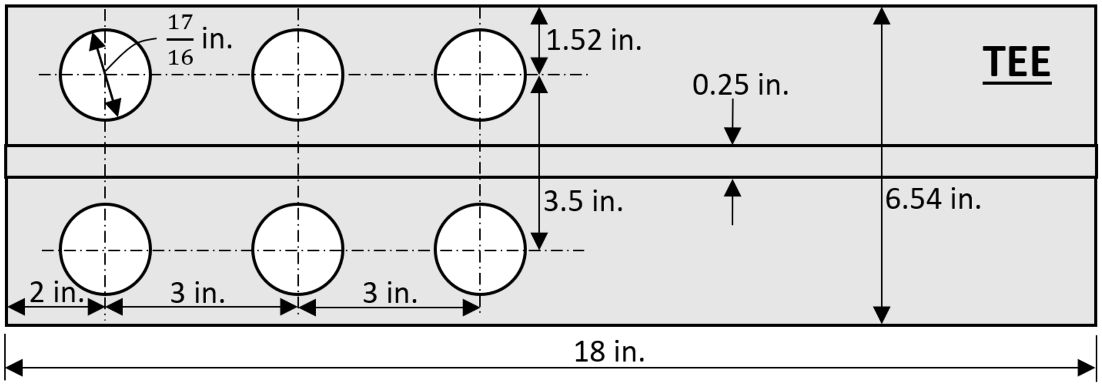

Figure 8: Dimensions of the steel tee

Table 2 gives a description of each model and the observations from the student testing the model to identify the error or lack thereof. Two students were used to test the models, one was part of this research project and therefore familiar with the HoloLens and error models, and the other student was from outside of the project and did not have experience with the HoloLens or error models.

Table 2: Description of each QR code used along with the results of testing each model

QR Code	Description	Observations of student familiar with the models	Observations of student with no knowledge of the models
P1	Plate width decreased to 7.875”	Able to recognize smaller plate	**Incorrect error** - thought holes were smaller
P2	Plate width increased to 8.125”	Able to recognize larger plate	Able to recognize larger plate
P3	13/16” bolt holes	Able to recognize smaller holes (very noticeable)	Able to recognize smaller holes
P4	15/16” bolt holes	Able to recognize smaller holes	Able to recognize smaller holes
P5	All holes 1/16” to the left	Able to recognize holes are all too far left	Not able to recognize - Holes looked smaller
P6	Hole 1, ⅛” to the left	Able to recognize hole 1 is too far left	Able to recognize hole 1 is too far left
P7	Hole 3, 1/16” to the right	Able to recognize hole 3 is too far right	**Not** able to recognize
P8	Holes 4 through 6, ⅛” down	Able to recognize holes 4-6 are too far down	**Not** able to recognize
P9	Original plate	Able to recognize	Able to recognize
T1	13/16” bolt holes	Able to recognize smaller holes (very noticeable)	Able to recognize smaller holes
T2	15/16” bolt holes	Able to recognize smaller holes	Able to recognize smaller holes
T3	All holes 1/16” to the left	**Not** able to recognize	**Not** able to recognize
T4	Hole 1, ⅛” to the left	Able to recognize hole 1 is too far left	**Incorrect error** - thought holes 1-3 were too far left
T5	Hole 3, 1/16” to the right	Able to recognize hole 3 is too far right	**Incorrect error** - thought holes 1-3 were too far right
T6	Holes 4 through 6, ⅛” down	**Not** able to recognize	**Not** able to recognize
T7	Original Tee	Able to recognize	Able to recognize

One observation from this test was that the tee models were harder to identify. Correct alignment of the QR code with the steel tee was important, as any variation would cause misalignment of the model and therefore made it harder to determine which model was displayed. Specifically, misalignment of the bolt holes was a common observation when testing out the QR codes making it difficult to determine if/which bolt holes were intentionally misaligned on the model. With no prior experience in using a HoloLens or using the AR program, the student tester from outside the project had trouble identifying the errors. The student found it difficult to figure out which model was shown when it did not line up completely with the steel tee or plate. The student also mentioned that it was confusing to see the model move as they moved slightly and that the model looked different from different angles (looking from above the model to beside it or next to it). There were four models where the student with no experience could not recognize the error and an additional three that the student identified an error but it was not the correct one.

Discussion

While this project made progress on the overall goal of creating an AR program to improve the process of steel fabrication, it also identified improvements that could be made for future success. As with any new technology, there was a long lead time for the initial program and the creation of the error models. Less time was available for testing of the AR program due to the amount of time required to finish programming it. In the future, having a workable program should allow for more rigorous testing and quicker improvements to the technology. One issue the student researchers ran into was with the two initial QR codes for the original plate and tee models where both QR codes displayed the tee model, as shown in Figure 9.

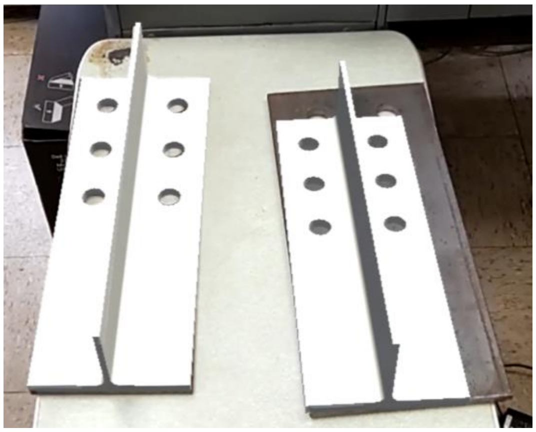

Figure 9: Screenshot of the problem found in the first version of the AR program where the tee model was displayed for both the tee and plate QR codes

Improvements in the sensitivity of QR code alignment would decrease the time spent lining the model up with the steel pieces. At times the QR code looked flush on the corner of the steel tee or plate, but on the HoloLens the model would show that it needed to be adjusted. This project used a small-scale steel tee and plate, so with full-scale steel fabrication, these misalignments would be even more noticeable. A potential solution to this problem is implementing multiple QR codes on a steel member. An example of this would be placing a QR code on the web of the tee or on the opposite corner along with the current corner placement, then the program would place the model after reading the first QR code and adjust the model after reading the second QR code so that the model properly fits between the codes.

References

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