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HoloLens Applications for the Demonstration of an Advanced Anthropomorphic Test Device for Under-Body Blast and the Dissemination of Finite Element Analysis Results

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ABSTRACT

The Warrior Injury Assessment Manikin (WIAMan) crash test dummy was developed in response to an Army need for better injury prediction capabilities in under-body blast testing. Concurrently, a finite element model (FEM, a physics-based computational model) was developed at the Johns Hopkins University Applied Physics Laboratory (APL) to accelerate the design process and provide simulated injury prediction capabilities. However, two main issues arose when presenting the work to a broad audience. First, it was difficult to convey the results and impact of the FEM. Augmented reality suited this problem well because of the technical nature of the work and the lack of an off-the-shelf software solution the layperson could use to manipulate the model. Second, it was necessary to circumvent the need for transporting the human-sized physical anthropomorphic test device (ATD). A new method for exploring the dummy was required, but one that still allowed an audience to experience the technology firsthand. Hence, two complementary Microsoft HoloLens applications were developed at APL to allow a user to explore the inner workings of the ATD and see it in a simulated blast environment. These apps connect the user with the project in their own surroundings while providing information about various ATD parts at the user's pace. The applications have been demonstrated to diverse audiences at various venues both locally and across the country and were successful in conveying the impact of the project.

INTRODUCTION

Under-body blast (UBB) is a significant cause of injury for the US warfighter in recent and current conflicts.[1] While federal law requires that major vehicle systems undergo survivability and lethality testing before being fielded, the current tool used to measure the likelihood of warfighter injury is inadequate.[2] Anthropomorphic test devices (ATDs), informally called crash test dummies, are used in Title 10 Live Fire testing to measure the likelihood of injury in a real UBB scenario; currently the Hybrid III[3] dummy is used.[4] The Hybrid III has served well to provide a cursory understanding of injury in UBB events, but the US Army required a more precise tool that could predict injuries relevant to UBB. In typical vehicle conditions during a UBB event, the lower extremities, pelvis, and lumbar spine are at particular risk for injury. The Hybrid III is inadequate for predicting injury in the pelvis and lumbar spine, in particular, because of the steel pelvic bone that punches through the foam flesh in vertical loading. Therefore, the Warrior Injury Assessment Manikin (WIAMan) ATD was developed to be a purpose-built tool to predict injury in vertical loading conditions, such as UBB.

Crash test dummies are useful to measure the accelerations and loads withstood during impacts, but there must be a linkage to human injury to make use of those measurements. This linkage is done through biomechanical testing where human injury thresholds, obtained through surrogates such as postmortem human subjects, are compared with crash test dummy measurements. In the field of automotive injury, this testing occurred over the course of decades to create injury prediction capabilities for the Hybrid III.[5] However, the WIAMan program aimed to complete this process in just under a decade to respond to a new threat to the warfighter. The use of computational modeling enabled the accelerated ATD design process. Specifically, a finite element model (FEM) of the ATD (Figure 1) was developed to help improve the ATD design and serve as a long-term complementary injury prediction tool to the physical ATD. The WIAMan FEM simulates the physical ATD's transient response to a given loading.

The WIAMan FEM served as a means for fast and effective design studies to improve the biofidelity, or human-like behavior, of the ATD. Dozens of simulations were run at less cost to the project than the equivalent physical experiments would have required.[6] However, validation was a necessary step before these simulations could be trusted. Correlation and Analysis (CORA)[7] was used to objectively evaluate the model signal traces against a reference (in this case the physical ATD). CORA has been shown to provide four independent evaluations of phase, magnitude, shape, and corridor (which accounts for variability in the reference).[8] In this case only the phase, magnitude, and shape correlations were made because the physical ATD proved highly repeatable so a corridor score was unnecessary. The objective evaluation of model validation provided confidence in design study simulations and, moving forward, in the model's ability to predict injury at a similar level of fidelity as the physical ATD.

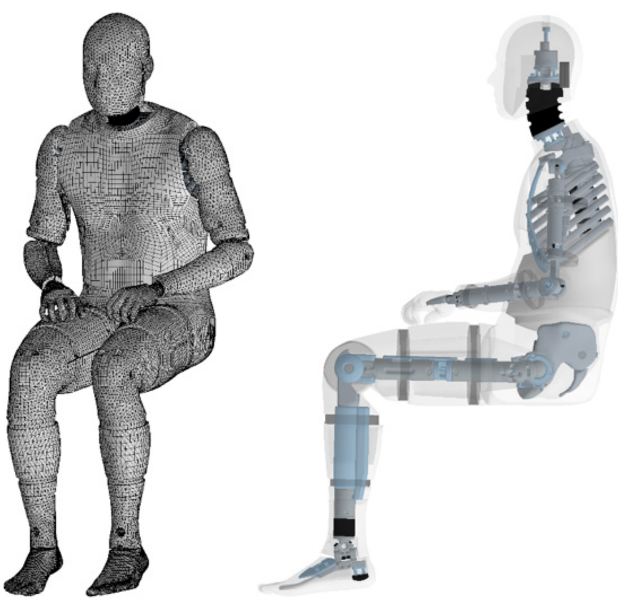

Figure 1. The WIAMan FEM. The model will be used by the Army for injury predictions in simulated vertical loading environments. HoloLens apps were developed to showcase the results and impact of the model.

Conveying the results and impact of this FEM work to a lay audience can be a challenge. For one, as with any computational model, there is no physical component to demonstrate. Further, the software used to process the model is highly specialized and experience is required to navigate it. Therefore, two Microsoft HoloLens apps were developed to allow a general audience to visualize the WIAMan FEM. Developing two apps allowed for flexibility to demonstrate across a wider range of venues to people with varying interests and technical knowledge. The first app is a static application that behaves like a self-guided museum exhibit. Users can explore the inner workings of the model and, thus, the physical ATD since the FEM is a virtual replication of the physical device. The second app is an animated application that demonstrates the results of the FEM. It shows the model in motion as it would be in a simulated UBB environment. Because the HoloLens apps were being developed while model validation was underway, a simulation of the laboratory loading environment, the APL Vertically Accelerated Load Transfer System (VALTS), was used. These apps were developed with the goal of allowing users to explore the FEM work directly and, as a corollary, to provide a means for exploring the physical ATD without necessitating transportation of the ~200-lb. physical device.

WIAMAN HOLOLENS APPLICATION DEVELOPMENT

The pipeline from FEM to HoloLens app consisted of four steps: (1) exporting FEM surface geometries, (2) reducing file sizes as necessary, (3) designing assets, and (4) developing the app. The end result is an augmented reality HoloLens app that immerses users in an environment where they can explore and interact with the WIAMan FEM and simulations. This section describes each of these four steps in further detail.

Exporting FEM Surface Geometries

High-resolution surface geometries can be exported from the FEM software LS-PrePost (LSTC, Livermore, CA) in the STL (stereolithography) file format, which is most commonly used in 3-D printing. For the static app, these surface geometries were exported from a single time instance of an FEM model (the initial state); for the animated app, these surface geometries were exported from a series of time instances from the FEM simulation. Custom MATLAB (MathWorks, Natick, MA) code was used to perform the conversion from FEM to STL by interfacing with LS-PrePost. The WIAMan FEM was divided into seven parts to allow for color-coding later in the process. Specifically, the FEM was broken into (1) the 6-degree-of-freedom (6DX) sensors, (2) the load cells, (3) the onboard data acquisition systems (DAS), (4) the compliant parts, (5) the boots, (6) the VALTS, and (7) all other parts such as the ATD skin and metal "skeletal" structures. These parts were selected to highlight significant aspects of the WIAMan ATD design—data collection aspects (6DX, load cells, DAS) and parts that allow it to act like a human (compliant parts). The remaining colors distinguished which parts were specific to the WIAMan and which were part of the test apparatus or protective equipment. For an FEM simulation that included hundreds of time points, the number of exported files could approach several gigabytes of disk space in total. This is important to consider when noting the hardware limitations of the HoloLens.

Reducing File Sizes as Necessary

Given that the onboard random access memory (RAM) of the HoloLens is only 2 GB, the size of the surface geometry files needed to be reduced for the animated app. For some applications, visualization streaming can be used, but for security reasons this was not a viable option for the WIAMan project. So to reduce file size, an open-source software called MeshLab (www.meshlab.net) was used, which has functions for processing triangular meshes, such as the STL files exported from LS-PrePost. In particular, a simplification algorithm in MeshLab called Quadric Edge Collapse Decimation was used, which takes as input a high-resolution triangular mesh and outputs a lower-resolution triangular mesh of similar geometry represented by a target number of faces. Each STL file was therefore imported into MeshLab, processed by the Quadric Edge Collapse Decimation algorithm, and re-exported so that the total size of all the files was within 1 GB. While these steps may be manually applied to each file within the MeshLab software itself, MeshLab also comes with scripting functionality in a package known as MeshLabServer. Therefore, the import, decimate, and export steps were scripted using MeshLabServer in conjunction with MATLAB to automate the task so that the hundreds of high-resolution STL files from a simulation could be batch-processed.

Designing Assets

A HoloLens app is typically composed of models, images, audio clips, and other files; these are generally known as assets. The STL files for the animation app from the previous step were combined by their parts so only seven assets (e.g., one for each part of WIAMan FEM) needed to be imported, rather than hundreds. Moreover, this allowed for each part to have a set of unique properties, such as color and shading, so it would have a certain appearance and be easily distinguished from other parts. An open-source software known as Blender (www.blender.org) along with a Blender add-on known as Stop Motion OBJ (https://github.com/neverhood311/Stop-motion-OBJ) provided a convenient way to accomplish these goals. Blender is a popular software suite for modeling, animating, and rendering 3-D objects and their interactions. Stop Motion OBJ is a convenient import tool to read the series of STL files as an animation in Blender, so it was used for the animation app. When all time instances from a particular FEM simulation of a part were imported by Stop Motion OBJ into Blender,

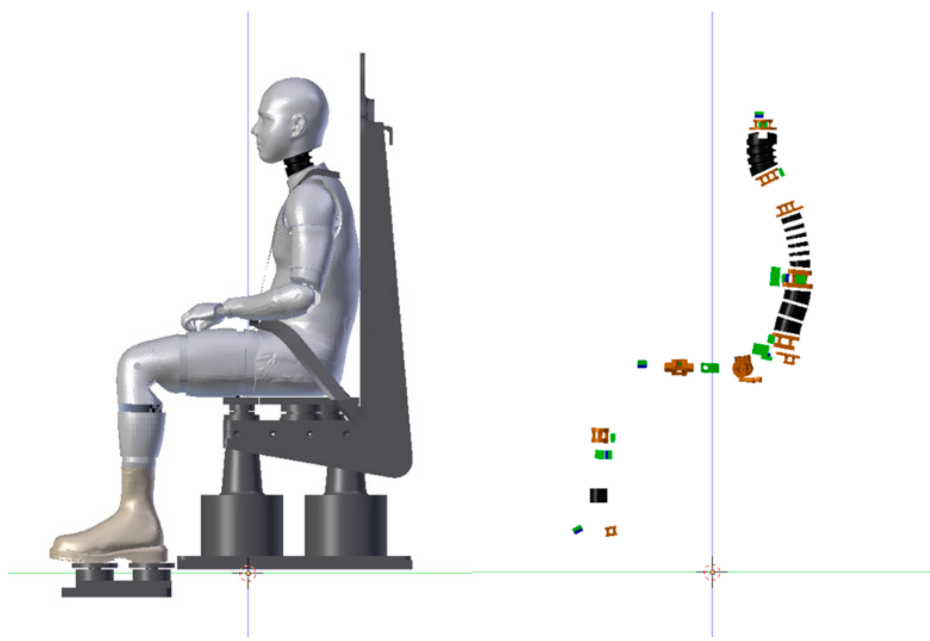

Figure 2. HoloLens app color-coding. The various components of the WIAMan ATD are color-coded for the user to explore how the ATD measures loads from UBB.

the properties of the models from every time instance of that part were modified singularly. For example, the colors of the WIAMan ATD parts were modified so that the 6DXs were green, the load cells were orange, the onboard DAS were blue, the compliant parts were black, the boots were beige, the VALTS was dark gray, and the skin and metal components were light gray (Figure 2). This allowed users to differentiate key aspects of the WIAMan design and allowed WIAMan team members to easily talk to the users about what they were seeing. Once the properties were modified, all time instances of a part were saved into a single file using the Blender-specific BLEND file format, which was then imported into a HoloLens app. A similar process was used for the static app, except that the Stop Motion OBJ add-on was unnecessary because only a single time state (initial) was included in the static app.

Developing the App

Once the assets were grouped and designed, the final step was to develop the HoloLens app with these assets as the main building blocks. Both of the WIAMan HoloLens apps were developed with the Microsoft-recommended software Unity (https://unity3d.com/). Additionally, the Mixed Reality Toolkit (https://github.com/Microsoft/MixedRealityToolkit) was used to take advantage of the full functionality of the HoloLens hardware. Some specific functionalities incorporated into the apps using the toolkit were gaze, gesture, spatial mapping, and voice. Gaze was integrated in the static app so that a user could hover their gaze on a specific part of an ATD model and see a virtual pop-up explanation. This served as the museum-like component of the application. Gesture was included in combination with spatial mapping so that a user could perform an air-tap gesture on an ATD to reposition it within the surrounding environment. Voice was also an integral part of the apps, with added functionality achieved through voice commands. For example, in the static app, a voice command was used to toggle between the WIAMan ATD and the Hybrid III ATD for comparison, as well as to toggle the visibility of the ATD skin so that the user could easily see the internal hardware (Figure 3). In the animated app, voice commands controlled playing and pausing of the animation, as well as the increasing, decreasing, or resetting the speed of animation.

Although the Mixed Reality Toolkit expedited the app development process with many built-in scripts, several custom scripts were still required. For example, in the static app, a custom script was developed to dictate the display of pop-up explanations, which allow a user to view the app with self-guided learning similar to a museum exhibit. Another script was developed to coordinate the timing of surface geometries being displayed so they appeared as a single object moving in

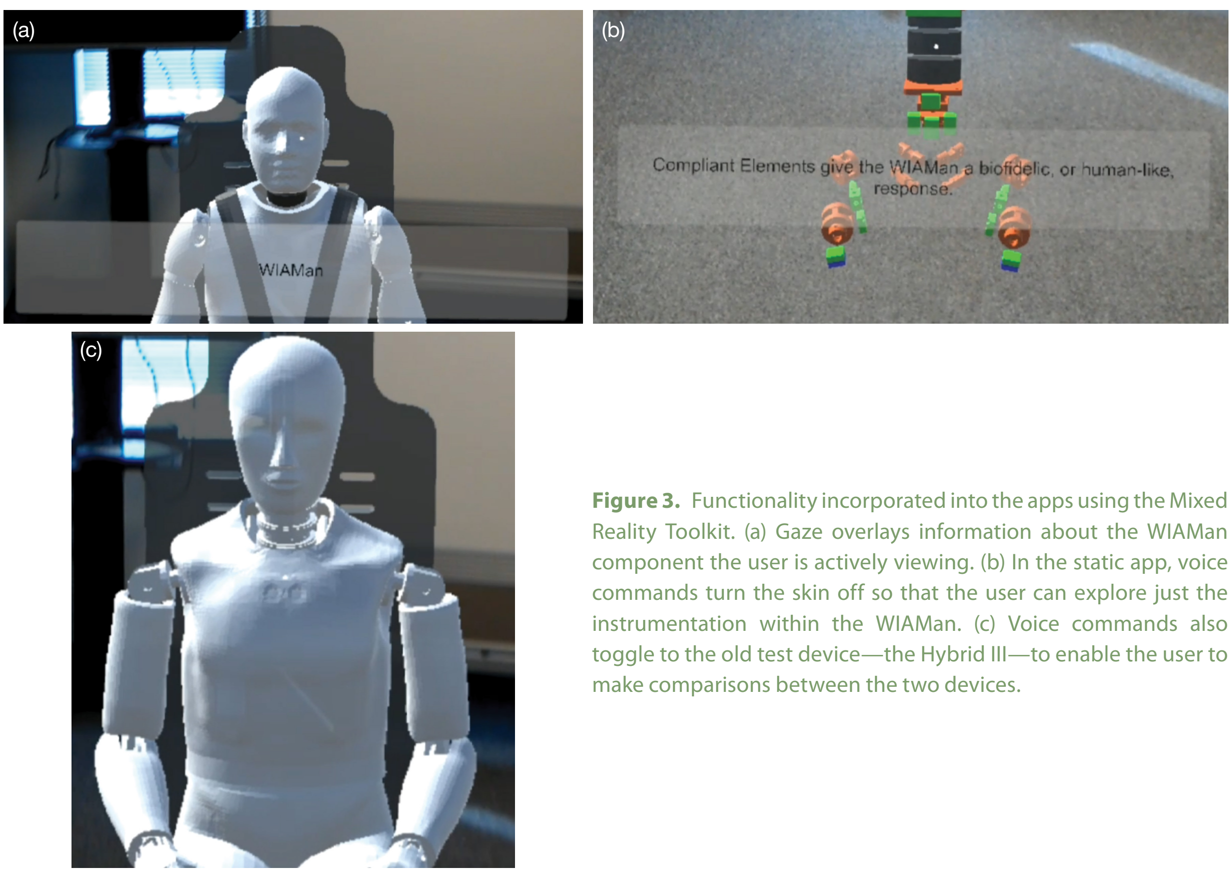

Figure 3. Functionality incorporated into the apps using the Mixed Reality Toolkit. (a) Gaze overlays information about the WIAMan component the user is actively viewing. (b) In the static app, voice commands turn the skin off so that the user can explore just the instrumentation within the WIAMan. (c) Voice commands also toggle to the old test device—the Hybrid III—to enable the user to make comparisons between the two devices.

Figure 4. Demonstrations of the HoloLens applications. The apps have been demonstrated at numerous conferences and events, including during a tour of the Army Research Lab (ARL) for congressional staffers from the Maryland delegation (left; photo credit: Jhi Scott[9]) and to the commanding general of RDECOM, now part of Army Futures Command (right; photo credit: Chad Johnson[10]).

space within the animation app. Putting it all together, with the imported assets from Blender and the scripts from the Mixed Reality Toolkit as well as the custom scripts, the app was built in Unity, compiled in Microsoft Visual Studio (https://visualstudio.microsoft.com/), and deployed as an app into the HoloLens.

Impact of the Applications

FEM results are typically displayed with 2-D videos, but it can be difficult to get a sense of the scope and size of a model through a video on a screen. The representation of a physical phenomenon in a video could be the size of a single engineered component or the size of a full military vehicle when fit to a display. The WIAMan HoloLens apps were built to convey the proper scale of the ATD. The user can experience the WIAMan FEM in their own world at the actual scale in both the static and animated apps. Especially in the animated app, a user can gain a sense of the severity of the impact to the WIAMan by seeing how far it travels over the course of about a tenth of a second. Further, users can speed up the app to real time to understand the timescale of the problem. The HoloLens applications enhance what was previously possible with videos on a monitor or screen.

More broadly, the HoloLens applications have promoted awareness of the WIAMan program and the problem it is trying to solve. The apps have been demonstrated at almost 20 events in the just over 2 years since their initial development. Events have ranged from internal expositions for APL staff to large conferences and trade shows such as the Association of the United States Army (AUSA) Global Force Symposium in Huntsville, Alabama. Similarly, the audience has ranged from civilians to Army generals. At a presentation to the commanding general of what was then called the US Army Research, Development and Engineering Command (RDECOM, now part of Army Futures Command) (see Figure 4), the feedback was that the HoloLens demos "stole the show." Similar feedback and enthusiasm has followed many demonstrations, with excitement both for the innovative use of a new technology and for the commitment to protecting our warfighters. The augmented reality format assuaged the concerns of those who suffer from motion sickness because their surroundings are still visible. Further, the use of cutting-edge technology, such as the HoloLens, drew people in and encouraged them to engage with the information more directly. The HoloLens applications have helped the WIAMan project stand out among the many presentations at conferences and trade shows.

SUMMARY

Two applications were developed on the Microsoft HoloLens for the WIAMan project. They demonstrate an advanced computational model that can predict injury in UBB and other vertical loading scenarios. The HoloLens apps have proven to be useful tools for the WIAMan program. In instances where it would otherwise be difficult to transport the physical ATD, which weighs about 200 lb., the HoloLens apps can be used instead. The applications have also conveyed the results of the FEM work, a critical part of the WIAMan program that will be a tool of its own used to help design safer vehicles that protect the warfighter in the vertical loading environment.

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