AUGMENTED REALITY VISUALIZATION TOOL FOR KINGS STORMWATER BRIDGE

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ABSTRACT

Augmented Reality (AR) is an emerging visualization technology that promises to change the way people see the world. The main goal of AR is to "enhance" a person's vision of the real world with useful information about the surrounding environment. Primarily this can be done through the use of a portable computer such as a laptop and a head-mounted display (HMD) unit. When such technology is made available to scientists and engineers, Augmented Reality can provide them with the freedom to do scientific analysis at the actual location of an experiment. With this idea in mind, the goal of this paper is to investigate the development of an AR system as a visualization tool for structural engineers. This particular application will focus on monitoring the "health" of the Kings Stormwater Bridge structure. Unfortunately, since AR is still in its infancy, much of the research devoted to it has focused mainly on technical issues rather than on the development of how this technology would be used by scientists. This has led to the development of "functional" AR systems that primarily can only be operated by the developer of the system ([1], [2], [3], [12], [14]). This paper avoids this trend by focusing on the design of the visualization system so that it is useful for structural engineers. As a result, this should produce a more robust Augmented Reality system that can be used by many different users. Thus, it is the goal of this paper to show how scientists would benefit by designing a visualization system with their needs in mind.

KEY WORDS
Scientific Visualization, Augmented Reality, Health Monitoring of Structures, Applications

1. Introduction: Kings Stormwater Bridge

Over the past few years, our research group has primarily focused on the construction of a robust Augmented Reality system. In previous research, we built a system that dynamically picked feature points [13] of articulated structures in order to recognize many different structures regardless of their environment [4]. Such a system allowed us to experiment with AR outdoors. Building upon this research, we also developed a technique that corrects for changing lighting conditions that would otherwise impair an Augmented Reality system [5]. At this point, we felt that it would be appropriate to start investigating real-world applications. It was decided to try and find a scientific application that would benefit from our research.

After spending some time looking into various scientific areas, it was found that the Structural Engineering Department at UCSD had a project that produced massive amounts of data but only had limited tools to visualize such data. This project focuses on monitoring the
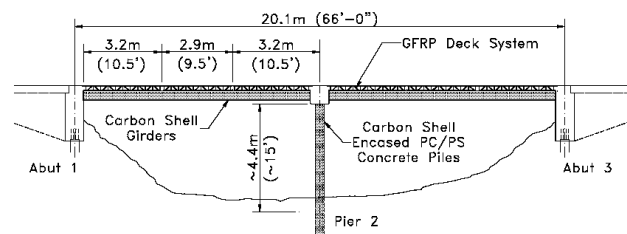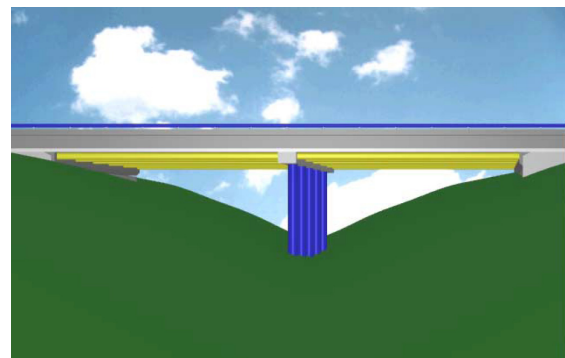

Figure 1: The top image shows the conceptual 3D model of the bridge before it was built. The bottom image shows a simple schematic of the bridge that shows where the carbon shells were placed. [15]

"health" of the Kings Stormwater Bridge located on State Route 86, near the Salton Sea in the California desert. By monitoring the bridge, a structural engineer is able to know how the structure behaves under different stress and strain conditions. This is important for evaluation purposes to determine whether the structure of the bridge itself can be deemed a success.

Before going into more detail about the health monitoring of the bridge, it is important to have some background about the bridge itself. UCSD, Caltrans, and DARPA (Defense Advanced Research Projects Agency) partnered together to construct the bridge in the year 2000. The project was complete in May 2001 when the bridge was officially opened. [10] The bridge is unique because it is primarily composed of glass and carbon composites instead of using steel rebar which is common in many structures today. As a result, the deck supports and girders in the bridge were designed as structural shells. These structural shells are tubes made of lightweight carbon fiber-reinforced polymers (CFRPs). Each of these shells are then filled with concrete at the construction site. One advantage of using composites over traditional materials is costly rebar work can often be eliminated. In addition, these composites do not corrode like steel rebar, are up to five times lighter than steel, and can be installed without the use of heavy construction equipment. It is also thought that the life expectancy of composite bridges will far exceed conventional bridges constructed from steel and concrete. As a result of this project and its initial success, structural engineers are now encouraged to rethink what kinds of materials can be used to build buildings and bridges.

Now that the bridge is built however, it is important that structural engineers be able to monitor the health of the bridge over time. This is especially important because the bridge experiences a high degree of traffic from large trucks passing through Imperial Valley en route to Mexico or Los Angeles. Thus, when the bridge was built, it was decided to wire the bridge with many different types of sensors in order to get a fairly accurate representation of the various stresses and strains that the bridge would endure. The bridge is primarily outfitted with the following sensors: 19 strain gages, 4 linear potentiometers, 42 accelerometers, and 1 temperature sensor. A strain gage is a resistor-based device that is attached to the surface of a material so that its resistance changes as the material deforms. Thus, it would measure deformations in the bridge. A linear potentiometer is basically a resistor arranged with a fixed connection on each end and a sliding connection between the two ends. It would measure sheer or sliding motion on the bridge. An accelerometer is a device that directly measures acceleration. In this case, when a car passes over the bridge, the accelerometer would vibrate thus creating an acceleration. Lastly, the temperature sensor would measure temperature data from the bridge and the surrounding environment. Thus, with the combination of all of these sensors, a structural engineer should get a good idea how the bridge responds in many different situations.

Unfortunately, the bridge is located in the middle of the desert and takes some time to get to. Thus, it was decided to connect the sensors on the bridge into the High Performance Wireless Research and Education Network (HPWREN). This network is meant to provide high-performance, wide-area, and wireless network access

Strain Gage Locations

Figure 2: The above image shows one of the lightweight carbon fiber-reinforced polymers (CFRPs) tubes that were used in the construction of the Kings Stormwater Bridge. In addition, this image also shows how strain gage sensors are attached to each tube on the bridge. These sensors will help determine the success of the bridge. [7]

Figure 3: This is an image of the bridge after it was completed. The metal antenna shown in the image connects the bridge to HPWREN so that sensor data can be sent wirelessly to laboratories at UCSD and CalTrans. [9]

throughout the San Diego and Riverside areas. Once installed, it gave researchers the ability to check on the status of the bridge remotely in a lab rather than be forced to make a long trip out to the bridge. In addition, engineers are able to download and store sensor data in the lab for future use. This is useful for analyzing the bridge's performance as old and new sensor data can be compared.

Now that we are familiar with the bridge and the health monitoring system, one can conclude that visualizing data from the bridge is not a trivial task. There are a lot of variables involved (weather, traffic load, vibrations in the earth, etc.) and it also depends on the accuracy of the sensors themselves. However, because this data is crucial to structural engineers, it is important that a tool is devised so that they can quickly and efficiently analyze how the bridge is performing at any time. Thus, it is the goal of this project to be able to provide these engineers with such a tool.

2. Structural Engineer Collaboration

In order to develop a successful tool for structural engineers utilizing Augmented Reality technology, it is important that time is spent collaborating with them to determine what visualization techniques would aid them best. We feel that this is a crucial step of the development process. As a result, we were in constant contact with the engineers and would receive feedback from them during all phases of this project.

Much of our time was spent communicating with graduate student Hong Guan. This particular graduate student had been working on analyzing data from the bridge for several years and was quite knowledgeable on the bridge's behavior. However, the vast majority of this analysis came from 2D waveforms. Hong and the other structural engineers who work with him use an Internet based client to connect to the bridge via HPWREN. Basically, this web client provides very basic analysis functionality by displaying only the 2D waveforms captured by sensor data. In our communication with him, it became immediately clear that he was not a big fan of analyzing the 2D waveforms because it took him much time to interpret the data. He said that it would be tremendously useful if he could look at the bridge data in 3D. He also mentioned that utilizing our Augmented Reality research out in the field would greatly speed up the analysis process.

During the communication process, Hong felt it was appropriate that we start out focusing only on the accelerometer data from the bridge. Since he does most of his bridge analysis on the accelerometers, he felt it would be better to not include the other sensors since it might be confusing to try and include them all at once. At this point, he provided us with a data set from the bridge

and informed us of how the data was gathered. For each data set, there are 500 records recorded at 200 Hz (or 0.005 seconds). All the records combined make up a data block that is 2.5 seconds long. This data is stored in millivolts, which is the raw data format of the sensors. Thankfully, Hong also provided us with values to transform the raw data into G-forces.

Thus, we now had enough information in order to start this project and design a visualization tool that would be useful to structural engineers. The development of the project is demonstrated in the next section.

3. Visualization Tool Development

Since our previous Augmented Reality research utilizes OpenGL to display computer graphics [4], we used it in the development of this visualization tool in order to simplify integration into our AR system later. By doing so, this also allowed us to quickly make changes to our software in order to accommodate the needs of the structural engineers. As a result, we were able to develop visualization techniques that the engineers felt comfortable with. The results of this system can be seen in the following subsections.

3.1 Color Scales

From the collaboration process, it was indicated that being able to distinguish the difference in data values that it would be of primary importance. Thus it was decided to come up with some color scales in order to do this. First, it was decided that a rainbow scale would provide a nice visualization mechanism for looking at different data values. In this case, values of low stress should be shown in blue and high stress values should be shown in red. Blue usually denotes "cool, non-excited" properties whereas red denotes "hot, rapidly changing" properties. However, in many cases, a data value probably is at neither extreme but rather somewhere in the middle. Thus, the rainbow scale is useful since it can provide a unique color for such a value. In this case the color green
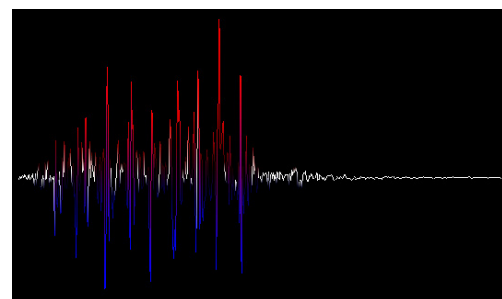

Figure 4: Users have the ability to look at individual waveforms from the bridge like the one shown above. This waveform uses a red/blue color scale so that it is easy to distinguish between positive, negative, and neutral values.

would probably denote a value in the middle of the rainbow scale.

Expanding upon the idea of red denoting extreme values and blue denoting "cool" values, a red/blue color scale was devised. The primary difference between this color scale and the rainbow scale is that no other colors are present. Rather, the color white is used as the "neutral" value between red and blue. This is usually a good scale to use if we are more concerned about how negative or positive a data value is. An example of this can be seen in Figure 4 on the previous page.

3.2 2D Object Types

For this project, various kinds of 2D object types were chosen. First, there is the use of a 2D grid. Each intersection point in the grid represents the location of an actual sensor in the bridge. In addition, it made sense to include a 3D model of the bridge with the 2D grid in order to better conceptualize the data. As for the 2D grid itself, each intersection point will fluctuate in color and displacement depending on the real data value. Essentially when all these intersection points are combined, it gives the user the idea that the grid is a physical structure that is being manipulated over time. This can be useful to give a structural engineer an idea of how the entire bridge is responding to a stimulus.

In addition to 2D grids, 2D planes and contours were also included for visualization. A 2D plane is useful as it can provide the user with an approximate idea of what is happening at all points of the bridge rather than just the sensor points. This is due to the fact that the colors in the 2D plane are linearly interpolated to provide a nice color distribution. 2D planes are best used when trying to get

an overall picture of what is happening on the entire bridge. 2D contours expand upon the idea 2D planes a bit by displaying data similar to that of a topographical map. By viewing data in this way a user can get a sense of where the data "hotspots" are. A nice feature of the 2D contours is that the user has the ability to specify how many contours are visible and thus change the resolution of the data.

Lastly, a user can decide to look at individual 2D waveforms from individual accelerometers from the bridge. This is of interest because there might be one particular accelerometer that contains the most useful information about the data being presented. In addition, these waveforms can also be played back and allow the user to determine the speed in which the waveform is constructed. By providing this functionality to structural engineers, they are able to decide how much detail they want to see when looking at individual parts of a data set.

3.3 3D Object Types

Expanding on the development of 2D object types, 3D objects can be constructed by the means of stacking 2D objects on top of each other. Basically, the idea is that it would be interesting to investigate stacking plane or contour data frames over time in order to create a volume. The primary reason why this is useful because it allows the user to see all time slices at the same time and potentially deduce a general trend for the entire data block. As seen in both the 3D plane volume and the 3D contour volume, one can see that there is a general trend of motion of data over time (probably right to left in the examples shown in this paper). This can indicate to the user how the data "flows" as a function of time. In addition, it is also important that the user be able to narrow down the important data in these volumes since much of it is not useful. Thus, with the use of range sliders, various aspects of the volumes can be cut out in order to see the data that is of primary importance. Also, there are 3D cutting planes available to allow the user to
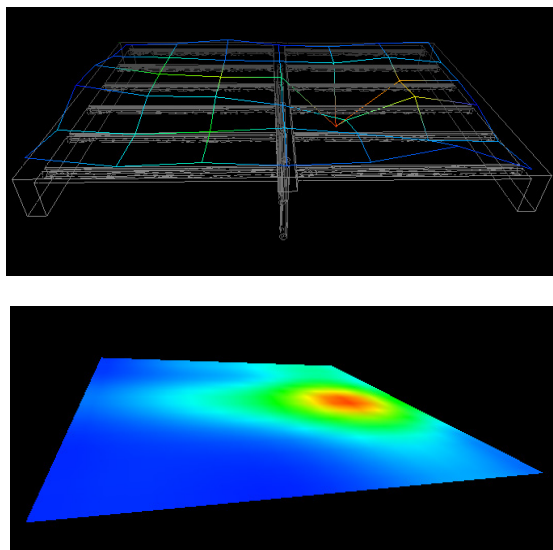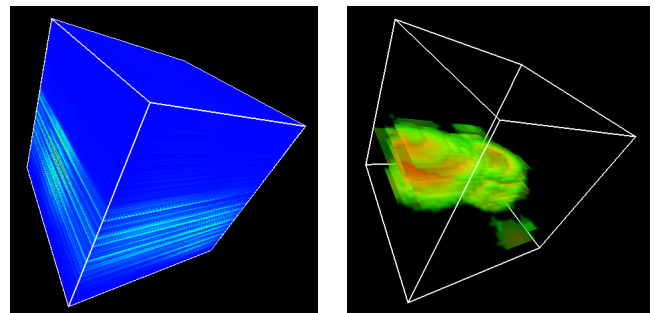

Figure 5: The top image shows a 3D model of the bridge with the 2D grid on top of it. Notice that the grid deforms depending on the data values. The bottom image shows a 2D plane in an instance of time.

Figure 6: By stacking all the 2D planes on top of each other, we are able to produce a "time" volume as seen in the left image. If we strip away all the non-important data values, we can produce the right image which focuses only on the key data and provides a rough sense of when it occurred.
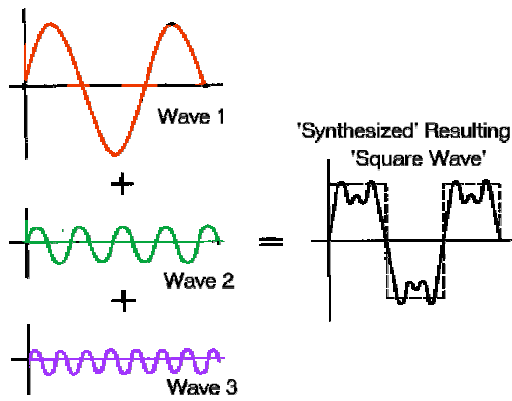
Figure 7: This image shows how three simple waveforms are combined to synthesize a square wave. For structural engineers, it would be useful to work backward and break apart complex waveforms such as this to determine its basic wave components (modes).

cut into the data and focus on a specific part of the volume. As a result, all of these techniques should provide useful data in relation to the passage of time.

4. Feedback and Future Work

After the completion of the visualization tool for AR, we spent some time with Hong Guan again to get his feedback on the project. He mentioned that all the various visualization options were useful and each one provided a unique advantage over the others. In his assessment, he felt that the 2D grid was probably the most useful as it gave him an idea of the displacement occurring on the bridge. He also mentioned that the motion of the grid gave him some clues into the potential waveforms (modes) that made up the motion. As a future project, he mentioned that it might be interesting to see if

the waveform of the bridge could be broken down into its core modes for analysis. By doing so, he and other structural engineers would be able to compare the results with a finite element simulation of the bridge. The finite element simulation is used as a baseline to simulate a "perfectly behaved" bridge and much of its analysis depends on basic mode waveforms. Thus, it would be very interesting to compare the individual modes from the real bridge with that of the finite element model to determine the differences between to two.

In addition, there are many other things that can be done from this point forward. First of all, the scientific data used for this project only focused on the accelerometers. Eventually it would be useful to be able to tap into all the sensors on the bridge and provide a visualization of the behavior of these sensors. In addition, there probably are some more visualization techniques that have not been explored yet but later could added to the application. For instance, in addition to plotting the individual waveforms from each accelerometer, it might be interesting to plot the velocity and displacement waveforms as well. Lastly, the visualization system that we have developed will need to be integrated into one of our Augmented Reality systems. During the course of this project, we simulated the completed system and received very promising results. The results of this simulation can be seen in Figure 8.

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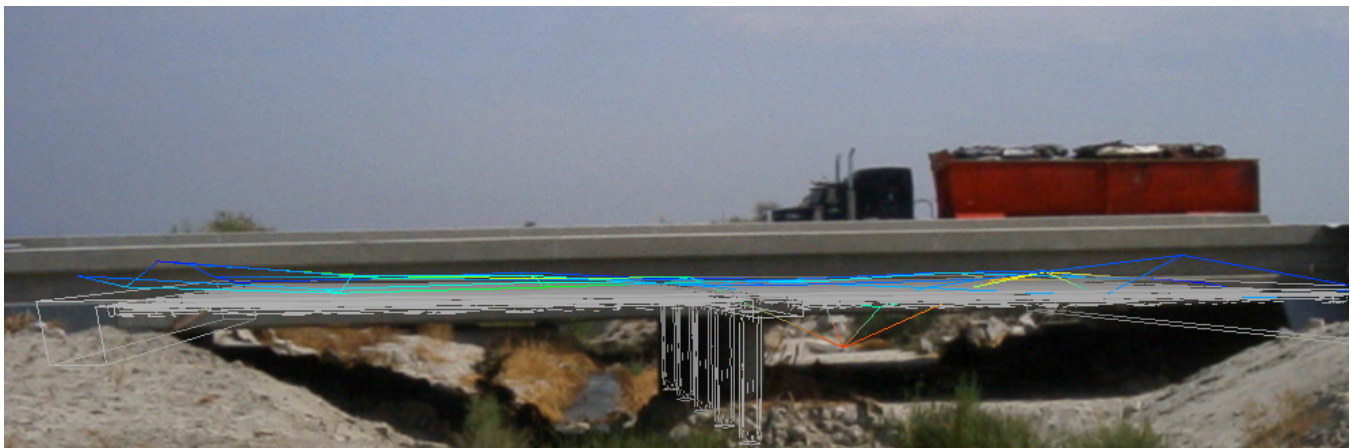

Figure 8: This shows what the Augmented Reality user would see if they were looking through a head-mounted display. Note that the main "stress" can be seen under the front wheel of the truck.

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5. Conclusion

As scientists continue to adopt new technology, like Augmented Reality, for experimental research, there will always be a need for developing tools to visualize data generated from those experiments. Thus, it is of primary importance that these tools are useful to scientists and are designed specifically for their needs. As a result, developers should make an effort to communicate with scientists in order to determine how they want to look at scientific data. As demonstrated in this paper, communication between developer and scientist is one of the most important factors in designing a visualization tool. Through communication, it is important to recognize the values of the scientist and understand what is important to them. This helps prevent the development of systems that have little value to the scientist and thus become unused. In order for Augmented Reality to mature and become more widely available, it is important that developers take these principles to heart. Since applications will soon drive the research behind AR, the significance of these ideas will continue to increase. Thus, it was the goal of this paper to show the importance of communication between developer and scientist and also to demonstrate useful visualization techniques for Augmented Reality.

6. Acknowledgements

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