Angle Dependent Visualization and Interaction of Data in Augmented Reality

by

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Abstract

Exploring clustered data can be difficult, in both a 2D or 3D space. This paper aims to use a new method of exploring data using augmented reality, as well as providing different methods of interaction based on where the user is at a given moment. A clustered data set is displayed using augmented reality and users can freely move around the visualization to view and interact with the data.

Contents

List of Figures

1 Introduction

1.1 Motivation

Data can be displayed in a variety of ways, and when a set of data is shown in a 3D visualization, the user can gain access to many new ways of viewing the data such as being able to see additional angles of the data. Traditionally, viewing items in 3D on a 2D screen has been shown to be problematic in the past, which is why we are considering augmented reality (AR). Additionally, many projects involve interacting with data in virtual reality (VR) or AR. Examples of projects about this topic are IATK [4] and DXR [10]. These present an immersive 3D visualization experience where users can interact or view data in VR, AR or mixed reality (MR). Although the user can have access to different ways of viewing the data such as rotating the data set, or moving around to see from different angles, users may begin to find difficulty in reading and understanding data in clustered data sets. For instance, a scatter plot can have cluster(s) that obscure a piece or group of data from a specific angle. Even if the user were to be able to freely move the model displaying the data, they may still find looking at data hidden behind clusters to be troublesome. In this thesis, our aim is to provide a method of guiding users to angles that may be of interest. We want to tell users the data they are looking at, as well as what they have seen. Additionally, we propose novel tools to help the user interact with data in different ways to better help them explore and read data. For example, we have tools to highlight pieces of data that the user may have an interest in. Lastly, we want to remove the use of expensive and/or head mounted devices (HMD), as we want the device to view the data to be easily accessible to users.

A common question that gets asked about this research is "Why do this in AR in the first place?" and "Why not just have it so the user can perform all these interactions on the touch screen?". This question can be answered in the case of providing the user a more natural and fluid experience. Additionally, we can take new approaches in providing user history in an AR experience. This idea comes from the Hindsight[5] study, as it proved that users performed better in terms of learning and recalling data when they were able to see their interaction history. Taking this into account, since this thesis revolves around data exploration, we thought that it is reasonable for the data to be presented using augmented reality. Additionally, the platform chosen is a mobile device, specifically a mobile phone or tablet. Using these platforms eliminates the need for purchasing an expensive HMD, and makes this widely accessible to users.

1.2 Problem Statement

Users who use a head-mounted device (HMD) to explore data in an immersive 3D environment, whether it is virtual reality (VR) or augmented reality (AR) tend to achieve a better understanding, as well as a more positive ability to recall the data they have seen [5]. While exploring 3D data in VR or AR has already been proven to provide users a positive experience, an existing issue that occurs when viewing data on a 2D screen also occurs when using a head-mounted device. One issue is the problem of not knowing where to go. As stated in the Hindsight [5] project, users often are not offered a method of revisiting the data they have looked at before. Additionally, users will not be aware of the history of data they have already explored. Some questions that may raise during exploring 3D data would be “How did I get here?” or “How do I go back to where I’ve looked before?” One goal in this project is to provide this type of context to the user, which is the context of history. Another problem exists specifically when looking at a clustered data set. Picture a set of data that is blocked by another set of data grouped together on a touch screen and using your fingers to rotate the model and zoom in. The same problem is transferred over to VR or AR when moving around to get a better view. This thesis introduces a novel method of exploring and interacting data in AR, where we include a data set with multiple clusters. This application includes features that help guide the user in exploring, as well as interacting with the data. In addition, we took an approach in utilizing each angle to provide the user a different type of interaction, based on the angle they are looking from.

1.2.1 Clustered Data Sets

The main scope of this thesis revolves around clustered data sets. As mentioned before, reading and understanding data when it is clustered can be difficult for the user. This problem is emphasized when the user doesn’t have an idea of what to look for.

Figure 1.1 shows the Iris data set when rotated to one side. It appears that from this angle the red and blue cluster is close together. However, looking at figure 1.2 it is revealed that the red and blue cluster are not as close as they initially appeared.

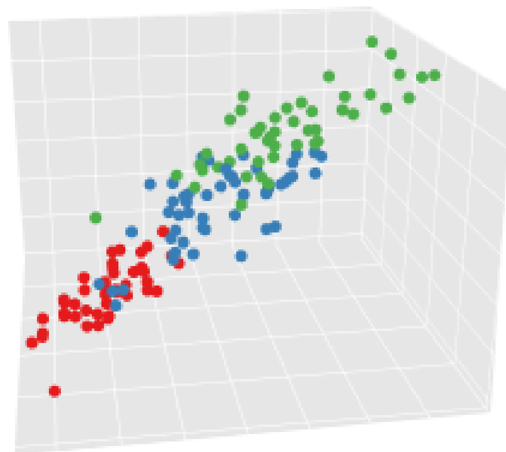


Figure 1.1: The Iris data set plotted in 3D, rotated to view from one side (Image courtesy of Esviia Alti from Kaggle

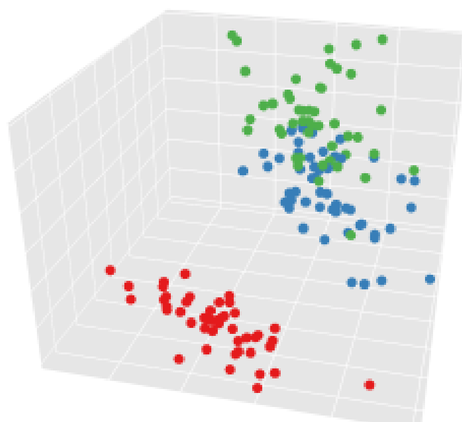


Figure 1.2: The Iris data set plotted in 3D, rotated to view from another angle (Image courtesy of Esviia Alti from Kaggle

1.2.2 Methodology

To combat this type of issue that exists in 3D exploration of a visualization, we look into augmented reality. With the visualization in AR, it opens opportunities for new features. The features implemented in this thesis are aimed provide usefulness for users when exploring clustered data. We took a novel approach in utilizing different angles to change the representation of data, as well as interaction of data. Additionally, we implemented a method of guiding the user during the exploration of data, as well as providing a sense of history by using bookmarks in AR.

2 Related Work

Research was done to gather more information about data visualizations in AR. In this chapter we will be discussing several papers that relate to this thesis, including topics such as interaction with data in augmented reality, purpose and other motivations for this thesis' features. The first section will talk about the general idea of 3D visualizations in AR. There are two projects we read that have done this type of visualization and gave us ideas about interacting with data. Additionally, since both papers use a HMD it stemmed the idea of moving away from using a HMD for this thesis. The second section will give motivation to use augmented reality for 3D data visualizations. In this section it discusses two papers that used 3D models in augmented reality for education. The third and fourth section is the topic of encoding user history in an AR experience. These papers goes in depth about the application and reasoning for user history.

2.1 Immersive AR Experiences with 3D Data Visualizations

Both IATK[4] and DXR[10] are projects that influenced a large part of this thesis, as they provide an immersive experience for data visualizations. IATK[4] provides a 3D visualization in VR using CSV data and includes user interaction. Users can interact by dragging and dropping, as well as highlighting (also called brushing) in order to select data. DXR[10] provides a similar experience in AR/VR (also called mixed reality), but lacks the ability to select specific data. Instead, users are able to build visualizations via inputs in different parameters. The main takeaway from these projects is making an immersive 3D visualization in augmented reality, as well as providing the user the ability to interact with the data. Taking in user input and displaying it in 3D isn't the scope of the project, as we primarily want to showcase a method of exploring clustered data. Therefore, the data set is constant.

Another feature that was derived from IATK[4] is highlighting selected pieces of data. This feature is important since if the user were to explore areas that they may find interesting, it would be reasonable to allow them to highlight those pieces of data. Lastly, we wanted to avoid having to use a HMD as both projects used one in order to view data. While a HMD would eliminate the stress of holding a device while traversing around the space to look at data, one objective in this thesis was to make this application widely accessible to users. We wanted to provide users the augmented reality experience just from their mobile device(s), specifically an Apple[1] mobile device such as the iPhone or iPad. This removes the need of having to purchase and use a HMD in order to get this AR experience. Additionally, with Apple's[1] recent hardware where they include a LiDAR scanner, in the iPhone 12 and iPad Pro, this further motivated us to make an application for AR as the evolving technology can potentially become more popular.

2.2 Augmented Reality for Education

Augmented reality has also been applied in education. A study such as an augmented reality application for calculus [8] modelled complex 3D shapes for engineering students. The model data was stored in a code on one paddle, then students can use a tablet camera to recognize the code, and augment the model on a blank paddle. This contributed to the idea of using augmented reality for our chosen data set, as both complex models and a clustered data set would be difficult to read on a textbook page, or screen. Allowing users to freely move around to achieve better views can make learning and exploring data easier. Another paper relating to this topic is using augmented reality for a periodic table [3]. The idea is similar as students use their phones to use an app in order to display each element's electric configuration. Additionally, the elements and molecules can be interacted via rotating on the touch screen. These projects further pushed our motivation to develop this thesis's application for mobile devices. As the purpose of these educational projects were to help users learn, as the same motivation can be carried over into this thesis as we aim to help users explore and understand data. Lastly, these projects further against motivated us to develop the application for mobile devices due to the ease of access.

2.3 Exploring Data in AR and Encoding User History

Hindsight[5] is a technique introduced to help visually encode user interaction history. This paper brought up the issue about the lack of attention when it comes to integrating history in the visualization. Part of the reasoning is due to the lack of evidence stating that making users aware of interaction history would benefit them in the first place. As a result a controlled experiment was conducted in an attempt to encourage people to visit more data and recall different insights after the interaction with data is complete. The study focused on Wexelblat and Maes' interaction history framework, where they specifically focused on two of the six design properties - degree of permeation and personal vs social. The degree of permeation is how history is directly tied to an object, while personal vs social is whether history represents a personal or group activity. These factors are weighed into designing history-rich tools, as they ask questions during a change in permeation such as “How did I get here?” to “Where have I been before” and perhaps “What is left to explore?”. This largely influenced the ring feature in this thesis, as it helps answer the two latter questions. The ring would highlight the previous locations the user has been, and the non-highlighted segments shows which of the remaining locations have yet to be explored. The bookmark feature can be used to answer the first question, as it replicates the camera’s position and angle upon activation. As long as the user placed few or more bookmarks, then it should tell the user how they eventually got to their location. In the paper’s conclusion, after they evaluated how encoding user history impacts the user’s exploration behaviour, they found that users were able to recall information immediately after interacting with the visualization. Ultimately, they emphasize on applying interaction support techniques in data visualizations, which can benefit people of any expertise. That goal is also applied in this thesis, as we aim to make the data exploration easy and accessible to many users.

2.4 Providing Recommendations in an AR experience

A project called HARVEST[6] was created to help everyday business workers in providing them a visualization tool for analyzing mass heaps of information for their job. They first considered the two extremes of the types of visualization systems, which range from casual visual collaborations such as ManyEyes[12] to commercial grade visual analytic systems such as Tableau[11]. However most of these tools will target either a dedicated information analyst, or a dashboard consumer who both generally have experiences in visualization software and computer skills. However, for a everyday business worker they have mass amounts of data to analyze but are not visualization nor computer experts. So HARVEST[6] has a target audience similar to this thesis’ project. Our target audience were also people who don’t have a high degree of computer/visualization experience, and this would also account for the hardware they potentially possess. Hence, why our project was built for mobile devices, rather than expensive HMD’s or other hardware for augmented reality. HARVEST[6] has several features such as a recommendation feature which recommends a visualization based on a set of inputs. The ring idea derives from this feature as it is a recommendation system as well. Part of the augmented reality experience involves guiding users to angles of interest so part the ring idea came from the idea of recommending. The other feature is called *semantics-based capture of insight provenance.* This feature is particularly complex but the main takeaway is the ability to automatically capture analytic trails, where users can revisit a task of which they performed. Combined with **bookmarks**, the user can make use of these trails rather than starting back from scratch. This idea, combined with Hindsight[5] plays a big role in this thesis' features regarding history - thus, motivating the bookmark feature. With that in mind, two key points can be taken from HARVEST[6]: accessibility and usability for users of all visualization/computer experience and providing history where users can revisit where they have been in the past.

3 Designing a Guided AR Visualization Experience

This chapter will describe each feature as well as the motivation for them.

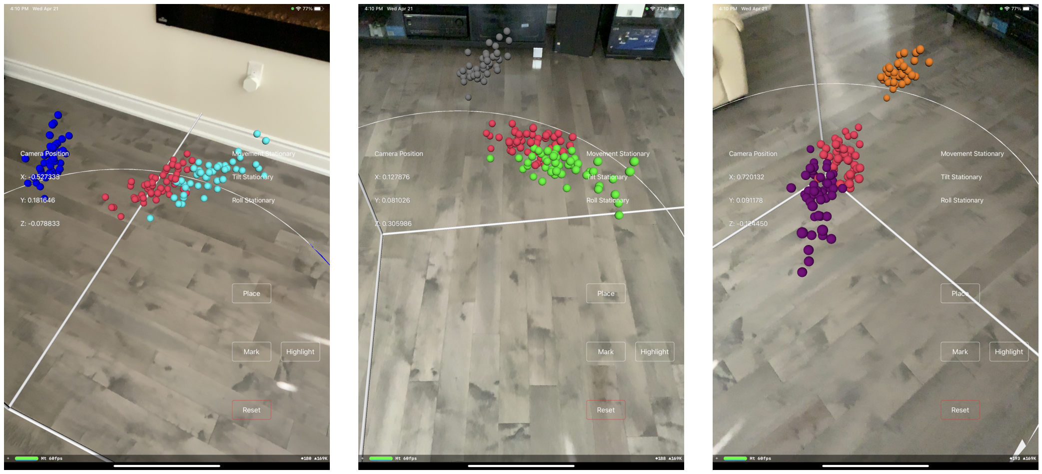
3.1 Data Set Visualization in Augmented Reality

Since we chose to represent a data set in augmented reality, each data point were to be presented as 3D objects. Provided the data set, each point's x, y and z values were copied over to a sphere using SceneKit [9]. After iterating through the data set, the spheres were assigned the positional values and then were added to the scene. Initially, the spheres were too high up in the scene with their default positional values so they were divided by 10 in order to fit them roughly above the ground. The axis were made using cylinders, each with a very low radius. The height for each cylinder was decided by the data set's highest values for their respective axis. For example, the x-axis' height was equal the highest x value in the data set - the same process was performed for the y and z axis. The cylinders were placed at the origin and each were rotated accordingly to properly represent the x, y and z axis in a 3D visualization.

3.2 Changing Representation at Different Angles

A novel approach was taken when changing the type of interaction and representation from different angles. As this project uses augmented reality, we saw much potential in the applications each feature could have. Therefore, our aim is to make practical use out of changing the representation and interaction when the user is at different angles. For example, at a certain angle of interest the user would have access to specific tools they wouldn't have at other angles. To work towards this idea, we opened up the possibility to change the properties of data when moving at different angles - this falls under the representation category.

This software currently has three angles that it can detect the user from: front, left and right. These sides are relative to the visualization. Looking at the visualization from these different angles will change what colour the clusters will be highlighted in as well as what will happen



(a) Visualization viewed from left side

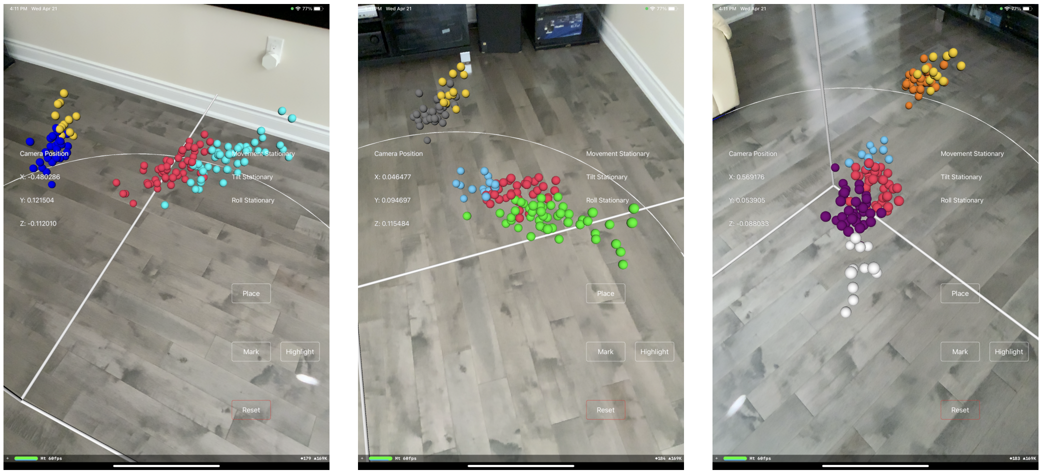
(b) Visualization viewed from front side

(c) Visualization viewed from right side

Figure 3.1: Representation changes depending on the angle the user is relative to the visualization

when the data points are tapped. Currently, looking at the front angle will highlight the front cluster as green and the back cluster grey. On the right side, the front cluster will be purple and back cluster will be orange. Lastly on the left side, the front cluster will be light blue and back cluster will be dark blue. Changing the colours of data is a stepping stone to new methods of changing representation based on using angles. Figures 3.1 demonstrates this feature in the three different angles.

Moving forward with the changing representation, we brought practical use out of this feature by highlighting a cluster of interest. The motivation behind this idea is a way to indicate to the user about a cluster of interest. The goal is to let the user know that there is some data worth investigating and that they should take a look. Referring back to figure 3.1, notice the red cluster in the middle. That specific cluster is the setosa cluster, which was derived from the original iris data set. Because the cluster does not change colour, it indicates to the user that the cluster is of some importance and should be investigated by the user. This is one way to implement of the feature regarding changing representation. However there can still be many more uses, which will be mentioned in the future work section.



(a) Left side: Some of the dark blue data points have been highlighted yellow.

(b) Front side: Some of the pink/red data points have been highlighted blue.

(c) Right side: Some of the purple data points have been highlighted white.

Figure 3.2: Interaction changes depending on the viewing angle.

3.3 Interaction of visualization

Similar to the previous topic about changing representation, we wanted to provide different outcomes of interacting with data at different angles. We believed being able to change interaction of data at different angles would work alongside with the previous idea of different ways to represent data at different angles. The only method to interact with data at the moment is by tapping the data points. There are currently two possible effects when tapping on data which are highlighting the data point a different colour and changing the transparency. A toggle button will change between the two effects. When pressed, the button will change its label between "Highlight" and "Hide", activating the respective effect of tapping.

3.3.1 Changing Interaction at Different Angles

When highlight mode is activated, tapping on data points from different angles will highlight the data a different colour. This is a solution to the initial problem of having data appear to be close to another cluster, but is actually revealed to be far from the cluster when looking at another angle. With the highlighting feature, the user can highlight some data points for their own meaning. For example, to indicate to themselves that the cluster is not as close as they seem. With the changing interaction at different angles, the user will be able to highlight data points different colours from their respective sides. In this thesis, tapping from the front side will highlight the data blue. Tapping from the right side will highlight the data white and tapping from the left side will highlight the data yellow. Figures 3.2a, 3.2b and 3.2c demonstrates this feature when interacting from the left side, then the middle and to the right of the visualization. Notice that the highlight colour remains the same even after changing sides, which supports our purpose of highlighting data at different sides. This can help the user keep track of where they highlighted the data points as they can see from any side of the visualization. Lastly, if the user wishes, the highlighted data points can be overrode to a new colour. For example, tapping on a data from the right side, which was previously highlighted from the left will change its colour from yellow to white.

3.3.2 Changing Transparency of Data

On the other hand when the button has "Hide" mode activated, tapping on data will change the transparency of the tapped data point. This feature is a solution to the problem of viewing clustered data in a visualization. The problem present in this scenario is that there is data blocking other data. If the user would want to view data being blocked, one method is to remove that piece of obstructing data. However, changing and removing data is not something we plan on doing - so we resorted to "hide" data without having to modify anything. Since we have the ability to change the properties such as colour of data points, it opened the opportunity for us to be able to change the transparency of those data points. Therefore, we chose to have a feature to tap on data in order to reduce transparency, so that the user can perform that function on whatever data they wish. Figure 3.3 demonstrates the highlighting feature.

Additionally, tapping on data that has had its transparency reduced will revert the transparency effects back to normal. Unlike the previous feature, the transparency mode is consistent in all angles so it will only perform one function no matter what angle the user is from.

These interaction features demonstrate some of the possibilities of utilizing the user's current angle relative to the data set in order to change their current interaction. There is much potential that can be added to the interaction features which will be mentioned in future work.

3.4 Encoding User History and Guiding in Augmented Reality

This section will go over the solutions we thought of in order to help users know what data they are seeing and/or what they have seen. Along with guiding the user, we propose the solution for revisiting, as in helping users know how they got to where they are.

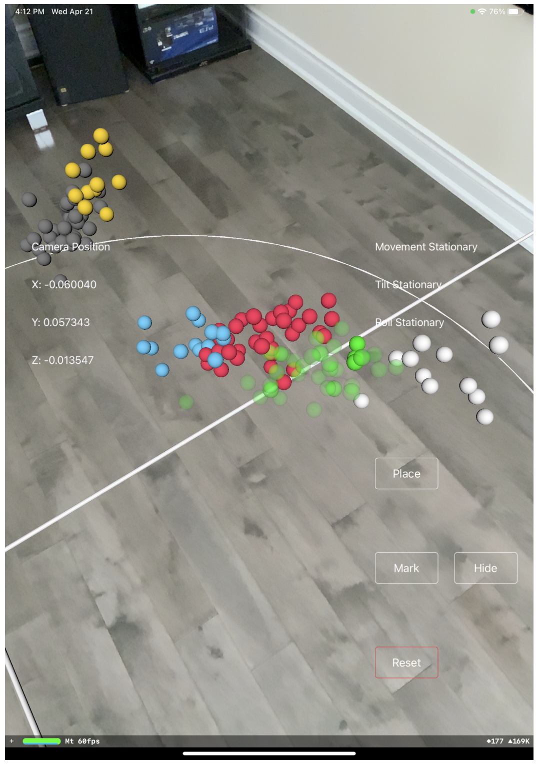
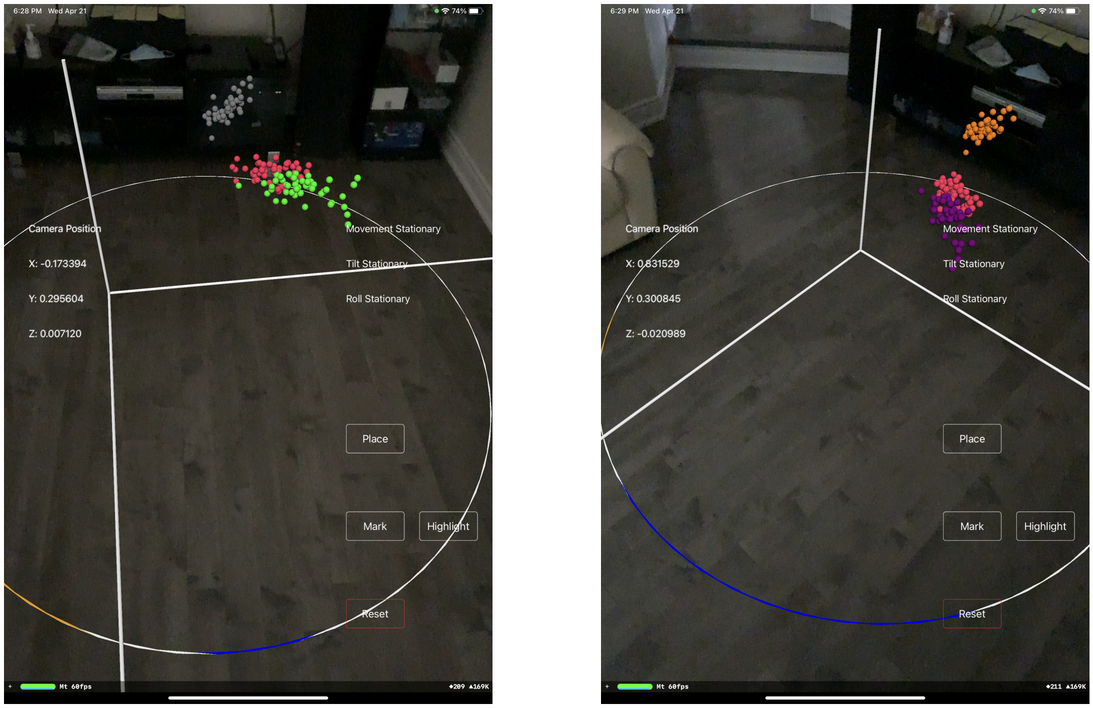


Figure 3.3: Transparency feature used on the green data points in order to get a better view of the red/pink data.

3.4.1 Ring

One goal in this thesis was to provide the user a sense of guidance, in order to remove the potential confusion that the user would have while exploring visualizations. If successfully done, the user would know where they are at any given moment while exploring the data. Our initial ideas included a ribbon trail, a dome around the visualization and a ring. While the first two ideas would potentially be able to encompass both guiding and history into a single feature, we thought that it would be too occlusive - especially in an augmented reality visualization. Therefore, our solution of supplying the user guidance is a visualization of a ring. By creating the ring, were able to implement a non-occlusive visualization that guides the user in exploring data in augmented reality.

The ring was created using primitive shapes which will be elaborated in Chapter 4. Generating the segments enabled us to add each segment as a node in the scene, thus allowing us to change the properties of individual segments. After detecting when the user traverses around the visualization, the corresponding ring segments will change their colour. The coloured segments are able to signify to the user which angles that they have been at as well as the angles



(a) The ring will appear completely white when the scene begins.

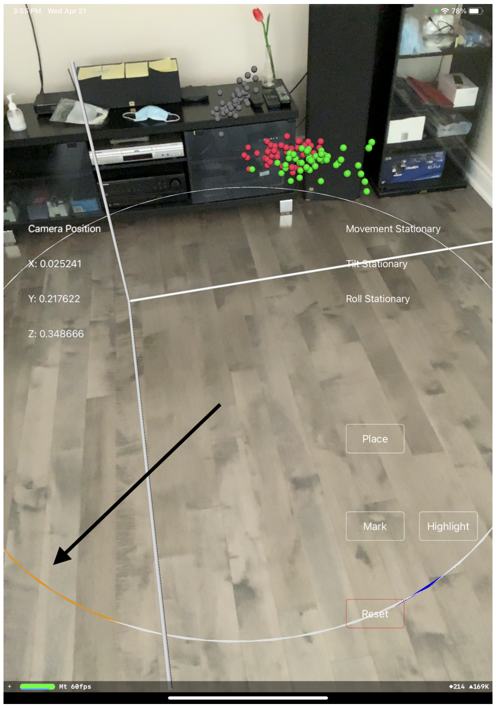
(b) Segments of the ring are highlighted as the user traverses around the visualization.

Figure 3.4: Demonstrating the ring's function by walking around the visualization

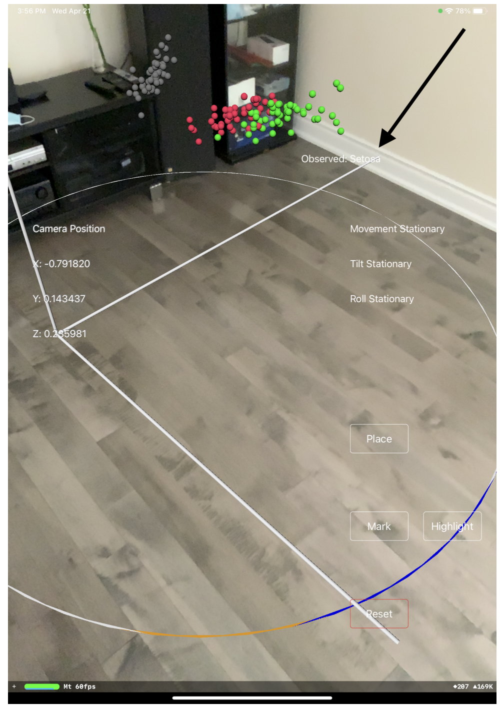
they have already seen. The white segments will mean the opposite - angles that the user have not been at and have not yet seen. Figures 3.4 demonstrates the ring's functionality. As a result, the ring can be used to guide the user into getting a full tour of the visualization. Perhaps more features can be added to the ring, which is possible due to being able to modify the individual segments. Similar to the previous feature of highlighting data points different colours, there is potential of rendering the ring segments with different colours as well. Doing so can bring out new meanings at different angles along with new effects.

3.4.2 Highlighting Angles of Interest

Another problem mentioned in this thesis is when the user comes across data that they may not understand. This motivated us to look for a method of telling the user precisely what data they are currently looking at. The solution we thought of was integrated within the ring. Since the ring is a guiding feature, we can render individual ring segments a different colour in order include another meaning to it. As a result, we decided to render several ring segments in an orange-yellow colour in order to indicate an angle of interest. When the user traverses over that



(a) Highlighted segment in orange at bottom left location. (The orange segment is indicated by the black arrow)



(b) After traversing over the angle of interest, a notice on the user interface displays the data being observed. (Indicated by black arrow)

Figure 3.5: Indicating an angle of interest by rendering ring segments a different colour.

segment, a notification will be displayed on the user interface, telling the user what data they are looking at. In this thesis, we designed a prototype using this rendering in order to tell the user that the angle of interest they are looking at is the setosa cluster. Helping the user know where they should look at is an addition to the guiding feature as it can help users of all skill levels know where they can find importance pieces of data. This is shown in figure 3.5. This feature is currently in the works of adjusting. It does not have optimal performance as it runs into bugs somewhat frequently.

3.4.3 Bookmarking

On the topic of history, we made a bookmarking feature. Referring back to Hindsight [5] and HARVEST [6], these papers mentioned providing the user their interaction history, while the user interacts with a visualization in order to improve user experience. As this thesis' topic is data exploration, we took that idea into account and wanted to provide to the user a sense of history that would be viable in an augmented reality environment. Providing users a sense of history enables them to easily backtrack to any previous places they have been. For example,

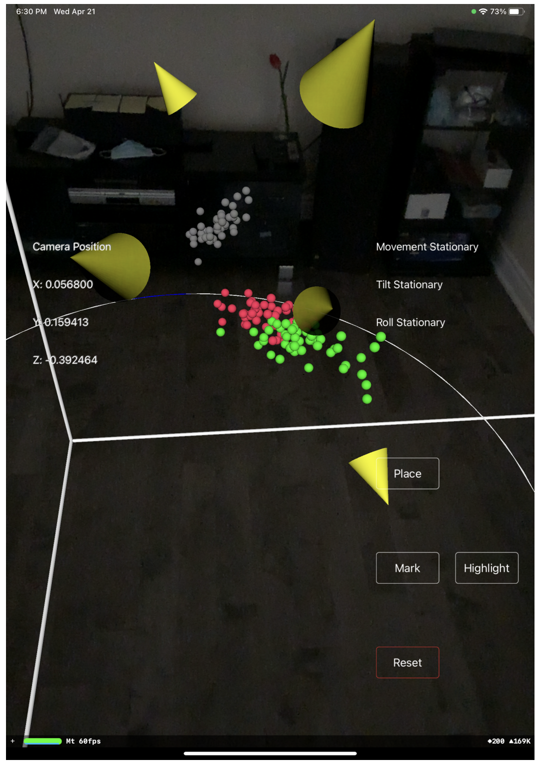


Figure 3.6: Markers placed in the scene. Replicates both position and angle of the camera when placed.

users may have an angle of interest that they may want to revisit after exploring some data. To help the user revisit angles, we created a bookmark feature where if the user presses the ”Mark” button, a cone will be created. This cone will be placed at the camera's exact location and also have its base angled towards where the camera was looking at. This is made to represent a ”viewing cone”, as we thought in order to have a bookmark work in augmented reality, it should also create an accurate representation of where the user was looking at. This feature is shown in figure 3.6

If the user wishes, they can revisit any of these bookmarks and since the cone is hollow, the camera can be placed inside of the cone to view the visualization. With these cones placed in the augmented reality space, users can keep track of their previous locations and angles, and revisit them with ease.

3.5 User Interface Features

The information provided on the user interface were initially for debugging purposes, but they can also be used for the user's own information. The first set of information is shown on the left column of the screen, which displays the user's current position in the scene. The user's position is displayed in x, y and z positions and will increase/decrease according to the user's movement. The second set of information on the user interface is the camera movement. Depending on the movement and/or rotation of the camera, the details about the camera's pitch, yaw and roll will update the user on what current movement the user is performing.

4 Implementation

This chapter goes over the toolkits and hardware used to develop this thesis. It will also briefly mention the techniques used to achieve this thesis' features.

4.1 SceneKit, ARKit and Hardware

This thesis was implemented using Apple's[1] toolkits SceneKit[9] and ARKit[2]. SceneKit[9] is a high level framework which offers the ability to create a scene in augmented reality. ARKit[2] was used alongside, which allows us to add objects to the scene, as well as many technical features such as combining device motion tracking to simplify the task of creating the augmented reality scene. These were made for Apple's mobile devices with an integrated LiDAR scanner, which helped offer a smooth and responsive augmented reality experience.

4.2 Detecting Different Angles

One of this thesis' unique features is the ability to change interaction and representation when the user reaches a different angle. Detecting the user's current angle was key, so it was achieved by utilizing a property from SceneKit, which is called `simdWorldRight`[9]. The property was paired together with a delegate[2] from ARKit. The property `simdWorldRight` provided the node's "right" direction (in the positive x-axis) relative to the world, which allowed us to find the "right side" of each node in the scene. The delegate used in this application is the "session" delegate, with the "ARFrame" property. To simplify things, this delegate enabled us to get camera data within each frame, including the camera's angle relative to the world such as pitch, yaw and roll. Piecing the data together, the camera's yaw was used to determine which direction the camera was looking. To determine the sides of each node, we made values for each node's front, right and left side. These were achieved by setting values based off of their `simdWorldRight` value. For example, the right side would have a boundary of the `simdWorldRight` value with the upper boundary of 45 degrees more and the lower boundary of 45 degrees less. Figure 4.1 illustrates how this property was used. This was continued on by using the lower boundary to determine the front and left side's upper and lower boundaries. Lastly, to determine which side

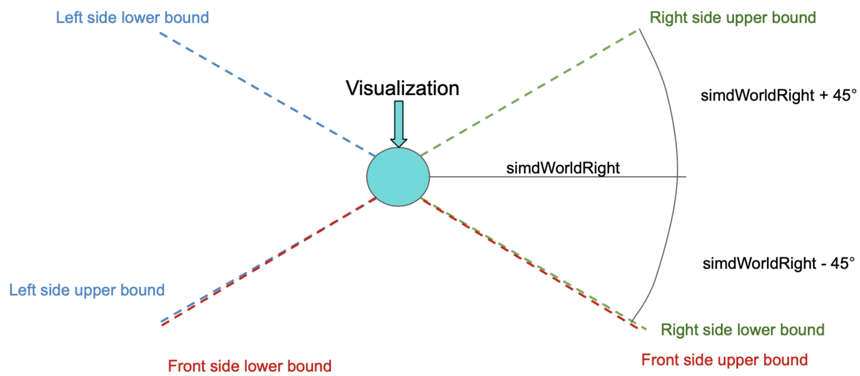


Figure 4.1: Bird's eye view illustration of using the `simdWorldRight` property to create the boundaries for each side. Drawn using Google Slides

the user is relative to the visualization, once the yaw is within one of those boundaries, then it is determined that the camera is looking at that respective side of each node. Once the side is determined, the specific representation and interaction is also determined via switch case.

4.3 Ring: Creating the Ring and Applying Interaction

The ring was a challenge in this thesis as our goal was to change individual segments of a ring as the user traverses around the visualization. However, this task wasn't possible with SceneKit's[9] premade 3D objects since we were only able to change the colour of the entire object at a given moment. We resorted to creating our own primitive shape by drawing a ring using a series triangles. The first step was defining our own data types for the parts that make up each triangle - the normals, color per vertex and the order of connecting each vertex. The next challenge was to generate the vertices and this was achieved by using an algorithm provided by a OpenGL Redbook demo [7]. This algorithm generated the vertices needed to create a full torus. Afterwards, several iterations of trial and error was performed to determine that 59 iterations of the torus algorithm was needed in order to create the ring we desired. After adjusting the rotation on the x-axis, the result is a thin ring around the visualization in augmented reality. Additionally, we were able to create each of the ring's segments as individual nodes, thus enabling us to interact with those segments and have its properties changed, such as its colour. While we achieved the ability to change the colour of individual segments of the ring, another problem arose as we found out that the positioning of each segment were the exact same for a reason we currently have not yet been able to solve. A workaround was implemented in order to perform the intended feature. This workaround involved spheres which were created alongside each segment and they were placed approximately at the same location of their respective segment, using the vertex locations from the torus algorithm. Each sphere had a ID that corresponded to their respective ring segment and each sphere had a boundary on the x-axis. This boundary ranges from the left (-x) and right side (+x) of each sphere. Once the camera's position is within a sphere's boundary, then the respective segment will have its colour changed. Lastly, each sphere is fully transparent as they only serve to be indicators for the backend of the application.

This was continued in order to implement the angle of interest. In the vertex algorithm for the torus, iterations 35 to 38 (inclusive) were coded to render segments a different colour. Additionally, the spheres were given a different ID in order to prevent their colour from changing. This enabled us to render 4 segments of the ring a different colour and disabled the colour changing property even when traversed. Lastly, the spheres that were used as indicators had their effect changed when traversed. This effect is to display on the user interface about the setosa cluster being in view. This ring feature is still in the process of improvement and will be continued in the future work section.

5 Conclusion

This chapter will go over the work we plan on undergoing in the future, how we would plan on evaluating this thesis and the work we have accomplished.

5.1 Future Work

There is a lot to be desired with the features we have introduced. Since this thesis has a novel method of exploring data in augmented reality, it serves as a stepping stone into new possibilities.

5.1.1 Functionalities when Changing Representation

One of the main problems addressed in this thesis is clustered data in a data visualization. With our current feature displaying the ability to change properties of data points, we can go further by changing the transparency automatically. This ties in with the feature of tapping to change transparency. If an algorithm to detect certain clusters was to be implemented, then we can change the transparency of certain data points in order to provide the optimal view of the data - when the user reaches a certain angle. Additionally, the same concept can be applied when highlighting data points. Perhaps some data can be highlighted a different colour when a certain angle is reached and can therefore signify to the user that there is another cluster of interest.

Additionally, adding indicators that point the user to angles of interest can be practical as well. This idea applies to the point about guiding users in data exploration.

5.1.2 Functionalities when Changing Interaction

Since we demonstrated the possibility of changing the highlight colour when interacting from different sides, this begs the question of what other properties we can change. Not only that, we can also ask ourselves if it is possible to bring more details upon interaction. With the highlighting and transparency tools available, we can open up to new ideas such as describing data points upon interaction. In addition to the current features, we can look into revealing the exact coordinates for the data points when they are tapped. Looking at the big picture, it can be possible to "translate" many of the currently existing interaction tools in other visualization software into this thesis. For example adding labels and changing the size of data points.

Another idea is due to the different sides available, we can provide a different set of tools based on the side the user is currently in. The variety of options can range from having the same options on each side, or varying options in a way that would make sense.

5.1.3 Ring Improvements and Additional Features

The ring doesn't work at its full potential at the moment. It is important to note that fixes need to be made to the ring to accurately depict the user's past viewing history.

Once the ring is at full functionality, there can be more features integrated into the ring. Making the ring interactive can open up new features such as dragging to rotate the visualization, or tapping to toggle the visibility of the ring. Removing the ring can minimize occlusion on the screen and allow the user to mainly focus on the data points. Additionally, we can implement new functions when tapping on angles of interest. For example, doing so will reveal details about that cluster of data. Another feature we have in mind is to provide a "mini-map" at the top of the screen, showing how much of the visualization has been seen. This mini-map can also be toggled, offering more possible ideas such as bringing up another UI of a bird's eye view of the visualization, as well as all of the hidden data points within the visualization.

With the topic of guiding, we also thought of placing subtle indicators to prompt the user about the angles or clusters of interest. Labels can be used to signify to the user about interesting data but it is important to keep them at minimal in terms obstruction and distraction to the visualization.

5.1.4 Technical Improvements

Guiding the user in using the application would be required if we plan on deploying it to the public. Even with Apple's toolkits and hardware built for augmented reality, there is still some setup required when launching the app. For example, scanning the room in order to map the surfaces. In this case, a new user would not know what is happening nor what to do when the application runs into bugs. To avoid this, a "coaching"xw system would be required to tell the user to perform the preliminary setup while running the application. In the case of having to scan the room, the coaching system can be used to instruct the user to do so. During this phase the buttons would be disabled to prevent the user from running into potential bugs.

Lastly, bug and performance fixes would be required. It isn't certain whether some performance issues could be due to the toolkit's limitation, or problems with the coding. Regardless it is worth investigating to ensure the application runs well.

5.2 Evaluation

Unfortunately due to the pandemic, we aren't able to evaluate this thesis with participants. However if the opportunity to evaluate the thesis was given, we would first gather participants that have a range of experiences in computers and/or visualization software - from none to a lot of experience. This is because the goal is to help a user of any expertise explore clustered data. We would conduct a laboratory study to ensure a controlled environment, as we would be able to provide an adequate amount of space for the user to move around. Another reason for a laboratory study is that we only need to have one participant at a time as the thesis is primarily made for individual users. Our hypothesis would ask if users would find exploring and recalling data easier via augmented reality with features that provide the user their exploration history and varying interactions. We can have several angles of interest highlighted as a preset for the user to explore. Possible variables in the study would involve independent variables such as time spent exploring each angle of interest and number of data points tapped. Dependent variables would include which feature was being used for tapping, whether it is highlighting or turning the data point transparent. A backend feature would most likely be used in this situation for recording the time for these variables as well as the feature being used.

The procedure is simple. We would first train the user to familiarize themselves with the application by having them do a quick tour of the data and try some of the existing features in a small time frame. Once that time is finished, the user would be presented a set of tasks to explore, read and try to understand the data. Additionally, the user would be asked to use the application's features. One set of tasks would prompt the user to try to find a set of data behind a cluster. For example, the user could use the transparency function to change the transparency of some points of data blocking the desired data. The next set of features to be tested would be the history features. We would ask the user to try to retrace their steps and look at previous angles of interests highlighted we as presets, along with any angles the user may have found interesting during their session. The amount of markers used as well as time spent during retracing their steps can also be added to our list of variables. Additionally, more than one trial of the procedure can be performed as the user may be more familiar with the features in real time during their later iterations. Even showing only parts of the data set (which are still clustered) per iteration can be done if we want more variety. For the instruments, we only need a iPad or iPhone - preferably with an integrated LiDAR scanner to ensure the best performance for the application. An iPad Pro would be ideal for the user as it provides a bigger screen but it could be up to the user to decide.

Lastly, when it comes to the analysis we can divide it into 2 parts: the technical analysis and the experimental analysis. The technical analysis would compare the variables gathered during the study. On the other hand, the experimental analysis would ask the user questions regarding their experience using the application - this can be done in a online survey. We can ask questions using Likert scales such as how much the user agrees to the usefulness of certain features and usability questions such as the ease of use. Also, we would ask the user questions such as what data they can recall, where in certain tasks they had the most trouble with if they had any, what feature they prefer the most/least and more. Ultimately, we want to find how much the application helped the users in exploring and understanding data in the procedures, and attempt to correlate it with our technical analysis.

5.3 Conclusion

In this thesis, we have shown a novel method of exploring data in augmented reality. We have addressed some of the problems in exploring data in a 3D visualization by providing the user history of the data they have seen, as well as tools to help them backtrack. We open the gateway to utilizing different angles to change what the representation and interaction of data will be. What continues on from this is using these changes in order to make practical use for more data sets.

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