DEVELOPMENT AND INITIAL TESTING OF XR-BASED FENCE DIAGRAMS FOR POLAR SCIENCE

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ABSTRACT

Earth's ice sheets are the largest contributor to sea level rise. For this reason, understanding the flow and topology of ice sheets is crucial for the development of accurate models and predictions. In order to aid in the generation of such models, ice penetrating radar is used to collect images of the ice sheet through both airborne and ground-based platforms. Glaciologists then take these images and visualize them in 3D fence diagrams on a flat 2D screen. We aim to consider the benefits that an XR visualization of these diagrams may provide to enable better data comprehension, annotation, and collaborative work. In this paper, we discuss our initial development and evaluation of such an XR system.

Index Terms— Ice sheet, XR, Ice-penetrating radar, Fence diagram, Visualization

1. INTRODUCTION

Earth's ice sheets are the largest source of uncertainty in models of future sea level rise [1]. While the systems governing ice loss are complex and have proven difficult to quantify, the topology of ice layers within the Greenland and Antarctic Ice Sheets contain information about the physical processes that govern ice dynamics. Layer shapes reflect spatial variability in the accumulation and flow of ice, and can therefore be used to constrain critical unknowns in ice flow models. Incorporating layer information into these models has the potential to reduce boundary condition uncertainty [2], and thereby to improve our projections of future ice flow behavior. Because ice flow (together with changes in surface mass balance) determines the ice sheet contribution to sea level rise [3, 4], accurate predictions are a matter of great societal concern.

The topology of Greenland's ice layers is captured in ice-penetrating radar imagery, collected from both airborne and ground-based platforms. The current approach to making scientific use of these images requires interpretation by domain specialists and often starts with the annotation of layers within the ice. However, three-dimensional (3D) structures are difficult to explain from a single, planar cross-section of the ice. To build context, multiple radar images are often visualized together, in an effort to evaluate the continuity and spatial extent of measured features. To do that, radar imagery is commonly visualized in 3D space as fence diagrams (Fig 1).

Fence diagrams are typically rendered on flat computer screens, despite being 3D scenes. While users of these 2D interfaces (e.g., in Matlab) can pan and rotate the content, they lack the immersion afforded by a headset-based XR interface. In other scientific disciplines, XR has been shown to support scientific discovery by enhancing the ability of domain experts to understand their own data [5, 6], by empowering researchers to make spatial annotations more quickly and more accurately [7, 8], and by immersing collaborators in a shared XR visualization [9]. We anticipate that hypothesis generation by polar scientists will be improved in speed and quality with an immersive view. In this work, we describe our development and initial evaluation of an XR-based system for 3D fence diagrams of polar radar images. To ensure compatibility between headsets and simplicity for polar scientists who may be novice XR users, our visualizations are developed in WebXR, allowing polar scientists to load the fence diagrams with no software installation required in most commodity headsets.

2. DATA

The Center for Remote Sensing of Ice Sheets (CReSIS) radar images are captured from overlapping flight paths in many areas of Greenland [10]. These cross-sections of the ice sheet show features which have arisen from the movement and formation of the layers over a period of more than 100,000 years. Historical events such as volcanic explosions, heavy precipitation, and melt are also recorded in layers within the sheet. By studying these cross-sections, scientists can determine flow and movement of ice over many years. For example, a set of three lines (the "three sisters") consistently appears on radar images taken across Greenland and the ice at these three layers is known to be $35,000$ to $55,000$ years old [11]. Deformations of these and other features have happened due to shifts in the ice in the time since then.

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3. SPATIAL POSITIONING IN XR

Due to the uneven altitude of the radar-equipped aircraft, the overall elevation varies across radar images. Therefore, we process each image to ensure a common elevation across each row of pixels [12]. We further introduce cropping to give a base elevation of $-2,000$ meters so that the bases of all the images align, and add padding so that each image is as tall as the highest calculated elevation. This ensures that the nth row of pixels in each image represents the same altitude as the nth row in the other images. Occasionally, there are slight differences in elevation within $\pm$5m. However, this error is almost negligible given the elevation range is in the thousands of meters.

Visually, these differences are occasionally noticeable but often the corresponding layers are easily identified. Additional information regarding the position of the radar slice, its time of collection, and its elevation data are collected and consolidated. These spatial data are then processed and transformed from latitude and longitude into the appropriate Cartesian coordinates needed to represent these images in XR. From this data we can determine the distance which the radar slice covers, its midpoint, and the direction along which the slice was captured. This directional information is vital to insuring the correct alignment in the visualization. Since each radar image has a unique identifier, which identifies its date of collection and radar parameters, we use this as a key when formatting into a JSON for the XR framework processing.

Two locations were chosen for initial diagrams as they provided both relatively simple crosshatch patterns as well as additional radar slices to incorporate once the orientation and direction of the images was determined. The first area is located in Northeastern Greenland (not pictured) and a small subset of 5 images were pulled from a much larger crosshatch pattern. Using the pre-processed and consolidated data, our framework is able to render the radar slices along the direction of collection with correct orientation and positioning between slices. In order to align the image with the correct orientation, we determined the relative position of the endpoints (East-West or North-South). By comparing the flight paths with the framework's positioning we were able to verify correct positioning.

Once this basis for aligning images was determined we moved on to another location in North Western Greenland which spans a larger area as depicted in Figure 3 and Figure 4. This allowed us to test the scalability of our design and ensure that we did not code to the specific case. The coordinate systems were different for the images and the XR world space, which cause the orientation to be mirrored. We adjusted the coordinates accordingly. Both regions also required curved paths for the images to lie along in order to accurately represent the flight paths and all local radar images. The initial development left these curved flight paths for future development as XR implementation of curved surfaces is significantly more complex than placement of the rectangles which result from straight portions of flight paths.

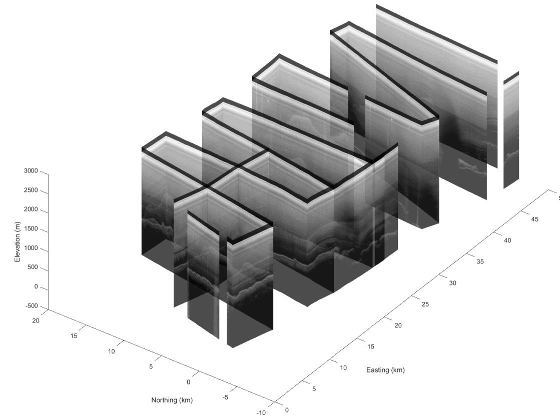

Fig. 1. Fence diagram of radar data collected at Hercules Dome, Antarctica.

4. USER INTERFACE IN XR

Initial development of the XR system began in BabylonJS. This provided the base for the code to generate the initial design and layout of the fence diagrams. This platform proved unsuitable as user controls and support were limited for the framework. By transitioning our development to A-Frame, we were able to leverage a wider range of community-developed tools for spatial navigation. We further developed controls which allow scientists to scale, rotate and move through the world with the handheld controllers. We programmed an interface which allows users to click-and-drag using a pair of controllers, fixing the controllers to two points in space and transforming the world as that pair of points is dragged in three dimensions. This functionality allows movement through the fence diagram in an intuitive way, while still allowing the user to move walk about the planes.

5. FUTURE WORK

Initial development of this system seems to suggest promising results for the utility of an XR visualization of fence diagrams. We hope to further develop this system to allow for annotation of the images in an exportable and collaborative manner. Developing controls for such layer annotation, combined with visualizations of automated annotation [13, 14], would further strengthen the understanding of ice sheet flow. We plan to allow XR-based glaciologists to select an area of interest from a floating 2D map of Greenland, with a 3D version of that scene automatically rendered in real time.

In addition to the capabilities of the software we also plan to develop a series of tasks and questions to best evaluate the

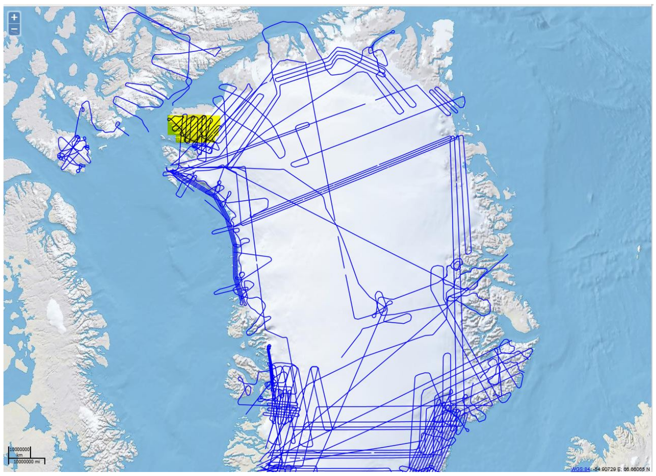

Fig. 2. Map of Greenland with flight paths of CReSIS data in blue. Yellow area is shown in detail in Fig. 3.

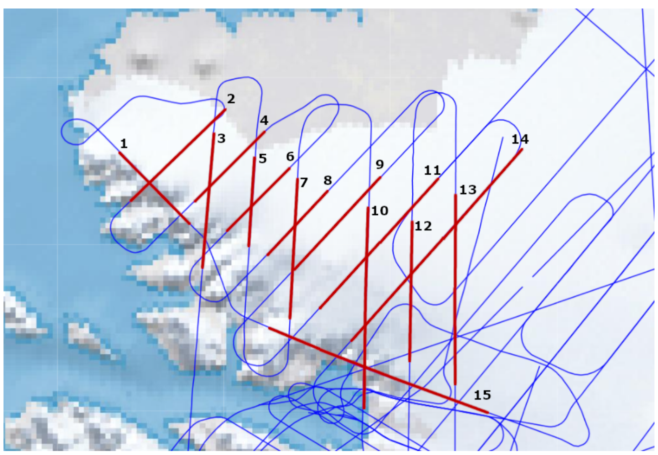

Fig. 3. Northwest Greeland with CReSIS flight paths in blue and red. Ice penetrating radar from red paths is shown in XR in Fig. 4.

efficacy of such a system. By including glaciologists in the development we are best able to tailor the system to best fit the needs and domain specific constrains. This also allows the evaluation metric to be more representative of the actual work being done by glaciologists.

These tasks and revisions aim to help answer our research questions:

RQ1 Are polar scientists able to navigate to areas of interest and develop hypotheses from an XR fence diagram visualization? How do they report the experience compared to doing similar hypothesis generation work compared to 2D fence diagrams?

RQ2 Given the size and quantity of radar images available, are there any hardware or software limitations which will be difficult to be overcome? What techniques (e.g., dividing images into quad trees) are necessary to ensure smooth performance?

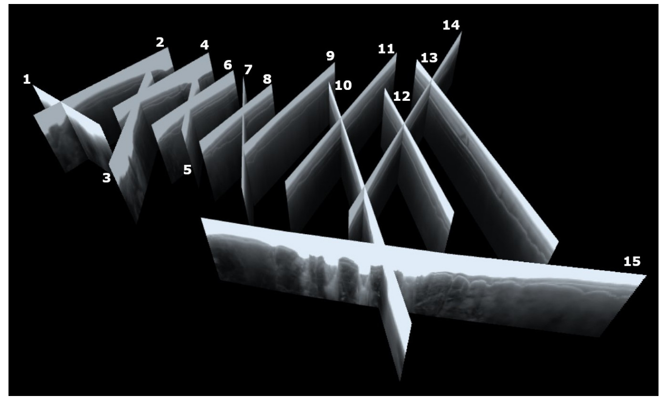

Fig. 4. XR fence diagram of radar data collected in Fig. 2 and referenced to flight paths as shown in Fig. 3.

RQ3 Do polar scientists (our study participants) report any challenges or discomfort with using XR for Fence Diagrams which should be considered against or alongside any benefits?

While this initial work is focused purely on XR-based visualization without any capacity for annotation, it serves as a foundation on which to build future manual layer annotation tools in XR, as well as a path forward for more efficient human evaluation of automated layer annotations.

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