Drones, Phones, and Stones: Visualization for Collaborative Digitization of Historic Cemeteries

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Figure 1: Our visualization tool, with editor permissions, at a medium zoom level.

ABSTRACT

Historic cemeteries face ravages of time, weather, and vandalism. We first captured hundreds of images for each of several unindexed historic cemeteries. We then used a high performance computing system to orthorectify these images into ultraresolution (billions of pixels), georeferenced, tiled images. Here, we describe the interactive visualization we developed using these tiled images to enable volunteers to collaboratively map graves and identify burials. Our ongoing work tests the capacity of this visualization to enable coordination between volunteers with distinct and often asynchronous assignments, including photography, mapping, research, and restoration.

CCS CONCEPTS

• **Human-centered computing → Collaborative and social computing systems and tools**; **Computer supported cooperative work**; **Geographic visualization**; • **Applied computing → Archaeology**.

KEYWORDS

interactive mapping, cultural heritage digitization

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1 INTRODUCTION

1.1 The Societal Need and Technological Opportunity

Cemeteries are important cultural heritage assets, providing physical representations of historical, social, and cultural identities. They offer insights into the beliefs, traditions, and practices of the recent and distant past and provide irreplaceable records of individuals, families, and communities. Historical cemeteries, with burials from at least 100 years in the past, face challenges including partially or completely worn inscriptions; fallen (Fig. 2) and potentially buried markers; overgrowth; and vandalism [13, 15, 17]. This problem is particularly acute for minority groups. Many historical African American cemeteries face disrepair due to discrimination against those sites and economic hardship of associated communities [5, 18]. Across Europe, many Jewish cemeteries were destroyed after their communities were eliminated in the Holocaust [10] and a Jewish cemetery in the authors' immediate area was subjected to antisemitic vandalism even while this project was underway [11].

Emerging technologies afford the opportunity to digitize decaying cemeteries. A variety of technologies now exist for locating lost burial locations, including ground-penetrating radar and aerial mapping for imagery and topography [3, 6, 7, 12, 14, 19]. Many of these technologies are offered to cemeteries on a commercial basis, but historic cemeteries in disrepair are often bereft of funds for such initiatives. Commercial web services are sold to those

Figure 2: A representative scene in a cemetery we scanned: two fallen stones, one face down. A third is broken.

cemeteries which can afford them, but are primarily focused on mapping of known burial information, rather than providing web-based tools for reconstructing this information. Free web services, such as findagrave.com and billiongraves.com, allows genealogists to request that volunteers find and photograph individual graves. Our project differs from all these offerings in that we are focused on comprehensive indexing of entire cemeteries by volunteers doing not only photography, but also document-based research, physical restoration, and mapping. The visualization we showcase herein is built with the coordination of these volunteers in mind [16].

1.2 Workflow that the Visualization Supports

Before volunteers begin their work digitizing a given cemetery, we prepare our visualization with an aerial, orthorectified view of that site. The visualization enables four interdependent types of volunteer work: photography, mapping, research, and restoration.

Photography volunteers take close-up and contextual photos of gravestones and their surrounding area using the cameras in their personal mobile phones. While most phones automatically geotag photos, the precision of these coordinates is insufficient to uniquely identify a stone. The mapping volunteers are expected to annotate points on the map as specific gravestones, so our visualization must have sufficient resolution for graves to be uniquely identified based on a rough location and visual details which are shared between the aerial view provided by our visualization and the ground-based perspective provided by our photography volunteers. Such details include landmarks in the distance, which are captured in the contextual photos, as well as details of individual stones, such as their shapes or inscriptions on their top faces. To ensure completeness in indexing, mapping volunteers must be able to identify objects in the aerial view which could be individual grave markers, for further investigation by photography volunteers.

To determine the required resolution, we measured the size of features of typical stones, such as their dimensions and the size of any inscriptions which could be seen from directly above. We established that a one centimeter ground sampling distance (i.e., a centimeter between neighboring pixel centers) would be sufficient to read large inscriptions occasionally present on the top faces of cuboid gravestones (e.g., "MOTHER") and to identify other gravestones by their relative shapes and sizes.

The annotated map is intended not only for a feedback between on-site photography volunteers and remote mapping volunteers, but also to inform restoration volunteers of which work is needed in which locations, and to show research volunteers the relative positions of known and unknown burials, which sometimes suggest familial or community relationships useful in resolving mystery interments (e.g., mostly illegible inscriptions).

There have been several related studies of computer-supported collaborative work on geospatial data [1, 2, 9], including studies of role-based collaboration [4], although we believe our project is the first to entail cultural heritage preservation and the first to entail the combination of roles similar to those which our work entails.

2 PREPARATION OF VISUALIZATION

2.1 Drone Flights

To ensure affordability that would allow this approach to be scaled and conducted by others, we chose a commodity drone at the lower end of the hobbyist price range - a Parrot Anafi, purchased for $370. With the Anafi's built-in camera, we were able to achieve the 1cm ground sampling distance described in Section 1.2 with a pre-programmed flight at 70 feet altitude (relative to the launch point) with 70% overlap between photos in both directions. For our initial three cemeteries, this resulted in 303, 485, and 1,009 photos. Due to variations in the terrain and our lack of experience in drone flight planning, our capture of three cemeteries included two collisions with taller trees along the edge of the property, and one of these crashes required that the drone be replaced with another copy of the same model. Our flights were preprogrammed using the free iOS application "Pix4Dcapture" and took about an hour per site, using up to three batteries for about 20 minutes each.

2.2 Orthorectification and Tiling

To create the aerial map layer of our visualization, the drone's images needed to be combined into a single orthorectified image, such that each pixel of the map represented what would be seen from directly above that point. For this orthorectification, we compared the output of the open source OpenDroneMap project, which we ran on our university's high performance computing facility, with the output of Pix4Dreact, a commercial service for orthorectification of drone images. The two produced similar results, particularly after adjusting the parameters for OpenDroneMap, but Pix4Dreact was simpler to use and provided the output for our final map layers. The GeoTIFF images we produced for our three initial cemeteries were 256 million, 1.6 billion, and 3.0 billion pixels. To enable web-based usage of these images, we transformed them into quadtrees at increasing zoom levels. These quadtrees were created using the gdal2tiles.py program included in the Geospatial Data Abstraction Library (GDAL) [8]. We then used JavaScript, PHP, mySQL, the OpenLayers JavaScript library, and the Google Sign-In API to create a web interface, described in the following section, for serving these tiles and allowing for collaborative annotations.

3 USER INTERFACE

Our user interface consists of a full-window base layer of lower-resolution Bing Map tiles on which our higher-resolution tiles are superimposed in the area of the cemetery. Without logging in, a visitor to the site is able to see a search bar at the top center and a login icon in the top right. Zooming is accomplished using a scroll wheel or the zoom buttons in the top left of the map. All visitors to the site also see annotations on the map, which initially present themselves as three colors of dots:

- Cyan dots are primary burial markers which have been fully indexed
- Dark blue dots are features on the map which could be confused with primary burial markers from the aerial view, but are not (e.g., foot stones, family section markers, small stone benches, and other decorative elements)
- Red dots are points on the map where further work is needed before indexing can take place (e.g., additional photography, restoration, or research)

Upon clicking on a dot, a popup label appears with text which has been entered by volunteers. For cyan dots, this text is the name of the interred person and it is hyperlinked to a corresponding entry on findagrave. There, volunteers from our project and/or other findagrave volunteers will have uploaded photographs of the grave site (both detailed and contextual) as well as more information about the person, such as birth date, death date, and family relationships (often linked to other findagrave entries).

The popup label associated with a dark blue dot provides a user with information about the visual feature, explaining what it is (e.g., "Smith family section marker"). Similarly, a red dot's popup label will explain the issue present at that location, such as "needs translation," "needs cleaning in order to be read," "stone has fallen face down," or "needs a (better) photo." Volunteers in each role work iteratively to add marks to the map and, when possible, resolve the issues reflected by the red dots.

The view available to an authorized user differs in that a yellow pencil icon appears next to the text in the popup labels. Upon clicking the pencil, an editor subview appears, which enables the authorized user to change the dot type (i.e., color), edit the label text, link cyan dots to findagrave entries, and link red dots to arbitrary URLs (typically a Google Drive folder with photos showing the problem at that location). Through the editor subview, authorized users can also delete dots.

Authorized users are able to create new dots by shift-clicking on the map and can reposition existing dots by shift-dragging them. The backend mySQL database records the full edit history of every dot (including those which have been deleted) and is presently the only way to add or remove Google accounts to the list of authorized users.

4 PRELIMINARY RESULTS

Of the three initial cemeteries, one is nearing completion. Volunteer engagement and performance across the four roles (photography, mapping, research, and restoration) have not matched our initial expectations and we are reworking the instructions and training we provide to the volunteers, as well as the questions we ask them as participants in our study. The preliminary results from our study participants will be shared separately in an upcoming publication. Highlights include 86% of volunteers being motivated by historical preservation, 57% of volunteers being motivated by an interest in genealogy, and almost all participants expressing an interest in continuing their contributions toward this work. Respondents indicated the most surprising aspects of the project were the extent of decay and the extent to which information could be recovered by using our tools in combination with site visits and various public records.

A major strength of the visualization has proven to be the ability to combine older photos (e.g., found on findagrave) with the spatial arrangements made apparent by the map interface. Graves which are now face-down, broken, missing, or otherwise impossible to read are often present and clearly readable in the background of older photos of nearby graves. For example, in the scene depicted in Figure 2, the face-down fallen stone was identified because a photo of the face-up fallen stone was found online, posted ten years earlier, with both stones still upright, and the stone in the rear was legible in the background. By using such spacial relationships, we were able to identify about ten burials which would have been impossible to resolve without the visualization's capacity to contextualize older photos with today's spatial relationships.

5 SYSTEM REQUIREMENTS

Because this visualization is web-based and the images are served as a quadtree of small image tiles, only a typical internet connection and computer with a web browser are required to make use of the visualization, whether as an authorized editor or as an anonymous viewer.

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