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A novel application of terrestrial LIDAR to characterize elevation change at human grave surfaces in support of narrowing down possible unmarked grave locations☆

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ABSTRACT

Unmarked graves are difficult to locate once the ground surface no longer shows visible evidence of disturbance, posing significant challenges to missing person investigations. This research evaluates the use of terrestrial LIDAR point data for measuring localized elevation change at human grave surfaces. Three differently sized human graves, one control-pit, and surrounding undisturbed ground, were scanned four times between February 2013 and November 2014 using a tripod-mounted terrestrial laser scanner. All the disturbed surfaces exhibited measurable and localized elevation change, allowing for separation of disturbed and undisturbed ground. This study is the first to quantify elevation changes to human graves over time and demonstrates that terrestrial LIDAR may contribute to multi-modal data collection approach to improve unmarked grave detection.

1. Introduction

Globally, millions of missing persons are unaccounted for, and their fates are unknown. Some of the missing are thought to be deceased and buried in unmarked graves. Unmarked human graves can be difficult to locate because their surfaces are often camouflaged through natural processes and/or deliberate concealment. Natural processes include new vegetation growth, dry leaf litter, or other debris accumulation. Deliberate concealment can involve perpetrators attempting to hide a body by mimicking these natural processes.

Locating unmarked graves and potentially associated contextual evidence is important to the families of the missing, for forensic investigations, and for post-conflict accounting of missing persons [6,21]. If located, a grave can be excavated to help reconstruct a narrative of events leading up to its creation [29]. If a grave is excavated, buried remains can be returned to the victims' families or communities, if that is desirable, so the living can perform culturally specific funerary rituals [4]. Without knowledge of the location of an unmarked grave, communities can endure prolonged distress over the unknown status of their missing relatives [17,24,27]. Without physical evidence of their crimes, perpetrators may benefit from impunity [29]. To address these important issues, it is necessary to continue building upon existing methods for locating unmarked human graves.

Witnesses can sometimes lead investigators to unmarked graves, but witness testimony is often imprecise or unavailable. For cases lacking witness testimony, investigators must decide which resources are necessary to help locate an unmarked grave. Other approaches to grave detection include ground-based and remote survey methods. Ground-based methods include pedestrian survey [1,5] or even more invasive and time-consuming methods, such as probing, collecting soil cores, or exploratory excavation [12,25]. While excavation is the only method that can confirm the presence or absence of human remains, it is time and labor intensive and the process is destructive. Excavation is typically used to confirm the location of a human grave once a larger search area has been narrowed through other means.

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Geophysical technologies such as ground penetrating radar (GPR), electrical resistivity, and magnetometry are ground-based methods that can assist with human grave detection by identifying non-specific subsurface anomalies. The common benefits to these technologies are that they are non-destructive and non-intrusive. However, since each sensor is usually operated systematically at the ground surface directly above a grave, the suspected location of a grave must already be somewhat narrow. Additionally, there is a growing body of research demonstrating temporal limitations [18] as well as performance limits in certain soil types [1].

Remote survey technologies are those that do not require people or instrumentation to be positioned at the approximate location of a burial, but within its line-of-sight. Such technologies can include terrestrial (ground stations), aerial (manned or unmanned aircraft), or orbital (satellites) sensing platforms. Researchers are exploring the potential utility of spectroscopy for human grave detection ([8–10,20,22,30]). However, the phenomena driving the spectral separation of human grave materials are still poorly understood. Moreover, spectral signatures are not always scalable to airborne or orbital platforms ([8,30]). Comprehensive remote sensing studies are best supported by ground truth data to establish phenomenology in high spatial resolution, which can be used to inform investigations involving other sensing platforms and environments.

Human graves change the ground surface. No matter their size, every grave contains a combination of disturbed soil and excess mass. Elevation changes at human grave surfaces are described anecdotally in the forensic archaeological literature as the result of initial interment and then the subsequent redistribution of buried mass, resulting sometimes in an apparent surface mound or depression, but sometimes not [3,13,14,23]. In an attempt to capture these changes, LIDAR was previously used to map cemetery grave plots with mixed results [28]. The inconclusive results are likely due to topographic variation (e.g., variable slope, anomalous surface depressions or mounds) that cannot be normalized with a single collection. To date, no one has measured and quantified grave surface elevation changes over time.

The goal of this study is to quantify what we will refer to as "localized elevation change," a morphological anomaly characterized over time by elevation gain or loss at the surface of human graves and a grave-like disturbance pit (control), relative to surrounding undisturbed ground. We hypothesize that elevation change at each disturbance surface is localized (i.e., observable to the horizontal extent of the disturbance) and measurable, and that the direction and magnitude of elevation change will correlate with naturally occurring and time-dependent factors, such as body decomposition, soil settling, and organic debris accumulation throughout the study area. The findings of this study may help identify signatures that can be used to isolate areas of disturbance, including unmarked burials, from their undisturbed surroundings. Our aim is that this study will ultimately support the narrowing down of possible unmarked grave locations.

2. Material and methods

2.1. Study area

This study was conducted at the University of Tennessee's outdoor Anthropological Research Facility (ARF), operated by the Forensic Anthropology Center (FAC). The study area is a controlled, natural, and undeveloped environment to simulate a clandestine grave scenario and had not been previously used for forensic research (Fig. 1). The ARF is located on the south bank of the Tennessee River in Knoxville, TN and its perimeter is bound by two nested security fences. The landscape is densely populated with mixed tree, underbrush, and grass species of both native and non-native origins, with primarily topsoil (0–10 cm below surface) and red clay (10+ cm below surface). During Spring and Summer seasons, the dense tree canopy obscures the study area view from above. During Autumn and Winter seasons, the study area is visible through the canopy, but decomposing organic debris covers the ground surfaces.

2.2. Human graves

During 13–15 February 2013, four pits of different sizes were hand-dug in level ground using shovels and pickaxes (Table 1, Fig. 2). Three pits contained individuals who donated their bodies for research to the FAC Body Donation Program. One grave

Fig. 1. The study area, adjacent to the William M. Bass Forensic Anthropology Building (west) and the Tennessee River (northeast) in Knoxville, TN. Image: Google Earth.

Table 1
Control plot and human grave contents.

ID	Soil volume (m^3)	Bodies	Body weight (lbs/kg)
C	4.8	0	0/0
G-1	1.2	1	178/81
G-3	2.4	3	403/183
G-6	4.8	6	618/280

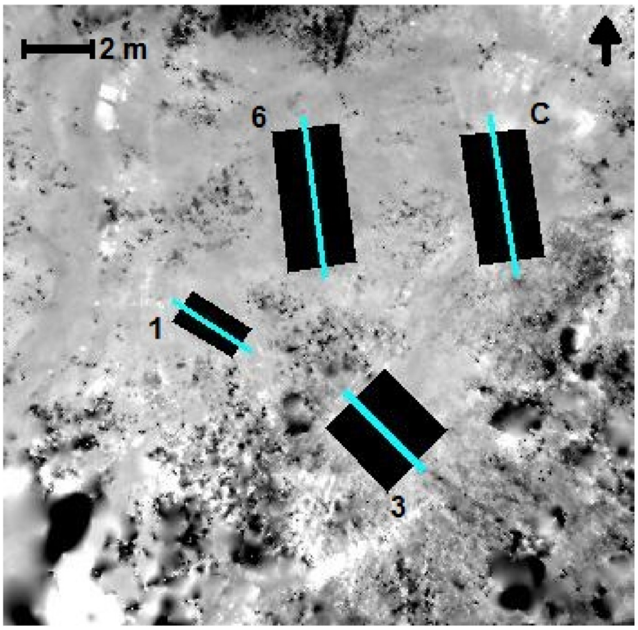

Fig. 2. Grave surface and transect locations superimposed on a sample LIDAR-derived change image.

contained a single individual (G-1), the second grave contained three bodies (G-3), and the third grave contained six bodies (G-6). The fourth pit served as a control (C) and was backfilled without human remains. The graves were separated at least 2 m from each other, and at least 10 m from other forensic experiments. Environmental conditions, such as precipitation and temperature, were identical throughout the study area. Fencing was used to limit foot traffic to within two meters of the graves.

The bodies were interred without coffins, body-bags, or any other type of impermeable boundary from the soil. Hands and feet were wrapped in plastic mesh to prevent commingling of skeletal elements, and a strip of thin plastic mesh was placed between adjacent bodies. Some bodies were partially clothed or bound with ligatures, and items such as bullet casings, keys, and gloves, were added during the backfilling process. Bodies were positioned such that the topmost body of each group was located approximately 10–15 cm below the ground surface plane in loamy soil, above the level of clay, to facilitate decomposition. For this same reason, the bodies in G-6 were concentrated at the north end of the grave pit. All four pits share the same depth of 0.60 m. The units were backfilled with the excavated soil and the original grass sod was replaced at each unit's surface. All soil we removed during the creation of each pit was stored on tarps adjacent to each pit and immediately replaced after body interment. We tamped down the loosened soil at each surface to minimize any obvious mounds, though subtle mounds persisted due to inevitable displacement. Three units (C, G-1, G-3) were completely backfilled prior to the first post-burial data collection. Poor weather prevented the first post-burial data collection of G-6 before it was completely backfilled. Additionally, the soil excavated from the G-6 pit was not completely backfilled into the unit, inadvertently redistributing some soil in the surrounding area. All digging activity was completed on 15 February 2013.

2.3. Data

The data used for this study are 3D point data collected on four dates using a tripod-mounted Riegl VZ-400 terrestrial laser scanner (Riegl USA) (Tables 2 and 3). Data were collected on 12 February 2013 ("pre-burial collection"), 15 February 2013 ("post-burial collection 1"), 03 June 2013 ("post-burial collection 2"), and 20 November 2014 ("post-burial collection 3"). Large trees and other natural obstructions within the study area resulted in significant gaps in the point clouds. To ensure adequate scan coverage throughout the study area, individual scans were made from several different positions, while always keeping at least one grave surface and three tripod-mounted reflectors in the scanner's field-of-view.

2.4. Data processing

Point clouds were co-registered and filtered using a workflow of existing and modified point management processes. The primary goal of this study is change detection, the success of which depends upon precise spatial alignment of elevation data across each collection. Point clouds were co-registered using the Iterative Closest Point (ICP) fine registration algorithm in Ref. [2], then merged to generate a single larger point cloud for each collection date. To achieve the best registration results, point clouds were first cropped to include only rigid structures in the scene, including a building corner and perimeter fence posts. Points representing non-rigid objects, such as vegetation, could not be used for registration because they sway in the wind. The ICP algorithm assumes objects represented in point clouds are rigid and stationary. Therefore, point clouds representing these rigid objects were registered to each other, producing a series of transformation matrices that were applied to their larger point clouds, respectively. The first scan of the first collection date was associated with coincident GPS data. This first scan was therefore used as a universal reference scan for all subsequent scans because its point cloud is considered the most geopositionally accurate.

After point cloud registration was completed, points were filtered using a modified Block Minimum approach originally developed for airborne LIDAR point clouds [26]. Terrestrial point clouds are denser than airborne point clouds and are collected beneath obstructive vegetation or structures, which means more points are representative of the ground surface versus tree canopy or building rooftops. However, many low-lying points represent non-ground objects, such as grass or shrubbery, and must be removed. There is currently no point filtering algorithm that successfully removes all and only non-ground points, but it is possible to estimate point membership based on scene statistics.

Using QT Modeler [15], registered point clouds were cropped to the extent of the study area fence line, then used to approximate a two-meter resolution ground surface using in-scene elevation statistics. Using this approximated surface, all points were

Table 2
Dates and grave age for each LIDAR collection at the study area. Burial date is 15 February 2013.

ID	Date	Age (days)
Pre-burial	12 Feb 2013	−3
Post-burial 1	15 Feb 2013	0
Post-burial 2	03 Jun 2013	108
Post-burial 3	20 Nov 2014	643

Table 3
Statistical distribution of individual surface elevation changes observed at the undisturbed, control, and grave surfaces between post-burial 1 and post-burial 2.

Surface	Min (m)	Mean (m)	Max (m)	St. dev (m)
Undisturbed	−0.693	0.021	0.898	0.101
Control	−0.024	0.067	0.190	0.032
G-1	−0.016	0.039	0.339	0.021
G-3	−0.130	0.041	0.167	0.038
G-6[a]	–	–	–	–

[a] Incomplete soil backfill at post-burial 1 collection; no available surface change data.

converted from elevation values to height above ground level (AGL) values. The approximated surface and resulting AGL values allowed for a rough first-pass filter of points representing tall vegetation and other elevation outliers located above a user-defined threshold; in this case, one-meter AGL. Remaining points were then thinned using Ref. [7] to produce a point cloud that includes only the single lowest point in a five-centimeter grid cell. Since point density is highest in the area immediately surrounding a terrestrial laser scanner, point thinning simulates a more even *x*, *y* point distribution as seen in airborne data sets. Thinning also simplifies the later conversion of point clouds to images by designating a maximum of one point for each image pixel to avoid unnecessary resampling. The thinned cloud is used to approximate a new ground surface at increased resolution. Approximating new surfaces is necessary during each iteration because the remaining points contain a higher proportion of ground points than the previous iteration. AGL statistics for each new surface were calculated and used to remove points with AGL values greater than the remaining point cloud's own statistical mean, plus one standard deviation. Points were iteratively removed using this method of calculating a statistical AGL threshold. Each new surface was increasingly representative of the bare earth, albeit with diminishing returns. At each iteration, point clouds were visually inspected to verify that no obvious non-ground points remained, and no significant data gaps were created during the filtering process. Point clouds were then converted to rasterized elevation images for analysis, where each remaining 3D point populates a five-centimeter image pixel displayed as an overhead view of the ground surface.

For the immediate study area, including human graves, the control plot, and undisturbed surfaces, we derived our final data products by subtracting a later elevation image from an earlier elevation image. Each of the post-burial elevation images was subtracted from the pre-burial image, and the same operation was performed for each logical post-burial image pair, for a total of six elevation change images. This process resulted in multiple images depicting ground surface elevation gain or loss at five-centimeter pixel resolution throughout the immediate study area. We present each image using a Gaussian image stretch to emphasize localized elevation anomalies in the scene. As a graphical complement to the elevation change images, we plotted the elevation change data along a five-centimeter-wide lengthwise central transect of each disturbance surface, which does not offer additional analytical benefit, but helps illustrate the spatial distribution of surface activity that is not always immediately apparent to readers in two-dimensional images as an overhead perspective.

3. Results

3.1. Elevation change images

Surface elevation changes extend to the edges of each feature, indicating localized surface activity. By "localized," we observe clearly delineated activity at the precise location and horizontal extent of each burial and the control unit (Fig. 3a–f). Net elevation change images at five-centimeter pixel resolution reveal localized activity at each of the grave's surfaces and at the control surface (Fig. 2 for grave placements) (Fig. 3a–f). Additionally, all disturbance surfaces exhibit a directional pattern of elevation activity, where elevation gain is observed between pre-burial and post-burial 1 (Fig. 3a), elevation loss is observed between post-burial 1 and post-burial 2 (Fig. 3d), and stasis is observed between post-burial 2 and post-burial 3 (Fig. 3f).

G-1 exhibits a distinctive elevation gain between the pre-burial collection (12 Feb 2013) and post-burial collection 1 (15 Feb 2013) (Fig. 3a). This elevation gain is followed by elevation loss between post-burial collection 1 and post-burial collection 2 (03 June 2013), at which point elevation approximates pre-burial values (Fig. 3b), followed by an absence of localized activity between post-burial collection 2 and post-burial collection 3 (20 November 2014) (Fig. 3f).

G-3 exhibits a similar elevation gain as observed at G-1 between the pre-burial collection and post-burial collection 1 (Fig. 3a). This elevation gain is also followed by elevation loss between post-burial collection 1 and post-burial collection 2, and between post-burial collection 1 and post-burial collection 3 (Fig. 3d and e). By post-burial collection 2, the elevation approximates pre-burial values (Fig. 3b). No additional localized elevation change was detected between post-burial collection 2 and post-burial collection 3 (Fig. 3f).

Post-burial collection 1 data are not available for G-6 surface elevation change comparisons because that unit was not completely backfilled at the time of data collection. This unit's backfill pile, located immediately adjacent to G-6, is depicted in Fig. 3a. However, elevation loss was observed between the pre-burial collection and post-burial collections 2 and 3 (Fig. 3b and c), confirming that less soil was returned during the backfilling process. Similar to G-1 and G-3, no elevation change was observed at G-6 after post-burial collection 2 (Fig. 3f). However, G-6 exhibited a difference in elevation change between the north and south portions of the unit, with greatest elevation loss observed in the northern portion directly over the six buried bodies.

Much like the human graves, the control exhibited an elevation gain between the pre-burial collection and post-burial collection 1 (Fig. 3a), followed by an elevation loss between post-burial collection 1 and post-burial collection 2 (Fig. 3d) with elevation at post-burial collection 2 that approximated pre-burial values (Fig. 3b). No change was observed for the control between post-burial collections 2 and 3 (Fig. 3f). The undisturbed ground surfaces exhibited minimal elevation change in spatial density, direction, and magnitude. Overall elevation in surrounding undisturbed areas gradually and consistently increased as leaf litter and other debris accumulated naturally due to seasonal change.

3.2. Surface transects

We plotted elevation change values along a five-centimeter-wide lengthwise center transect (Figs. 4–7), where data points are spaced five-centimeters apart (Fig. 2 for transect placements). Figs. 4–6 depict elevation change along each transect for the G-1 (Fig. 4), and G-3 (Fig. 5), and the Control (Fig. 6). Elevation loss values described here are inverted for clarity, to emphasize directionality.

G-1 exhibits an overall trend of elevation gain ranging from 2.2 to 8.4 cm between baseline and post-burial collection 1, elevation loss ranging from 3.5 to 9.2 cm between post-burial collection 1 and post-burial collection 2, followed by elevation gain ranging from 0.9 to 9.5 cm between post-burial collection 2 and post-burial collection 3. G-3 exhibits a trend of elevation gain ranging from −8.2 to 9.9 cm between baseline and post-burial collection 1,

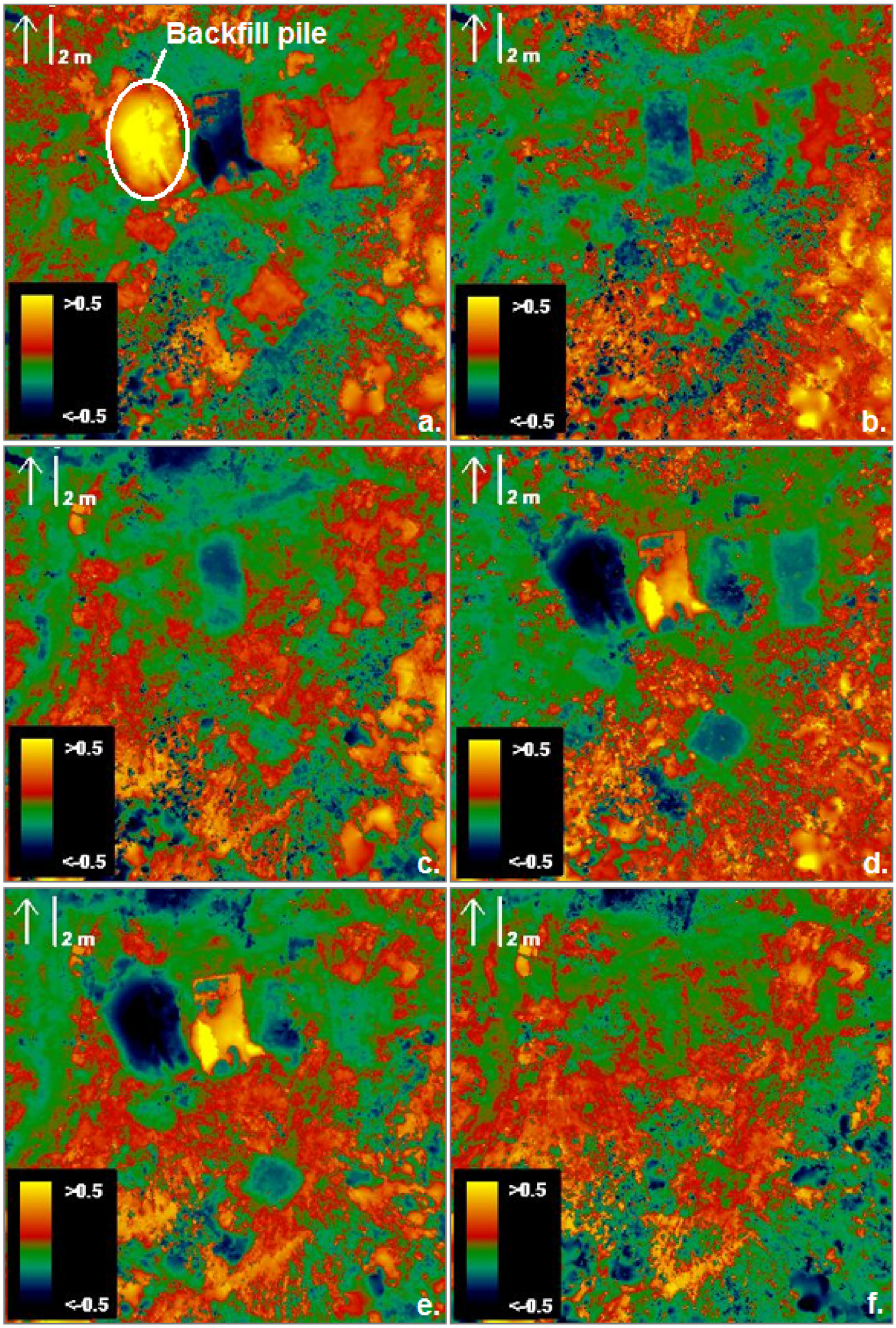

Fig. 3. Images depicting elevation change (m), where each image is the difference of an earlier elevation surface image subtracted from a later elevation surface image. Refer to Fig. 2 for grave placements: (a) pre-burial to post-burial 1 elevation change; (b) pre-burial to post-burial 2 elevation change; (c) pre-burial to post-burial 3 elevation change; (d) post-burial 1 to post-burial 2 elevation change; (e) post-burial 1 to post-burial 3 elevation change; (f) post-burial 2 to post-burial 3 elevation change.

elevation loss ranging from −5.3 to 12.4 cm between post-burial collection 1 and post-burial collection 2, and elevation gain ranging from −1.1 to 6.5 cm between post-burial collection 2 and post-burial collection 3. A few points deviated at some surfaces, which do not influence the overall trends. The control exhibits an overall trend of elevation gain ranging from 0.0 to 11.0 cm between baseline and post-burial collection 1, elevation loss ranging from 2.1 to 10.4 cm between post-burial collection 1 and post-burial collection 2, followed by elevation gain ranging from 0.8 to 11.2 cm between post-burial collection 2 and post-burial collection 3.

G-6 comparisons were made between baseline and post-burial collection 2, baseline and post-burial collection 3, and between post-burial collection 2 and post-burial collection 3. Similar to the other disturbed units, elevation loss values were inverted to emphasize directionality. G-6 exhibits a trend of elevation loss ranging from −0.5 to 8.4 cm between baseline and post-burial

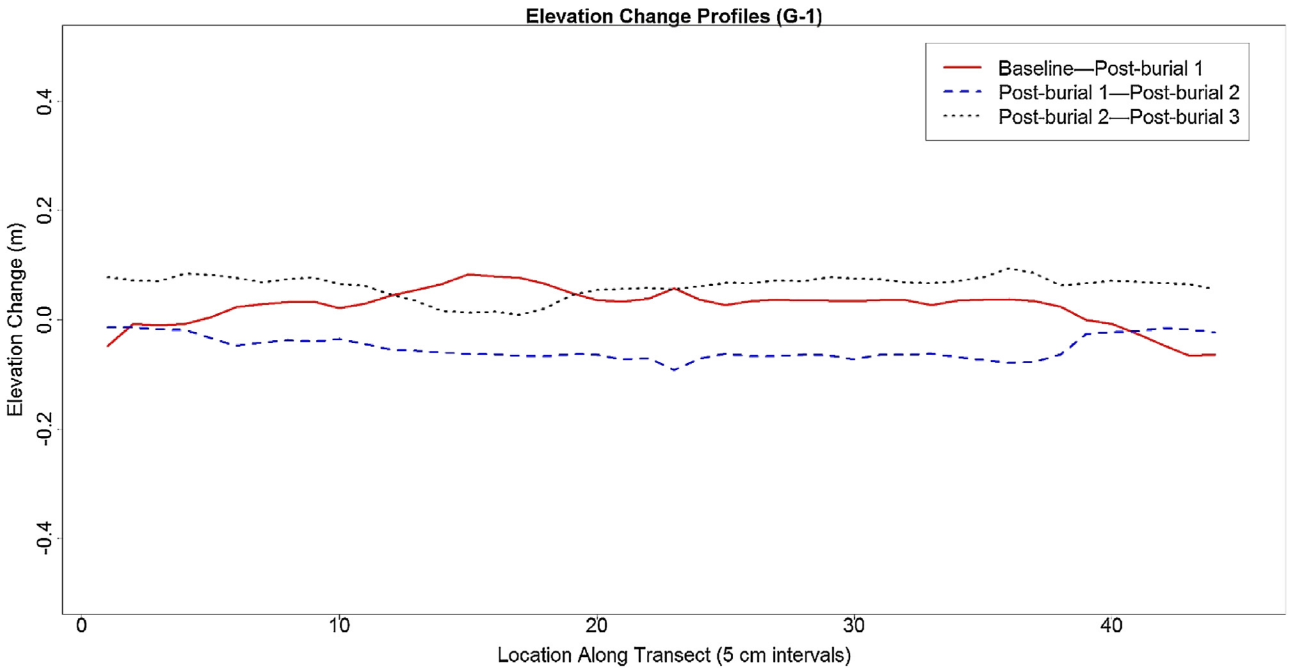

Fig. 4. Elevation change profiles for comparisons at the G-1 surface along a 5 cm-wide lengthwise center transect.

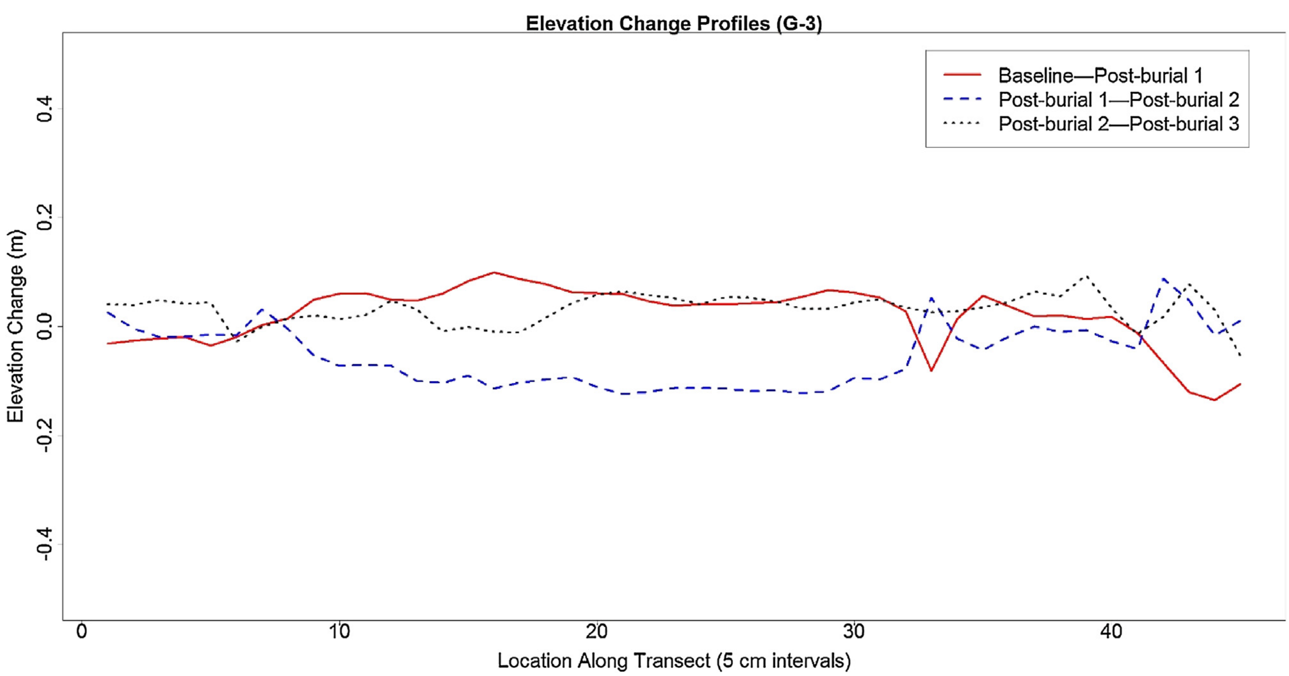

Fig. 5. Elevation change profiles for comparisons at the G-3 surface along a 5 cm-wide lengthwise center transect.

collection 2, elevation loss ranging from −0.5 to 8.7 cm between baseline and post-burial collection 3, and elevation gain ranging from −1.4 to 4.3 cm between post-burial collection 2 and post-burial collection 3. Similar to the other surfaces, some points deviated, but do not influence the overall trends.

At all disturbance surfaces, elevation change – gain or loss – was localized between pre-burial and the first two post-burial collections, and between the first two post-burial collections. That is to say, the extent of elevation change appears unique to the disturbance surfaces and is not observed to the same magnitude or distributed at the same density across the surrounding undisturbed surfaces. Elevation change observed within undisturbed surrounding areas are smaller, amorphic (i.e., not elongated features), and not clustered in the same spatial density as observed at disturbed surfaces. Between post-burial collections 2 and 3 elevation change appears uniform throughout the entire study area.

4. Discussion

Surface activity over human graves, disturbed ground without interred remains, and undisturbed ground is measurable and expressed as localized elevation changes (i.e., clearly delineated

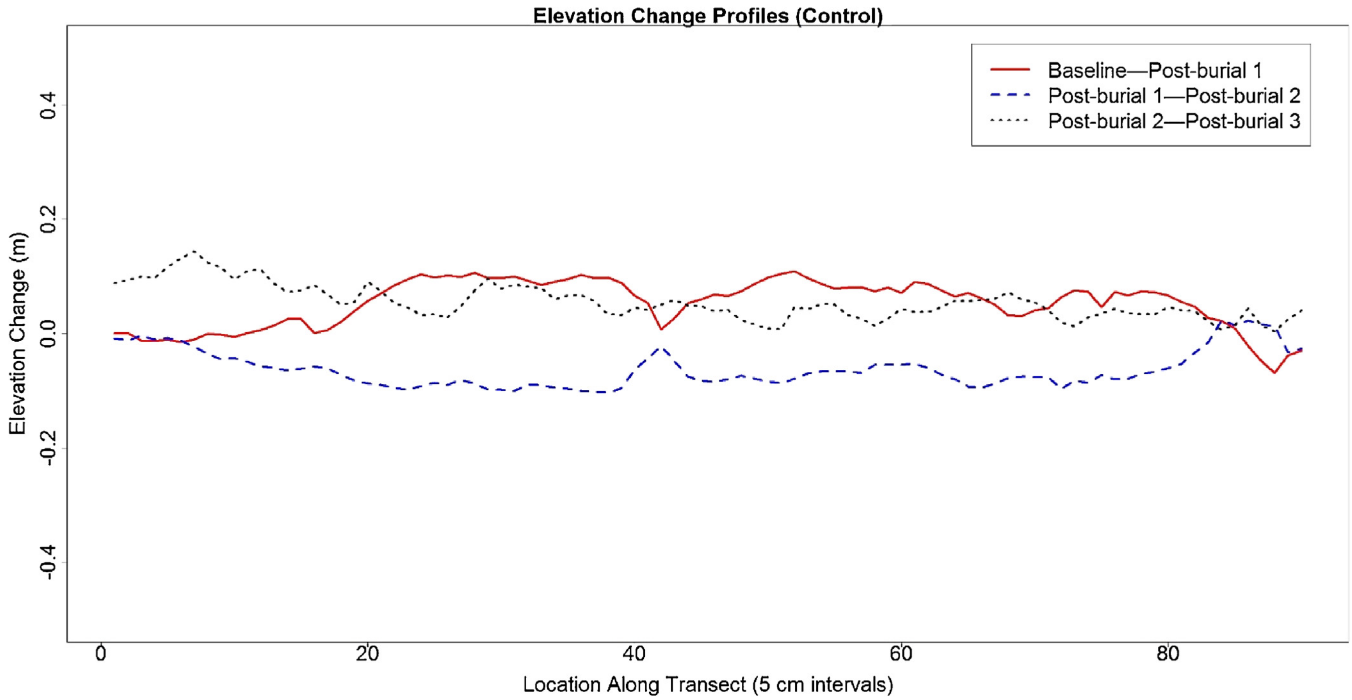

Fig. 6. Elevation change profiles for comparisons at the control plot surface along a 5 cm-wide lengthwise center transect.

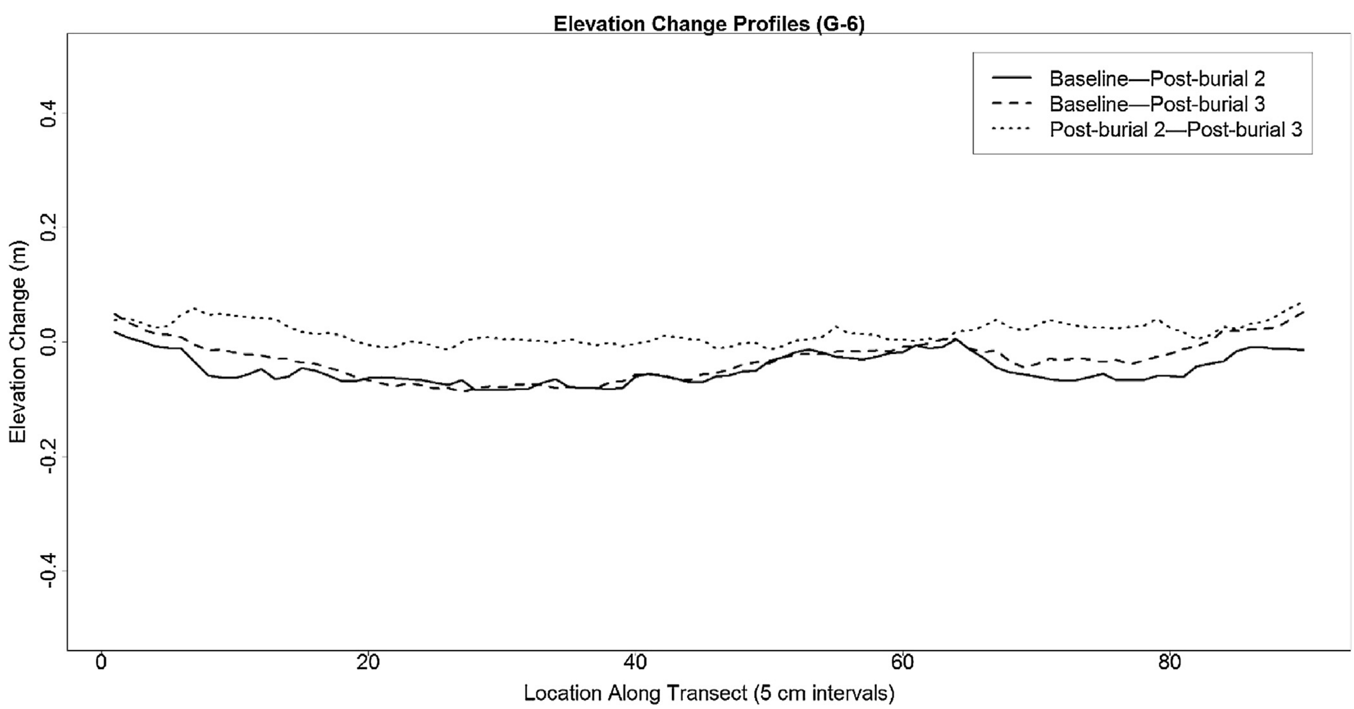

Fig. 7. Elevation change profiles for comparisons (omitting the post-burial 1 collection) at the G-6 surface along a 5 cm-wide lengthwise center transect.

activity at the precise location and extent of each disturbance). The direction and magnitude of surface change is dependent on burial context and elapsed time. Burial context can differ, for example, in the number of interred individuals, the size of the grave, the completeness of backfilling. Other factors may include the amount of time that has passed since the interment event, as well as natural processes, such as soil settling, body decomposition, and organic debris accumulation throughout the study area.

Elevation activity associated with both human burials and the control unit are separable from elevation activity occurring on undisturbed ground. Localized elevation change at the burial and the control surfaces is characterized by the qualities of the change. Localized change typically falls into two categories, (1) elevation change to the full extent of the grave/disturbance footprint, and (2) change directly atop where the bodies are interred, indicating soil disturbance and underlying body decomposition. While elevation changes are observed at undisturbed surfaces, they do not share these qualities we describe as localized.

Elevation change over a human grave can be explained through the processes of creating the grave, evidenced by an increase, and natural soil settling and body decomposition processes, evidenced by a decrease. Digging a grave loosens compacted soil, which when backfilled, occupies more space than before the soil was disturbed. Interring a body introduces a solid mass into the grave-space, simultaneously occupying more volume. The mound that forms after the grave is backfilled, described in the results as an initial surface elevation gain, arises from the loosened backfilled soil occupying more space than its original compact nature, and space once occupied by soil now displaced by the interred body. A similar mound formed at the surface of the control unit from backfilling the loosened dirt, though without an interred body. The burial mound and the mound over the control unit are difficult to distinguish from each other. We are aware that in many cases, perpetrators will attempt to flatten the surface of a burial to mimic an untouched surface, with the goal of camouflaging evidence of disturbance. Though, despite considerable effort to minimize a surface mound, as in the case of this experimental study, the disturbance will still result in elevation gain, which is inevitable due to displacement resulting from burying a body in soil. Perhaps it is the case that such attempts would minimize a surface mound so that it is not apparent to the unassisted observer, but this study demonstrates that LIDAR can reveal subtle differences in elevation change that might otherwise be invisible, and therefore overlooked.

Loosened soil, whether from a burial or a control unit, gradually settles due to gravity and other natural occurrences, such as precipitation. However, we found preliminary evidence to suggest differences in elevation change between the human burials and the control unit. These differences are likely influenced by the effects of interred human remains. Bodies eventually decompose, reducing the mass directly under the burial surface and creating unoccupied space within the grave unit. Soil is redistributed as it fills in areas once occupied by soft tissues. These volumetric changes cause the surface elevation to change, the timing and magnitude of which can depend on the degree of soil compaction and the rate of body decomposition [11,16]. Decomposition rates may be influenced by the number and size of the individual, as well as variation in temperature and precipitation [11,16,19]. The control unit does not mimic the phenomenon of soil redistribution. Further research is necessary to determine whether body decomposition is responsible for elevation change differences between the graves and the control, and whether the differences can be leveraged to distinguish human graves from similarly disturbed ground that does not contain a body.

Localized changes in elevation extend to the edges of each feature. The observed elevation changes over buried remains are in agreement with the timing of decomposition [11,16]. The immediate elevation gain, followed by a gradual elevation loss, coupled with an agreement in the observed localized elevation change with the timing of decomposition, is a strong indicator that both burials and non-burial disturbance possess a degree of elevation change predictability. Elevation changes of the same characteristics are not observed in the surrounding undisturbed surfaces. Elevation changes at undisturbed surfaces are less patterned than changes observed at the disturbance surfaces, both in vertical magnitude, horizontal density, and directional patterning. Where elevation changes do exist in undisturbed surroundings, they are potentially due to non-ground data points that were not successfully removed by the point filtering process. However, an equally plausible explanation for these elevation changes is that they are remnant backfill soil deposits, resulting in actual modifications to the surrounding ground surface during the initial digging activity.

Without carrying out a separate study, we cannot offer empirical data to establish whether the depth of a disturbance or the vicinity of bodies relative to the surface may have influenced the observed elevation change signatures. We fixed the depth of each disturbance pit at 0.60 m to avoid too many confounding variables in the study, and therefore cannot draw conclusions about the influence of depth on the manifestation of elevation change signatures. However, we are reasonably confident the placement of bodies so near to the surface has not substantially influenced the elevation signatures with respect to magnitude or morphology. Our reasoning follows that elevation changes at the surface appear to be more closely linked to the presence or absence of disturbed soil, rather than the volume of soil placed directly above or below a buried body. We conclude that, in addition to the redistribution of soft tissues during decomposition, a loss of surface elevation is explained by the settling of loosened soil. The settling of loosened soil takes place within the entire grave space surrounding a decomposing body, including the spaces directly above and below buried bodies, ultimately contributing to a net elevation change observable at the surface.

Researchers attempting to identify burial surfaces by measuring elevation data at a single point in time have encountered challenges with topographic anomalies, which we believe reinforces the need for more change detection studies [28]. Multiple collections allow investigators to normalize uniform change, to highlight localized change. Change must be recorded due to the extent of topographic variation within the study area that helps disguise the disturbance features, which must be normalized. Naturally occurring mounds and depressions are common in different landscapes, and can easily be mistaken for human burials or overlooked as natural landscape variation. By documenting surface elevation gain or loss (as opposed to surface mounds or depressions), investigators may eventually identify reliable topographic signatures indicative of unmarked burial surfaces.

5. Conclusions

This study established that localized elevation change at human burial and non-burial disturbance surfaces is measurable and separable from changes at undisturbed surroundings. Three observable – and potentially overlapping – phases of elevation change are noted from our limited collections: (1) localized elevation gain following initial burial, (2) localized elevation loss during soil settling and decomposition, and (3) stasis, characterized as uniform elevation change across all surfaces. Measuring elevation change with terrestrial LIDAR may prove useful in identifying a disturbance signature for narrowing down unmarked graves.

In addition to measuring elevation change at burial surfaces is the technology's ability to aid in the monitoring of ongoing disturbance activity. This benefit is demonstrated by the case of G6 in this study, where a backfill pile is located immediately adjacent to the unit in the earliest post-burial collection. The backfill pile is represented by an extreme elevation gain, and a corresponding open grave pit is represented by an elevation loss of similar volume. If used at opportune moments, LIDAR technology may allow for additional remote monitoring and evidence gathering of similar features (e.g., backfill piles, open grave pits, heavy machinery) during an ongoing crisis.

While the spatial resolution of LIDAR data was ideal to document surface elevation change, the current study was limited by the temporal resolution of data collections. By not collecting critical data points, such as the first post-burial collection of G-6, we are unable to support definitive conclusions about optimal signature timing. Future studies should collect more frequent and systematic data to discern individual contributions of soil settling and decomposition to surface elevation loss. Additionally, we acknowledge the many potential extrinsic contributors to a surface anomaly's magnitude and morphological manifestation following burial. We encourage future research to incorporate important data related to local geology, hydrology, entomology, scavenging activity, and vegetation species to more fully characterize their influence in this application area. Without supporting environmental data, investigators may face challenges in their application of this study's findings in a different environment.

Localized elevation change in a landscape – particularly if it follows the directional trends observed in this study – is a strong sign of disturbance. We acknowledge that signs of disturbance are not necessarily signs of burial activity, but the aim for this study is to support the narrowing down of possible unmarked grave locations. The spatial clustering of elevation change at disturbed surfaces indicates that change detection has a clear application in non-experimental contexts. Elevation change detection data may complement other burial detection methods in the field, such as pedestrian survey, soil probing, or ground-based geophysical technologies. An approach that combines LIDAR data with other established methods may improve overall results. While observed elevation change that is consistent with the directional trends presented in this study may not indicate human burial disturbance, specifically, the presence of this pattern would indeed present a strong case for follow up investigation. Additional research is needed to better understand temporal factors, additional environmental factors, as well as to directly observe differences between human burials and non-burial disturbance.

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