Photogrammetry and Electrical Resistivity Tomography for the Investigation of the Clandestine Graves in Colombia

Jonathan Drake, Carlos Martín Molina, Edier Fernando Avila, and Alejandra Baena

Photogrammetric Engineering & Remote Sensing
Vol. 87, No. 9, September 2021, pp. 597–604.
0099-1112/21/597–604

doi: 10.14358/PERS.87.9.597

Introduction

Forced disappearances are a serious crime against humanity. A forced disappearance consists of the deprivation of liberty of an individual and the refusal to recognize or give information related to their whereabouts (CED, 2017; MP, 2020). Presently, Colombia has approximately 100,000 missing people, among which, 26,000 are forced disappearances. It is assumed that most, probably about one-half, are related to armed conflicts in Colombia between the government and guerrilla and paramilitary groups (INML, 2020). Unfortunately, the primary sources of information in Colombia contain conflicting data; therefore, it is possible that there are more missing people than reported in databases. (RUV, 2020; INML, 2020).

Located in the central-eastern region of Colombia, the Casanare Province was one of the many zones strongly impacted by armed conflicts. Probably more than 150 people were forced to disappear from Chámeza and Recetor, two small towns in the southwest area of the Casanare Province. These disappearances were from 2002-2003 and attributed to one of the illegal armed groups in Colombia. These groups are well known as Paramilitaries or the United Self Defense of Casanare (AUC, by its Spanish abbreviation) (EQUITAS, 2015). Until now, the remains of only 14 forced disappearances have been found and returned to their families. The main causes of these disappointing numbers are the lack of integrated information and the non-sophisticated search methods that are being employed in the process of finding victims (FGN, 2020).

Presently, Colombia is in a peace process to end the armed conflict with the Revolutionary Armed Forces of Colombia (FARC–EP), complying with the peace agreement signed in 2016. During the peace negotiation process, access to the truth was a crucial step for the reparation to the victims. This was an important step towards justice after the conflict (OACP, 2020). Consequently, finding the victims contributes to the reparation process. To investigate human rights infringement in Chámeza and Recetor, a non-profit association, EQUITAS, an independent forensic team, developed a strategic regional plan to aid in the search for victims. This plan, Predictive Spatial and Statistical Modelling (MESP, by its Spanish abbreviation), produced a predictive heatmap model that indicated the areas with the highest probability to find clandestine graves (EQUITAS, 2015).

To take advantage of the information provided by MESP and accomplish our goal properly, it was important that a field procedure was developed prior to starting a controlled excavation. This procedure included several types of analyses: surface geomorphology changes, soil type, visual observation of the vegetation variations and near-surface geophysics (Ruffell and Mckinley, 2014). In the process of investigating, there are a variety of geophysical methods that can be used. Ground Penetrating Radar GPR, the most commonly used in forensic search, has several limitations related to environmental features such as soil moisture, waterlogged, clayrich (Pringle et al., 2012). In our case studies, the zones with wooded topography and difficult terrain access were not suitable for GPR. Therefore, Electrical Resistivity Tomography (ERT) was evaluated as a more reliable method in this investigation. ERT is a near-surface geophysical method and permits surveying in wooded terrain. Furthermore, it has been widely used for the detection of clandestine graves (Pringle et al., 2012), ancient burials (Dick et al., 2015) and controlled experiments (France et al., 1992).

ERT is based on the application of an electric current penetrating into the ground to measure the intensity of the electric resistivity generated in the response. We were able to obtain information on the electric resistivity properties of the analyzed material, passing an electrical current and applying Ohm's law ($R = V/I$) where R is the electrical resistance, V is the potential difference between the electrodes and I the current intensity. The use of ERT as a complement to other geophysical methods has been very useful in various applications, such as water search, plume detection, location of leaks, soil study in agriculture and determination of geological strata.

Given the above, a multidisciplinary approach has been proposed using modeling and high-resolution techniques to study the cases in Casanare Colombia (Molina et al., 2019). This integration of technologies guarantees the appropriate scientific methodology is used to assist the investigators in Colombia in finding missing people (Brilis, 2001; Grip et al., 2000). Furthermore, it could be very advantageous to start with a large-scale method such as, remote sensing and photogrammetry, before the near-surface method. Doing this could offer digital support to the preliminary visual observations and allows for the appropriate fieldwork planning.

Geospatial information is a useful tool for field researchers, and over the past decade has been employed extensively in human rights research. Along with traditional data products such as maps, photographs, and field sketches, remotely-sensed data in the form of satellite imagery has increasingly been a key component of this research. This is due to remotely-sensed data ability to provide information about remote, dangerous, or otherwise inaccessible locations (AAFS, 2013; Marx and Goward, 2013). With a ground sample distance of 30 centimeters per pixel even the highest-resolution commercial satellite imagery is limited when the subject of interest is on the scale of individual clandestine burials. In places like Colombia the difficulties associated with this data product are further compounded by local factors such as frequent cloud cover, and/or the presence of continuous forest canopy. In situations like these, however, many of the difficulties associated with satellite imagery can be overcome by conducting photogrammetric mapping on-site.

The use of photogrammetry to enhance field research has already proven useful in a number of fields, including geology, civil engineering, and city planning (Shugar et al., 2017). Additional applications of these tools have also emerged in the fields of archaeology where they have been useful in reconstructing damaged cultural heritage sites, and in law enforcement where they have supplemented the traditional role of the crime-scene photographer in preserving evidence (Al-Ruzouq et al., 2012). While these latter applications are in many ways similar to the documentation of clandestine grave sites in the human rights context, multi-image photogrammetry has yet to be applied to this type of investigation.

In the context of research on clandestine graves, photogrammetry has the potential of benefiting investigations in three primary ways: by providing field researchers with enhanced situational awareness; by facilitating the identification of potential burial sites; and by enhancing the documentation of gravesites once they have been discovered. Traditionally, satellite imagery has been used in the first and second roles, however as mentioned above, its use is limited by weather, tree cover, and resolution. Therefore, its usefulness in investigations is often limited to the very largest of gravesites or providing historical or contemporary context about the surrounding terrain. The output of photogrammetry may be able to transcend these limitations. For example, when the input images contain geotags in their EXIF data, which many GPS-enabled cameras generate automatically, the processing software can use this information to produce fully georeferenced orthomosaics and digital surface models (DSMs) with significantly higher resolution than comparable satellite data.

This article presents the study of two places of interest to detect graves and find missing people in Casanare Colombia. It was organized as follows: Materials and Methods describes the features of the zones of interest we studied and the methodologies used to study and explore these sites. Results presents the results from the multidisciplinary approach with focus on clandestine graves detection. Discussion and Perspectives expounds the advantages and limitations of the reported methodologies and techniques for this kind of human rights projects.

Materials and Methods

Study Sites

Chámeza Zone

The first study site determined by MESP is located at an altitude of 2018 meters above sea level with coordinates 5.0^{o} 8.0´ 4.4˝N and 72^{o} 51´ 2.0˝E. The San José Mountain Ridge is at this location. Due to the steep, densely wooded terrain and lack of roads access is difficult and the only practical means of accessing the site is via pack horse or mule train using a narrow, winding path. The topography is undulating, covered with dense vegetation and many rock fragments as shown in Figure 1a. The environment is a humid tropical forest with predominately clay soil.

To begin the search, first the ground zone was evaluated. Observations of the soil showed the presence of extensive leaf litter of between 0.1m to 0.15m in thickness, which was necessary to remove before the use of ERT. This was done to establish good contact of the ERT electrodes with the ground. The soil presents a black color for the first 0.1m of depth, which indicates the presence of organic matter. Below this, a second stratum of 0.m to 0.2m in thickness, exhibited gray color. This was in turn underlaid by yellow clay. In Figure 1b, a picture of an ERT line at the location is presented.

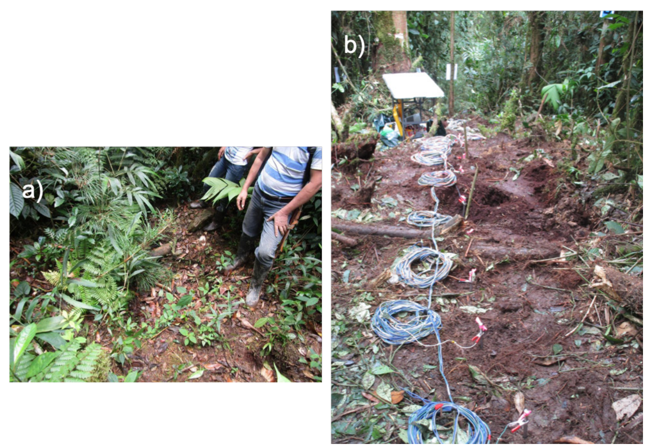

Figure 1. The study site in the Chameza Zone. a) The place indicated by the families of the victims as a possible location of interest; b) ERT line within the search area.

Recetor Zone

The second area of interest identified by MESP is located at an altitude of 1658 meters above sea level with coordinates 5.0^{o} 9.0´ 46˝N and 72^{o} 55´ 24˝E. This specific site is known as Teguita Alta, and referred to as “The School” by the local inhabitants due to its former use as a training camp for illegal armed groups. This site is illustrated in Figure 2a. Access to this site was less difficult than Chámeza and motorized transport was possible, although the roads are unpaved. The landscape presented smooth slopes with “isolated” vegetation. The methods used to conduct the initial search were the same as at Chámeza. Figure 2b, shows the electrical resistivity tomography ERT GEOAMP 202 in the location where animal bones were found.

Figure 2. The study site in the Recetor Zone. a) Topography at the area of interest in Recetor. b) Electrical Resistivity Tomography (ERT) with GEOAMP 202 equipment at the site where a grave containing animal bones was found.

Photogrammetry

Alongside ERT, this investigation attempted to apply both air and ground-based photogrammetry to the two sites of interest, which were selected by MESP as having the highest probabilities of finding the remains of missing people. The first goal of the investigation was to evaluate the technique's usefulness as a tool for enhancing the situational awareness of field researchers conducting forensic investigations in rugged, unfamiliar terrain.

The Recetor Zone called Teguita Alta 1, and Teguita Alta 2, consisted of open fields, which allowed the mapping to be conducted using UAS. At these sites, a stock DJI Phantom 4 was used for this purpose. The UAS was controlled using a tablet computer attached to its remote-control unit, which allowed for automated flight with the possibility of manual intervention at any time. Two different applications were used to upload flight plans to the aircraft, Pix4DCapture and DroneDeploy. Both Pix4DCapture and Drone Deploy would normally rely on internet access to retrieve online maps to facilitate the process of defining the survey area. As no connectivity was available at the sites, the area was defined using a laser rangefinder and, where possible, by walking the perimeter of the site while holding the tablet, thereby establishing its boundaries using the tablet's built-in GPS.

The survey flights were conducted under computer control, without direct pilot input except in case of emergency. In order to ensure that the UAS would not be in danger of encountering any obstacles during these autonomous flights, a manual test flight was conducted prior to each survey flight. This test flight established the minimum altitude at which the aircraft could safely fly without encountering trees, terrain, or other obstructions. The final parameter of the flight involved defining the exact path followed by the UAS. The flight over the first site, conducted using DroneDeploy, was defined as a single-grid mission followed by a single circular orbit of the site. For the second site, controlled by Pix4DCapture, a double-grid mission was flown, in which the flight path consisted of overlapping grid paths, rotated at ninety degrees to one-another. At both sites, the amount of visual overlap between subsequent images was defined as 80%. Whenever possible, the area to be mapped was cleared of personnel prior to each flight to minimize the potential for error caused by motion in the scene. When this was not possible, everyone in the mapped area was asked to remain still.

The San José site in the Chameza Zone was located under dense forest canopy, on the side of a north-south facing hill slope where dense vegetation precluded the automated flight of the UAS. Manual flight, while possible, was deemed too risky due to the potential for crashing the UAS. For this reason, mapping at this site was performed on the ground using a Canon 6D Digital Single-Lens Reflex Camera with a Sigma 8mm circular fisheye lens; the camera's built-in GPS provided geolocation data. This lens provided a 180-degree field of view, which allowed for the maximum possible amount of overlap between successive images. The mapping proceeded on foot in an over-lapping grid pattern, with the first pass covering the site through a series of traverses in an east-west direction at right angles to the slope, followed by a second series that covered the site via traverses in a north-south direction. Photographs were taken at approximately one-meter intervals, though the pattern often diverged from a perfect grid due to the practical considerations associated with navigating the uneven terrain on foot. The locations of the images acquired at this site are shown in Figure 3a.

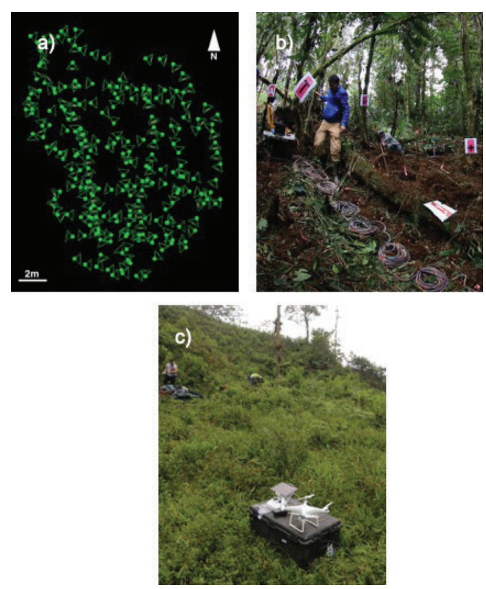

Figure 3. Phtoogrammetry at San Jose. a) Locations of images acquired; the pattern of overlapping grids is crude, but visible. b) Photograph showing the alignment markers used to facilitate 3-D reconstruction, as well as the challenges of overhanging vegetation. c) The DJI Phantom UAS used for conducting aerial mapping.

Due to the high level of visual complexity associated with the jungle terrain, the similarity of many features (e.g., leaves, tree branches, etc.), as well as the frequent rain showers, it was considered highly likely that automated matching of the images would fail. In order to correct for this, large color-coded alphanumeric markers were placed on the sides of trees and logs at a variety of elevations throughout the site to provide unique, easily identifiable 3-D reference points during processing, as shown in Figure 3b. Although these markers were placed at high density throughout most of the study area, in order to evaluate whether it was possible to use natural features as manual tie-points in this type of terrain, none were placed in the northeast quadrant of the study area.

Once collected, the data was downloaded and processed using Pix4D Desktop. For UAS flights, the default processing parameters for 3-D mapping produced good results from automatic image alignment. The adjustment process gave a maximum of only 2.5 percent of images uncalibrated; it was because there was no overlap of the edge of the images, which primarily corresponds to outside the study area where the images included a significant presence of trees. As expected, for the ground-based mapping, automatic image alignment was far less successful. As a result, the images were manually calibrated with one another using the alphanumeric markers described above. Following this manual process, 221 out of 236 images were correctly calibrated. Since total sation or survey-grade GPS was not available at the three sites, ground control points, used to improve the geolocation data generated by the cameras onboard GPS, were not available. Instead, Pix4D's "scale and orient" tool was used to adjust the size and rotation of the model by referencing stakes and measurement tapes that had been placed on the ground in the field site for this purpose. The 15 images that failed to calibrate even after manual matching were located almost exclusively in the northeast quadrant where artificial references had been deliberately omitted. The calibrated images were then processed into a 3-D point cloud using Pix4D's standard matching algorithm. The resulting point cloud contained a large number of points that corresponded to overhanging vegetation, and which interfered with interpretation of the scene. In order to simplify the resulting model, the point cloud was manually edited to remove features that were not of interest to the investigation, including branches, leaves, and other elements that had the potential of obscuring the surface of the terrain in the final mosaic. The lower ends of tree trunks, however, were preserved, as were logs already on the ground, because both of these are part of the landscape and can serve as useful reference points should the model be used to guide subsequent investigations. The edited point cloud was then processed into a 3-D model using a custom set of processing parameters that maximized the number of triangles in the completed mesh.

Geophysics

There is little existing literature on applying forensic geophysical methods to clandestine burials sites in South America (Sagripanti et al., 2013; Molina et al., 2015). The few studies that do exist in this area have shown good results with detecting simulated graves using methods similar to the ones discusses in this article in controlled conditions. However, the success of these techniques depends on many factors, such as time since burial, burial style, local soil type, vegetation, and the locations climate (Molina et al., 2016). In the current investigation, ERT was used to explore the areas of interest determined by MESP. This method enables the exploration of remote, difficult to access areas with mountainous terrain and challenging environmental conditions as described above (Molina et al., 2013).

Electrical Resistivity Tomography (ERT)

In the study zone, the data were acquired by a GeoAmp 303 electric tomography apparatus using the Wenner method. In Chámeza, the experimental design consisted of eight tomography lines, each being 15.5 m long and separated by 0,5m between successive lines. This configuration was chosen in order to obtain data every 0.30m. Earthimager Software v. 2.4.1 (https://www.agiusa.com/) was used to process the data in direct mode.

In the Recetor Zone, only one-line of ERT was made, using the same configuration as in Chámeza. At this site, the results of the line enabled the detection of a grave containing animal bones.

Results

Photogrammetry

The aerial data collected using UAS produced high-quality mosaics and digital elevation models with minimum effort. Ground sample distance in the orthomosaics produced by autonomous flight was approximately 2 cm per pixel, over 10 times better than the best available satellite imagery. After being generated by Pix4D, the 3-D Analyst Toolbox in Esri ArcMap was used to convert the digital surface models (DSMs) into slope maps, which were able to reveal several small depressions and areas of level ground that were not immediately obvious or accessible to the team in the field. These could be promising future targets for investigation using subsurface tomography. Examples of airborne-derived DSMs are shown in Figure 4.

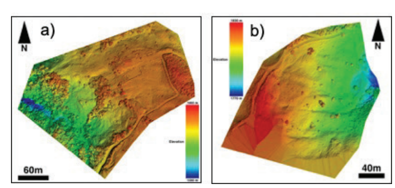

Figure 4. Digital Surface Models derived from UAS imagery. a) Teguita Alta site one and (b) site two.

Following point cloud editing, the 3-D model generated from the ground-based images acquired at San José successfully reproduced the essential features of the landscape, including fallen logs, tomographic equipment, and test pits dug during the course of the fieldwork. At the highest magnification, many areas of this model's texture map were blurry, or contain multiple overlapping "ghosts" of the same feature. This is likely due to the large number of images that overlap a given point in this model, combined with small errors in the manual image calibration. Nonetheless, features as small as the heads of tomography electrodes are easily distinguishable as such in the model. Based on the dimensions of these features, the model's texture map has an estimated spatial resolution of approximately 0.01 m per pixel. Despite the qualitative fidelity of the 3-D model, however, the orthomosaic generated from the ground-based images contained numerous image artifacts that could not be eliminated using the editing tools available in Pix4D. In order to produce a useful mosaic, the 3-D model, which was not subject to these errors, was viewed in orthographic projection at high magnification. By stitching together multiple vignettes and georeferencing the resulting mosaic according to the model's geolocation data, a more faithful orthomosaic was produced. This output depicts the terrain located beneath the jungle canopy as it appeared during the collection of subsurface tomography data, and can inform the placement of subsequent tomography soundings. An overview of this mosaic is shown in Figure 5a. As described above, the lack of data in the northeast quadrant is due to failed image calibration resulting from a lack of alignment markers in that region. The artifacts associated with the orthomosaic did not extend to the digital surface model derived from the ground-based photography. This output, like the 3-D model, reproduced the contours of the terrain and associated features, as shown in Figure 5b. Measurements conducted on objects of known length within this model show that the geometric corrections applied by the "scale and orient" tools did result in a model that faithfully reproduces their dimensions at a local scale. However, due to the lack of ground control points in this case whether geometric consistency applies over greater distances could not be validated. Similarly, the elevations of the DSM, being solely based on the camera's built-in GPS, may vary significantly from the terrain in an absolute sense.

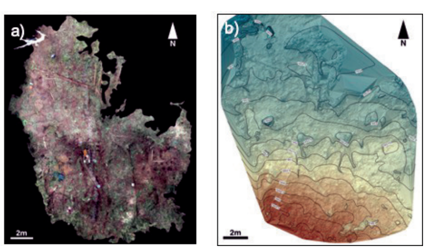

Figure 5. Two views of the San José site. a) Orthomosaic with overhanging vegetation digitally removed and b) digital surface model with elevation contours. Both results were derived from ground-based imagery.

Geophysics

Chámeza

ERT produced eight-lines of tomographic data, each of which show the apparent electrical resistivity along a transect of the area of interest in 2D. Between lines one and two, there is a negative anomaly visible as an area of blue color within the black circle in Figure 6. The rest of the tomography lines did not produce resistivity profiles of any interest.

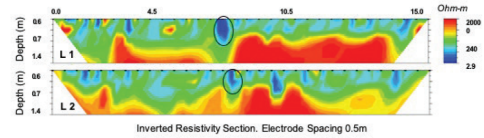

Figure 6. Tomographic data from ERT Lines one and two, which show a negative (blue) anomaly of interest, indicated by a black circle on both transects. The anomaly was attributed to rock fragments found at the corresponding location.

Recetor

The ERT line identified a significant positive anomaly at this location. As a result, a grave 0.60 m x 0.50 m x 1.40 m was detected. Instead of the remains of victims of forced disappearance, however, this grave contained animal bones, as shown in Figure 7. Furthermore, subsequent data processing identified two small additional anomalies (not shown), which could be interesting to verify during the next field season.

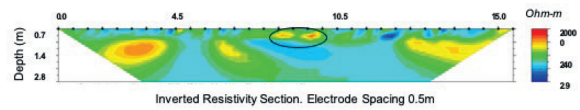

Figure 7. Tomography data from ERT Line. The black circle highlights the positive anomaly related to animal bones found.

Discussion and Perspectives

This work demonstrates that photogrammetry, in addition to enhancing the situational awareness of field teams in remote environments, is a powerful and effective tool in facilitating the search for and documentation of gravesites in the context of human rights.

Where the terrain is sufficiently clear of obstacles to allow for automated flight operations, UAS-based photogrammetry can be a valuable tool for providing a broad overview of a site at a resolution significantly higher than the best available satellite imagery. Under dense tree cover, ground-based imagery can also be used for this purpose. However, this method can be time-consuming in both the set-up phase (alignment markers are essential to the technique's success and must be carefully placed beforehand, and low-lying vegetation must be cleared to allow for walking), and the processing phase (the resulting images must be manually aligned and calibrated). Due to the amount of effort necessary to create good results using ground-based photogrammetry in jungle terrain, it therefore cannot be recommended as a tool for surveying a large area. In all cases, confidence in the results of photogrammetric surveys would be significantly enhanced through the use of ground control points to constrain the resulting model. These results would be further improved by using a real-time kinematic (RTK) GPS receiver to calibrate a total station, rather than the handheld units available for this work.

The multidisciplinary approach of integrating geophysics techniques such as ERT alongside photogrammetry using remote sensors is a very important and useful tool for investigators. The possibility of visualizing and locating depressions or subsidence in the area of interest can be consistent with the anomalies identified via ERT; thus, both results together could enable a robust detection of probable locations for a mass grave.

Electrical Resistivity Tomography (ERT) is a recommended geophysical method for searching for clandestine graves in forested or otherwise difficult-to-access areas, which are the features of many places in Colombia. In Chameza and Recetor it was possible to detect anomalies associated with objects buried under the soil such as rock fragments and animals remain; therefore, the findings demonstrate that ERT is a valuable technique when searching for clandestine graves in these particular conditions. Furthermore, its handling will permit access to other wooded zones revealed by MESP and proposed by testimonies from victim's families.

The MESP model is likewise important, as it enables a significant reduction in the search area, and correspondingly, the time spent searching for gravesites. Because of this, such desk-based work is highly important before going out into the field.

Currently, American Association for the Advancement of Science AAAS is exploring a number of applications of this technique that have the potential to increase its value to human rights advocates in the future. One such application involves correlating the orthomosaics generated from modern photogrammetric surveys with declassified US government satellite imagery acquired around the time that many of these graves were suspected to have been dug. Preliminary work suggests it may improve the interpretability of contemporary data by providing relevant historical context. Another application involves using photogrammetry, not just to document remains as they are exhumed in the field, but in the laboratory as well. When the model resulting from these experiments was shared with a professional medical examiner, he indicated that the level of detail was sufficient to come to a forensic conclusion about the remains. In the future, this technique could be an important way of preserving the record of trauma associated with the remains, even after they have been returned to families for re-interment. Such models might even be 3-D printed, so that an accurate physical representation of the remains can be presented in court cases where the remains themselves are no longer accessible.

The potential use of this evidence in court raises another important issue associated with this technique. As an emerging technology that continues to evolve, developing consistent, workable standards and best practices for collecting and analyzing photogrammetric evidence in a legal context will be essential if its use in human rights investigations is to expand beyond the current proof-of-concept as shown in Figure 8a and Figure 8b. To do this, conversations will need to take place among geospatial technologists, forensic scientists, human rights practitioners, lawyers, and members of the judiciary regarding the potential legal implications of the methods used to create these models. Training will necessarily be an important component of these conversations. Through these and similar efforts, the continued exploration of this and other emerging technologies will continue to improve the landscape of human rights practice, and form a core component of the Scientific Responsibility, Human Rights, and Law Program promoted by the American Association of the Advancement of Science. Additionally, fostering and facilitating the responsible practice and applications of science is contributing to the program of the truth, justice, and reparation of victims in the context of the peace agreements in Colombia.

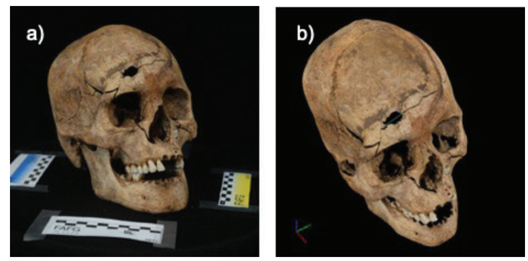

Figure 8. Proof-of-concept for the use of photogrammetry for forensic documentation of human remains in a laboratory context. a) Photograph of a human skull with a traumatic injury; one of a series taken from a stationary camera while the skull rotates on a turntable. b) View of the 3-D model resulting from photogrammetry, enabling measurements of the bullet wound (in this case, 0.017 m), even after the remains are reinterred.

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Authors

Jonathan Drake, American Association for the Advancement of Science, 1200 New York Ave NW, Washington, DC. jdrake@aaas.org.

Carlos Martín Molina, Instituto Nacional de Medicina Legal y Ciencias Forenses, Bogotá, Colombia and Universidad Antonio Nariño, Facultad de Ingeniería Ambiental y Civil, Bogotá, Colombia. martin.molina@uan.edu.co.

Edier Fernando Avila, Universidad de Cundinamarca, Facultad de Ciencias Agropecuarias, Colombia. efernando-avila@ucundinamarca.edu.co.

Alejandra Baena, Universidad Antonio Nariño, Facultad de Ciencias, Bogotá, Colombia. alejandra.baena@uan.edu.co.