



TECHNICAL NOTE

Anthropology

ICPUTRD: Image Cloud Platform for use in tagging and research on decomposition

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Abstract

Human decomposition studies aim to understand the various factors influencing human decay to assess the deceased and develop postmortem interval (PMI) estimation methods. These types of studies are typically conducted through physical experiments examining the deceased; however, big data systems have the potential to transform how large-scale forensic anthropology research questions can be addressed with curated images of donors with known demographic, climatic, and postmortem historical data. This study introduces ICPUTRD (Image Cloud Platform for Use in Tagging and Research on Decomposition), a web-based software system, which enables forensic scientists to easily access, enhance (or curate), and analyze very large photographic collections documenting the longitudinal process of human decomposition. ICPUTRD, a JavaScript-based application, was designed and built through a combination of the Waterfall and Agile software development life-cycle methods and provides an image search and tagging features with a predefined nomenclature of forensic-related keywords. To evaluate the system, a user study was conducted, involving 27 participants who completed pre- and post-study surveys and three research tasks. Analysis of the study results confirmed the feasibility and practicality of ICPUTRD to facilitate aspects of forensic research and casework involving large collections of digital photographs of human decomposition. It was observed that the nomenclature lacked certain law enforcement keywords, so future work will focus on expanding it to ensure ICPUTRD is suited for all its intended users.

KEYWORDS

big data systems, cloud platform, forensic anthropology, forensic science, human decomposition, image curation, software systems

Highlights

- ICPUTRD enables the visualization and analysis of images documenting human decomposition.
- It allows subject-specific and forensic content-based image searches.
- It can be used for forensic-related image tagging to further enhance the data.
- A user study confirmed the feasibility of ICPUTRD for its intended users and use cases.

Anna-Maria Nau and Sara Mousavi contributed to this work equally.

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1 | INTRODUCTION

Human decomposition studies aim to identify both the individual and environmental factors affecting human decay to be able to assess unique features of the deceased as well as develop methods for postmortem interval estimation (PMI), an important aspect of forensic investigation [1, 2]. The Forensic Anthropology Center (FAC) at the University of Tennessee, Knoxville (UTK), houses the Anthropology Research Facility (ARF), popularly known as the “Body Farm,” which is the first outdoor decomposition laboratory. Individuals can choose to register for self-donation of their bodies during their lifetime, while legal next of kin can also choose to donate the bodies of their loved ones through the FAC Body Donation Program. Each year, approximately 100 donors are placed at the ARF to facilitate investigations of human decay. Since 2011, photographs of these donors have been taken daily from the moment they are placed at the facility until advanced decay and skeletonization occur, whereby photographs were taken weekly or monthly. Until recently, this large photographic collection was stored in individual file folders, making analytical tasks difficult and tedious. However, if this valuable image data were more accessible, it has the potential to transform fieldwork-intensive research. For instance, unlike physical donors, images can be re-examined at any given time and from various perspectives depending on the research study and at a potentially lower cost when compared to physical experiments. In addition, such a large photographic collection offers the opportunity to extrapolate from larger and statistically relevant samples, thereby supporting rigorous quantification of critical forensic estimates, such as the PMI—a significant challenge in forensic investigation [3, 4].

Making large image collections in the forensic decomposition domain suitable for research and casework has received little attention. This study aims to introduce the Image Cloud Platform for Use in Tagging and Research on Decomposition, abbreviated as ICPUTRD, a big data, collaborative, cloud-based image platform developed to address this limitation and thereby facilitate research on human decomposition. The main objective of this platform is to enable the analysis into how both intrinsic factors (e.g., age, biological sex, body composition, etc.) and extrinsic factors (e.g., temperature and moisture, animal scavenging, clothing, etc.) impact the decomposition process in a consistent and replicable manner. Specifically, ICPUTRD was designed for two key purposes: (1) to enable image searches using both pre-existing and newly generated metadata, including demographic information (i.e., age, sex, body weight, etc.), temperature and humidity data, and forensic-related keywords (i.e., anatomical, stages of decomposition, presence of scavenging, etc.), and (2) to enhance existing images through an image tagging feature that simultaneously enriches the metadata associated with the images. Notably, the platform's tagging feature allows individual images to be labeled (or tagged) with relevant decomposition information using a pre-defined set of forensic-related keywords, thereby generating new image metadata. ICPUTRD was developed using a combination of

JavaScript-based technologies and includes a user-friendly interface. The source code and documentation can be found at <https://bitbucket.org/icputrd/platform>.

To the best of our knowledge, this is the first tool that met all system requirements. Specifically, the tool should be capable of addressing the following three key tasks: (1) supporting large-scale data visualization, storage, and analysis; (2) facilitating data curation (i.e., organizing, enhancing, and preserving data); and (3) offering extensibility (i.e., allowing for new functionalities or modifications of existing ones). Additionally, none of the available tools were designed and evaluated with the intention of being used for human decay-related use cases. Consequently, they may be limited in their applicability, potentially requiring additional technical setups and further development.

2 | MATERIALS AND METHODS

ICPUTRD was designed and built through a collaboration of two software development life cycles (SDLC), Waterfall and Agile methods, as shown in Figure 1. Specifically, the Waterfall methodology was used to make a high-level design plan, which involved the following four sequential phases: (1) requirement gathering, (2) design, (3) implementation, and (4) system evaluation. Unlike Waterfall, which follows a linear process (i.e., a phase cannot commence until the previous phase has been completed, nor can it be revisited once completed), the Agile method is a more iterative approach that does not demand one phase to conclude before the next one begins, but allows for multiple phases to be worked on simultaneously and permits revisiting phases later in the development life cycle to respond to changing user requirements [5–7]. Details on the requirement gathering, design, implementation, and system evaluation phases are provided in the following sections.

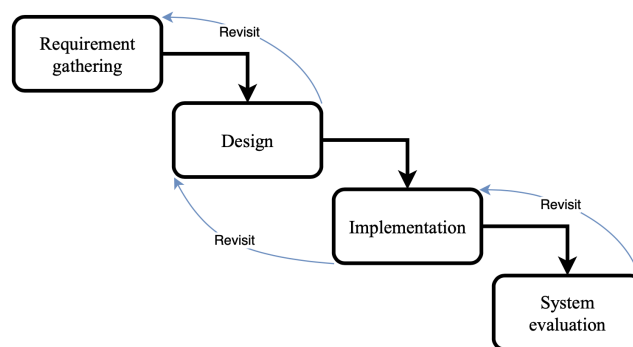


FIGURE 1 An overview of the Waterfall-Agile software development life cycles approach used for the development of Image Cloud Platform for Use in Tagging and Research on Decomposition. In the figure, the black boxes and arrows represent the linear phases of the Waterfall method, while the blue arrows illustrate the integration of the Agile method to enable the revisiting of phases as needed and to allow multiple phases to be worked on simultaneously, making it easier to respond to changing product requirements.

2.1 | Requirement gathering

The requirements of ICPUTRD were defined based on its use cases, including the ability to search for and analyze (1) images of a specific donor and date and (2) images containing specific forensic-related features (i.e., anatomical, stages of decomposition, presence of scavenging, etc.). In order for ICPUTRD to be a system that can facilitate such use cases, it must meet the following two main requirements: (1) an image search feature, providing the capability to search for and browse images using different search filters, and (2) an image tagging feature, allowing users to further enrich the data by annotating images with forensic-relevant information. The first requirement concerns effective searching essential to find relevant photos among over one million images. Specifically, the system's search feature should provide the ability to find images based on the subjects, demographic information, and temperature and humidity data associated with the time of decomposition, and the content of the images themselves (e.g., images of heads or images containing flies, mummified tissue, etc.). Since the metadata associated with the human decomposition images only includes the donor ID and the time a particular image was taken, the image data needs to be enhanced for a user to be able to make content-based image searches, which is part of the first requirement. The second system requirement aims to address this limitation through a process called tagging, which is where a particular area of an image is "tagged" or "labeled" with a keyword. More specifically, the system should provide users with a suitable interface that facilitates this enrichment or tagging process via a nomenclature. This nomenclature of keywords should be carefully defined by domain experts to ensure that the metadata created during tagging is both useful and relevant for forensic research and casework, especially in cases where PMI is part of the analysis. In addition, a solid and predefined set of keywords ensures consistency across different users and prevents misspellings during tagging. Finally, the created image tags should be stored reliably and available for viewing, editing, and deletion when needed.

2.2 | Design and implementation

Once the requirements were gathered, a high-level design plan including the system architecture (i.e., the main system components and their relationships) and technology stack (i.e., programming languages, frameworks, data storage, front-end and back-end tools, etc.) was created with respect to the system's two requirements: (1) image search feature and (2) image tagging feature for data enhancement. To be able to search for images, the information must be available; users should be provided with an interface that allows image searches by the nomenclature, and the interface should be able to communicate with the stored data, extract the necessary data, and present it to the users. As a result, ICPUTRD's search feature consists of three main components: (1) the client-side: a user interface that enables user-friendly image searching;

(2) the database system: a program that facilitates data storage, retrieval, and modification at any time; and (3) the server-side: also called the back-end, which handles all incoming requests from the client-side and provides the logic for the communication between the client-side and the database. These components were implemented using the MEAN stack [8], a JavaScript-based framework for web application development, which is named after and powered by MongoDB [9] as the database server, ExpressJS [10] as the server-side JavaScript framework, AngularJS [11] as the client-side JavaScript framework, and NodeJS [12] as the server-side JavaScript runtime.

The user interface resides on the client-side within a web browser and was implemented using AngularJS. It can be accessed across the web by permitted users to search for images. ICPUTRD uses MongoDB, an open-source, cross-platform database, as its storage system. It stores data in key-value pairs, using the widely used JSON format. Specifically, MongoDB was used to store all human decomposition image paths along with its metadata, and all users who have access to ICPUTRD along with their user activity. ICPUTRD's server-side, which oversees all logical operations and computations in response to user interactions, was implemented using NodeJS and Express.js, two back-end JavaScript web application frameworks. The architecture diagram shown in Figure 2 provides an overview of how these different software components interact. When users interact with the web browser user interface, their request is initially processed by AngularJS on the client-side. Subsequently, it is routed to the server-side, where NodeJS manages it before forwarding it to Express.js. Express.js then communicates with the MongoDB database to retrieve the requested data. MongoDB fetches the data and sends it back to Express.js, which, in turn, forwards it to NodeJS and then to AngularJS where it is then displayed to the user through the web browser.

ICPUTRD's tagging feature was also implemented using the MEAN stack, but in addition, the Annotorious library [13], a JavaScript image annotation library, was used. Like the platform's search feature, the tagging feature involves the client-side, server-side, and database. Specifically, the tagging interface (i.e., the client-side) displays an image to the user in full size through the web user interface. When the interface loads, the server-side accesses the MongoDB database to look for any existing tags associated with the displayed image to show to the user. The user can then view and modify any existing tags as well as create new tags for the displayed image. As mentioned before, the tags created come from a predefined nomenclature of keywords, which was developed by forensic experts from the ARF ensuring the keywords were relevant for various types of end users and research studies. Specifically, the development of the nomenclature involved an iterative process of forensic experts tagging a set of images with forensic information, including anatomical (e.g., head, torso, leg, etc.), decomposition (e.g., bloat, fresh, mummification, etc.), insect activity (e.g., fly, insect, maggot, etc.), and scavenging information. This was followed by the computer and data scientists extracting the tags, sorting by

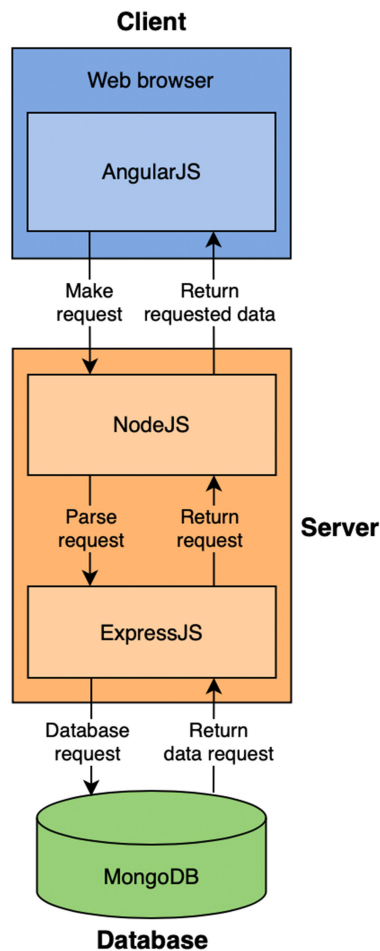


FIGURE 2 An architecture diagram illustrating the construction and interplay of the various components of the Image Cloud Platform for Use in Tagging and Research on Decomposition web application. When a user interacts with the web browser user interface on the client-side, a request is generated. This request is first processed by AngularJS before being sent to the server-side, where it is managed by NodeJS. Subsequently, it is directed to Express.js, which communicates with the MongoDB database to retrieve the requested data. MongoDB retrieves the data and sends it back to Express.js, which forwards it to NodeJS, and in turn, to AngularJS, which finally displays the data to the user through the web browser.

frequency (in descending order), and detecting and normalizing synonyms (e.g., “mummification” was chosen instead of “mummified,” or “mummified skin”). The final nomenclature of keywords was then implemented into ICPUTRD to accommodate its tagging and search features.

2.3 | System evaluation

To ensure that the implementation of ICPUTRD satisfies all the defined requirements and to investigate whether the target audience of forensic scientists finds the system acceptable for conducting

TABLE 1 Example keywords from the final nomenclature of forensic-related keywords.

Category	Keyword examples
Anatomic	head, torso, backside, leg, foot, hand, eye
Decay-related	fresh, bloat, early decomposition, advanced decomposition, skeletonization, mummification, purge
Other	fly, maggot, insect, scavenging, beetles, larvae

several research tasks, an IRB-approved user study was designed and executed. The user study involved four main steps: (1) study design, (2) recruitment of participants, (3) execution of the study, and (4) analysis of the results.

An empirical evaluation method, following Nielsen [14], was applied to assess three system usability measures: (1) effectiveness (i.e., a user's ability to complete the tasks), (2) efficiency (i.e., the number of resources used to complete the user study tasks), and (3) satisfaction (i.e., a user's experience with interacting with the system) [15, 16]. More specifically, potential users were exposed to the system by completing three research tasks designed with the goal of evaluating ICPUTRD's search and tagging features. The first task attempted to gauge the effectiveness of the current implementation with a simple task of finding images by specific tags. The purpose of the second task was to evaluate the range of keywords potential users may be interested in. The aim of the third task was to evaluate ICPUTRD's tagging feature. It is important to note that prior to the user study, at least one tag for each keyword from the predefined nomenclature was created by forensic experts to ensure the image search tasks could be performed successfully. The exact user study task instructions were as follows:

1. “Search for images using keywords (up to five) from the predefined nomenclature.” The purpose of this task was to evaluate ICPUTRD's search feature and user-friendliness.
2. “Using up to five keywords of your choice (different from the five from task 1), search for images that you might want to use for your research or work, or both.” The purpose of this task was to see whether any keywords were missing from the current predefined nomenclature and to determine what keywords were most frequently used by the participants.
3. “Given the provided image, create five tags.” For this task, all participants were shown the same image. The purpose of this task was to evaluate the usability of ICPUTRD's tagging feature.

In addition to the above-described tasks, the user study involved a pre-study survey to get a general idea about the background of the users on certain concepts, and a post-study survey to learn about the users' experience from interacting with the system and performing the tasks. The pre-study survey collected information on a participant's level of familiarity with the following four concepts: multimedia curation, image database (db), forensic work, and human

Donors

Search by ID:

Sort by:

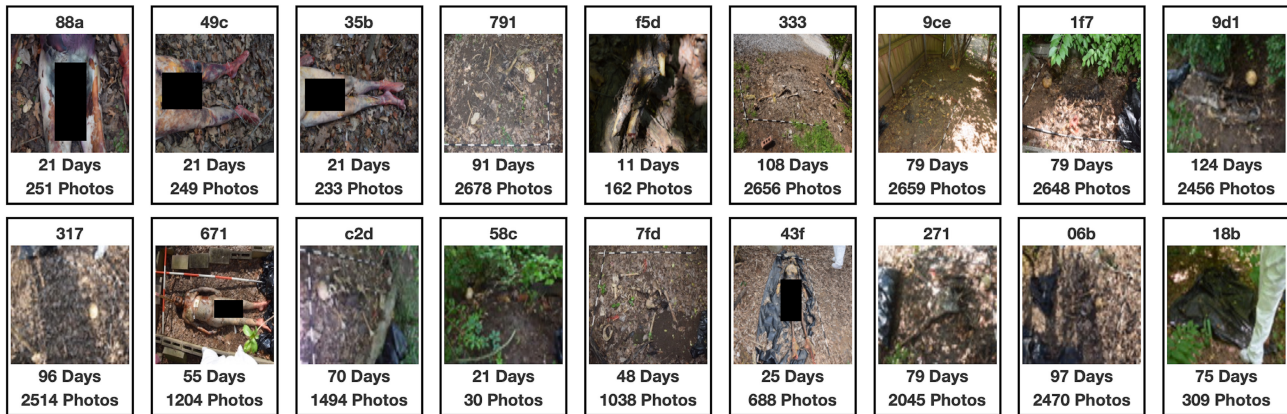


FIGURE 3 The Image Cloud Platform for Use in Tagging and Research on Decomposition user interface showing the search-by-subject feature. Each thumbnail represents one donor along with the anonymized donor ID (e.g., donor 88a: first thumbnail in the first row), the total number of days photos have been taken for that donor, and the total number of images of that donor. Images of specific donors can be searched for using the “Search by ID” search bar. The “Sort by” dropdown menu can be used to sort the donors either by (1) the total number of days or (2) the total number of photos.

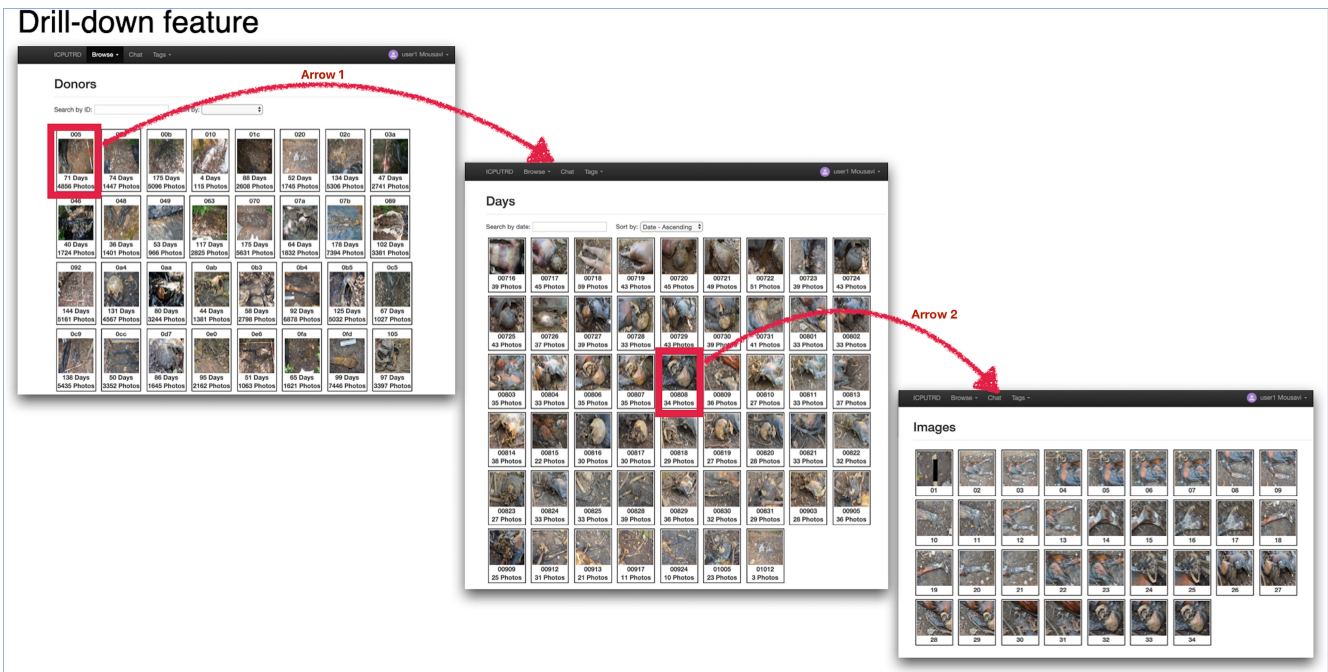


FIGURE 4 The Image Cloud Platform for Use in Tagging and Research on Decomposition user interface showing the search-by-subject drill-down feature, which allows users to browse images of a specific donor. For example, when the user clicks the donor thumbnail with donor ID 005 (left red box), the user is presented with the “Days” view (follow “Arrow 1”) where each thumbnail represents a specific day along with the date (e.g., date 00808 enclosed by the right red box, which follows the pattern of [x][mmdd], where x is the number of years in the ARF, mm the month, and dd the day) and the total number of photographs taken on that date. From here, a user can search for a specific day by using the “Search by date” search bar or use the “Sort by” dropdown menu to sort the day thumbnails by (1) the date in ascending order, (2) the date in descending order, or (3) the total number of photos in descending order. In addition, a user can click on a specific day, such as date 00808 (right red box) to be presented with the “Images” view (follow “Arrow 2”), which displays all photographs for that day. From this point, a user can click on an image and be presented with a larger version, which can directly be tagged as demonstrated by Figure 6.

Tag Search

Text Search

Enter comma separated Tags, like- tag1,tag2,...

Select search type (AND will only show images with all searched tags present, OR will show images with one or more searched tags present):

AND OR

Search

Clear

Checkbox Search

- | | | | |
|-------------------------------------|--|--|------------------------------------|
| <input type="checkbox"/> fluid | <input type="checkbox"/> purge | <input type="checkbox"/> mummification | <input type="checkbox"/> adult fly |
| <input type="checkbox"/> eggs | <input type="checkbox"/> larvae | <input type="checkbox"/> discoloration | <input type="checkbox"/> adipocere |
| <input type="checkbox"/> scavenging | <input type="checkbox"/> skin slippage | <input type="checkbox"/> lividity | <input type="checkbox"/> bloat |
| <input type="checkbox"/> marbling | <input type="checkbox"/> tattoo | <input type="checkbox"/> mold | <input type="checkbox"/> insect |
| <input type="checkbox"/> leg | <input type="checkbox"/> arm | <input type="checkbox"/> bone | <input type="checkbox"/> head |
| <input type="checkbox"/> skin | <input type="checkbox"/> foot | <input type="checkbox"/> eye | <input type="checkbox"/> nose |
| <input type="checkbox"/> hand | <input type="checkbox"/> mouth | <input type="checkbox"/> genitals | <input type="checkbox"/> hair |
| <input type="checkbox"/> ear | | | |

Checkbox Search

Total has "0" images

FIGURE 5 The Image Cloud Platform for Use in Tagging and Research on Decomposition user interface showing the search-by-image-content feature. Here, a user can search for previously tagged images by either using the “Text Search” or “Checkbox Search” option. The “Text Search” allows a user to enter multiple tags separated by a comma without any space (e.g., tag1,tag2,tag3), and select the option between “AND” (i.e., “logical AND” operator) and “OR” (i.e., “logical OR” operator), while the “Checkbox Search” allows a user to select tags from the list of pre-existing tags and select the option between “AND” (i.e., “logical AND” operator) and “OR” (i.e., “logical OR” operator). Once one of the search buttons is hit, all images that were previously tagged with the chosen tags are presented to the user.

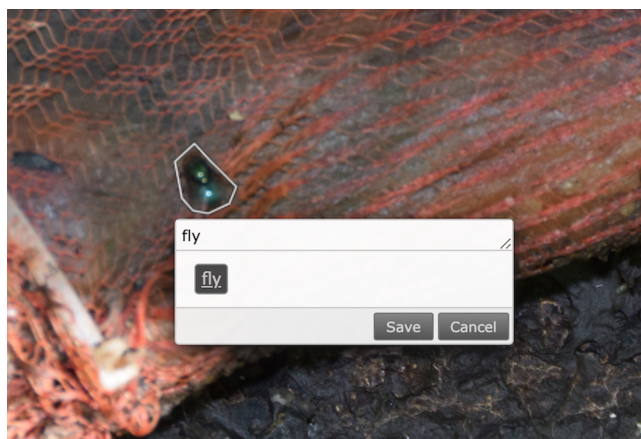


FIGURE 6 Demonstration of Image Cloud Platform for Use in Tagging and Research on Decomposition's tagging feature. Here, a user drew a polygon around the area that was then presented with a text box where he/she entered “fly”, selected the tag, and hit the “Save” button to create the tag. The “Cancel” button can be used to delete the current polygon and restart. Note: If the keyword that was entered into the text box does not exist in the predefined nomenclature, no tag can be created for that keyword.

decomposition. Specifically, each concept was given a score ranging from 1 (not familiar) to 5 (very familiar), which were then added to obtain a participant's final familiarity score. The post-study survey

collected information on (1) whether a participant was able to complete each task, and (2) the difficulty they associated with each task ranging from 1 (very difficult) to 5 (very easy), which were again added to obtain each participant's total difficulty score.

The participants of the study were recruited from the target population of ICPURD users, including forensic anthropology researchers, professors and students, and law enforcement officers. Each participant was given 30 min to complete the user study and surveys (pre- and post-study). This 30-min timeframe was based on how long, approximately, it should take each participant to complete the user study tasks and surveys.

3 | RESULTS AND DISCUSSION

3.1 | Requirement gathering, design, and implementation

Over a period of approximately 1 month, the image search feature and image tagging feature were defined based on iterative discussions (virtual and face-to-face) with domain experts from computer and data science and forensic anthropology.

The design and implementation of the system took approximately 6 months. This involved the developers writing all the code of the system, testing individual components for usability, and

installing the system for its intended use. The forensic experts from the ARF provided the human decomposition image data along with its metadata. The images included overall images of donors, close-ups (e.g., head, torso, arm, legs, etc.), and forensic items of interest (e.g., animal scavenging), and the metadata included donor ID and date, demographic information, and temperature and humidity data associated with each image. The amount of storage needed to store the compressed images was approximately 4TB. Storing images that were planned to be both edited and augmented would increase the storage needs approximately eightfold, requiring at least 32 TB of storage, resulting in very slow and inefficient image search and retrieval. Therefore, instead of storing all the images in the MongoDB database, they were stored directly on the file system and only their file paths were stored inside the database. Using a combination of MongoDB and the file system for image storage, drastically accelerated the data search and retrieval process. The carefully developed nomenclature of keywords consisted of 132 terms (see Appendix S1). Table 1 shows example keywords of the final developed nomenclature. Note, the nomenclature is frequently updated through continuous user feedback loops.

The current version of ICPUTRD's search feature can perform the following two types of searches:

1. Search-by-subject, as shown in Figure 3, allows users to search for all images associated with a particular subject or donor at a given time. A subject's anonymized user ID (i.e., three-digit hex number) is used here as well as the system's drill-down feature (Figure 4) to find images for a specific date.
2. Search-by-image content, as shown in Figure 5, allows users to search for images containing specific forensic-related keywords (e.g., hand, mummified, discolored skin, mold, maggots, liquid purge, etc.). More specifically, given a keyword, this search type retrieves all images previously tagged with that keyword using ICPUTRD's tagging feature.

Note, since the image metadata also included demographic and temperature and humidity data, future work will focus on incorporating this data into ICPUTRD's search feature. For now, this data is securely stored in the MongoDB database.

The ICPUTRD tagging feature is shown in Figure 6 where a "fly" tag was created. More specifically, the tagging feature works as follows: each click creates a vertex that will be connected to the

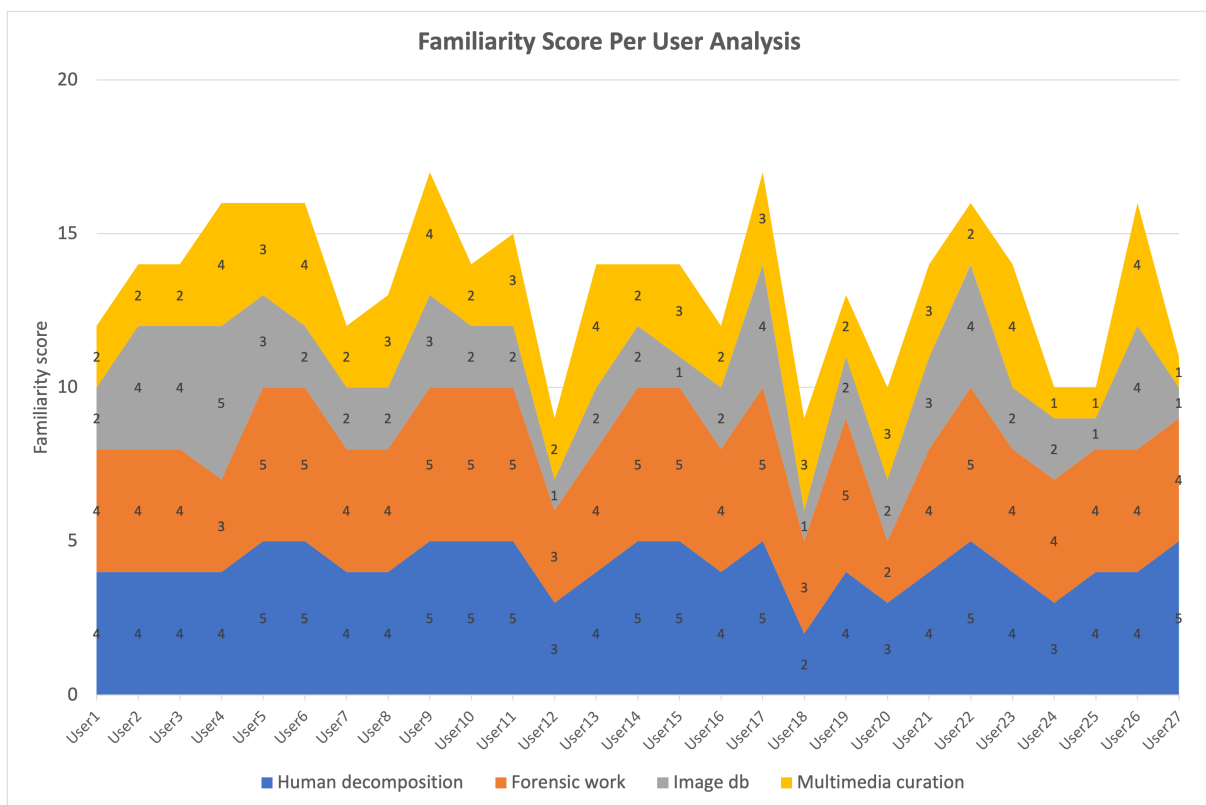


FIGURE 7 The pre-study survey results summarized as a stacked area graph. Specifically, the graph shows each participant's (x-axis; User1=participant 1, User2=participant 2, etc.) total familiarity score (y-axis), ranging from 1 (not familiar) to 20 (very familiar). The integers within each colored region indicate a user's familiarity score for the different concepts. For example, "User1" has the familiarity scores 4, 4, 2, and 2 for the concepts human decomposition, forensic work, image db, and multimedia curation, respectively, resulting in a total familiarity score of 12. It can be seen that the lowest familiarity score was 9 and the highest was 17, with most of the users being more familiar with human decomposition and forensic work, and less with multimedia curation and image databases.

next one until the user reaches the starting point and the polygon is closed. Once the polygon is completely drawn, a pop-up text box appears so that the user can type the desired keyword for the selected area. After typing the first three letters, all keywords from the predefined nomenclature that start with those letters are displayed to the user who then can either select the desired keyword, click the "Save" button to create the tag or click the "Cancel" button to discard the entire selection and start over. When a tag is created, the tag along with the polygon's coordinates, the user's ID, the date, and the file path of the image are stored in MongoDB for later retrieval using the search-by-image-content feature. The first version of the tagging feature only allowed rectangles to be drawn, but user feedback suggested that polygons would allow a more accurate tagging, and so changes were made accordingly.

3.2 | System evaluation via a user study

A total of 27 participants were recruited for the user study, including one forensic anthropology researcher (MA degree), one professor from the Forensic Anthropology Department at UTK (PhD degree), one master and seven Ph.D. students from the Anthropology

Department at UTK, 11 osteology students from the ARF, and six law enforcement officers.

The pre-study survey results are shown in Figure 7, which is a stacked area graph showing each participant's familiarity score, ranging from 1 (not familiar) to 5 (very familiar), and total familiarity score, ranging from 1 (not familiar) to 20 (very familiar). The lowest total familiarity score was 9 and the highest was 17, with most of the participants being more familiar with human decomposition and forensic work, and less with multimedia curation and image databases. Given that the educational backgrounds of the participants were mostly forensic- and law-related, this was expected.

The task difficulty scores recorded during the post-study survey are shown by the stacked area graph in Figure 8, ranging from 1 (very difficult) to 5 (very easy), and total difficulty score, ranging from 1 (very difficult) to 15 (very easy). The lowest total difficulty score was 5 and the highest total difficulty score was 15, with most of the participants rating Tasks 1 and 2 as the easiest. Additionally, according to the post-study results, 27 (100%), 26 (93.2%), and 24 (88.9%) participants successfully completed Tasks 1, 2, and 3, respectively, given the 30-min time limit.

Since Task 2 was not successfully completed by all participants, its results were further analyzed. Task 2 had two possible

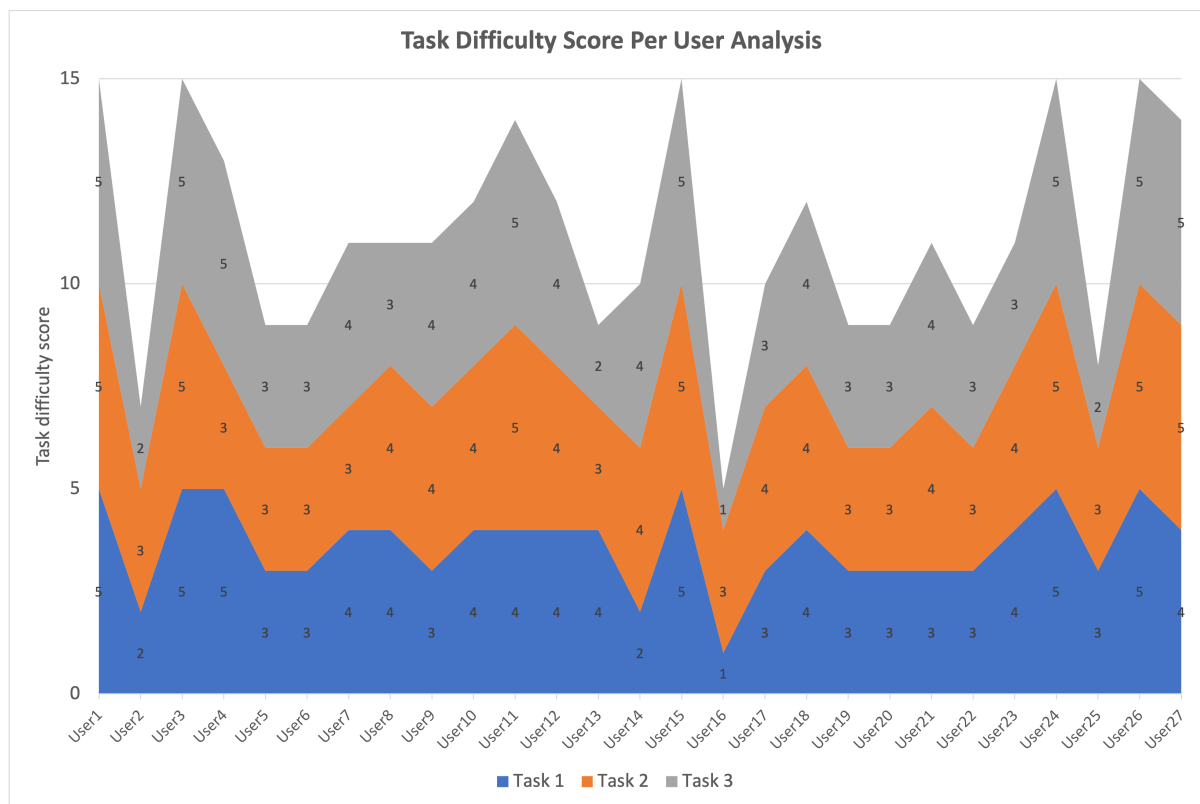


FIGURE 8 The post-study survey results summarized as a stacked area graph. Specifically, the graph shows each participant's (x-axis; User1=participant 1, User2=participant 2, etc.) total difficulty score (y-axis), ranging from 1 (very difficult) to 15 (very easy). The integers within each colored region indicate a user's difficulty score for the different tasks. For example, "User1" has the task difficulty scores 5, 5, and 5 for the tasks 1–3, respectively, resulting in a total difficulty score of 15. It can be seen that the lowest total difficulty score was 5 and the highest total difficulty score was 15, with most of the participants rating Tasks 1 and 2 as the easiest.

outcomes: (1) the participant was able to find at least one image for each of the five keywords of their choice, or (2) the participant was not able to find at least one image for each of the five keywords of their choice. Outcome (1) was recorded as success, while outcome (2) was recorded as failure and further analyzed, specifically the keyword(s) for which no images were found, meaning they were not included in the nomenclature of keywords. Through further analysis, keywords, such as “gunshot wounds,” “knife wounds,” “rigor mortis,” “blister,” “soldier fly,” “pupae,” and “foam,” were discovered to not be in the existing nomenclature. It is important to note that majority of these keywords came from the law enforcement participants who did not participate in the development of the nomenclature. These findings were used in future work to further improve the nomenclature to ensure ICPUTRD meets the needs of all target users.

Since the post-study survey showed that only 24 out of the total 27 participants were able to successfully complete Task 3, the results of the three unsuccessful participants were further analyzed. Based on this analysis, it was concluded that one of the following may be the reason for unsuccessful completion of Task 3: (1) a participant's low level of familiarity with the concepts addressed in the pre-study survey (i.e., multimedia curation, image databases, forensic work, and/or human decomposition), (2) ICPUTRD is not sufficiently user-friendly, and/or (3) the 30-min timeframe was not long enough. Such findings will be considered in future work to further improve the usability of ICPUTRD's tagging feature.

Furthermore, user study feedback suggested that manually performing certain administrative tasks, such as detecting privacy violations (e.g., images of stakes showing the donor ID), and removing irrelevant content (e.g., images of plastic bags covering the body), as well as domain tasks, such as body part and forensic feature identification, are limited from both a time and resource-perspective and suggest the need for process automation. The field of artificial intelligence (AI) provides a variety of automation technologies that can be used to analyze the human decomposition images, learn from them, and then perform certain manual tasks. Therefore, future work will focus on integrating AI technologies into ICPUTRD for automated data curation to reduce costs and increase efficiency.

In summary, the usability of ICPUTRD was found to be adequate for the tasks performed in the user study, and the keyword nomenclature was found to be sufficiently comprehensive to cover most basic scenarios. However, it was identified that the existing nomenclature lacked certain keywords, particularly terms related to law enforcement. To address this gap, further investigation will be conducted to determine the necessity of adding these missing keywords to the current nomenclature, ensuring its suitability for all intended users. Additionally, due to the time-consuming and costly nature of manual data curation, AI integration will be explored to automate the process. It is worth noting that ICPUTRD is currently being deployed at the FAC and the Department of Anthropology at UTK, to contribute to both ongoing and new research efforts.

4 | CONCLUSION

Historically, forensic research and casework have predominantly relied on physical experiments. The reported work aims to enhance the accessibility of forensic information through ICPUTRD, an image cloud-based platform that utilizes an extensive collection of digital photographs documenting the longitudinal process of human decomposition. The current implementation offers a search engine (specifically, search-by-subject and search-by-image-content functionalities) and a forensic-related image tagging tool, which enable easy data access, visualization, and enhancement. To assess ICPUTRD's efficacy within the intended user community and purposes, a user study was conducted, which found it to be adequate for the study tasks and the keyword nomenclature to be sufficiently comprehensive for covering most basic use cases. However, since it was identified that the existing nomenclature lacked certain keywords, future work will focus on expanding the current nomenclature to ensure ICPUTRD is well-suited for all its intended users.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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REFERENCES

- Wescott DJ. Recent advances in forensic anthropology: decomposition research. *Forensic Sci Res.* 2018;3(4):327–42. <https://doi.org/10.1080/20961790.2018.1488571>
- Ciaffi R, Feola A, Perfetti E, Manciocchi S, Potenza S, Marella GL. Overview on the estimation of post mortem interval in forensic anthropology: review of the literature and practical experience. *Rom J Leg Med.* 2018;26(4):403–11. <https://doi.org/10.4323/rjlm.2018.403>
- Megyési MS, Nawrocki SP, Haskell NH. Using accumulated degree-days to estimate the postmortem interval from decomposed human remains. *J Forensic Sci.* 2005;50(3):618–26. <https://doi.org/10.1520/JFS2004017>
- Marhoff SJ, Fahey P, Forbes SL, Green H. Estimating post-mortem interval using accumulated degree-days and a degree of decomposition index in Australia: a validation study. *Aust J Forensic Sci.* 2016;48(1):24–36. <https://doi.org/10.1080/00450618.2015.1021378>
- Huo M, Verner J, Zhu L, Babar MA. Software quality and agile methods. In: *Proceedings of the 28th Annual International Computer Software and Applications Conference*; 2004 Sept 28–30; Hong Kong, China. Piscataway, NJ: IEEE; 2004. p. 520–5.
- Balaji S, Murugaiyan MS. Waterfall vs. V-Model vs. Agile: a comparative study on SDLC. *Int J Inf Technol Bus Manag.* 2012;2(1):26–30.
- Cockburn A. *Agile software development: the cooperative game.* 2nd ed. London: Pearson Education; 2006. p. 244–60.

8. MEAN.JS. [cited 2022 June 20]. Available from: <http://meanjs.org>
9. MongoDB. [cited 2022 June 20]. Available from: <https://www.mongodb.com/>
10. Express. [cited 2022 June 20]. Available from: <https://expressjs.com/>
11. Angular. [cited 2022 June 20]. Available from: <https://angular.io>
12. Node.JS. [cited 2022 June 20]. Available from: <https://nodejs.org/en/>
13. ANNOTORIOUS. [cited 2022 July 20]. Available from: <https://recogito.github.io/annotorious/>
14. Nielsen J, Mack RL, editors. Usability inspection methods. New York, NY: John Wiley & Sons; 1994. p. 413–4.
15. Bevan N, Macleod M. Usability measurement in context. *Behav Inf Technol.* 1994;13(1–2):132–45. <https://doi.org/10.1080/01449299408914592>
16. Brooke J. Sus: a 'quick and dirty' usability scale. In: Jordan PW, Thomas B, McClelland IL, Weerdmeester B, editors. Usability evaluation in industry. London: Taylor & Francis; 1996. p. 107–15.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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