The ART of CSI: An Augmented Reality Tool (ART) to Annotate Crime Scenes in Forensic Investigation

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Abstract. Forensic professionals have to collect evidence at crime scenes quickly and without contamination. A handheld Augmented Reality (AR) annotation tool allows these users to virtually tag evidence traces at crime scenes and to review, share and export evidence lists. In an user walkthrough with this tool, eight end-users annotated a virtual crime scene while thinking aloud. Qualitative results show that annotation could improve orientation on the crime scene, speed up the collection process and diminish administrative pressure. While the current prototype suffered from technical limitations due to slow feature tracking, AR annotation was found to be a promising, usable and valuable tool in crime scene investigation.

Keywords: Augmented Reality, Indoor Positioning, User Walkthrough, Forensics.

1 Introduction

The main aim of crime scene investigation (CSI) is to find, examine and secure traces left by perpetrators. Forensic professionals involved in CSI have to collect evidence in a secure, traceable manner for juridical purposes. In recording the crime scene, it is very important to not erase, alter or contaminate evidence. Most often – due to costs and clearance of the area – it is also important to work quickly. Augmented Reality (AR) annotation enables adding virtual information to surfaces or objects in real life. In this way, evidence traces can be tagged and visualized right at the crime scene. Applying AR annotation to forensics may accelerate investigation while avoiding interference with evidence by virtually highlighting relevant items and locations. Furthermore, it may assist collaboration and coordination, as well as transfer of findings between forensic investigators. At a glance it is known which trace has been found where and which areas still need to be searched, which helps the spatial perception of the evidence at a crime scene and minimize miscommunication.

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This paper presents the design and evaluation of an AR annotation tool for forensic professionals. The question guiding this research is: 'To what extent will the concept and features of an augmented reality application provide added value for forensic professionals in their work process for securing traces?' First, related work in AR annotation, also for forensic professionals, is presented. Then, the work processes involved in CSI and the subsequent design of the AR annotation tool is presented. The method and results of a qualitative evaluation with twelve forensic end-users are detailed, in which the added value of this tool for the forensic process is assessed. Finally, the main findings, benefits and drawbacks of the tool are discussed.

2 Related Work

Augmented Reality (AR) refers to adding virtual information to real life scenes. AR has become fashionable since the 1990's, and has been applied in education, medicine, military, entertainment, and industry [1]. The most common use of AR is attaching annotations or virtual "tags" to real world objects, which can be seen through a display device (e.g. an iPad with camera). AR annotation is contrasted with 2D map annotations in that it displays tags in a 3D real world view. Until recently, this has been implemented mainly for entertainment purposes, such as museum, games or city-tours [2], and relying on content that is generated off-line by others. Not many applications allow users to create new or modify annotations on-the-go (online). To our knowledge, online annotation has not yet been implemented to benefit professional domains such as law enforcement or military organizations.

2.1 Enabling Technology for AR Annotation

Enabling technology for AR annotation has made significant progress. However, two important technical issues need to be addressed in order for online, indoor AR annotation to work: perceptual issues and positioning issues. Perceptual issues in working with AR systems include: inaccurate depth perception, inaccurate depth ordering, object matching, and low visibility due to displays [3]. [3] concluded in their survey that: "Users are regularly unable to correctly match the overlaid information to the real world,…". This is a serious risk for user acceptance when AR techniques are applied to professional domains. These perceptual issues are further influenced by whether a handheld or head-mounted device (HMD) is used. While the head-mounted devices leave users' hands free for other tasks, it has been shown that using HMD's over longer periods of time can cause visual discomfort or even motion sickness [4]. Also inputting information using a HMD is more difficult than using a handheld device, but here gesture recognition could be a solution (see e.g. [5]).

Augmented Reality annotation systems rely on position and orientation information to accurately display tags. Outdoor Augmented Reality systems can use GPS tracking to obtain location information (see e.g. [6]), but indoor positioning remains a challenge. To solve the issue of indoor navigation and positioning, [7] propose a vision-based location positioning system based on a large, preconstructed image set.

Their solution recognized key features from the real world and matched these to the image set to determine the location of the user. Using this setup, they achieved almost 90% reliable recognition of location. This approach could be feasible in predictable, small-scale and known environments, but not for forensic professionals. Crime scenes are by definition unknown and unpredictable, where creating an image set for the whole scene would take too much time and effort. In this paper, we propose a similar approach based on feature tracking, but processing is done in real-time. This has its own challenges, as will be elaborated in the discussion.

2.2 AR Annotation in Forensics

As application domain, we are primarily concerned how crime scene investigation would be aided by AR annotation. A related effort to implement AR for forensic professionals used GPS and indoor localization with Ultra Wide Band beacons to create a virtual incident map [8]. Interestingly, this allowed users to tag annotations to objects, take pictures and send these to a central processing bureau. This seems a useful approach, although no users were involved in the design or assessment of the application. Also, relying on UWB beacons requires bringing more equipment to a crime scene that has to be calibrated and can potentially contaminate evidence. A recent related effort in the forensics domain employed a HMD display to support crime scene annotation and collaboration (e.g. with an expert or coordinator) across distances [9]. Users wear a tailor-made, non-see-through head mounted display. An expert at a distance could "look over the shoulder" for collaboration. However, the tags that a user could virtually "leave" at a crime scene primarily indicate the no-go areas and not traces of evidence that we focus on. Consequently, their analysis focused more on the added benefit of AR for collaboration than for the primary forensic process (securing traces). As said before, securing traces and inputting the necessary information in a system will not be very comfortable using a HMD over longer periods of time.

2.3 Involving End-Users in the Design

To optimize the potential of an Augmented Reality tool for forensic professionals, these end-users should be included in the design and evaluation stages of such a tool [10]. Perceived usefulness is a high determinant of whether or not Augmented Reality applications will be accepted and used [11]. This stresses the need to incorporate end-users early in the design approach of AR tools to maximize the perceived usefulness for a specific target group. When innovative solutions, such as AR tools, are applied to new domains, evaluation methods should be selected carefully and tuned to domain specific criteria [12]. In the current paper, end-users are included in the design stage (to acquire operational demands and user requirements for the AR tool) as well as in the prototype evaluation (to acquire qualitative feedback on added value of the AR tool for forensic work processes). This approach is similar to that of [6] in that it uses an AR annotation prototype to collect feedback on different measures from end-users.

3 AR Tool Design

Contrary to earlier efforts, this paper presents an entire design and evaluation iteration of a prototype handheld AR annotation tool for CSI. Starting out, interviews with forensic experts explicated the operational demands of forensic investigation. High-level requirements were outlined and detailed into interface features, which were implemented in the prototype to gather end-user feedback in an early stage.

3.1 Operational Demands

To understand the operational demands in crime scene investigation and to guide our design effort, we held three interviews with two forensic professionals about their primary work process (securing traces at a crime scene), the preconditions for their work and the challenges they encountered. Currently, their work process encompasses the collection of physical trace evidence ("traces") at a crime scene. For each trace, the physical location, type, method of collection and remarks are recorded on a paper-based evidence list. Traces are uniquely numbered, and based on these numbers, photographs of the traces are collected and added to a database at a later stage. Forensic professionals create a 2D map of the crime scene, showing locations of all traces. In addition to this paperwork, the traces have to be carefully collected, packaged, labeled and transported to the CSI lab. At the lab, the traces and evidence lists need to be reviewed for completion and correctly filed for the judicial process.

From the interviews, the following preconditions for this process were identified:

Crime scenes should not be contaminated. No evidence at the scene should be altered or destroyed, requiring that the process of securing traces proceeds fast and sterile. All equipment brought on the scene is carefully decontaminated and personnel at the scene wear special clothing (mask, gloves, suit). The first officer arriving at the scene is responsible for keeping it as untouched as possible.

Crime scenes should not be visited longer than necessary. This lowers the risk of contamination, but any number of reasons can increase the time pressure on the forensic team. For example, victims wanting to return to their home, mortal remains that have to be cleared, or decaying biological evidence. Forensic professionals work as fast as possible while at the scene, as there is one chance of visiting a crime scene.

Crime scenes should not be visited by more people than necessary. Forensic professionals need to coordinate and collaborate with others while collecting evidence. With the supervisor or trace coordinator, task allocation is coordinated (who collects which traces at which parts of the scene?), but also collaboration with trace experts is required (e.g. radiological experts). The need for coordination and collaboration increases with the complexity of the crime scene.

Crime scenes should be documented as completely and accurately as possible. This includes all traces found at the scene, who visited the scene, methods of investigation, collection and transportation used. This is required to aid the judicial process and increase the chance that the evidence can be used for a conviction in a court of law.

Major challenges that forensic professionals face in their work process include inefficient documentation and administration (e.g. copying paper-based evidence lists in multiple databases, digitizing a paper-based map sketched at the scene), time pressure while having to work accurately (due to the preconditions outlined above), the inability to visit the crime scene again, and limited means of communication.

3.2 Design Requirements

Due to these challenging operational demands, the design requirements for the AR tool focused on making interaction with the tool as intuitive and effortless as possible. Adding tags should proceed via a point-and-shoot interaction mechanism, using a touchscreen and a camera. Trace information, photographs and details should be automatically coupled, to avoid double work. Storing, retrieving and exporting this information to relevant databases should be easy. Importantly, previously annotated crime scenes should be accessible even when not at the scene. This is expected to improve briefings, reduce collection time and improve documentation. Furthermore, users should be able to work with the tool wearing protective clothing such as gloves, and the equipment should be easily cleanable. Its functioning should not rely on bringing additional equipment (e.g. indoor positioning beacons) to the scene [8, 9].

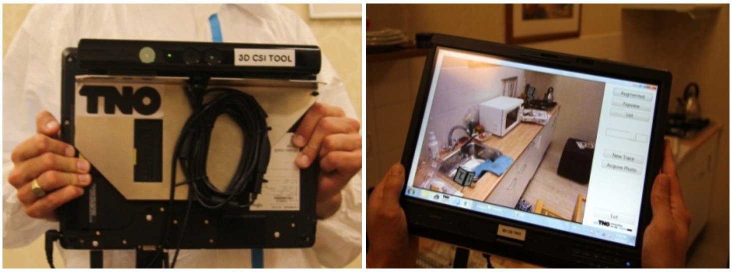

Fig. 1. The implemented AR tool on the tablet in operation at the simulated crime scene

3.3 Hardware and Sensor Technology

The most challenging part to display the virtual tags was generating accurate position and orientation information without relying on indoor positioning systems. The AR tool was implemented on a Toshiba tablet PC with touchscreen (Fig. 1) and programmed in Windows Presentation Foundation. To the tablet PC, a Microsoft Kinect camera was connected (through USB), powered by a portable battery. The 3D position and orientation is estimated using feature tracking on color images combined with depth images from the Kinect. Dedicated feature tracking software (written in C++) for a handheld 3D scan device ran in the background to provide position and orientation information. This enabled the tool to display AR annotations (tags) with sufficient accuracy and redisplay the tags when the tool pointed in the same direction again. While this setup allowed relatively accurate 3D positioning, it required that the tablet started a recording from a fixed starting point and that the tablet did not move too fast to allow the feature tracking to keep up.

3.4 AR Tool Interface

The AR tool interface consisted of a camera view that filled up most of the screen, and a button toolbar at the right of the screen. Users could select between three views: an Augmented Reality view (Fig. 2), a map view (Fig. 3), and a trace-list view (Fig. 4). The toolbar contained buttons to switch between views and two buttons to add a new tag or a photo. The slider on the toolbar adjusted the size of the tags (numbered gray cubes) in the AR view and map view. The exit button below closed the tool.

When adding a new tag, a green cross-hairs in the AR view could be used to point to the location of a trace. Pressing the button "New Trace" added a virtual tag to the indicated surface (e.g. a table), shown in AR view as a numbered cube (Fig. 2). Clicking on this tag opened a trace property window in which trace information could be added or changed (number, date, location, trace type and subtype). Clicking on "Acquire Photo" switched to the AR view to add photos to the current tag. In the trace-list view the complete list of traces could be reviewed, saved and exported. Also, a previously annotated crime scene could be loaded.

Fig. 2. The AR tool interface showing the AR view with a tag near the sink

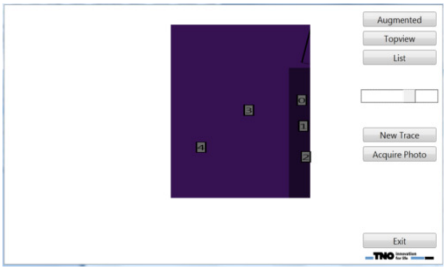

Fig. 3. The AR tool interface showing the 2D map view

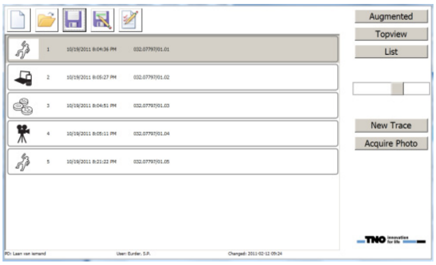

Fig. 4. The AR tool interface showing the trace-list view

As said, proper display of tags required accurate position information. If no position information was available, due to loss of feature tracking, the tool showed cross-hairs in red, to indicate that no tag could be added at that moment. In addition, a small still image appeared in the top left corner, showing the last image the feature tracking software had recognized. When users lined up the AR view with this image, feature tracking resumed as normal and the cross-hairs turned green again.

4 Evaluation Method

To ascertain the added value of the AR tool, forensic professionals conducted a walk-through of the tool at a simulated crime scene followed by a plenary discussion.

4.1 Participants

Twelve male participants, aged between 30 and 55 years, attended the evaluation. All were experienced forensic professionals from either the Dutch police force, the Dutch Police Academy or the Netherlands Forensic Institute. Their specializations included technical detectives, forensic detectives and forensic advisers. All participants attended the plenary sessions, while eight of them performed the user walkthrough.

Fig. 5. A forensic professional working with the AR tool during the user walkthrough (*left*) and an overview of the simulated crime scene (*right*)

4.2 Procedure and Data Collection

In total, the evaluation lasted six hours. Three walkthrough sessions of 40 minutes each were held in small groups (2-3 participants) with eight participants in total, guided by two test leaders. First, participants were briefed on the functionalities of the AR tool. Next, they were introduced to the tool at the simulated crime scene (Fig. 5). In turn, each participant moved from the starting point around the room with the AR tool to conduct a series of standard forensic tasks. First, they looked to see which traces already had been secured. Then, each participant secured a number of interesting traces themselves (e.g. knife in the kitchen sink, cigarettes in the ashtray). They added these traces to the trace list, included a photo and detailed information. Upon completion, they reviewed the trace list and the map view of the crime scene. During the walkthrough, the test leaders gave extra instruction to participants when necessary. They posed questions and stimulated participants to discuss specific features aloud while working with the tool. After the three groups completed the walkthrough, a plenary discussion was held with all twelve participants. All participants in the plenary discussion had either completed the walkthrough or watched the walkthrough via remote video connection. Video and audio recordings were made for analysis purposes. In the plenary discussion, specific statements were posed to the group and based on the subsequent discussion, remarks from the group were recorded. All qualitative feedback from the participants (statements) were grouped into five categories: added value of the concept, added value of the features, usability of the tool, impact on the forensic operational process, and necessary improvements and additions to the tool.

4.3 Results

Added Value of Concept and Features. Most participants were positive about the added value of the concept of adding virtual tags. They expect that it will improve their awareness of a crime scene and reduce the time needed for a first orientation on the scene. They found the usability of adding and reviewing tags very intuitive and easy. The screen size and accuracy of displaying tags in the AR view was sufficient for this application as well as for coordination tasks away from the crime scene. Most criticisms dealt with the current prototype implementation using online feature tracking. This required a fixed starting point and severely limited the speed of movement due to the computationally intensive feature tracking. Participants felt they had to move unnaturally slow with the prototype tool. The tablet PC, Kinect and battery made the current tool too heavy for prolonged use.

Usability. Concerning the visualization of tags, the gray cubes could obscure an object in the AR view. Scaling the size of the tag with the slider did not mitigate this completely. Instead, participants mentioned that tags should be moveable and displayed next to an object with a connector line. Another option is to display a circle around an object as a tag. Minor usability drawbacks were that the tool requires a certain level of lighting (which is absent in some crime scenes) and that numbering of tags should be improved (showing trace numbers in photographs). Also, the "exit" button should be moved to a proper place. Participants thought this button saved the trace-list to file, while in reality clicking on it quit the application altogether.

Impact on Forensic Processes. Participants were very positive about the expected impact of the tool on the forensic processes. They think it will be very useful for speeding up the whole trace collection process, specifically because traces are captured digitally and trace numbers are directly coupled to a crime case. They expect that digital collection of trace lists and tags on a 2D map will reduce time needed for documentation. Furthermore, having a quick overview of traces improves coordination, specifically in deciding on collection methods, and collaboration with trace experts at the bureau. The tool is applicable for most types of crime scenes, except for very complex ones for which a higher accuracy is needed. It will especially help forensic professionals in routine cases (high-volume crimes) that involve a lot of paperwork (e.g. burglary). The tool allows for remote viewing of a digital video stream from the crime scene (not implemented). Participants thought this would improve collaboration with external team members, such as the trace coordinator or subject matter experts.

An interesting objection to implementing an AR tool for forensics was raised by one participant. He was concerned that users might focus attention too much on the tool, thereby overlooking or even destroying evidence. Two others objected to 'yet another tool'. Should this AR tool be implemented, it should substitute paper-based trace lists and be used during the whole operational and juridical process.

Further Improvements. Participants required more freedom in manipulating the tags. For example, they like to use their fingers on the touchscreen to pinpoint the exact location of a new tag, instead of having to point cross-hairs. This allows adding multiple tags in a single camera view, possibly speeding up the first orientation on the scene even further. Suggestions for added functionality include a chronological timeline of added tags to evidence traces, instead of only a numbered list, an indication of no-go areas, an indication of non-localized traces (such as smells and sounds) and the ability to add spoken annotations, to free up the use of their hands more. Concerned for crime scene contamination, users stressed that the tool should be very easy to decontaminate and clean (by wrapping it in a transparent plastic sleeve), and a handlebar should be added for a more natural grip. Incorporating a flashlight would improve the tool's performance even in low lighting conditions.

5 Discussion and Conclusions

This paper presented the design and evaluation of a prototype Augmented Reality annotation tool for crime scene investigation. This tool added virtual tags to evidence traces, based on position information from feature tracking software. The trace list could be digitally completed, reviewed and exported to a database, contrary to current paper-based evidence lists. With twelve forensic professionals, the added value and impact on the forensic process was qualitatively evaluated in a user walkthrough and discussion. In general, end-users were positive about the expected impact of the tool on forensic processes. They considered AR annotation to speed up the trace collection process, reduce the amount of time needed for documentation and found adding and reviewing virtual tags usable and intuitive. However, because the tool was a prototype, the weight and required slow movements (due to feature tracking and processing) constituted technical drawbacks. In addition, flexibility of tag manipulation and visualization should be improved. Functionalities should be extended to include speech recognition software, indication of no-go areas, and a chronological timeline. Finally, the tool should be easier to hold and easier to clean and decontaminate.

These results confirm the added value of AR annotation hypothesized in earlier work [2, 8, 9]. On a broader note, this evaluation again raised the question whether to use a handheld platform or a platform that keeps the hands free (i.e. head-mounted display). While the participants disagreed on this issue, they stressed the need to be able to see the crime scene unmediated for the collection of evidence traces, e.g. without a display in front of their eyes. This would favor the current handheld solution over an HMD. Following hardware developments, the technical limitations in weight and processing are likely to be overcome in the next few years. Moreover, future opportunities of using this AR tool include creating an accurate 3D model representation of the crime scene, complete with features, textures, traces and tags, using the same feature tracking software. Such a model could be used for crime scene reconstruction, and even for juridical purposes in a court of law.

Forensic professionals considered that this AR tool will have added value in terms of speed of trace collection and transfer of information for coordination and collaboration. This evaluation limited itself to collecting qualitative data after a short usage period. Further research over longer periods of time and in real forensic settings should show whether implementing such relatively simple AR tools for crime scene investigation will actually improve performance and collaboration.

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