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Advancing the State-of-the-Art for Virtual Autopsies – Initial Forensic Workflow Study

Isabella Scandurra[a], Camilla Forsell[b], Anders Ynnerman[b], Patric Ljung[c], Claes Lundström[d], Anders Persson[e]

[a] *APRI | eHealth AB, Örnsköldsvik, Sweden*
[b] *Visual Information Technology and Applications, Department of Science and Technology, Linköping University, Sweden*
[c] *Siemens Corporate Research, Princeton, New Jersey, USA*
[d] *Sectra Imtec AB, Linköping, Sweden*
[e] *CMIV, Center for Medical Image Science and Visualization, Linköping University, Linköping, Sweden*

Abstract

There are numerous advantages described of how imaging technology can support forensic examinations. However, post-mortem examinations of bodies are mainly performed to address demands which differ from those of traditional clinical image processing. This needs to be kept in mind when gathering information from image data sets for forensic purposes. To support radiologists and forensic clinicians using Virtual Autopsy technologies, an initial workflow study regarding post-mortem imaging has been performed, aiming to receive an improved understanding of how Virtual Autopsy workstations, image data sets and processes can be adjusted to support and improve conventional autopsies. This paper presents potential impacts and a current forensic Virtual Autopsy workflow aiming to form a foundation for collaborative procedures that increase the value of Virtual Autopsy. The workflow study will provide an increased and mutual understanding of involved professionals. In addition, insight into future forensic workflows based on demands from both forensic and radiologist perspectives bring visualization and medical informatics researchers together to develop and improve the technology and software needed.

Keywords:

Human engineering, Task performance and analysis, Forensic medicine, Radiology, Tomography, X-ray computed, Post-mortem imaging, 3D visualization, Virtual autopsy

Introduction

Thanks to new imaging technology cold human bodies can be virtually examined and the cause of death determined. New Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) technology present new opportunities within post-mortems and forensic medicine. A recent addition to the autopsy workflow is the possibility of conducting post-mortem imaging. In its three-dimensional (3D) version, this is also called Virtual Autopsy (VA), where CT/MRI data from scans of corpses are post-processed with 3D Direct Volume Rendering (DVR) techniques [1-4].

Some of the most apparent potential advantages of VA, compared to conventional autopsies are:

- The VA is time saving and provides novel analysis opportunities. It can also improve the efficiency of the physical autopsy by improved prior knowledge of the case.
- The VA procedure does not alter evidence; the data sets can be stored indefinitely allowing subsequent re-examination by other pathologists.
- The VA can be an option when a conventional autopsy is rejected by family members due to religious beliefs, or threatens the health of coroners, pathologists, and medical examiners from highly infectious diseases.

There are several additional advantages and benefits of VA that, in the long run, will also make a significant wider contribution to healthcare and medicine. An interdisciplinary team of researchers and clinicians, further described below, works in a project to develop VA technology and procedures. To summarize, the mission of the *Advancing the State-of-the-Art for Virtual Autopsies* project is: To develop VA technologies and methodologies that enable widespread use of virtual autopsies in the standard forensic workflow. [5]

Methods and Materials

Previous research efforts have successfully shown the basic and technological benefits of VA [4, 6, 7]. This project aims to fulfill the mission by taking the next steps: to enhance the existing methods by addressing new research challenges and to prove that the full envisioned potential of VA is attainable. The needed advances encompass both technology and workflow issues in VA procedures. To address the required advancement of VA technology and procedure the work is organized into the following areas: Data Capture, Data Management, Virtual Autopsy Workstation, *Virtual Autopsy Workflow Studies*, and Demonstrator Integration (figure 1). The objective of the Data Capture area is to develop scanning procedures tailored for VA, for synthetic MRI, CT and Dual Energy CT. The Data Management research aims to extend and enhance the existing multi-resolution framework in a PACS environment. The VA workstation area will develop visualization tools to increase quality and efficiency of the VA procedures at both the radiology and the forensics departments. The development of the VA Workstation will depend on the non-technical contributions, such as the VA Workflow Studies and the Demonstrator. [5]

Purpose of the VA workflow studies

VA workflow studies aim to develop collaborative procedures that increase the value of VA and exploit the novel visualization techniques and thus establish documented procedures for VA. In parallel, there is an integration project that puts together the results from previous innovations in a demonstrator system, the Virtual Autopsy Table [8], for dissemination use. The demonstrator and the workflow studies will mutually feed each other's development processes (Figure 1).

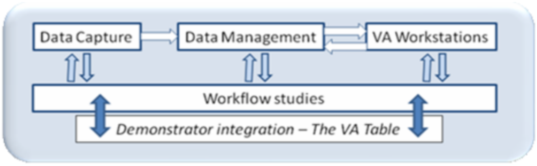


Figure 1-Project work areas' exchange of knowledge.

Methods for the VA workflow study

The technical work is a foundation for the VA deployment, but it is also important to use these tools in an optimal way. There are several aspects to consider; communication, such as instant interplay and asynchronous messaging between different professionals, documentation, the flow of data and documentation items, as well as physical scanning and transport of the deceased.

The workflow studies contain usage and process studies and result in documentation of current workflow and designs of future routines and procedures. The method used is based on a new multi-disciplinary method [9] for user needs analysis and requirements specification in the context of health information systems. This method origins from established theories from the fields of participatory design and computer supported co-operative work (CSCW). Whereas conventional methods imply a separate, sequential needs analysis for each profession, the "multi-disciplinary thematic seminar" (MdTS) method uses a collaborative design process [9]. Application of the method in previous research resulted in developed health information systems as well as new work procedures that were well adapted to the intended user groups. Vital information in the intersection points between different healthcare professions was elicited and a holistic view of the entire process was obtained. MdTS was perceived to efficiently identify in-context user needs, and transformed these directly into requirements specifications for further development [10].

Here, the initial work consists of field studies, observations and interviews, conducted by health informaticians and usability specialists, to understand current work situations and to capture users' tacit knowledge. This is particularly important in situations where different medical professions are, or will be, cooperating. The method further consists of multi-disciplinary work in inter- and intra-professional groups analyzing different topics, or themes, aiming to encompass the necessary knowledge of clinical work situations and procedures in the integrated work. The seminars contain both a holistic and a detailed perspective. In the detailed perspective seminars results from the holistic perspective are further analyzed, examining intersection points and specific details for each profession, items that are necessary for development of medical systems that actually support the integrated clinical work [9].

Materials for the VA workflow studies

There are many actors involved in a Virtual Autopsy procedure: the forensic pathologist, the radiologist, the police, and the court officials. Focus of the workflow studies are the staff of the National Board of Forensic Medicine and the staff at the Radiology Department of the University Hospital in Linköping, Sweden. Researchers working at the CMIV (Centre for Medical Imaging Sciences and Visualization) and the VITA division (Visual Information Technology and Applications) of the Department of Science and Technology at Linköping University and their industrial partners are involved in the study and subject for interviews and observations.

National Board of Forensic Medicine

The National Board of Forensic Medicine is a central government agency. It operates at ten different locations around Sweden and has 370 employees. The principal task of the agency is to produce reports required in legal cases, commissioned by the courts, the police and the prosecutors. There are four different fields of operation: forensic medicine, forensic psychiatry, forensic toxicology and forensic genetics. Experts in forensic medicine perform more than 5000 examinations per year, on both living and deceased persons, at six departments in Sweden, where Linköping is the one studied in this project. The department in Linköping performs around 900 autopsies per year related to unnatural death. Less than 3%, 20-30 of 900, are suspected murder cases. [11]

Östergötland county council

The Östergötland county council operates some forty care centers, four hospitals, of which the University Hospital in Linköping is the largest, and includes highly specialized medical healthcare, in some specialist areas working with all of Sweden as a catchment area.

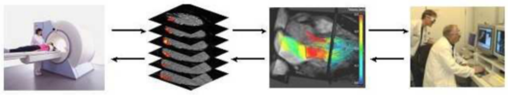
Intensive development work with medical healthcare has been ongoing for several years. Training and research are organized in close collaboration with the Faculty of Health Sciences, the medical faculty at the University of Linköping. [12] Staff from the radiology clinic is involved in this project.

CMIV

Center for Medical Image Science and Visualization (CMIV) is a multidisciplinary research center initiated by Linköping University, Östergötland county council, and Sectra Imtec AB. CMIV conducts focused front-line research within multidisciplinary projects providing solutions to tomorrow's clinical issues. The mission is to develop future methods and tools for image analysis and visualization for applications within healthcare and medical research.

Research within CMIV is based on earlier work within medical image science and visualization. Future directions will strengthen the interdisciplinary approach to enhance the possibilities of image-based diagnosis and treatment. At CMIV research is conducted within several medical problem areas, combining a number of technologies for novel application within clinical routine, medical research and dissemination of information.

Research activities within CMIV include the following four areas (Figure 2), with special emphasis on integration of these areas of expertise. [13]



Data Acquisition/ Image Reconstruction | Image Analysis/ Modeling | Visualization/ Simulation | Medical Application

Figure 2-Research activities within CMIV

The latest generation of CT, synthetic MRI and ultrasound scanners generate multidimensional data sets of rapidly increasing size. Obstacles associated with the handling and analysis of these large-scale data sets are of growing and immediate concern. Medical diagnosis is now facing serious data navigation and management problems. Focused research is required to solve these problems and to fully exploit the possibilities of the new technologies. [13]

VITA

The division for Visual Information Technology and Applications (VITA) contains five different research groups,

- Scientific Visualization,
- Information and Geo Visualization,
- Computer Graphics and Virtual Reality,
- Structural and Civil Engineering,
- Visual Learning and Communication.

The Scientific Visualization group is closely affiliated with the CMIV where the VA examinations take place. The Scientific Visualization research is conducted in the context of medical applications. Main research efforts regard volume rendering of large datasets, multimodal volume visualization and data visualization using augmented reality. The research groups are also affiliated to the Norrköping Visualization and Interaction Studio (NVIS) and share access to the laboratory and state-of-the-art equipment [14], such as the virtual autopsy table [8], Figure 4.

By using the latest technique within medical visualization, on the virtual autopsy table it is possible to study details of volume rendered 3D data sets of real scanned bodies. The user can interact with the 3D images, for instance remove certain layers of the body to look into specific details such as brain, skeleton, heart or the skin. The images are created with for example Dual Energy CT and new methods from the field of MRI and are post-processed by using different tools of image analysis and visualization [8].

Results

VA is currently used in Linköping as a complement to the autopsy procedure in cases of unnatural death [7]. To date approximately 300 cases have preceded a virtual autopsy. They are examined through a CT or MRI scan and the subsequent image analysis. Interviews, field studies and observations from both medical and forensic perspectives report an added value and future potential of virtual autopsies.

Although technological equipment and applications have passed the prototype state and are fully working, the organizational workflow is not yet optimized. This results in that the scanned cases are used mainly for research purposes and not yet smoothly inserted in the routine work of forensic pathologists.

Current Forensic Virtual Autopsy Workflow

In most cases the forensic pathologist investigates the crime scene together with the police and oversees the handling of the body, which is placed in a sealed body bag before being transported to the forensic department and placed in a cold storage. The following morning a full body virtual autopsy is performed using Dual Energy CT. Dual Energy CT is applied in all VA cases whereas MRI and synthetic MRI are applied in specific adult cases and for children, Using Multi Detector CT (MDCT) up to 25000 images can routinely be reconstructed [7]. The radiologist nurse walks through the images and makes short annotations of the findings. If there is additional information available about the body more detailed scans can be performed on specific body parts, e.g. head and thorax. Creating, storing and transfer of images are time consuming; often the pathologist has access to the images in the afternoon after the morning scan. The radiologist and the pathologist would perform a collaborative 3D DVR session in preparation for the physical autopsy and in immediate conjunction with the scanning. To save time however, as the DVD with the 3D images arrives at the forensic department later, in current procedure the radiologist summarizes the findings of the scans orally direct after the scanning is performed.

One advantage of the VA is that the captured MDCT data is stored, in case new circumstances arise. Compared to conventional post-mortems where you only get one chance, iterations of the procedure can answer new questions and reexamination of the VA images can put new light on the facts found during the physical autopsy.

The workflow of the forensic procedure is summarized in figure 3. The conventional physical autopsy is extended by adding the VA activities (shown in red rectangles) which enables an iterative approach. The possibility of a continuous interaction between radiologists and pathologists benefit the postmortem examinations. Unfortunately current restrictions of the data transfer results in that the workflow often is serial and ends after the phone call between the radiologist and the pathologist. The potential to use the images to a greater extent is stated as high and the workflow will undergo further studies.

The interviewees agree that the technology however could revolutionize forensic medicine. Using the VA procedure, there are cases where completely new findings are detected. For instance, the brains of deceased children can be scanned in order to rule out abuse. Also, with new CT technology, small metal particles which are not visible in any other way can shine clearly and the tiniest fractures show up. Hitherto unrecognized signs of strangulation, fractures and foreign bodies are found and some suspected murder cases have been reassessed after having undergone a virtual autopsy.

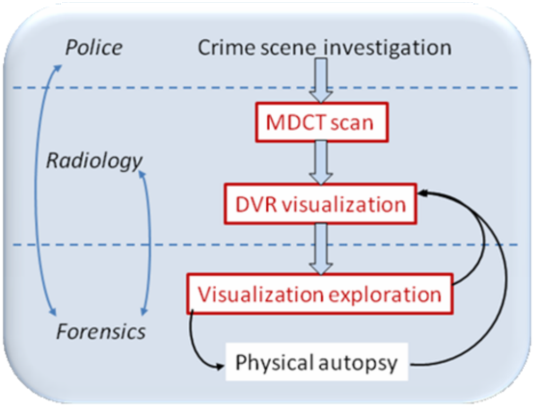


Figure 3-Overview of the forensic autopsy procedure. The VA activities are shown in red, enabling iterations. [7]

In short, the virtual autopsy is a newly developed procedure that will significantly enhance the autopsy, giving it the capacity to achieve more reliable results and by improving the VA workflow for the involved professionals.

Potential research impact

In some cases the virtual autopsy may replace the conventional autopsy procedure. Research on the unique aspects of post-mortem radiology must, however, be undertaken to identify cases and validate procedures. The interviewees foresee that novel visualization, interface and interaction design as well as data management techniques will be generated from this work. The contribution to medical and forensic fields is also imminent from establishing visualization techniques validated against histology and tissue examinations. VA technologies and methodologies will enable widespread use of virtual autopsies in the standard forensic workflow. Furthermore, VA will give a unique opportunity, in many medical research fields, to serve as the real "gold standard".

Potential impact on the society

The outcome of this project will have a significant impact on society at large. The decrease in the number of physical autopsies and some of its consequences can be counteracted, specifically in cases where religion and cultural requirements, in the multicultural society of today, prevent conventional autopsies. Since VA can also play an important role in improving forensics, and enable faster and more accurate crime solving, advancing VA technology and procedures further is of high value. Many aspects of VA can be directly transferred to healthcare in general, improving the quality of medical imaging and diagnosis for society as a whole. VA can also be used in non-forensic autopsies and solve the problem with the decreasing capacity for hospital autopsies.

Potential industrial impact

A major impact for industry is the possibility to commercialize and sell VA-related products. Given the tight collaboration with industrial partners that already have major international products in medical imaging; the commercialization will be easy to bring about. An additional positive impact from the PACS perspective is that VA constitutes a "worst case scenario" when it comes to large data set handling. The VA examinations are, in many ways, like any other diagnostic CT examinations, with the exception that radiation dose is not an issue. This means that a PACS that can handle VA is well equipped for the future challenges of traditional PACS tasks. This work furthermore widens today's applications for the MRI technique which will open a new market for the supply industry of MR scanners and its visualization techniques. Finally, when the applications improve, a second-hand market of CT and MRI equipment from the hospital domain could benefit the dissemination and use of VA worldwide in the standard forensic workflow.

Figure 4- Virtual Autopsy demonstrator: the VA table:

Discussion

The workflow analyses are ongoing; therefore we can not yet summarize all details. Although the potential impacts are clear, the technology is best used in conjunction with regular post-mortems. There are significant differences between living and dead bodies; for example on a deceased the arteries collapse and the veins get thicker, gas arises in different locations. Therefore it is important that the radiologist nurse and physician learn how to correctly interpret the VA images. Whereas other sites that have adopted the VA technology involve sub-specialities, as thorax and neurology, for examination of the VA images, this full-body examination procedure results in a coherent report and not disparate answers. Moreover, recurrent and iterative communication between radiologists and forensics in this workflow is unique and results in improved knowledge of how to interpret VA images. An evolving profession will be the forensic radiologist, skilled in analysing radiology and 3D images of deceased bodies.

Future work will be to put more effort on developing intuitive user interaction tools and smooth workflows. Human interaction with the visualization is a crucial part of arriving at the goal of creating insight. A forensic pathologist does not want to, nor should he need to, interact with the system using technical constructs. The pathologist, and to a large extent also the radiologist, should be able to stay in their respective familiar professional domain. This means that a mapping must be established between the natural semantics of autopsies and classifiers that can identify the corresponding features in the data. Furthermore, the workflow must be adjusted for both radiologists and forensic pathologists.

Conclusion

The VA technology could revolutionize forensic medicine. Using the VA procedure, there are cases where completely new findings are detected. Although technological equipment and applications are fully working, the organizational workflow is not yet optimized. To bring the VA procedure into the standard forensic workflow, however, the specific demands of forensic examinations need to be adhered to. Virtual Autopsy workstation and image data sets need to be adjusted to support and improve conventional post-mortems. The future forensic VA workflow that is to be cooperatively designed and deployed is required to improve both the radiology and the forensic departments' collaborative and individual work situations.

In conclusion, virtual autopsy is a newly developed procedure that will significantly enhance the autopsy, giving it the capacity to achieve more reliable results and by improving the VA workflow for the involved professionals.

Furthermore, advances of VA resulting from this work are foreseen to play an important role to improve forensics in terms of enabling faster and more accurate crime solving.

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Address for correspondence

Isabella.Scandurra@aprigroup.se