Research Article

A Design Study Investigating Augmented Reality and Photograph Annotation in a Digitalized Grossing Workstation

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Abstract

Context: Within digital pathology, digitalization of the grossing procedure has been relatively underexplored in comparison to digitalization of pathology slides. **Aims:** Our investigation focuses on the interaction design of an augmented reality gross pathology workstation and refining the interface so that information and visualizations are easily recorded and displayed in a thoughtful view. **Settings and Design:** The work in this project occurred in two phases: the first phase focused on implementation of an augmented reality grossing workstation prototype while the second phase focused on the implementation of an incremental prototype in parallel with a deeper design study. **Subjects and Methods:** Our research institute focused on an experimental and "designerly" approach to create a digital gross pathology prototype as opposed to focusing on developing a system for immediate clinical deployment. **Statistical Analysis Used:** Evaluation has not been limited to user tests and interviews, but rather key insights were uncovered through design methods such as "*rapid ethnography*" and "*conversation with materials*". **Results:** We developed an augmented reality enhanced digital grossing station prototype to assist pathology technicians in capturing data during examination. The prototype uses a magnetically tracked scalpel to annotate planned cuts and dimensions onto photographs taken of the work surface. This article focuses on the use of qualitative design methods to evaluate and refine the prototype. Our aims were to build on the strengths of the prototype's technology, improve the ergonomics of the digital/physical workstation by considering numerous alternative design directions, and to consider the effects of digitalization on personnel and the pathology diagnostics information flow from a wider perspective. A proposed interface design allows the pathology technician to place images in relation to its orientation, annotate directly on the image, and create linked information. **Conclusions:** The augmented reality magnetically tracked scalpel reduces tool switching though limitations in today's augmented reality technology fall short of creating an ideal immersive workflow by requiring the use of a monitor. While this technology catches up, we recommend focusing efforts on enabling the easy creation of layered, complex reports, linking, and viewing information across systems. Reflecting upon our results, we argue for digitalization to focus not only on how to record increasing amounts of data but also how these data can be accessed in a more thoughtful way that draws upon the expertise and creativity of pathology professionals using the systems.

Keywords: Augmented reality, design methods, gross pathology, human–computer interaction,interface design, visualization

Introduction

Motivation

Digitalizing pathology promises to decrease cancer diagnostic time, increase efficiency and quality of patient care, as well as provide more secure and accessible records. As interaction designers and researchers focused on future facing societal issues, we wanted to keep a critical eye on the effects of digitalization on medical personnel, and how this information flow fits into the broader perspective of pathology diagnostics. As interaction designers, it is argued that we should take responsibility to design devices that do not harm and to reflect upon the long-term effects of devices that we design.[1]

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Project scope

The authors of this article have used an experimental and designerly approach,[2] moving back and forth between low-fidelity design investigations and high-fidelity prototyping, making evaluations using qualitative design methods. This

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evaluation may be seen as subjective, fuzzy, and less vigorously structured compared to scientific research methods. However, design is a practice in its own right, particularly when it comes to solving "messy" design situations that require a deep understanding of design as a unique human activity of inquiry and action.[3] Woźniak *et al*. share their challenges in deploying design methods in a clinical environment, where the "beginning of the design process seems to be an abstract thought," where low-fidelity prototypes are often not viewed as, "serious."[4] This article presents an investigation into our high-fidelity prototypes and attempts to demystify our process of developing ideas using low-fidelity prototypes. The work in this project occurred in two phases: the first phase focused on implementation of an augmented reality grossing workstation prototype (referred to as "Digipat2" for simplicity though this work was a part of a larger consortium project); the second phase focused on the implementation of an incremental prototype "Digipat3" in parallel with a deeper design study "Digipat4." Both project phases [Figure 1] included low-fidelity design investigations, implementation of high-fidelity prototypes, and evaluations using design methods.

The aim with Digipat2 was to create a futuristic, proof-of-concept workstation prototype that would aid the gross pathology technician toward a digital workflow. The aim with Digipat3/4 was to build upon the strengths of Digipat2, move one step closer to a product, and improve the ergonomics with consideration to the greasy work environment. There are ergonomic solutions available such as location adjustable monitors, height adjustable furniture to reduce reach, and reducing annoyances such as smudging such as using washable keyboards, which is why our project focuses on cognitive ergonomics, though any new technology introduced should not worsen the current physical setup.

Relation to other work

Much of the efforts within digital pathology focuses on histology (whole slide imaging), diagnostics, and clinical deployment[5-7] while we have focused on the gross pathology procedure at a prototype and conceptual level. This grossing workstation prototype introduces augmented reality into the pathology laboratory, whereas up to now augmented reality has been mainly used in medical training and education.[8] This review[8] of what exists as of January 2016 concludes

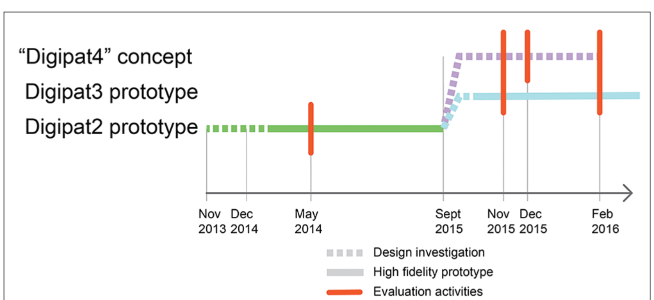

Figure 1: Timeline over project phases including design reflect upon, evaluate, and refine ideas

that augmented reality solutions are promising but have yet to support evidence of information transfer to the user.

Amin *et al*. make recommendations[9] regarding technical aspects for accessibility in picture archiving and communication system. They verify that "access to these images has also allowed surgeons to more easily interpret the text-based gross description, including the locations of lesions and the orientation of the specimen, in the pathology reports they receive." Digitalization considers not only how to record information but also how information is visualized and consumed. There is evidence[10] of the impact of interface design on viewing and navigating high-resolution whole slide images. Interaction design approaches[11] have been used to investigate recording digital pathology findings through annotation of images during the reviewing pathologist's process though we focus on grossing. A fully digital pathology lab recommends[12] displaying digital slide images alongside macroscopic gross images and communication between several systems: "Within-slide viewers, measurements, and annotation can be made, which can be added to the pathology report or saved for a future reference." Our result provides a concrete proposal of how this might look, with annotations that appear not only on the images themselves but also integrated into linked and alternate views.

There are similar products on the market such as Milestone MacroPATH pro-X system, a touch screen grossing station which combines video recording, photographs, measurements, and annotation in an integrated solution encompassing interface design, hardware, and ergonomic physical workstation. There are similarities to our concept lending credibility to our design though we emphasize that our process and reflections are a central part of our work presented in this article.

Subjects and Methods

Methods

The methods employed in this design study are based in the interaction design tradition of producing materials in the form of sketches, prototypes, and partially formed ideas.[13,14] From these partially formed ideas, designers have a "conversation" with these materials[2] using them as artifacts to reflect upon, evaluate, and refine ideas.

Through this "conversation with materials" (sketches and prototypes), we moved between iterative cycles of making and thinking, using it as material for evaluation and eliciting feedback. Reflecting on findings uncovered throughout the design process guided the next steps of the project. Activities undertaken during this project can be categorized as research, sketching/prototyping, or evaluation, in iterative and parallel processes. Research activities include investigating new technologies, semi-structured interviews, and rapid ethnography. Rapid ethnography is a design method used to rapidly understand an unfamiliar context.[13,14] Interviews and observations of grossing occurred at Linköping University Hospital and simulated with our high-fidelity prototype Digipat2/3 at three conferences. A key complement to our rapid ethnography research was through watching grossing videos on YouTube produced for educational purposes;[15,16] the value of using online tools for education are starting to be recognized and used more often in pathology.[17,18]

Sketching/prototyping activities encompass low-fidelity to high-fidelity realizations of ideas. Low-fidelity methods included writing out fictional stories where a pathology technician performed the grossing procedure using new technologies, sketching storyboards based on these stories, scenario development, and sketching wireframes.[14] Using one method called act it out,[13] we reenacted one of the gross pathology videos[15] using a model of a large intestine made out of play dough [Figure 2]. High-fidelity prototyping was used for developing our ideas and gathering feedback.

Evaluation closely resembles our research activities through interviews, demonstrations, and observations of the use of our high-fidelity prototype at hospital and conferences, as well as trying it out[13] ourselves. These design activities are a type of "serious play,"[19] intended to uncover insights, problems, and hidden knowledge that is self-evident to expert users (those that work with pathology), yet need to be considered by the designers of technological systems who have only a shallow understanding of the context. Eliciting feedback by asking questions or having experts give feedback of their own free hand is a good starting point, but the advantage of design methods is to uncover this obvious knowledge. "Observing real people in real contexts is a critical complement to asking, to help identify patterns and extremes of behavior, unarticulated needs, and places where peoples' actions, and stories about what they do differ in important ways…. As simple as the framework seems, asking, observing, and performing are never so neat and sequential in practice."[20]

Figure 2: Act it out: Reenacting gross pathology of an intestine using dough model

Digipat2/3/4 prototypes and concepts

Early concepts explored during Digipat2

Technologies considered during Digipat2 were a depth camera/multiple cameras to create a three-dimensional (3D) model, automatic segmentation of tissue, automatic form generation carried over from the patient's case file, automatic tracking of sampling location, voice recognition, and 3D digital dissection and reassembly. Automation would reduce the amount of manual work required by the pathology technician though the design of such a system is challenging - for example, with automatic sampling location tracking, the coordinate system is lost, requiring a system "smart" enough to track these changes, or require input from the pathology technician, in which case the interface design needs also to be carefully designed.

Of these concepts, it was decided to continue with 2D visualization of the tissue using a depth camera, tracking the scalpel in real time, using a multitouch computer monitor to ease input. The ideas and continued work on the prototype were done in close collaboration with pathology assistants, who were involved in continuous testing and iterative refinement.

Early concepts explored during Digipat3/4

Implementation of speech recognition was explored early on in this project phase, but we found that the technology was not reliable, as the user would need to repeat themselves. Optical tracking was also explored for improving the stability of the workstation, but we decided to delay further development until an evaluation of the Digipat2 prototype was made. Other technologies considered during this phase were eye tracking, gestural interfaces (such as Leap 3D and Celluon evoMouse which turns a nearby surface into a touchpad), touchpads, projected display/touchscreen, and augmented reality glasses (such as Google Glass or HoloLens) though these technologies would not have been more stable (more robust when it comes to calibration issues) than Stylaero magnetic tracking used in Digipat2, which is why we did not continue with these technologies.

Some of the early ideas we sketched out in stories and storyboards were inspired by the technologies we researched. These included a workstation where the entire gross pathology session was recorded on video, with points of interest marked in a visual timeline, which the pathologist could quickly watch and speed up less important sections, slowing down at highlighted sections of interest. Another early concept included an immersive interface with display projected directly onto the workstation or using augmented reality glasses. This would reduce the amount of time spent looking at the screen to instead focus on the physical specimens, with projected visuals/sounds/haptics to indicate when actions have been registered. Ideas using automation included measurements and automatic labeling of samples/slides to sampling location through proximity based sensors.

One key concept was a Cintiq desktop "map creation tool," where photographs could be arranged freely in relation to one another, with the ability to write text and measurements on the appropriate photographs, to create a closer relationship between text and images. In contrast to this concept was one that explored the idea of creating a "single schematic image" - with all information in one concise view, with the aim to edit down the report to the most essential and important information.

Description of the augmented reality workstation prototype Digipat2/3

Components of the workstation [Figure 3]:

1. *High-resolution camera mounted above the table
2. *Capture card – Intensity shuttle, Blackmagic design
3. *Camera box.
    - Scalpel with magnets mounted
    - Foot pedal used to activate the camera as well as initiate interface commands such as making measurements with the magnetically tracked scalpel
    - Stylaero magnetic tracking sensors (mounted under the table work surface)
    - All-in-one computer running Windows operating system with a multitouch screen.

(*The Digipat2 web camera measures depth, but this camera was exchanged in Digipat3 for a high-resolution camera, with additional necessary components added and integration to software).

The augmented reality digital gross pathology workstation prototype Digipat2/3 uses a camera which displays a live view of the work surface, along with an augmented layer of information [Figure 4]. Magnets are installed on the scalpel, which are tracked through sensors mounted underneath the work surface. With the prototype, one can take photographs of the specimen by the foot pedal, mark cuts on photographs by holding the scalpel over the specimen and the foot pedal [Figure 5], record measurements in the horizontal plane by the foot pedal, and "dragging" over the specimen with the scalpel using Stylaero magnetic tracking [Figure 6]. The measurements and cuts a, b, c, etc., are automatically recorded in the interface.

Description of the concept Digipat4

Based on the early concepts, we created a new interface design for the gross pathology workstation that works with the existing components of the prototype. Extending the use of the magnetically tracked scalpel, the scalpel can be used as a mouse, using the foot pedal to register commands. The interface accordingly has large target areas to activate form fields. Figure 7 illustrates the interface with the form already partially filled in, and the technician is able to save images to specific orientations in this case, a photograph has been saved of the anterior view. The live view of the camera is only displayed on the monitor while taking photographs, reducing distraction from movements on camera.

The key concept behind the new interface design is for the pathology technician to create only the number of photographs needed to create a comprehensive report,

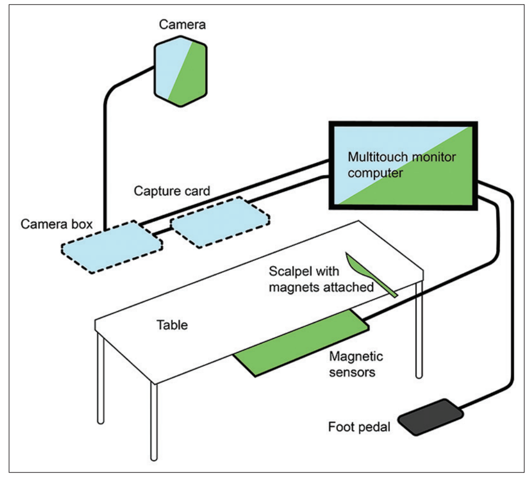

Figure 3: Simplified schematic of Digipat2/3 prototype (dark green = Digipat2, light blue = Digipat3 additions)

Figure 4: Digipat2 workstation prototype demonstration

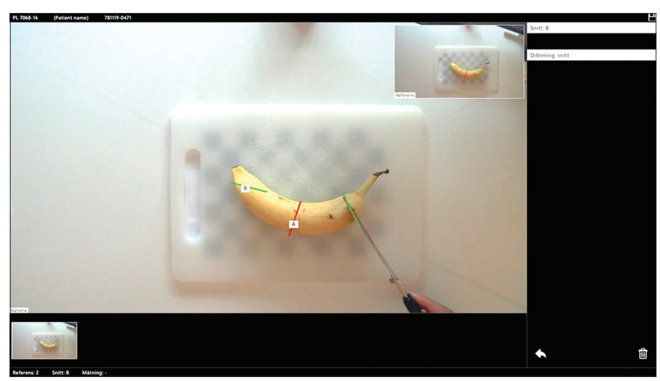

Figure 5: Marking cuts on the image using the magnetically tracked scalpel and foot pedal

reducing time required for the pathologist to read the report. Clicking on the blue hot spot shown in Figure 7 brings the user to an overview of anterior information [Figure 8] with additional notes overlaid by the pathology technician. This displays an overview of all information relating to the anterior orientation such as overview photograph with

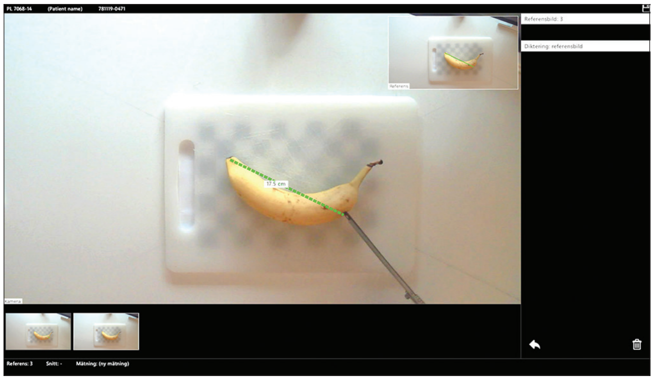

Figure 6: Making measurements using the magnetically tracked scalpel and foot pedal

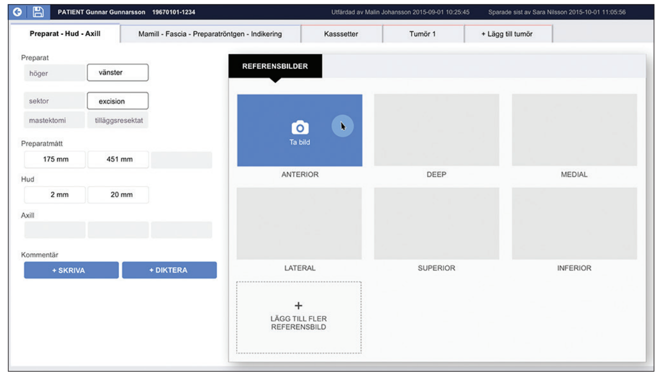

Figure 7: Interface with form partially filled in

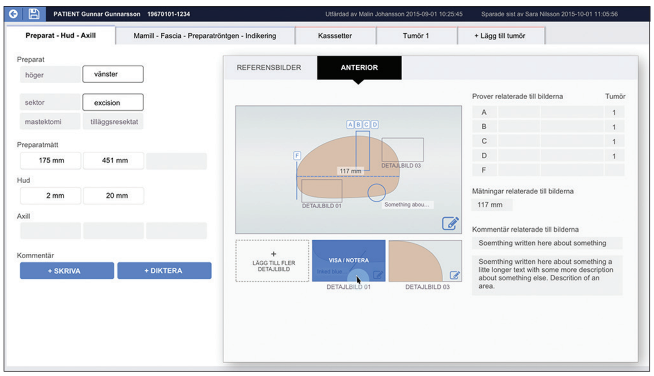

Figure 8: Overview of anterior orientation with linked information

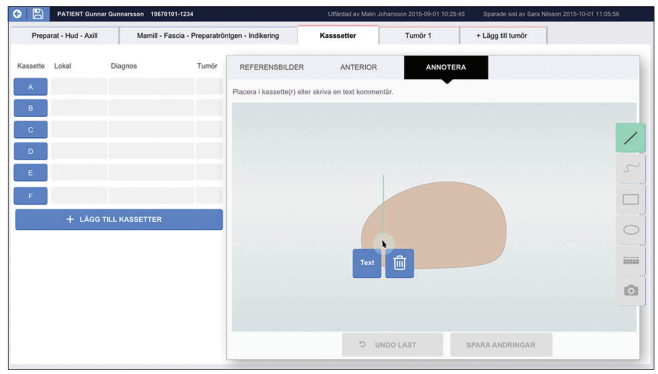

Figure 9: Technician creates a link between cassettes and location in the specimen

annotated dimensions and comments, submitted tissue blocks and its corresponding original location, and nested detail photographs.

Figure 9 illustrates how the pathology technician uses the interface to create annotations on images in this particular case, marking where cassettes a, b, and c came from in relation to the anterior orientation. This interface supports annotations that can be overlaid onto a photograph in the form of straight and freehand lines, boxes, circles/ovals, cassette/block label, text, or detail photograph.

Results

Evaluation and discussion

In the evaluation of the prototypes, we disregarded issues related to the Stylaero magnetic tracking technology such as robustness, frequent recalibration due to drift, affect by nearby conductive objects, and imprecision, as it was intended as a proof-of-concept using technology that is still under development.

Evaluation has been integral and continuous to our internal and external design activities. Evaluation has not been limited to user tests and interviews, but rather key insights were uncovered through design methods such as "rapid ethnography" and "conversation with materials." These evaluations fall into two general categories: (1) The user's physical ergonomics and workflow and (2) quality and efficiency of work produced.

Physical ergonomics and workflow

One aim with the prototype was streamline the pathology technician's workflow by moving toward measurement automation. User tests of Digipat2/3 demonstrated that with the Stylaero magnetic tracking, the pathology technician can make note of cuts and track measurements and is able to easily produce photographs with annotated cuts and measurements without requiring the use of a keyboard or mouse, reducing physical switching of tools.

In attempting to come up with new ideas on how to improve Digipat2/3, through "act it out" [Figure 2], we reenacted the grossing procedure of a YouTube grossing video.[15] What we learned was that while holding a dough model of an intestine that it was not easy to hold the tissue and measure the distance from an observed tumor to the surgical cuts, both in the air and on the cutting board, as the tissue is soft and tends to bend over. This is embodied knowledge to those who perform grossing but was not verbalized as a potential concern to consider when making measurements with a new tool, as it is too obvious to state. However, for the authors, it was only through embodied "play-acting" that we learned this, which then prompted a question about the usefulness of how measurements were made with Digipat2/3.

Reviewing prior observations, we realized that at times, the technician measured tissues with the sample in the air; it would have been difficult to make that angle of measurement with the tissue laying on the cutting board, due to the tissue's sloppiness and instability, in which case the magnetically tracked measurements of the prototype would not suffice, and the technician would need another measuring device (such as the plastic ruler they use today). Inspiration could be taken from digital histology slide imaging, where measurements can be made directly on the computer images rather than in reality during grossing.

During user tests of Digipat3, we received feedback that some would like automatic depth measurement (which was possible with the depth camera in Digipat2 though not fully functional), to calculate a 3D volume of the tumor. Another pathologist raised an important point about measurements: measurements made during grossing are not always correct as sometimes there is fibrosis surrounding the tumor, which is uncovered during histology. Therefore, there would be improved quality of patient care and diagnosis if this measurement could be adjusted after the slides are viewed (through, for example, reconstruction or computational recalculation, whether automatic or manual), to calculate the actual tumor diameter and not the measurement observed during grossing. Inexperienced doctors may have difficulty in determining how large this dimension is and overprescribe a treatment plan based on the larger diameter.

The Digipat2/3 prototype provides a novel way of measuring, but its strength is in reducing tool switching during annotation. In Digipat4, we propose extending its functionality to be used in place of a mouse including additional annotations. The disadvantages with this system are that the technician will have to use the foot pedal more often and train their muscle memory to link the movement of the scalpel as a mouse though there is evidence[10] that once new interaction mechanisms are learned, they may be preferable and more efficient.

We observed that users nearly always looked at the monitor and rarely at the tissue and cutting surface, sometimes nearly cutting themselves with the scalpel. We hypothesize that this could be due to several reasons: insufficient feedback and/or trust in the system; users want to double check to see that information was registered; "live" view from the camera is a distraction; the displayed position of the scalpel in the monitor does not match up exactly to the real space; and the steps involved in taking measurements required several verification steps. Additional feedback would reduce attention division such as through sound, haptic feedback, immersive, or projected display directly onto the work surface. In Digipat4, we propose a modification where the camera would only be displayed while the user is taking a photograph and propose an interface layout that minimizes cutting oneself.

Quality and efficiency of work produced

A key goal is the communication of findings and information before and during gross pathology to the diagnosing pathologist. Digitalization of the pathology technician's work process has potential to improve the quality and efficiency of this process. The biggest advantage of Digipat2/3/4 is being able to take photographs throughout the grossing procedure, preserving information about the original tissue providing a safety mechanism if a patient case needs to be looked at in closer detail. A digital camera is able to capture more detail than can be reasonably drawn by a technician. Pathologists verified in interviews that a photograph conveys more information than words, as the effectiveness of words to communicate depends on the skill and experience of the person's ability to accurately describe what they see, which is often less descriptive in the case of inexperienced personnel.

From videos,[11] technicians photographed an overview of slices, printed out the photograph, and annotated on top of the paper printouts. With Digipat4 technicians can do this digitally in the interface, eliminating steps required to do this on paper, decreasing administrative time, as well as enabling better image quality than paper printouts. Another video[15] showed how a pathology technician mentally kept track of from which part of the tissue the submitted cassette/block came from; it would be ideal to offload this cognitive task to software systems such as by location-based sensors that link cassettes on the work surface to the location of the specimen, or through a projected/immersive displays where the technician could make notes directly "on" the cassettes as they worked. In the Digipat4 concept, we built upon this finding by creating an adaptation of how cassettes can be tracked and recorded during grossing [Figure 9].

We confirmed through our evaluation that it was important to be able to point out specific things in photographs as it was easy to miss something when browsing a photograph. In addition, we observed users trying to rotate the scalpel to point at something in the interface and recommend modifying the green line cursor in Digipat2/3 to a dot or a line with a point on the end.

We evaluated that it was very easy to take photographs with Digipat2/3. The downside is that the number of photographs quickly became difficult to navigate, as many photographs looked very similar to one another after rotating the tissue; it was difficult to recall what orientation we had rotated the tissue between photographs. Digipat4 addresses this concern through an interface where one can label and track orientation through sorting and assigning images to the correct category as well as overlay annotations (sketches, text, and dictation) directly on the corresponding images. Multiple, alternate, and linked views would "automatically" be created through this orientation labeling, enabling the pathology technician freedom to create layered reports and visualizations, which we anticipate to be advantageous though further testing is required. As Digipat4 is not completely automated, the technician will have to spend some time with linking cassette/block information to its location. The benefit from this additional work is more sophisticated visuals and better communication.

Feedback received from pathology technicians pointed out that sometimes technicians need to submit information about samples that are not necessarily linked to a visible or known tumor, so an interface needs to provide flexibility to submit other types of information. We interpret this as a recommendation to take caution with automation and overconstraining a system interface, as individuals have their own preferences as to how they like to work. Therefore, a system should not force the user to work in a preprescribed way but be flexible enough to allow different ways of inputting information, such as dictation, being able to create custom forms, allowing free-text entry, and being able to annotate freely.

Discussion

Conclusions and future work

The aim of the high-fidelity prototype was to reach a functioning demonstrator that shows a potential future scenario of what gross pathology could look like, to disrupt expectations and provoke discussions. With a high-fidelity prototype, it is easier to engage and elicit feedback than through low-fidelity mockups that require more explanation and cannot be fully interacted with. The downside with a prototype is that it requires more development time and having such a convincing and impressive demonstrator may have made people more reluctant to express negative views. Verbal feedback alone did not capture some problems that we observed by people using the prototype.

The project would have benefitted if it was run in one continuous project rather than in two shorter phases, with the opportunity to do many low-fidelity experiments in parallel with the development of the higher-fidelity prototype. As illustrated in Figure 1, an investigation using low-fidelity design methods aims to not only incrementally improve the design but also to aim higher.

The technologies which we would have liked to explore (HoloLens, projected interfaces, gestural interfaces, and data storage limitations of film capture) were not more stable than our prototype. For the next few years, information workers will be tied to the monitor, but in our study, we found that the screen could be considered a distraction, and we attempted to bridge this distance by the proposed concept. Technology moves very fast, and though the reliability of Stylaero magnetic tracking will improve, newer technologies such as HoloLens will improve within the next few years to be usable, enabling a more ideal, immersive workflow. Increased data storage capabilities could also enable video capture and automation of coordinated data across systems.

Through our proposed interface design, we argue that the goal with digitalization should not be in capturing increasing amounts of data and images, but to draw upon how we can record and display this in a thoughtful, intelligent way for higher quality communication which makes the use of pathology professionals' experience and creative problem-solving. In addition, a strong candidate for making an impact with digitalization is in linking information from gross pathology reports (i.e., location in original tissue where block specimen comes from and its corresponding slides) and viewing this across systems. We hope that our work will inspire other digital pathology efforts to incorporate designerly approaches in their projects, as well as thoughtful reflection over the possible long-term effects of digitalization.

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Conflicts of interest

One of the authors is employed by Sectra AB.

References

1. Jonas L, Stolterman E. Thoughtful Interaction Design: A Design Perspective on Information Technology. Cambridge, Massachusetts: MIT Press; 2004.
2. Cross N. Designerly ways of knowing: Design discipline versus design science. Des Issues 2001;17:49-55.
3. Stolterman E. The nature of design practice and implications for interaction design research. Int J Des 2008;2:55-65.
4. Woźniak P, Romanowski A, Yantaç AE, Fjeld M. Notes from the front lines: Lessons learnt from designing for improving medical imaging data sharing. In: Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational. Helsinki, Finland: ACM; 2014. p. 381-90.
5. Al-Janabi S, Huisman A, Van Diest PJ. Digital pathology: Current status and future perspectives. Histopathology 2012;61:1-9.
6. Pantanowitz L. Digital images and the future of digital pathology. J Pathol Inform 2010;1. pii: 15.
7. Lundström C, Thorstenson S, Waltersson M, Persson A, Treanor D. Summary of 2nd Nordic symposium on digital pathology. J Pathol Inform 2015;6:5.
8. Barsom EZ, Graafland M, Schijven MP. Systematic review on the effectiveness of augmented reality applications in medical training. Surg Endosc 2016;30:4174-83.
9. Amin M, Sharma G, Parwani AV, Anderson R, Kolowitz BJ, Piccoli A, *et al.* Integration of digital gross pathology images for enterprise-wide access. J Pathol Inform 2012;3:10.
10. Ruddle RA, Thomas RG, Randell R, Quirke P, Treanor D. The design and evaluation of interfaces for navigating gigapixel images in digital pathology. ACM Trans Comput Hum Interact 2016;23:5.
11. Cervin I, Molin J, Lundström C. Improving the creation and reporting of structured findings during digital pathology review. J Pathol Inform 2016;7:32.
12. Stathonikos N, Veta M, Huisman A, van Diest PJ. Going fully digital: Perspective of a Dutch academic pathology lab. J Pathol Inform 2013;4:15.
13. VIDEO Method Cards. Available from: https://www.ideo.com/post/method-cards. [Last accessed 2017 Jan 27].
14. Buxton B. Sketching User Experiences: Getting the Design Right and the Right Design. San Francisco, CA, US: Morgan Kaufmann; 2010.
15. Farmer B. Various Gross Pathology Videos; 2014. Available from: https://www.youtube.com/channel/UCbI_XOmfdK3P0foueIjMobA/videos. [Last accessed 2017 Jan 27].
16. LLU Pathology Tutorials. LLU Pathology (FMO) Breast Grossing

Tutorial; 2015. Available from: https://www.youtube.com/watch?v=tyoUzqDSdY4. [Last accessed 2017 Jan 27].
17. Park S, Parwani A, Macpherson T, Pantanowitz L. Use of a wiki as an interactive teaching tool in pathology residency education: Experience with a genomics, research, and informatics in pathology course. J Pathol Inform 2012;3:32.
18. Molin J, Lundström C, Fjeld M. A comparative study of input devices for digital slide navigation. J Pathol Inform 2015;6:7.
19. Schrage M. Serious Play: How the World's Best Companies Simulate to Innovate. Boston, Massachusetts: Harvard Business Press; 2013.
20. Laurel B, editor. Design Research: Methods and Perspectives. Cambridge, Massachusetts: MIT Press; 2003. p. 48.