New trends in radiology workstation design

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ABSTRACT

In the radiology workstation design, the race for adding more features is now morphing into an iterative user centric design with the focus on ergonomics and usability. The extent of the list of features for the radiology workstation used to be one of the most significant factors for a Picture Archiving and Communication System (PACS) vendor's ability to sell the radiology workstation. Not anymore! The list of features and tools offered by a radiology workstation is now very much the same between the major players in the PACS market. How these features work together distinguishes different radiology workstations. Integration (with the PACS/Radiology Information System (RIS) systems, with the 3D tool, Reporting Tool etc.), usability (user specific preferences, advanced display protocols, smart activation of tools etc.) and efficiency (what is the output a radiologist can generate with the workstation) are now core factors for selecting a workstation. This paper discusses these new trends in radiology workstation design.

We demonstrate the importance of the interaction between the PACS vendor (software engineers) and the customer (radiologists) during the radiology workstation design. We focus on iterative aspects of the workstation development, such as the presentation of early prototypes to as many representative users as possible during the software development cycle and present the results of a survey of 8 radiologists on designing a radiology workstation.

KEYWORDS: radiology workstation design, code refactoring, usability, DICOM, PACS.

1 INTRODUCTION

1.1 OVERVIEW

The radiology workstation market has become mature, and the 2001 Radiological Society of North America (RSNA) exhibitor show was the proof for this. Workstations are more stable than a few years ago, when most vendors were struggling to port their software from Operating Systems like Sun/Mac/Next etc. to Microsoft platforms (Windows NT/2000) and to move from mini-PACS and mini-workstations to full scale PACS and multi-modality workstations.

Radiology workstations have become more and more popular, they include more tools and they run faster. The speed increase is partly due to code optimizations, such as faster 3D rendering algorithms, improved image processing response time, and heavy use of parallel processing and multithreading. The extra performance also comes from the increased computational power: faster processors, multiple-processor configurations, and more memory.

Workstation design should balance the addition of features with the stress on the radiologist to learn and manipulate these tools and the brain fatigue this co-lateral process is introducing. The research and consulting firm KLAS of Draper completed a customer survey of 143 healthcare institutions that are using PACS networks from eight different vendors[1]. According to the KLAS report, "functionality/ease of use" was the third most important reason for choosing a PACS vendor, just slightly behind "relationship/partnering" and "price". This is hard evidence that vendors should focus not only on providing more features, but also on the overall workstation usability and the integration of the tools and components. This paper will focus on the importance of an iterative user-centric design of a radiology workstation and a workflow-centric PACS system that should take into account the main objective: creation of accurate diagnostic reports!

1.2 EVOLUTIONARY STAGES OF RADIOLOGY WORKSTATION

The market for modern full-scale radiology workstations has passed its infancy age only recently. There was a first stage (early 1990s) of the radiology workstation when every vendor flirted with the idea, either by stuffing its mini-workstation with a few extra features, or by presenting a prototype for validation. These first attempts mostly

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represented an engineer's rather clumsy solution to a problem poorly defined due to lack of experience and understanding of radiologists' workflow[2]. Mostly an awkward "one monitor, one-image-per-monitor" display paradigm was used.

The second stage (late 1990s) was characterized by porting these experiments from platforms like UNIX, Next or Macintosh into the "Wintel" mainstream. Most workstations in this stage used a (slow) Digital Imaging and Communications in Medicine (DICOM) query mechanism to get the images into the local cache. Some of the new features included cine (variable speed, sequential playback of images in a series), window/level presets, magnifying glass and support for basic measurements.

The third stage of the radiology workstation is marked by a significant improvement from the previous /generation. These advances are due to more complete requirements, a better understanding of the medical imaging field and improved software development policy that incorporates more feedback from the end users[2]. In order to expand the potential of a digital hospital, re-engineering the radiology processes resulted in significant changes in the workflow. These improvements were previewed at RSNA 2001. During this exhibition full-featured radiology workstations - including reporting (eventually with speech recognition), 3D reconstruction, advanced "mark and measure" tools, better support for user profiles and web-based teleradiology, full support for color, JPEG2000 or wavelet compressed images etc. – were introduced to the prospective customers. Despite all this progress, this stage is still marked by the lack of convenient navigation tools and hanging protocols. Hanging protocols refer to a set of rules defining the way medical information (such as images, radiology reports etc.) are arranged on the computer screen immediately after opening a study.

It will take several years before these third generation radiology workstations will reach the "golden age", where the focus will shift from adding more features onto interactive aspects. Instead of the user (radiologist, ICU physician, technologist etc.) accessing several computer stations, each one with its own operating system, user interface (UI) and limitations, one workstation will provide integrated access to all the required functionality. This will allow for a tighter integration between the vendors ("plug-and-play" PACS technology) in the context of the extension of the current standards and guidelines, such as DICOM, Health Level Seven and Integrated Healthcare Enterprise. The new workstations will represent different flavors of the same product, customized for accessing the RIS system, the schedule and the reports, for reading Ultrasound, Nuclear Medicine, CT/MR/CR studies, for the 3D reconstruction, for the Quality Assurance station, for the administration station, the Dictaphone for the dictation of reports etc. The deployment of Web technology and initiatives like Microsoft's .Net[3] platform will allow for thin clients responsible only for connecting to the central Web server. The necessary software components will be automatically launched based on the user's role and type of data accessed. On-the-fly activation of the latest version of the software from the central server allows for easy software update, maintenance and support for several computer platforms.

2 ITERATIVE USER-CENTRIC DESIGN

2.1 PROVIDING THE CONTEXT

The prospective customers will stop asking the question "who has the most features" and replace it with "which workstation best fits our workflow", and this will also apply to the entire PACS, the RIS/HIS, the acquisition and printing devices. The radiology workstation should target the natural completion of tasks specific to the radiological practice, providing the capability of adapting to both customer and user specific needs.

A high performance implementation of each tool, without concern for the integration, will only produce local optimal functionality, with sub optimal efficiency in the overall completion of the radiology task. It is very much like in a game of bridge: no matter how good the two individuals in the team are, if they don't work well together their game will suffer.

One condition for a well-integrated functionality is the user centric design. This means the application should provide a consistent paradigm, by building a mental model for the user that should naturally integrate the workstation functionality[4]. A unity should be visible between the UI elements of the workstation (color scheme, menus, dialogs etc.)

and between the workstation implementation and the operating system in use. The success for the implementation of this goal should be assessed using metrics like intuitiveness, ergonomics and user fatigue.

In the radiology workstation design one must also deal[5] with the tradeoff between portability (platform independence) and performance, generality (all-purpose, "workhorse[6]" workstation) and specialization (dedicated workstation). Other choices to be made for workstation design include choosing between thin clients and independent workstations, local workstations or remote server processing.

Most of the time the current software is patched or extended with new features or capabilities (rather than developing a brand new product) because it is usually cheaper and faster than writing everything from scratch. From the business point of view, when a brand new software version is released, it should be at least at the levels of functionality and stability of the version it replaces. This could be possible because vendors have a better understanding of the domain, so they can learn from the mistakes done in the past and come up with a more flexible architecture and user-centric design. Redesigning software is an investment in the future of the product, when it is necessary to take it to the next level because it is too costly to stuff more features in the old software than to start from scratch. Redesigning the software is still an expensive process; so it usually happens only when there is no alternative, and usually involves a lot of interaction between the Product Manager, Project Manager, Technical Lead and the Analyst, as described below.

2.2 PLAYERS

The Product Manager is responsible for collecting the requests directly from the customers, from the sales people or from marketing and come up with "High-Level Requirement Specifications" (HLRS) document – a "wish list" with a brief description of the features, tools and bug fixes to be included in the new release.

The Project Manager (PM) is responsible for planning and managing the development of the new product, assembling and leading cross-functional teams through all phases of the development process. The PM must ensure that product development activities fully support marketing defined requirements. The PM is working in an environment wherein facts may be incomplete or in a form not readily usable, where the requirements can change in order to get a big order or because an important customer is requesting for a specific feature.

The Technical Lead (TL) is the responsible for the overall architectural design and implementation, selection of the technologies used etc. Ideally the TL should also have the medical imaging field experience. The TL's expertise in this area can be achieved by repeated interaction and visits to various customers, on the background of a high level of specialized education (a Master or a Ph.D. in medical imaging).

2.3 REFACTORING

The software entropy occurs when a program is extended, sometimes in a manner the program's architecture was not intended to support. In theory a program should be redesigned when such an addition is requested, but redesigning will require extra work and new bugs and limitations will be generated. Due to dynamic requirements and a better understanding of a fast changing medical imaging field, the software engineers are learning what they should do while they are half-way through with the implementation. More features mean a bigger project. This extra complexity will build up, generating penalties in terms of stability, maintainability, modularity etc.

Code refactoring is needed in order to reduce the short-term pain of redesigning[7]. The scope is not to extend the functionality of the application, but to update its architecture in order to remove some limitations and/or to improve modularity, stability or maintainability. Unfortunately it is difficult to determine what is the optimum refactoring required, and the internal aspects of the application must be balanced with the requirements coming from the marketing department. Code refactoring requires some effort with no immediate visible advantage for the sales team.

2.4 DOMAIN KNOWLEDGE

Domain knowledge is essential for providing a good design. A company can have this knowledge available through an in-house technologist or a radiologist working as consultant. Their expertise is essential[8], but it mostly works only as a validation method, a way to get a feedback for an idea or a prototype.

Instead, it is imperative to have somebody ("The Analyst") with a vision, somebody that has both the medical expertise and the technical skills to come up with the UI design. This person is not the one responsible for small items like recommending the fonts, icons and color scheme, but a person that must envision the paradigm behind the radiology workstation. If we see the radiology workstation software like a puzzle, whose pieces are the different tools and components, then the analyst is responsible for giving the user the visual cues for assembling the pieces together. The analyst's job is complicated by the rapidly changing requirements and the necessity to add customer-specific features.

2.5 ITERATIVE PLANNING

Consider an example on the interaction for planning an incremental new release of the radiology workstation. The analyst should use HLRS as the skeleton and come up with the big picture and a draft for the "Detailed Requirement Specifications" (DRS). A balance between the "wish list" and what is technically feasible should be reached, and here is where the role of the TL kicks in. The TL should discuss with the Product Manager and the analyst the technical limitations based on the current architectures and technologies used. They should revise the DRS to reflect a set of features that will map naturally and intuitively on the current software architecture.

After each iteration, the entire product must be evaluated, not just the extensions. The necessity for a "regression testing" is due to possible side effects or inconsistencies (breaking the rules for the mental model created for the user). A metric should be defined and used to asses the product is still coherent. After each iteration the entire product should be checked to confirm the quality of the changes are keeping the application above a certain threshold of this metric. One way to accomplish this goal is to request user feedback through an informal survey, such as the one we describe in section 4.

3 IMPLEMENTATION

In case of the radiology workstation implementation, it is preferable to come up with two or three software releases (not all of them major) every year and provide the customers with incrementally more tools, rather than coming up with a major new release every 1.5-2 years. A vendor should personalize its radiology workstation services and accommodate the preferences of the many different end-users, such as radiologists, surgeons, referring physicians, residents, technologists and PACS administrators, each with different needs, expectations and profiles.

Long projects, requiring considerable manpower, are more prone to fail (not deliver in time or not at all or delivery surrogate solutions). Failure occurs because a lot of changes in the requirements can be accumulated during their development cycle. Furthermore big projects produce significant overhead with the project and product management. There is also a big risk the software engineers may come up with a "technically good" solution that can prove impractical for the end user! Some of the big PACS vendors (mostly corporations for which PACS is not their main business) prefer to deliver upgrades and new software versions after considerably larger time intervals than some smaller, PACS dedicated vendors. These smaller PACS vendors are usually faster in addressing customer specific requests, competing for their market share by bringing technological advances sooner to their customers, instead of relying heavily on the brand name.

Special attention must be placed on the workstation's ability to allow for **dynamic enhancements** of its feature set. The capabilities of the hanging protocols could be extended by providing a scripting mechanism that will allow for direct interaction with the user via the workstation's UI and integrated voice recognition system. Image processing researchers at various medical institutions would like to be able to apply their new algorithms on the thousands of images available through the PACS archive. This objective should be reached without any major revision of the architecture and without waiting an entire development cycle (implementation, testing and release) from the PACS vendor. One solution to this problem is offered by the use of software plug-ins[9], a documented interface provided with the radiology workstation that can be used to extend the system with tools for image analysis, virtual surgery etc. Another approach consists in enabling the software for arbitrary manipulation of digitized images through an image processing interpreter like the portable line picture editor POPI[10] or its Java counterpart JPopi[11].

4 GATHERING USER FEEDBACK

In December 1999 we performed a user survey in an outpatient radiology clinic equipped with state-of-the-art PACS and imaging scanners. The first section of the survey (described in this paper) assesses the benefits of PACS vs. film, and it was meant to provide feedback for improving the design of the radiology workstation. The second section of the survey provided radiologist feedback on the use of hanging protocols[12].

The goal of this study was to determine the requirements for the design of a third generation radiology workstation. We asked the radiologists to provide the pros and cons for both the film and softcopy interpretation process. It was clear to us that for the softcopy paradigm to succeed, we had to avoid a one-to-one translation of the steps involved in the film-specific workflow. Workflow reengineering for CT examinations allowed for a 60% increase in efficiency for the technologist[13] and a 16.2% reduction in the interpretation time by the radiologist[14].

4.1 USER PROFILES

All eight board-certified radiologists involved in our study were familiar with soft-copy interpretation. Prior to our study, each radiologist used at least 3 different radiology workstations, and were involved in soft-copy diagnostic interpretation for at least 3 years. Two radiologists specialized in cross-sectional examinations (CT/MR), two radiologists focused on projection radiography and the 4 remaining radiologists specialized in US radiography. Table 1 summarizes the average daily workload distribution for these radiologists (based on their own estimation) in either film or soft-copy environment.

Table 1: Profiles of the radiologists involved in our study

Rad.	Number of radiology workstations used	Years of experience with softcopy interpretation	Average daily workload					
			Film			**Softcopy**		
			CT/MR	**CR/RF**	**US**	**CT/MR**	**CR/RF**	**US**
1	**3**	**6**	**32**			**35**		
2	**3**	**7**				**25**	**15**	**5-10**
3	**5**	**3**				**3**	**2**	**35**
4	**8**	**5**	**18**	**50**		**4**		**35**
5	**4**	**3 1/2**	**30**	**100**		**3**		**50**
6	**4**	**4**				**7-8**		**35**
7	**3**	**3**		**50-60**			**55-70**	
8	**3**	**8**		**75**			**60-70**	

4.2 RESULTS AND DISCUSSION

The most commonly mentioned drawback of the film interpretation (expressed by 7 of the 8 users) was the inability to perform post processing, such as changing the W/L settings. Other reported disadvantages for the use of film (see Table 2) included difficulty handling increasingly more images (especially for study comparison), inability to conveniently zoom, measure and annotate, difficulty in locating films from previous examinations.

Table 2: Drawbacks of the film interpretation mode

Rad.	MR/CT	CR/RF	US
1	No cross reference; too many films for view box capacity; availability of old study		
2	Post processing missing (W/L, zoom)	Inconvenience to see previous exams; lost film or signed to doctors	
3	Too many films; cannot post process measurements	Too many films	It cannot enlarge
4	Stack missing, post processing (W/L, Hounsefield measurement)	W/L, zoom	Comparison available; more efficient on computer
5	No W/L changes, finding and location of the previous films if applicable		
6	Post processing (magnifying glass); increased number of images for bone/soft, W/L settings; getting previous exams		
7		Exposure, quality, lost films	
8	It cannot change W/L (post processing); access to previous studies; it can be lost		

Table 3 summarizes the radiologists' complaints about the softcopy interpretation process, reflecting flaws of radiology workstation design typical to their second evolutionary stage. Transfer speed was slow due to the limitations in the file transfer protocols used, such as the DICOM standard for image communication. The lack of usable hanging protocols aggravate this situation by increasing the amount of time wasted by radiologists from study selection until all images were displayed in a format suitable for interpretation.

Table 3: Drawbacks of the softcopy interpretation mode

Rad.	MR/CT	CR/RF	US
1	Stability, lack of detail in context, compatibility between systems		
2	Speed of displaying; comparing (space limitation)	Setup desktop (window position, size not fix)	User interface not friendly (SUN)
3	Time spent, setting up viewing; too many variables	Resolution, slow speed, complexity	
4	Comparing studies		
5	Time	W/L, Cine play	
6	Speed		
7		Learning curve, poor printing	
8	Resolution; loading and arranging time		

Despite all the inconveniences listed above, the radiologists involved in our study showed strong support for softcopy interpretation. Some of them even mentioned they will "never go back to reading film". This "enthusiasm" is very likely related to the set of features commonly used by radiologists for softcopy interpretation, as shown in Table 4. Image manipulation tools can potentially increase the amount of information relevant to the diagnosis process, thus increasing the accuracy and confidence of the radiological interpretation. Since inability to adjust W/L settings was the major drawback reported for film interpretation, it comes at no surprise that W/L processing was the most commonly used tool for softcopy interpretation, together with image zoom and pan. For cross-sectional imaging, ability to link (navigate synchronously) multiple series displayed in stack mode was mentioned by most of the radiologists involved in CT/MR interpretation.

Table 4: Most used features for the radiology workstation as of December 1999

Rad.	MR/CT	CR/RF	US
1	W/L, cross reference, zoom		
2	W/L, zoom, clip and zoom, measure, VP, linking		
3	W/L, zoom, clip and zoom, measure, VP, linking	Invert/zoom/pan	Comparison
4	Link, measurements, ROI, W/L	W/L, and zoom	Less processing and measurements done by tech.
5	Zoom, magnifying glass		
6	W/L, measure, link (more for MR than CT)		
7		W/L, zooming, measuring	
8	W/L, zoom, invert, measure, magnifying glass (edge enhancement - compensates for loss in resolution)		

Table 5 summarizes the "wish list" for the radiologists involved in our study. Cross-sectional specific features include advanced mark-and-measure (such as labeling the vertebrae or measuring the Hounsefield units on CT studies), multi-planar reformatting (MPR) and inter-study linking. All these features were demonstrated during RSNA 2001. The wish list also includes rotation with an arbitrary angle, open-study notification (to signal when a study is opened for interpretation), improved viewing protocols and ability to save the user's arrangement of images for interpretation.

The DICOM standards committee acknowledged the importance for consistent image presentation through the creation of the DICOM Workgroup 11. The scope of DICOM Workgroup 11 is to develop a display function standard and DICOM services related to image presentation objects[15], such as the DICOM Grayscale Softcopy Presentation State and DICOM support for interchangeable hanging protocols (currently under development).

Table 5: Most useful new features required for the radiology workstation as of December 1999

Rad.	MR/CT	CR/RF	US
1	MPR; linking two studies		
2	VP- list of freq. used protocols; enhanced mark and measure capabilities (numbering on spine)	Know if somebody is also looking at the study; saving user settings when doing a study	Know if somebody is also looking at the study; saving user settings when doing a study
3	Healthy study (H.U. measurement continuous state)		Zoom, marks and measurements
4			
5	Display healthy study example		
6	Linking images from two different exams; calibrated images		
7		Edge enhancement	
8	Viewing protocols; fast and reliable; arbitrary rotation		

5 CONCLUSIONS

A good policy for workstation development is to present early prototypes to as many representative users as possible. What an engineer may think is an optimal solution (it is "technically better") can be considered a sub-optical solution by the radiologist. To avoid such pitfalls, user surveys, such as the one we presented, can be performed to obtain user feedback early on the development stage.

Most of the time we see the current software patched or extended with new features or capabilities rather than replaced by a brand new product. Due to dynamic requirements and a better understanding of a fast changing medical imaging field, we learn what has to be done while halfway through the implementation. More features mean a bigger project. This extra complexity will build up, generating penalties in terms of stability, maintainability, modularity etc. Code refactoring can reduce the short-term pain of redesigning. One must balance the internal architecture and limitations of the application with the requirements coming from marketing.

Iterative user centric design is the key for the migration of the radiology workstation into the new evolutionary stage, with accent on integration and productivity. Standards and guidelines, such as DICOM, Health Level Seven and Integrated Healthcare Enterprise, still have a long way ahead before being able to provide the framework for this tighter integration.

6 FUTURE WORK

In order to improve the decision-making process for selecting a radiology workstation, several metrics for appraising the workstation could be defined and standardized. For example, to rate the fault tolerance of the workstation one could use a system similar to the five star crash-rating test conducted by National Highway Traffic Safety Administration in the automotive industry. Examples of criteria for competitive ranking that should be standardized include productivity (a standard set of scenarios can be created, with a list of tasks to be completed by various type of users), intuitiveness, user friendliness, ergonomics, integration of various components (reporting, voice recognition, 3D tool etc.). Other criteria will reflect PACS attributes such as reliability, ease of upgrading and ease of remote installation, servicing, configuration, flexibility of user profiles, online help and usefulness of the user manual, security, privacy and encryption features, and of course, price.

Ideally, it will be great to come up with an overall widely accepted score when evaluating the workstation, but this will be very difficult due to both the complexity and specificity of the conditions of each customer. Still, the standard scores from the criteria above could be used in the context of several sets of weights, which can be more or less customized to the specific conditions of the customer.

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