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Design Requirements for Radiology Workstations

Adrian Moise, PhD, and M. Stella Atkins, PhD

This article stresses the importance of capturing feedback from representative users in the early stages of product development. We present our solution to producing quality requirement specifications for radiology workstations, specifications that remain valid over time because we successfully anticipated the industry trends and the user's needs. We present the results from a user study performed in December 1999 in a radiology clinic equipped with state-of-the-art Picture Archiving and Communications Systems (PACS) and imaging scanners. The study involved eight radiologists who answered questions and provided comments on three complementary research topics. First, we asked our subjects to enumerate the advantages and the disadvantages for both softcopy and hardcopy reading. We identified the two major factors for productivity improvement through the use of PACS workstations: workflow re-engineering and process automation. Second, we collected radiologist feedback on the use of hanging protocols (HPs). The results indicated the high importance of automatic image organization through HPs, with the potential effect of reducing the interpretation time by 10–20%. Our subjects estimated that 10–15 HPs would cover about 85%–95% of the regular radiological examinations. Third, we investigated the impact of the display devices on the radiologist's workflow. Our results indicated that the number and the properties of the monitors is a modality-specific requirement. The main results from this study on key functional requirements for softcopy interpretation only recently were incorporated in most of the current, successful PACS workstations.

KEY WORDS: Radiology workstation, PACS, hanging protocols, ergonomics

AS RADIOLOGISTS PROGRESS from reading images presented on film to modern computer systems with images presented on high-resolution displays, many new problems arise. Although the digital medium has many advantages, the radiologist's job becomes cluttered with many new tasks related to image manipulation. Consequently, it is imperative to design the radiology workstation in a way that merges the benefits of the digital management of information with the simplicity of hardcopy reading.

This article stresses the importance of capturing feedback from representative users in the early stages of product development.[1] We present our approach to producing requirement specifications for the radiology workstation, specifications that remain valid in time by anticipating the industry trends and the users' needs.

MATERIALS AND METHODS

There are several approaches for determining the requirements of diagnostic workstations[2]:

1. Observing and then interviewing the radiologists
2. Building functional models of the radiologists' working tasks and combining these with principles of the human–computer interface design
3. Using an interactive process consisting of building prototypes, evaluation by radiologists, and prototype refining. This process would stop when the radiologists express a high level of satisfaction with the result.

This article presents the results from a user study we performed in December 1999 in an outpatient radiology clinic equipped with state-of-the-art PACS and imaging scanners. The study involved eight radiologists who answered questions and provided comments on three complementary research topics. The questionnaire we used for this user study is presented in the Appendix. The first section of the study assessed the benefits of PACS versus film, and it was meant

From the Department of Computing Science, Simon Fraser University, Burnaby, British Columbia, Canada.

Correspondence to: Adrian Moise, PhD, tel: 604-456-3443; fax: 604-291-3045; e-mail: amoise@cs.sfu.ca

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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.[2] In the third section we investigated the impact of the display devices on the radiologists' workflow.

User Profiles

All eight board-certified radiologists involved in our study were familiar with softcopy interpretation. Prior to our study, each radiologist used at least three different radiology workstations and were involved in softcopy diagnostic interpretation for at least three years, as shown in Table 1. Two radiologists specialized in cross-sectional examinations, two radiologists focused on projection radiography, and the four remaining radiologists specialized in ultrasound (US) radiography.

Table 2 summarizes the average daily workload distribution for these radiologists, based on their own estimation, in either hardcopy or softcopy environment. For some of the radiologists in our study, the transition from hardcopy to softcopy involved a change in the type of exams they read. Consequently, we can compare radiologists' productivity with hardcopy and softcopy only for radiologists 1, 7, and 8. For these three radiologists, the number of studies read in either environment was roughly the same, according to their own estimation.

Table 1. Profiles of the Radiologists Involved in Our Study

Rad.	Number of radiology workstations used	Years of experience with softcopy reading
1	3	6
2	3	7
3	5	3
4	8	5
5	4	3 1/2
6	4	4
7	3	3
8	3	8

Table 2. Average Daily Workload for Our Radiologists

	Hardcopy			Softcopy		
Rad.	CT/MR	CR/RF	US	CT/MR	CR/RF	US
1	32			35		
2				25	15	5–10
3				3	2	35
4	18	50		4		35
5	30	100		3		50
6				7–8		35
7		50–60			55–70	
8		75			60–70	

RESULTS

PACS Versus Film

In this section of our user study, our goal was to determine the requirements for the design of a next-generation radiology workstation. We asked the radiologists to provide the pros and cons for both the hardcopy and the softcopy interpretation process. We hypothesized that softcopy can succeed only if a one-to-one translation of the steps involved in the film-specific workflow is avoided; workflow re-engineering is necessary for switching from hardcopy to softcopy reading. Workflow re-engineering associated with the use of the PACS has resulted in increased efficiencies of the technologists by 20%–60%, of the clerical staff by more than 50%, and of the radiologists by more than 40%.[4]

The most commonly mentioned drawback of the hardcopy interpretation, as expressed by 7 of the 8 users, was the inability to perform postprocessing, such as changing the width and level (W/L) settings. Other reported disadvantages for hardcopy include difficulty in handling increasingly more images, inability to conveniently zoom regions of interest, difficulty measuring and annotating, and difficulty in locating films from previous examinations.

In comparison, disadvantages of the softcopy interpretation process reflected flaws of radiology workstation design typical of the 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 aggravated 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. The radiologists also complained about the learning curve for softcopy and the complexity of the user interface.

Despite these inconveniences, the radiologists involved in our study showed strong support for softcopy interpretation. Some of them even said 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 3. Image manipulation tools can potentially in-

Table 3. 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, HP, linking		
3	W/L, zoom, clip and zoom, measure, HP, linking	Invert/zoom/pan	Study comparison
4	Link, measurements, ROI, W/L	W/L and zoom	Less processing and measurements done by technologist
5	Zoom, magnifying glass		
6	W/L, measure, link (more for MR than CT)		
7		W/L, zoom, measure	
8	W/L, zoom, invert, measure, magnifying glass, edge enhancement		

Table 4. 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	HP list of frequently 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	Display healthy study (Hounsfield 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		

crease 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 hardcopy interpretation, it comes as 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, the advantage of being able to link (navigate synchronously) multiple series displayed in stack mode was mentioned by most of the radiologists involved in CT/MR interpretation.

Table 4 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), multiplanar 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 in fall 1998. The scope of DICOM Workgroup 11 is to develop a display function standard and DICOM services related to image presentation objects, such as the DICOM Grayscale Softcopy Presentation State, and DICOM support for interchangeable hanging protocols, which is currently under development.

Hierarchical Hanging Protocols (HPs)

In this section, our goal was threefold: to asses the need for developing HPs, to validate

Table 5. Hardcopy Versus Softcopy—Image Organization Time

	Image organization (min)					
	Hardcopy			Softcopy		
Rad.	CT/MR	CR/RF	US	CT/MR	CR/RF	US
1	2			1		
2	1–2			2	2	
3	1	1	1	10	4	4
4	1	0.5		1	3–5	
5	0.5–5	12			12	
6	2	1		1		
7		0.8–1			0.17	
8						

Table 6. Hierarchical HP Organization

General	MR	*Extremity*	Knee	Left Knee	Left Knee with Contrast
				Right Knee	
			Arm	Left Arm	
		Spine	Spine Lumbar		
			Spine Cervical		
	CR	*Chest*	Chest Lateral		
		Extremity	Lower Extremity		
			Upper Extremity		

our hypothesis toward a hierarchical structure of HPs, and to determine the average number of HPs required, so we can estimate how practical it will be for radiologists to define and use HPs.

We investigated the perceived impact on the radiologist's productivity and accuracy as a result of switching from hardcopy to softcopy presentation. Only one radiologist (radiologist #2) rated hardcopy superior to softcopy. This result indicated an increasing acceptance for softcopy reading.

Table 5 summarizes each radiologist's estimation of the average time spent on "image organization" (ie, the time spent preparing a study for interpretation) and on the quality of the diagnosis. According to the data presented in Table 5, radiologists spend a significant amount of time arranging studies for interpretation, which stresses the importance of automatic image organization through HP.

The HP selection paradigm that we evaluated consisted of the following filters: modality, procedure type (see "aliases"), body part (anatomy), name and number of series, number and type of relevant prior examinations, and configuration of the displays. All the radiologists were interested in our idea of organizing the HPs in a hierarchical structure: Root → Modality → Body part → Procedure type → Priors. A matching HP can be searched on the deepest level on the tree. If the node is empty, the search should go up in the tree, eventually reaching the modality level. However, this hierarchical HP organization does not offer a perfect solution for choosing the order (priority) of the filtering. An example of the HP tree presented for their validation is illustrated in Table 6.

In order to estimate the applicability of radiologists defining their own HP, we investigated the number of HPs that each radiologist would use to cover most of the daily work for each modality. We expected the number of HPs to be proportional to the number of body parts imaged with each modality. Table 7 reflects the estimated number of HPs each radiologist thought would be required, and the percentage of the studies that will be covered by these HPs.

Impact of Display Devices

We also investigated the impact of the display devices on the radiologists' workflow. The radiologists were familiar with monitors with dif-

Table 7. Estimated Number of HP and Percentage of the Studies Covered

	Estimated of # of HP required		Percentage of studies covered	
Rad.	CT/MR	CR/RF	CT/MR	CR/RF
1	>15		90–95	
2	3/10	5	90–95	75
3	20	15/5	85	80/90
4	6	50	>90	>90
5	50–100		75–90	
6	2		>95	
7		15–20		>90
8				

Table 8. Effect of Displays Devices: Number of Monitors and Spatial Resolution

	Preferred number of monitors			Importance of spatial resolution		
Rad.	CT/MR	CR/RF	US	CT/MR	CR/RF	US
1	4			same		
2	2	3				
3	3	2	2	4	4	3
4	1	4	0	1	3	0
5				2	4	0
6				1		
7		2			3	
8		3			4	

ferent properties: gray scale and color, portrait and landscape, and spatial resolution of 1, 2, 3, or 5 megapixels. We investigated the importance of the spatial resolution by comparing two types of high-resolution gray-scale monitors: 1728 × 2304 versus 2048 × 2560. We used a 0–4 scale, with 0-not important, and 4-most important. The preferred number of monitors (1–4) and display resolution are presented in Table 8.

We inquired about the "frame effect" produced by two adjacent monitors: Half the radiologists would prefer a bigger monitor to replace the two smaller ones, and half said the frame effect is not disturbing.

DISCUSSION

Our hypothesis that the radiologists need an automatic arrangement of images was confirmed, with the potential effect of reducing the interpretation time by 10–20%. The data collected suggest that 10–20 HPs per modality can accommodate the radiologists' needs in 80%–90% of the studies displayed for interpretation. Less than 20 HPs per modality will not be too difficult for the radiologist to generate nor for the radiology workstation to manage and select from. The remaining 10%–20% of examinations will be impractical to cover under HPs. These remaining studies represent either very rare examination types or exceptions that will occur in situations such as when the patient moved and the technician had to add another series or when the study was sent twice from modality to PACS so each series is duplicated. Based on these results, we believe HPs will be critical in combating the limitations of the screen real estate, especially for complex situations like MR brain/angiography, or in the ICU when comparison with prior examinations becomes critical.[5]

CONCLUSIONS

With this user study, the main observation was that for digital radiology to succeed, one should avoid a one-to-one translation of the steps involved in the film-specific workflow. We identified that process automation is a major factor for productivity improvement through the use of PACS workstations. Therefore, we concluded that productivity improvement with softcopy reading is conditioned by the integra-

Table 9. Productivity, Quality of Diagnosis, and Time Spent Arranging the Study (%)

	MR/CT		CR		RF		US		Other	
Question	Film	Filmless	Film	Filmless	Film	Filmless	Film	Filmless	Film	Filmless
Productivity										
Productivity										
Quality of the diagnosis										
Time spent arranging the study (%)										

Table 10. Present Drawbacks, Most Used Features, and Proposed New Features

		Filmless		
Modality	Film Drawbacks	Drawbacks	Most used features	New Features
MR/CT				
CR				
RF				
US				
Other				

tion of mechanisms such as study prefetching and hanging protocols.

We collected radiologists' feedback on the use of HPs. The results indicated the high importance of automatic image organization through HPs, with the potential effect of reducing the interpretation time by 10%–20%. Our subjects estimated that 10–15 HPs would cover about 85%–95% of the regular radiological examinations. The hierarchical structure we proposed in December 1999, based on modality, anatomical region, and radiological procedure type, was very well received at that time.

We also investigated the impact of the display devices on the radiologists' workflow. Our results indicated that monitors with different properties would be required for different modalities.

These main results from 1999 on key functional requirements for softcopy interpretation only recently were incorporated in most of the current, successful PACS workstations. For example, the tools our study identified as the most commonly used, such as adjustment of window width and level, image zoom, and the stack mode, are now always available for immediate use. The speed for study loading and the optimal arrangement of images for interpretation is much improved nowadays by hanging protocols that also include the automatic retrieval and display of relevant prior examinations.

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APPENDIX: USER QUESTIONNAIRE

Hardcopy versus Softcopy

Please use Table 9 for questions 1–4:

1. How many computer image-viewers did you use and for how long?
2. Productivity: How many studies do you review per day? Each row signifies a typical day.
3. Quality of the diagnosis: Which mode do you think is more accurate and why (use <, = and > between columns).

What fraction of the Table 10 for questions 5–7.

4. What are the major drawbacks of each mode?

• Example: (I) Small screen size; (II) lack of detail in context; (III) reduced resolution; (IV) reduced productivity; (V) personal preference.

Table 11. Hierarchical HP Organization

General	MR	Extremity	Knee	Left Knee	Left Knee with Contrast
				Right Knee	
			Arm	Left Arm	
		Spine	Spine Lumbar		
			Spine Cervical		
	CR	*Chest*	Chest Lateral		
		Extremity	Lower Extremity		
			Upper Extremity		

Table 12. Proposed New Features Versus Importance

New feature vs. importance	All modalities	MR/CT	CR	RF	US
1.					
2.					
3.					

Table 13. Templates

	MR/CT		CR		RF		US	
	#	%	#	%	#	%	#	%
Templates								

5. What are the most used features?

• Example: (1) Window/Level; (2) Zoom; (3) Pan; (4) Magnifying glass; (5) Cine play; (6) use previous studies for comparison; (7) linking series in stack mode.

6. What would be the most important features that you would want to have?

• Example: (a) Duplicate instances of a series with different W/L settings; (b) Hounsefield measurement on CT images; (c) enhanced printing capabilities; (d) enhanced mark & measure capabilities; (e) display healthy study example.

Viewing Protocols

We propose implementing a viewing protocol like a collection of predefined settings (W/L, zoom, rotation, arrangement of the series in the viewports) that the system uses to display the images upon loading a study for review. It would be used to reduce the time spent preparing a study for review. A viewing protocol template could be defined for each type of study, using a hierarchical architecture similar to the one presented in Table 11.

For plain film studies, such as CR, DR, and X-rays, you would most likely define protocols at the study level, where the same settings are used for all series in the study. These protocols contain general parameters such as the initial layout, viewing mode (stack or tile).

For cross-sectional studies, such as MR and CT, you may want to define protocols at the series level so that you can define the number of series within the study and then set the parameters, such as the window settings and orientation, for each series separately.

1. What other user preference (such as size and color of annotations, user-specific W/L settings) should be stored in the viewing protocols and how important do you consider this feature for each modality? Please write your suggestions in Table 12.

For the following two questions, please write your answer in Table 13. If templates for viewing preferences were to be defined (like "MRI of right knee without contrast"):

2. How many do you think you will need?
3. What percentage of studies do you think will fit in these templates (requiring minimal/no further adjustment)?

Displaying Images

4. How important is the resolution (1728 × 2304 versus 2048 × 2560)?

• Size versus resolution: show different images (from different modalities) at different layouts

(7 × 9 MRI images fit in 1728 × 2304; they prefer a 2 × 2 layout, stack mode).

5. What is the preferred number of monitors for each resolution?
6. Would you prefer a single big monitor instead of several smaller ones ("frame effect")?
7. How are these preferences dependent on the modality?
8. Which modality do you think best fits for each mode?
9. Can you fit all of the image into a single Multi-Modality viewer?

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