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Henriette S. M. Cramer · V. Evers · E. V. Zudilova
P. M. A. Sloot

Context analysis to support development of virtual reality applications

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Abstract To develop a usable Virtual Reality system, the prospective context of use of such a system may need to be considered in order to make sure it meets the requirements and restrictions of that context. In this paper, a contextual analysis is described for a virtual reality system to aid medical diagnosis and treatment planning of vascular disorders. Semi-structured interviews were coupled with observations in an ethnographic approach to requirements gathering in the daily work environment of (interventional) radiologists and vascular surgeons. The identified potential usability problems of a fully immersive prototype, coupled with the needs, requirements and real-life environment of the end-users lead to guidelines for the development of a VR application on a semi-immersive desktop environment. The findings lead us to believe that contextual analysis can be a powerful way to inform the design of a VR application by offering an understanding of the context of use and to inform developers of the most appropriate degree of immersiveness of the VR environment.

Keywords Desktop virtual reality · Usability · Contextual design · Ethnography

1 Introduction

Virtual reality (VR) applications are often developed relatively independent from the real contexts in which they are going to be used. However, it is recognised that user needs should play a central role in the development of virtual environments that are to be used in a real-life context (e.g. [7]), an insight that has existed in the systems development community for years (e.g. [11]).

Three categories of VR often used are desktop, semi-immersive and fully immersive VR. Definitions offered in literature for different types of VR seem inconsistent. For a starting point on a framework of VR, see [15]. A great variety of interpretations exist for the term 'immersive' itself; see [24] for a number of interpretations. For the purposes of this study, the focus is on the visual immersion offered by technological means, not on psychological effects or sense of 'presence'. The following characterisations for various VR categories are used here; fully immersive systems are considered as CAVE-like systems and head-mounted displays. Semi-immersive systems are other stereoscopic visualisations in virtual reality. Non-immersive systems will, for the purposes of this study, be considered non-stereoscopic VR applications offering 3D simulation and visualisation. In our interpretation, 'fish tank' VR is provided by applications which make use of equipment that enables users to actually 'reach in' and grab an object, such as virtual workbenches (see e.g. [27, 18, 16]). We define desktop VR as VR on a PC-type workstation. Desktop VR can be offered as either immersive with, for example, shutter glasses, or non-immersive without specialised equipment. Currently, data on the appropriate degree of immersion for a given situation is scarce. There is no complete framework available facilitating the choice whether a (non-VR) desktop application, desktop virtual reality, fish tank, semi-immersive or completely immersive virtual reality application might be the best choice for a particular system and context of use. The choice between these options can only be made after considerations of usability criteria for an application and analysis of the context in which a system will be used.

Usability can be defined as encompassing both ease of use and acceptability of a product [4, 5]. Ease of use

H. S. M. Cramer (✉) · V. Evers
Section Social Science Informatics,
University of Amsterdam, Roetersstraat 15,
1018 WB Amsterdam, The Netherlands
E-mail: cramer@swi.psy.uva.nl
Tel.: +31-20-5256789
Fax: +31-20-5256896

E. V. Zudilova · P. M. A. Sloot
Section Computational Science,
University of Amsterdam, Roetersstraat 15,
1018 WB Amsterdam, The Netherlands

determines whether a product itself can be used. Acceptability determines whether a system will be used and in what way. Both ease of use and acceptability are specific to a particular class of users, for a particular task, in a specific context. The ISO 9241–11 standard [12] definition of usability builds upon this by defining usability as "the extent to which a product can be used by specific users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." For the purposes of this study, we adhere to this definition, which stresses the importance of specificity of users, their goals and context of use in achieving usability. Context of use seems to have various, similar definitions. Preece et al. [19] define context of use as the social, organisational and physical environment in which a system will be used. Bevan et al. [4] define context as the user, task and physical and social environment. They include users but do not explicitly name technical context, which is considered in this paper. For the purposes of this research, context of use includes users and their tasks, as well as the technical, social, organisational and physical environment of users that could potentially affect system use.

This paper discusses contextual analysis in VR application development, applied to the case of the virtual radiology explorer (VRE) system aiding medical diagnosis and planning [22]. The VRE prototype has been developed in response to expressed needs from the medical world for research into VR visualisation and simulation of physiological properties. The prototype is an experimental set-up that provides advanced functionalities to explore a patient's condition and make a decision on the best treatment. It has been realised that solutions for potential usability problems can not be found without involvement of prospective end-users and more detailed knowledge about the VRE's context of use. The contextual analysis has been conducted to contribute to the usability of the system in the future. The remaining sections will discuss the methodology, its results and the ways in which these findings impact development of the VRE. Insights into criteria for VR development in general, degree of immersiveness and type of VR environment, as well as the applicability of contextual analysis in VR development are discussed. Finally, limitations and plans for future research are explained.

2 The virtual radiology explorer (VRE)

The VRE is a system for 3D visualisation of patient data obtained by medical scanning and simulation of possible treatments for pre-surgical planning and training in virtual reality. Its goal is to assist in the pre-surgical planning of abdominal vascular bypasses. Potential users of the system are surgeons, radiologists, medical lecturers and students. The working prototype of the VRE system (shown in Fig. 1) provides visualisation of the results of blood flow simulation before and after adding a simulated bypass. The 3D reconstructions of scan data can be explored interactively and measurements can be conducted if necessary. The simulation component of the system simulates the parameters of the vascular blood flow: velocity, pressure and shear-stress [23]. Both the artery geometry and the simulated blood flow can be visualised in 3D and time (4D, see [3]).

The evaluated fully immersive VRE version runs on the semi-immersive distributed real-time interactive virtual environment (DRIVE) system, where stereoscopic images are offered, on one large screen, to a user wearing shutter glasses. Navigation and selection are achieved by voice recognition and/or manipulating a 'wand'; three buttons, one joystick with two degrees of freedom and a tracking sensor, mounted in a single device. Extensive information about the VRE and the DRIVE can be found in [1, 3, 31, 23, 30].

3 Problem statement

After a heuristic usability evaluation of the VRE system, a need to investigate the demands of real end-users was identified. The study described in this paper aims to guide the VRE's development. It aims to answer a number of questions about the real-life tasks and the context that the VRE should support, functionality of such a system and its grade of immersiveness. For this purpose, the following research questions were stated:

– What are the contextual requirements and constraints for a system such as the VRE?
– What type of (VR) environment would be most suitable in this context?

The study was also expected to offer insight into the effectiveness of contextual analysis and the applicability of ethnographic methods into investigating system requirements to support development of VR applications in general.

4 Methodology

In order to ensure that the VRE's functionality would be developed supporting real-life demands, the choice was made to conduct a small-scale exploratory study to investigate the daily working context of two end-user groups; (interventional) radiologists and vascular surgeons. Nine Dutch hospitals were visited. A study into the tasks of diagnosis and planning of interventions for vascular disorders was conducted, combining exploratory, semi-structured interviewing with observational methods. In order to collect a diverse set of data, methods were adapted from ethnographic research, which has been successfully applied for a great number of years in software development [10] and is also not unknown in VR application development (e.g. [7]). Interviews were carried out to gain insight into the work

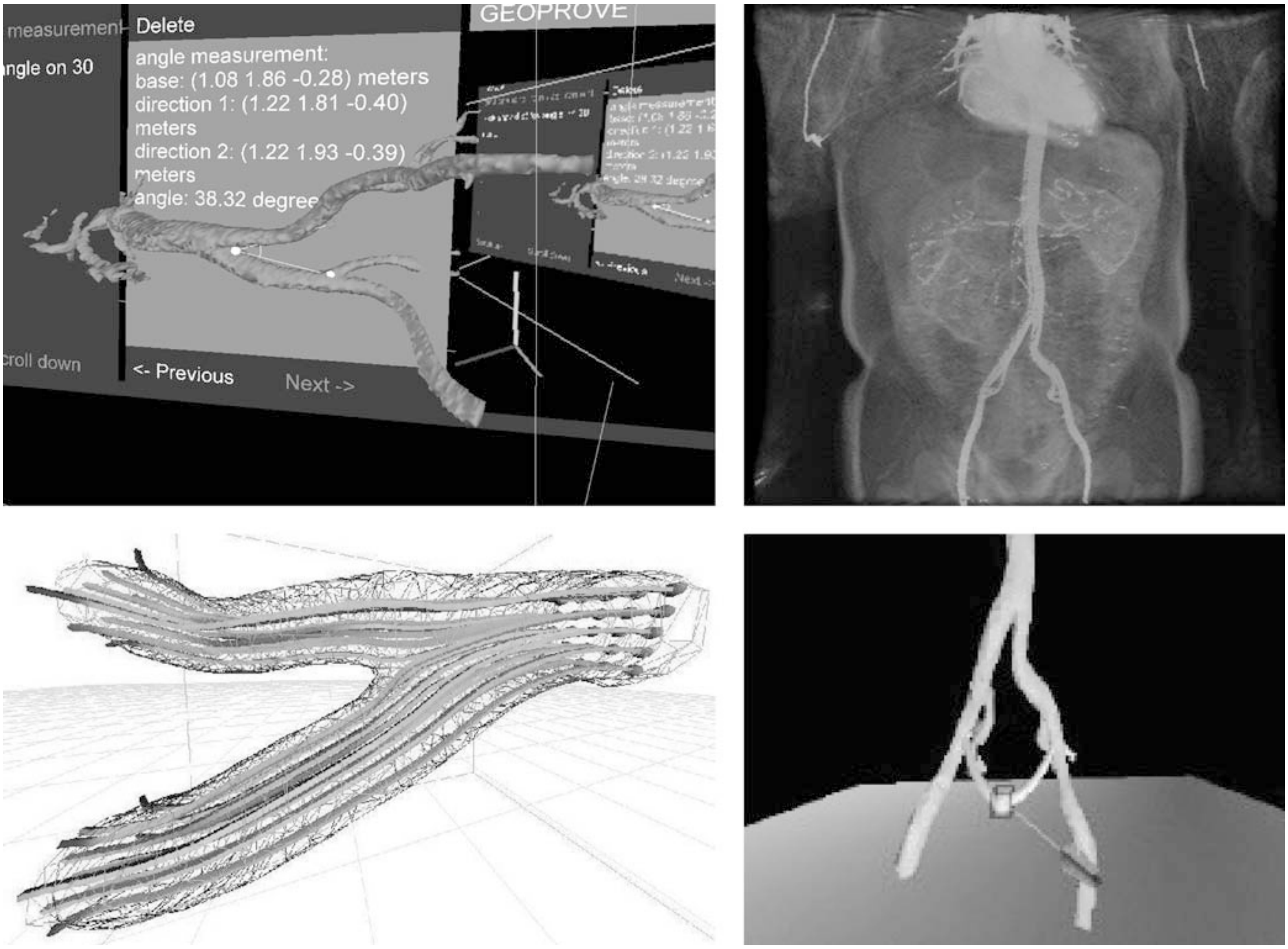

Fig. 1 The VRE. *Upper left*: Visualisation of a vessel within the first prototype of the VRE, shown together with the floating menus of GEOPROVE, a measurement system applied within the VRE [2]. *Upper right*: Exploration of patient data in VR ([31], image courtesy of D. Shamonin). *Lower left*: 3D flow visualisation via streamlines originated by a particle plane ([1], image courtesy of H. Ragas). *Lower right*: adding a simulated bypass in the VRE

processes surrounding the tasks of diagnosis and treatment planning for vascular disorders. These served as preparation for the observation sessions that followed. Observations were carried out to gain detailed understanding of the tasks and the context in which these tasks were performed. In particular, the assessment of medical scan images was evaluated. Every opportunity to observe real work being carried out by the study's participants was followed up by the researcher.

Contextual analysis using interviewing and observation was preferred over other methods for involving users in the development process. The advantage of this combination of methods is the possibility to study tasks and users in a real-life environment. Participants do not have to leave their workplace and the researcher does not have to rely on only self-reported data, as is the case with e.g. interviews, surveys and discussion groups. The combination of interviewing with observation provides a variety of data. Interviewing participants first to gain an insight in work processes provides a greater understanding of observations made later. An overview of other methods for involving users in system development and participatory design can be found in, for example, [19, 9]. A description of the interviewing and observation sessions follows.

4.1 Interviewing

Participants were asked about their responsibilities and activities concerning the tasks of diagnosis and treatment planning in one-on-one interviews. Work-processes and information used in these processes were identified. Current bottlenecks in the users' task set were assessed in order to gain understanding of where system support could be useful. Participants' current use of 3D data was evaluated as well as wishes they might have for future medical visualisation tools. The intention towards use of blood flow simulation data was explored to investigate the need for the simulation capabilities of the VRE. Interviews were taped and paper notes were made. Interview reports were compared for similarities and differences and frequency of opinions.

4.2 Observation

The observations included the entire trajectory of diagnosis and treatment planning for vascular disorders. Assessment of scans as part of a number of activities within this trajectory could, potentially, be supported by a system such as the VRE. Amongst other activities, the following were observed:

– Consultations with a patient by a vascular surgeon, where preliminary diagnosis and treatment plan are constructed
– Scanning of a patient and post-processing of scans by technicians
– Assessment of scan images and formal reporting by both radiologists and vascular surgeons, as well as informal discussions
– Scheduled, mostly weekly, vascular meetings where official conclusions on patients' disorders and treatments are made
– Performance of both intravenous and open-surgery interventions by interventional radiologists and surgeons

Observations were carried out in a manner resembling contextual inquiry [6] by one observer. Participants were observed in an unobtrusive manner by the researcher while being in the vicinity of the participants. Paper notes were made and photographs were taken whenever possible and allowed. At unobtrusive moments during or after the sessions, questions were asked to verify the information gathered during the interviews. Artefacts, such as forms showing the data that clinicians recorded and reported in certain assessment tasks, were gathered as well.

4.3 Analysing the data

Information gathered during the interviews and observation sessions about workflow and information flow was structured into flow diagrams. Each task and information item, including scans, forms and measurements, were described in adapted worksheets of the CommonKADS method geared to knowledge engineering [21]. Worksheets were also used to document and analyse the roles of actors involved in the process. Additionally, work models of the contextual design method [6] were used.

4.4 Sample

Nine hospitals were involved in the study. The hospitals were geographically spread out within the Netherlands. They varied in size and were both academic and non-academic. Fourteen specialist participants, composed of seven (interventional) radiologists and seven vascular surgeons, were individually interviewed and/or observed. All individually interviewed and observed radiologists and surgeons were male and over forty years old. Two female radiology technicians were observed during the post-processing of scans and two other technicians briefly demonstrated and offered opinions on the software they used. Table 1 provides an overview of the hospitals and participants. Additional (varying from one to about fifteen per activity) radiologists, vascular surgeons, other specialists, technicians, nurses and assistants were observed during vascular meetings, surgery and informal discussions on scan assessment. Some of them answered questions, or provided comments, but they were not extensively individually interviewed and are not counted as individual participants.

5 Findings

This section discusses the general results of the contextual analysis. Some major findings concerning the real-life tasks, as well as the technical, social, organisational and physical environment of users that could potentially affect the VRE's use, are described.

5.1 Processes and tasks

Figure 2 presents a simplified diagram of the main processes in vascular diagnosis and treatment planning. It was surprising to find that the actual time spent on individual assessment of scans was considerably less than originally assumed by the development team. Experts could assess 2D slices within minutes. Before scan assessment, preliminary treatment plans were made 'in seconds' after hearing the patients' complaints during the first consultation. The tasks following the initial consultation were mostly used to verify this first diagnosis. Finally, conclusions on final diagnosis and decisions on treatment were mostly drawn collectively by radiologists and surgeons during vascular meetings. Other findings concerning tasks and processes follow below.

Extra subtasks, such as making a 3D reconstruction of scan data to gain extra insight into the geometry of complex vascular structures, are usually only performed when necessary, e.g. if the review of 2D slices hasn't yielded enough information.

5.2 Users

Unexpectedly, an extra potential user group was identified. These were technicians who currently use diagnosis and planning systems to prepare scan images for radiologists and surgeons; experts can then efficiently perform the assessment of these images.

All observed participants were usually unaccustomed to working with VR systems, but all had experience in using advanced equipment and PCs for work. Most were

Table 1 Brief overview of the nine hospitals and the activities and personnel observed. Some of the data on the amount of beds, specialists and personnel have been derived from hospital websites. A hospital may have multiple 'locations'

N	Hospital size	Participants: Surgeons/radiologists/ technicians (**I**nterview/**O**bservation**)	Activities observed	Regular scan assessment (prints/screen)
Non-academic teaching hospitals				
1	Beds: >1000 Specialists: 180 Personnel: 3800	Surgeons: 1 (I and O) Radiologists: 0	Consultations, vascular meeting*	Prints
2	Beds: >500 Specialists: 200 Personnel: >3000	Surgeons: 1 (I) Radiologists: 3 (I and O)	Bypass intervention*, vascular meeting*, cooperative scan assessment by 2 radiologists	Prints, screen (2D/3D in special cases)
3	Beds: >400 Specialists: ±100 Personnel: >2000	Surgeons: 0 Radiologists: 1 (I and O) Technicians: 3 (I and O)	Patient scanning, scan manipulation (technicians 1 and 2), scan assessment* (radiologist), demonstration software*** (technician 3)	Prints, screen (2D)
4	Beds: >580 Specialists: 150 Personnel: >2600	Surgeons: 0 Radiologists: 1 (I and O)	Endovascular interventions*	Prints, screen (2D and 3D)
5	Beds: >530 Specialists: n/a Personnel: >2500	Surgeons: 1 (I and O) Radiologists: 0	Vascular meeting*	Prints, screen (2D)
6	Beds: >600 Specialists: 150 Personnel: >3000	Surgeons: 1 (I and O) Radiologists: 0 Technicians: 1 (I and O)	Consultations*, demonstration software***	Prints
7	Beds: >900 Specialists: n/a (Medical staff: >150) Personnel: >2300	Surgeons: 1 (I and O) Radiologists: 0	Cooperative scan assessment (surgeon and radiologist*)	Prints, screen (2D and advanced reconstructions)
Academic hospitals				
1	Beds: >1000 Specialists: n/a Personnel: >5500	Surgeons: 2 (I and O) Radiologists: 1 (O)	Endovascular intervention*, consultations*, vascular meeting*	Prints, screen (2D)
2	Beds: >1000 Specialists: n/a Personnel: >6000	Surgeons: 0 Radiologists: 1 (I)	Short tour of radiology scan assessment rooms	Screen (2D)

*Activity involves scan assessment
**All observations include asking interview questions to the main participant
***Demonstrations of software includes interviewing demonstrator about software use

interested in new technology and some were involved in technological research projects.

5.3 Use of 3D

Even though 3D visualisation is now available in most hospitals, it was found that the available systems are not always used. A number of reasons have been expressed by participants, varying from lack of training to lacking integration with other systems used. One of the main reasons for not using 3D is efficiency. Only when the added value of 3D outweighs the time it takes to construct and interpret a 3D visualisation will it be used. This is a good reason to think about a better performance and more efficient interface. Improvements in automated segmentation of anatomic structures in medical images seem desirable as well.

Currently, no intervention is carried out by the evaluation of 3D visualisations alone. Training of radiologists and surgeons still focuses on the assessment of 2D images of scan slices. A system such as the VRE would need to support the need for 2D visualisation as well as advanced 3D functionality. 3D visualisations are appreciated most to get an overview of intricate vascular structures.

5.4 Social and organisational environment

Formal rules and hierarchical responsibilities govern the process of diagnosis and treatments. These rules will have to be taken into account for any system developed in this context. Collaboration between colleagues (e.g. Fig. 3) is highly valued and should be supported in a system. Exchange of data between departments and hospitals could be supported as well. This may provide chances for Grid developments in connection with the VRE [23]; connectivity between distant locations, interoperability between different kinds of systems and

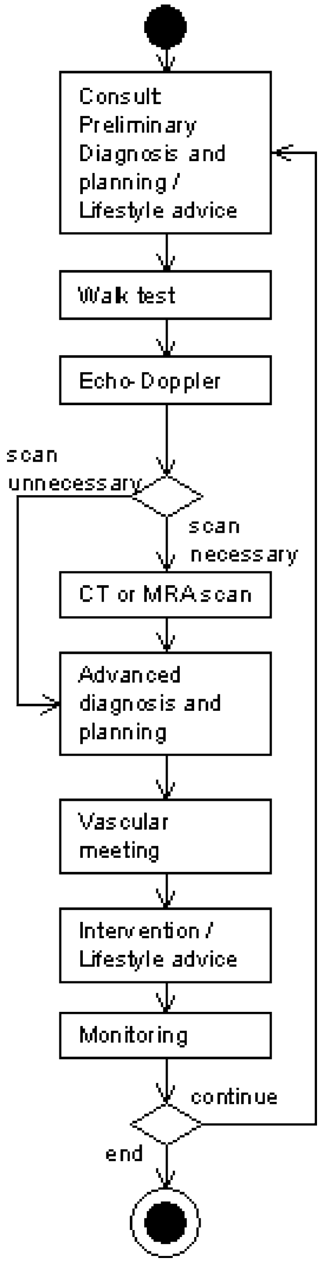

Fig. 2 Simplified trajectory vascular diagnosis and treatment planning

Fig. 3 Collaboration during scan assessment on large light boxes, amidst other systems and equipment

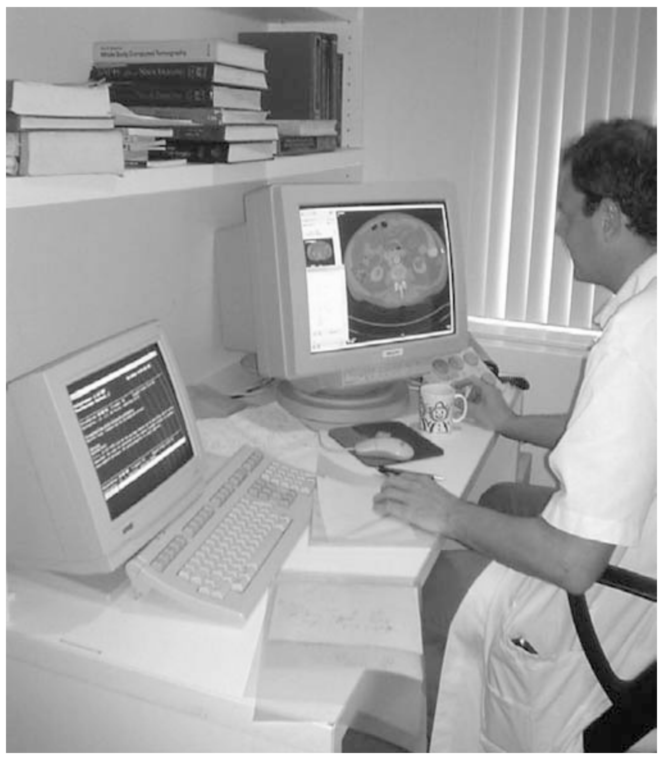

Fig. 4 Individual scan assessment using single person workstation

resources and high levels of computational performance are some of the most promising characteristics of the Grid.

5.5 Physical environment

Most of the facilities and rooms used for assessment of scans are dimly lit to help the human eye in assessing scan prints. The equipment used, where scan prints are assessed, are mainly large automatic light boxes (Fig. 3), pens for pointing, rulers for measurements, voice recorders and telephones. The environment is hectic and noisy, a large number of people is present in the departments, informal discussions are going on, sudden emergencies occur, beepers go off and calls have to be made. When electronic patient files are used, other documents and information are often being viewed simultaneously on extra monitors and stacks of paper files are kept at hand (Fig. 4). Some hospitals have rooms especially for group assessment of scans, such as vascular meetings, where beamers are used, with a staff member operating (a) workstation(s).

5.6 Technological environment

A wide array of technology, software, tools and equipment is already in use in radiology and surgery departments. Possible input from, and output to, these systems needs to be considered. Some available systems were not used because they could not exchange data with systems that had been in use before. Most of the visited hospitals were in varying stages of transferring to use of electronic patient files, and not all patient data was available electronically yet or electronically exchangeable between departments. Limitations with respect to data storage in the hospitals need to be considered. Some hospitals do save scan data to CDs, but scan data was not saved permanently in most hospitals. Data is often simply overwritten when the data storage capacity of post-processing workstations has run out.

5.7 Imaging trends

The findings generally fit in with the three trends in medical imaging procedures as reported in [20]:

1. Additional costs of better diagnosis alone are no longer accepted; most clinical pictures can be diagnosed sufficiently. Extra expenses are only accepted if the additional information has an impact on the therapy procedure. Related in the study is the efficiency requested and the expressed consideration that extra tests and imaging are only applied if they are perceived as truly valuable to diagnosis and treatment success.
2. Imaging procedures are increasingly used during interventions and not only during diagnosis. In this study, this was especially true for possibilities for improved imaging during endovascular interventions.
3. Moving from 2D to 3D. 3D information is gathered with new scanning techniques and this information is used. However, from this study, it seems that, predominantly, 2D representations are still used. The findings suggest that improvements in efficiency and accuracy of use of 3D reconstructions are needed.

The following section will discuss the implications that the findings might have on the development process of the VRE.

6 Discussion and conclusion

In this section, the practical implications for system development will be derived from the results. Additionally, possible criteria are discussed for the most appropriate degree of immersiveness for VR applications. Finally, the applicability of contextual analysis methods to support the development of VR applications will be discussed.

6.1 Practical implications for system development

In answering the first research question, a number of requirements and constraints can be identified for systems supporting scan assessment in the study results. Effectiveness, efficiency and cost limitations are of great concern in the hectic environment of radiology and vascular departments and should be supported in the VRE's development. The main issues and constraints identified for redevelopment efforts are listed below:

- Data availability, integration and compatibility. There is limited data storage available in hospitals, limited availability of complete scan data sets and the need for incorporation of other electronic data and hard-copy information. For a system to be successful, it needs to be compatible with work practices and systems already in use.
- Choosing the appropriate input mode. The observed environments are often noisy and hectic, which leads to the conclusion that the use of voice recognition would be difficult. The system should support cooperative work and vocal discussion.
- Physical environment. Limited space is available for new pieces of large equipment. It has to be possible to use systems in hectic, dimmed conditions with a large amount of background noise.
- Needs for simulation capability. Simulation and measurements should be adapted to the user's needs and requirements. One of the main success-factors for a system like the VRE is the reliability of simulation results. Specifically, in a medical context, simulation has to have been verified with real data.
- 2D and 3D visualisation. Current expertise of prospective users lead to the conclusion that both 2D and 3D should be offered in a system. Quick and easy switching or dual-presentation should be available. Issues with 3D visualisation and manipulation, such as difficulties in navigation and orientation, need to be dealt with.
- Less is more. Functionality offering information that is perceived as unnecessary or already readily available is not appreciated.
- Speed. Long computation times and inefficient interaction via the user interface with systems are unacceptable.
- Collaboration. It is vital that a system supports collaboration, provides possibilities to interact with data concurrently and that ample physical room is available. Responsibilities and hierarchies within prospective user groups should be respected.
- Budget. Budget is constrained. The added value of a system has to be confirmed by research and accepted by prospective users.

These constraints are not only relevant to the VRE, but for other systems applied in both similar contexts and those outside a medical environment. Many issues identified in this contextual analysis are similar to general considerations for system design offered in literature, such as [9] and [19]. The identified issues are examples of information relevant to system development that can be gained from contextual analysis.

6.2 When is choosing VR right and how to choose 'the right VR'?

The second research question concerned the type of system and the degree of immersiveness appropriate for a VR system for a particular context of use. The findings indicate that a desktop application would be more suitable in the explored context of use than a large, completely immersive virtual environment. The reduction in hardware costs coupled with the greater familiarity of users with desktop computing make desktop VR a viable alternative to an immersive application. In the case of the VRE, it was concluded that a desktop application might be more suitable in a clinical setting. Findings suggest that, in the domain of vascular diagnosis and intervention planning, fully immersive systems offering simulated operating theatres might be more suited to teaching situations. Effectiveness of these systems for training purposes needs further research.

The findings offer an indication of factors which influence the effectiveness of a VR system and the appropriate degree of immersiveness. Table 2 offers an overview of a number of possible criteria.

This list is certainly not argued to be a complete overview. Future research is hoped to provide more insight into these criteria so that a concise set of guidelines can be developed. Demiralp et al. [8] have performed an anecdotal, very small scale study comparing VR modalities resulting in similar, and additional, criteria. Their hypothesis, similar to our view, is that for exocentric applications, which focus on simulating an object desktop VR (in our definitions), would be preferable to a CAVE. More thorough research is, however, needed in this area.

Parallels can be drawn to other guidelines offered in literature on human–computer interaction. General (ergonomic) guidelines on system development are offered by, for example, [9]. Guidelines on the design of virtual environments have been offered in the form of VR-specific usability heuristics in [13, 25, 14, 26, 17, 29]. These do not usually deal with choosing a particular kind of VR. Beyond the limits of scope, it also needs to be kept in mind that guidelines have other limitations, (see, for example, [9, 28]); new technologies can also render specific guidelines obsolete, or new ones necessary, in the rapidly developing field of VR that this is to be considered.

Table 2 Possible criteria for choice of VR environment and degree of immersion

	Desktop VR	'Fish tank' VR	Fully immersive VR
Budget	Constrained budget	Relatively constrained budget	Ample budget
Focus	Exocentric focus	Exocentric focus.	Focus on exploring environments
Space	No room for specialised equipment	Physical space available for a limited volume of extra equipment	Ample dedicated physical space available
Time	No extra time can be spent on using specialised equipment and complex manipulation. Hectic context of use, users need to switch tasks quickly	Insight into a complex structure is needed and decision speed is less vital	Insight into a complex structure is needed and decision speed is less vital, dedicated context of use can be supplied
Training	Users are less inclined to learn to use new equipment and technology	Users are willing to learn to use new equipment and technology	Users are willing to learn to use new equipment and technology
Compatibility and integration	Compatibility and integration of different types of data is very important and not attainable with current immersive environments	Compatibility and integration of different types of data is sufficiently attainable with fish tank/immersive environments	Compatibility and integration of different types of data is sufficiently attainable with immersive environments
Stereoscopy	Stereoscopic visualisation and immersion do not significantly add to task performance, or 3D images would have to be combined with 2D images	Stereoscopic visualisation and immersion significantly add to task performance	Stereoscopic visualisation and immersion significantly add to task performance
Use in education	For individual 'tutorial' training, for example at home [31]	For individual training when e.g. haptic feedback is of value	Education in lecture modes [31]
Collaboration	Quick, informal collaboration of a small user group needs to be supported	Collaboration of large groups is not necessary. Very small groups can be supported	Collaboration can be supported by ample interaction devices and physical room

6.3 Contextual analysis and ethnographic methods in the VR development cycle

Contextual analysis offered useful information to support development of the VRE. Some considerations could have been identified using other methodologies in human–computer interaction, such as pluralistic walkthroughs, prototype evaluation and user involvement, as described by [19, 9]. However, important insights gained in this study to guide system design would unlikely be discovered without contextual analysis of the environment of use. The chosen ethnographic approach to contextual analysis, combining interviewing with observation, proved to be useful for exploring context of use. Without interviews, observations would be more difficult to frame in the work process, and would not be understood quite as easily. Interviews alone were not found to yield enough insight. This was illustrated by comments during interviews that the researcher should see things for herself in a real-life situation because they are difficult to explain. Most of the surprising pieces of information were gathered through informal discussion during observations. Since these could not be anticipated, they could not likely have been gathered during a formal interview.

When conducting an ethnographic study to aid system development, it is useful to keep in mind concerns about non-anthropologists doing small-scale semi-ethnographic work, such as limited generalisation possibilities of small studies and methodological knowledge needed [10]. Taking an opportunistic approach and using participants as starting points to recruit more participants is useful, but can result in a biased sample, and participants may be self-selected because of their interest in technology. In this study, this effect was controlled by trying to recruit various participants from different hospitals, but the effect cannot be ruled out. It should be noted that ethical considerations have to be made in studies such as these, especially in a medical context, where the researcher can be confronted with personal patient information and emotionally charged situations. The researcher should be trained in ethnographic methods, interviewing, observation and analysis. Contextual analysis takes considerable time and effort and a defining success factor of contextual studies in system development is making sure that findings are fed back into the development process.

Taking such issues into account, this study shows that carefully studying users and context of use offers crucial information for the development of VR systems. Context analysis can help decide whether VR, and which type of VR, would be most applicable for a given situation. Even a small-scale study, such as that reported in this paper, proved to be extremely useful in identifying needs and potential user-problems with a VR system in development.

7 Limitations and future research

Currently desktop and 'fish tank' VRE versions are in development to try and cater for user needs and requirements in varying contexts. Future research should investigate which evaluation methods are most applicable for systems such as the VRE, and which methods are the most applicable in exploring context of use. Research is needed to gain more insight into real-life needs and requirements for systems such as the VRE. Future research will take into account the limitations of this study. Development of the VRE will include more representative user involvement [31]. More detailed contextual analysis and quantitative analysis into the general issues that this study raises is planned for the future. The research described here has been carried out for a specialised application area, but the methodology and its results can be applied more broadly. Considering context of use and usability is very important in achieving usable systems that are applied outside the laboratory.

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