On the Usage of Different Work Analysis Methods for Collaborative Review of Large Scale 3D CAD Models

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Abstract. Human work interaction design is an emerging discipline that aims to encourage empirical studies and conceptualizations of the interaction among humans, their variegated social contexts and the technology they use both within and across these contexts. In this paper we describe and elaborate around the usage of different work analysis methods in a complex, real world work domain: collaborative review of large-scale 3D engineering models. The analysis is based on (i) input from experts in the oil platform engineering field, (ii) previous and related work and (iii) application of different methods considering the recent advances in technology. We conclude that hierarchical task analysis was not effective in obtaining a clear, common vision about the work domain. Storyboarding was the most useful technique as it allowed discovering novelty factors that differentiate the solution and improve the usability of the product, thereby supporting the human work at offshore engineering design and review sessions.

1 Introduction

Human work interaction design [1] is an emerging research field within HCI that is focused on the user's experience of tasks (procedures) and the artifact environment (constraints in the work domain). That analysis and interpretation of human work is eventually manifested in the design of novel, technology-based products, systems and applications [1]. In this paper, we report on a seven-month research study around the requirements elicitation, scenario design and storyboarding processes for creating a new Virtual Reality (VR) distributed application to support a complex work domain: the collaborative review of large scale 3D engineering models, in the context of the oil and gas industry at a very large organization [2].

The current way of designing industrial plants relies on the communication among experts in several areas of the field, and on tools that allow the specification and simulation of the site. VR resources are used to visualize and interact with complex 3D environments in real time. Several engineering simulations employ VR to foresee the results of complex industrial operations.

In this paper, we analyze the user tasks at stake during collaborative sessions of 3D CAD models design and review in the specific context of the oil and gas industry. By studying the users' work and needs, the related existing work and the possibilities that recent advances in multimodal technologies, we expect to shed new light into how an integrated environment should be conceived and designed in order to positively influence the collaboration levels between dispersed teams of engineers that need to review oil platform problems and to design solutions for those problems.

Our main contribution to the Human Work Interaction Design (HWID) field is the comparison of the effectiveness of different work analysis and design methods towards establishing a common vision regarding a new product for the oil and gas industry engineering models' review, in a collaborative manner. This is especially important for gaining new insight about the relative advantages between the different methods in a highly complex, real world work domain.

2 Background and Related Work

Human Work Interaction Design (HWID) is an emerging approach that promotes a better understanding of the relationship between work-domain based empirical studies and the iterative design of prototypes and new technologies [1]. HWID's goal is to encourage empirical studies and conceptualizations of the interaction among humans, their variegated social contexts and the technology they use both within and across these contexts.

To achieve this, HWID promotes the use of knowledge, concepts, methods and techniques that enable user studies to procure a better apprehension of the complex interplay between individual, social and organizational contexts and thereby a better understanding of how and why people work in the ways they do. Therefore, one of the main characteristics of HWID as an interaction design approach is to focus the analysis on the how's and why's of people's work. HWID also tries to promote a better understanding of the relationship between work-domain based empirical studies and iterative design of prototypes and new technologies [12]. HWID's roots lie in Cognitive Work Analysis (CWA) [1, 6]. Cognitive Work Analysis (CWA) is a multidisciplinary framework for the analysis, design, and evaluation of human work developed by Rasmussen, and colleagues [7]. Its purpose is to guide the design of technology for use in the work place. CWA helps an analyst identify the activities and agents that are needed for a system to effectively fulfill its functional purpose. CWA can also be regarded as a formative process that focuses on an ever-increasing number of dynamic constraints that systems present nowadays, rather than prescriptive methods of working.

Storyboarding [4] is a common technique in HCI and design for demonstrating system interfaces and contexts of use. Despite its recognized benefits, novice designers still encounter challenges in the creation of storyboards. Many researchers have studied the benefits and disadvantages of storyboards, including Truong and colleagues [4], who presented two formative studies designed to uncover the important elements of storyboards.

Activity-based analysis [5], in particular activity theory methods, incorporates the notions of intentionality, history, mediation, motivation, understanding, culture and community into design. In particular, it provides a framework in which the critical issue of context can be taken into account.

In hierarchical analysis [3], another work analysis method, the instructional designer breaks down a task from top to bottom, thereby, showing a hierarchical relationship amongst the tasks, and then the instruction is sequenced bottom up. Task analysis often results in a hierarchical representation of what steps it takes to perform a task for which there is a goal and for which there is some lowest-level "action" that is performed [3].

3 Usage of Different Work Analysis Methods

In the offshore engineering field, the project of deep-water production systems, including oil platforms, ships and all the subsea equipment that plays a part in the production process, is currently designed by means of complex computer modeling systems. The design of a new production unit is a lengthy and expensive process, which can last many years and consume hundreds of millions of dollars, depending on the complexity of the unit and the maturity of the technology required to make the project technically and economically feasible.

Offshore engineering projects involve not only geographically distributed teams but also teams of specialists in different areas using different software tools, both commercial and internally developed. While the interoperability of those tools is still an issue, it is a mandatory requirement for any collaborative solution.

One of the objectives we had was to establish a sound requirements document stating clearly the desired project's objectives, requirements and specifications, as well as outlining scenarios for the solutions proposed and their evaluation procedures.

We used the resources available at Tecgraf-PUC Rio (the research arm of Brazil's largest oil industry company, Petrobrás) [2] to conduct user observations and informal interviews with the engineers involved in collaborative engineering design and review activities. The final result we obtain is very important, since it allows us to understand: (i) the application domain, (ii) the problem of designing and reviewing CAD models, and (iii) the needs and constraints of the system's stakeholders. Additionally, and perhaps most importantly, we elaborate on the relative advantages and disadvantages we faced when applying different work analysis methods: activity-based analysis [5], hierarchical analysis [3] and storyboarding as a way to understand the value of possible solutions [4].

3.1 Activity-based analysis

Activity 1: Designing and reviewing engineering models. Design review is the process of checking the correctness and consistency of an engineering project while making the necessary adjustments [2]. In the session, users can manipulate objects, highlight and create annotations, do measurements, check the proper ergonomic design. The ability to move, rotate and scale objects is important for various purposes, such as joining models, viewing hidden areas, planning the placement of new devices, and simulating a maintenance or intervention operation in a process plant. Moreover, integration with an engineering database from the CAD system is useful to create annotations emphasizing critical parts (Figure 1). Comments attached to objects can also be used as recommendations for project management. Figure 1 shows a measurement taken for planning the movement of a large tank in a production unit. Users create annotations to guide the maintenance procedure and animate the entire operation. Finally it is possible also to confirm if the space distribution of the engineering devices conforms to the ergonomic needs for operation and maintenance.

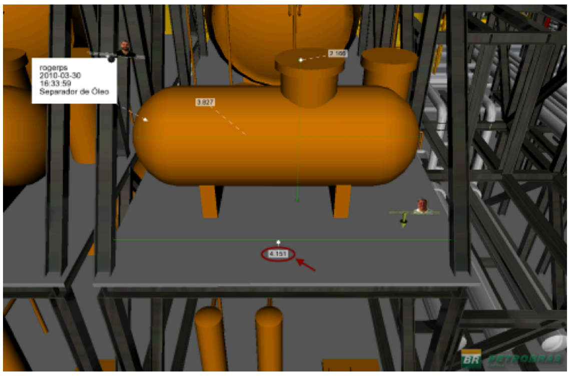

Fig. 1. Annotating and measuring activities involved during design and review.

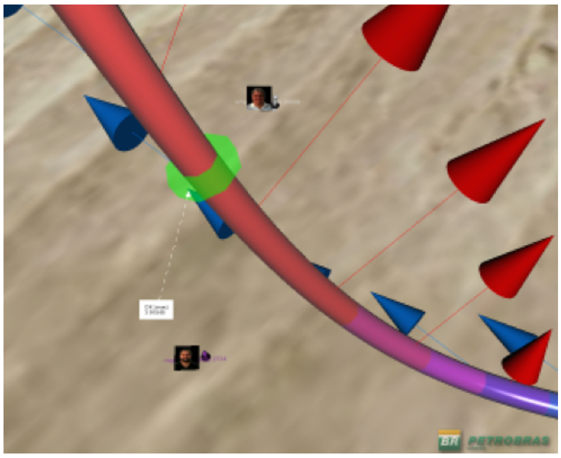

Fig. 2. The second activity identified: riser analysis.

Activity 2: Riser analysis workflow. An important step in deep-water oil exploitation is the elevation of the oil from depths over one thousand meters to the surface. Oil platforms use ascending pipes, called risers, which are tubular structures that convey oil and/or gas from the wellhead on the sea floor to the platform's separator system tanks [2]. To certificate the operation of the risers for their entire lifecycle (30 years or so), simulations of the stress applied to the riser system are conducted based on meteo-oceanographic data about wind, tide and water currents. Simulations are made under extreme environment conditions to test stress resistance. It is important to perform fatigue analysis studies to evaluate the most critical regions of the risers affected by cyclical stress in order to guarantee their integrity during their lifetime.

Conclusions after the activity analysis. The problem of providing engineering teams with effective tools for collaborative work is becoming increasingly important, not only because teams are increasingly working distributed throughout the world, but also because current tools still lack support for collaborative engineering design and review, either in co-located or distributed settings. The oil industry is especially well positioned as a potential demonstrator for research developments in this field, since it's one of the largest user bases of high-end hardware and software.

Collaborative Virtual Environments (CVEs) place the emphasis on providing a common virtual space of interaction to distributed teams, a space where they can meet as if they were face to face, while sharing and manipulating the relevant work artifacts, in real time. In the case of this application domain, the oil industry, there is a relevant issue that motivates this project: the working force is aging, and the industry is not attracting younger generations of workers. Therefore, the trend of conceiving "digital oil fields" capable of being controlled remotely is becoming strategic for oil companies.

The essential scenario for solving this problem is a 3D interactive environment that represents the oil platform and associated subsea equipment, in a multi-touch virtual control room approach. The oil industry application domain, as referred in the previous section, fits well into the design and evaluation of novel environments, because of several factors. First of all, the very nature of the work performed by the engineers themselves, which is often carried out in collaborative, geographically apart settings. Secondly, because they can provide real world data in the form of large-scale CAD models, thus acting as reliable demonstrators of the project's results. And finally, because there are - to our knowledge - very few research efforts specifically targeted at this application domain.

The final product the team performing this work analysis identified is essentially a large-scale virtual environment based on multi-touch and remote collaboration features for increased awareness and increased sense of presence among teams of oil industry engineers. The final prototype should consist of a set of computer clusters for multi-projection environments running the software designed, developed and evaluated throughout the project.

The main idea underlying this vision is that if we provide engineers with multi-touch collaborative tables and walls, we can achieve a state-of-the-art environment with an interesting application to the oil industry: a system that finally allows these users to find, navigate and visualize their complex CAD models' data in a much more satisfying and effective way. This goal can be measured in two dimensions: the usability dimension, making use of well-know Human-Computer Interaction (HCI) evaluation methods and the collaborative dimension, using traditional measures for determining the levels of remote collaboration between geographically dispersed teams.

3.2 Hierarchical task analysis

In this work analysis, the hierarchical task breakdown was actually the first step the team took. The analysis was based on input from experts in the oil platform engineering field, several brainstorming sessions, semi-structured interviews and other meetings. The result (after many iterations) is shown in Figure 3. One of the positive aspects was the fact that the team was able to identify the most important tasks and the most intense tasks from a cognitive perspective. The downside was that the team remained without a clear picture about what should be designed and implemented, what was more important and what was less relevant. Other methods, as we will see in the next section, proved far more efficient in gaining a common vision.

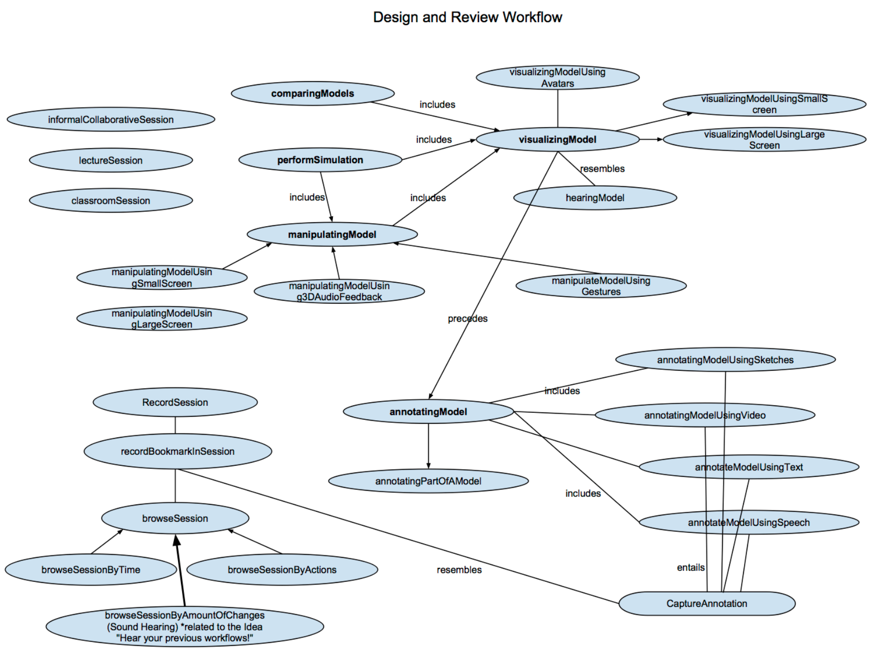

Fig. 3. Task case map for our work domain analysis.

3.3 Storyboard-based analysis

Since the team had difficulties in synthesizing the work of offshore engineering design and review teams, we decided to employ storyboards [4] to facilitate the ideation process as well as to better explore the possible design concepts. Figure 4 illustrates a particular one (textual descriptions omitted for brevity).

Storyboarding was particularly beneficial to this project's HCI design. It allowed matching the possibilities offered by recent advances in mobile, multitouch technologies with the cognitive tasks at stake.

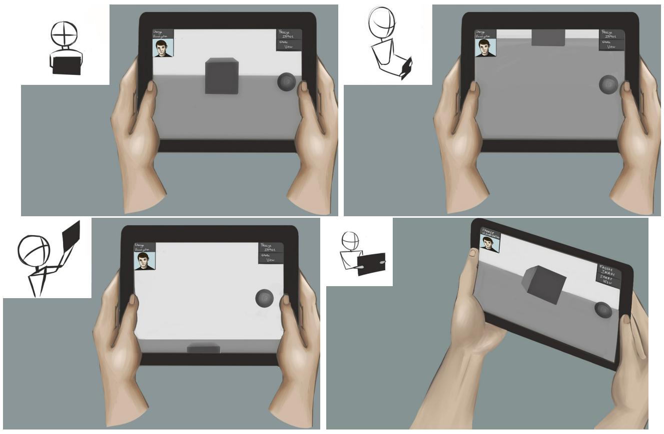

Fig. 4. A particular part of the storyboards created, illustrating one of the navigation modes.

After long discussions, the team chose to employ the power of tablets to create different navigation modes in a collaborative prototype where CAD models are simultaneously shared and visualized through Wi-Fi, while the user can also videoconference with other remotely located engineers. One of the navigation modes is depicted in Figure 4. The storyboard illustrates the use of sensors to control the camera's orientation. Translations are performed through multi-touch gestures. The user is free to work whenever he wishes to, which is a significant step further regarding the current system being used by the company (based on traditional desktop-based PCs). Therefore, we can conclude that storyboarding was an effective technique to identify novelty factors that could enhance the usability of the proposed product.

3.4 Final Solution

The system is built upon the concepts of intuitive visualization and cooperation. To achieve our objectives while using those concepts we built several test navigation modes. Two of them ended up being selected for further improvement. Despite an apparent similarity on interaction styles, the two modes are quite different in both the technical and user interaction components: The first version uses built-in inertial sensors to position the virtual camera in a first person view manner, just as if the user was holding a real video camera and filming around. To allow the user to move around, it uses an in-screen touch-based joystick. The second version uses the tablet's camera to track its position and orientation, relative to a tracker. It works as if the user was filming the object on top of a table allowing all the natural movements he would do.

The second version can't use the built-in inertial sensors exclusively as none of them gives translation (the position can be doubly integrated from acceleration but the errors and drift are too significant to be useful). GPS, another possible alternative, can only work outdoors and doesn't have enough accuracy for this problem. The solution is to use the camera to track an object and from that deduce the tablet's position and orientation. The camera tracking is a suitable solution as it provides a surprisingly accurate translation, rotation and, indirectly, zooming without the need of another artificial input (like the virtual joystick on the first-person view navigation mode). The first-person version can be shared between multiple tablets allowing one user to guide or show some feature on the model to the other users. Figure 5 illustrates this. The microphones and the front cameras are shared between multiple tablets, creating a videoconference that improves the cooperativeness of the system. A minor feature (freezing the camera) was also implemented. It allows users to freeze the current view and move around the tablet without fearing that the movements performed will change the camera's position and without stressing body positions. This feature can be used when showing certain features on the models or even when working on the models themselves on future work.

Fig. 5. Two engineers engaged in a co-located collaborative design and review session.

4 Comparison between the different methods

Hierarchical task analysis was the first method employed in this product's HCI design. Perhaps because of that it was the method that required more effort in order to produce a reasonable set of artifacts describing the engineers' work.

Task analysis taken from a hierarchical perspective had its advantages. First, it allowed the entire team to understand the priorities in the design that should be taken into account. It also had the advantage of promoting discussion around a single diagram, which made it easier to reason about human work without losing the "big picture". However, this method was the least efficient of all. The team remained without a completely clear picture about what should be designed and implemented, what was more important and what was less relevant.

Secondly, the method for trying out a more efficient work analysis was activity-based analysis. We tried to write a complete, detailed description of the collaborative engineering activities that are performed by offshore engineering teams, working both in the oil platform as well as in the central company's offices.

The activity-based analysis effort was overall positive. By forcing a detailed description of the activities at stake, the team spent a lot of time and effort, but at least was able to reach a better work analysis. It allowed identifying a final, concrete product, essentially a large-scale virtual environment based on multi-touch and remote collaboration features for increased awareness and increased sense of presence among teams of oil industry engineers. The disadvantage we encountered was the fact that activity-based analysis did not allow the identification of novel ideas, and the brainstorming processes that usually lead to better UI designs was not well undertaken.

As mentioned before, storyboarding was the most useful technique as it allowed discovering novelty factors that differentiate the solution and improve the usability of the product, thereby supporting the human work at offshore engineering design and review sessions.

5 Conclusions

Supporting the needs of offshore engineering teams is an important industrial problem that should be addressed taking into account the rapid evolution in user interaction styles available. The potential for innovative solutions that is brought by tablet-based computing is enormous. In this paper, we described the industrial creation and evaluation experience of a new mobile system for collaboratively navigating and reviewing 3D engineering models, applied to the oil industry. We highlight that storyboards and scenarios were an effective way to elicit requirements together with oil industry experts, as opposed to high-level task analysis.

Our main contribution to the Human Work Interaction Design (HWID) field is the comparison of the effectiveness of different work analysis and design methods towards establishing a common vision regarding a new product for the oil and gas industry engineering models' review, in a collaborative manner. This is especially important for gaining new insight about the relative advantages between the different methods in a highly complex, real world work domain.

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