A Multimodal Tablet-based Interface for Designing and Reviewing 3D Engineering Models

Pedro Campos
Madeira Interactive
Technologies Institute
Caminho da Penteada
9020-105 Funchal
351 291 721 006
pedro.campos@m-iti.org

Hildegardo Noronha
Madeira Interactive
Technologies Institute
Caminho da Penteada
9020-105 Funchal
351 291 721 006
hildegardo.noronha@m-iti.org

ABSTRACT
The usage of multimodal user interfaces has revolutionized many different activities. However, most of the interactive technologies deployed in real world engineering contexts are still difficult to use, especially when engineering teams need to collaboratively visualize and review large-scale 3D CAD (Computer-Aided Design) models. This is the case of the oil platform industry, which necessarily involves the review and manipulation of large CAD models. In this paper we present a novel solution, based on multitouch and accelerometer input, which was designed and evaluated in close cooperation with researchers and engineers of a large oil industry company. We evaluated two different conditions: using multitouch-only input and using multitouch coupled with accelerometer-based input. Statistical analysis of quantitative data suggests that the second condition is faster and less error-prone than simply using multitouch-only input. Additionally, qualitative data showed that users perceive the multitouch-only interface as being more accurate, but more difficult to understand and use.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – Input devices and strategies

General Terms
Design, Human Factors

Keywords
Multimodal interfaces, CAD, motion-based input, multitouch user interfaces

1. INTRODUCTION
Multimodal user interfaces have revolutionized the way we work by combining different input modalities [1]. On the other hand, multitouch technology has become mainstream and tablet-based multitouch has emerged as a mobile interaction style standard, especially due to the success of products such as the iPad.

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Despite these significant advances, most of the interactive technologies deployed in real world design and engineering contexts are still regarded as being difficult to use, especially when engineering teams need to collaboratively visualize and review large scale 3D CAD (Computer-Aided Design) models. This is what happens with the oil platform industry, which necessarily involves large teams that review, manipulate and discuss around large CAD models, which are sometimes difficult to visualize and navigate through.

In this paper, we argue that the manipulation of CAD models can benefit significantly from the so-called natural interaction techniques [2]. More specifically we hypothesize that multitouch accelerometer-enabled tablets can be useful for engineering teams that are interested in design and review tasks. We present a novel multimodal interface designed to support those tasks in a mobile context of usage (e.g. one engineer at the offshore oil platform, another engineer at the central office in the mainland).

This paper is organized in the following way: First, we review the state of the art in two different aspects: (i) tools and environments for visualization, design and review of CAD models, and (ii) recent advances in multimodal user interfaces. Secondly, we present a mobile user interface specifically conceived through close collaboration with researchers and practitioners at a large oil platform company. CEDAR is an acronym for “Collaborative Engineering Design And Review”, which is the ultimate goal of our research. We also describe the results from a user study where we performed a statistical analysis of the performance in terms of task completion times, number of errors and subjective preference, in two different conditions: using multitouch-only and using multitouch coupled with accelerometer-based input. We conclude by describing some of the lessons learned and outline novel research avenues for the near future.

2. RELATED WORK
Several tools and research prototypes have been developed with the goal of improving the visualization, manipulation, design and review of 3D CAD models. Giga-Walk [3] and REVIEW [4] are academic solutions for real time visualization of very large models. They use advanced techniques such as occlusion culling to achieve good performance levels. Nevertheless, they lack integration with VR (Virtual Reality) resources, such as different displays and interaction devices, while also exhibiting some difficulties when rendering complex models.

Recent studies focused on the impact that CAD tools may have on creative problem solving for engineering. Researchers have examined how the computational environment may influence the engineers' ability to design creatively [5]. Surveys have shown good support for enhanced visualization and communication, circumscribed thinking – when the designer's ideas are circumscribed by the CAD tool's abilities – and for premature design fixation (premature commitment to a given design solution) [5]. Other studies went one step further and investigated how to reduce the visual cluttering through the use of auditory cues [6], an interesting approach that is currently outside of our scope, but that could be considered in the future.

This paper is focused on design review of CAD models, i.e. the process of checking the correctness and consistency of an engineering model, and performing the necessary corrections to it [7]. The application domain we chose, for reasons explained ahead, is the oil industry. In this domain, visualization techniques and multimodal user interfaces can be particularly helpful in the engineering design and review process, for instance to assess the safeness of different emergency-escape pathways in the event of an emergency occurring in the oil platform [7]. Current tools have problems dealing with models featuring a high level of details [SaRaSo08], since they have to provide the user with a real time interactive visualization of the model(s). Our approach proposes the usage of mobile tablets with multitouch input combined with motion-based input to aid these tasks. Simultaneously it has the advantage of allowing engineers to visualize CAD models "in the wild", which is particularly advantageous for oil platform engineering teams.

Other examples of multimodal user interfaces in professional work environments include real-time simulation of 3D complex phenomena, training and edutainment, telepresence and telerobotics, and even simple business meetings [8]. However, our purpose here is to focus on the oil and gas industry. This industry is well positioned to drive the directions of future research since it's one of the biggest users of high-end hardware and software [8, 9]. The cognitive processes involved in the three-dimensional engineering tasks at stake are also the perfect playgrounds for evaluating novel multimodal user interfaces like the one we present in the following section.

3. CEDAR MOBILE USER INTERFACE

3.1 Task Analysis

One of the main objectives of the engineering departments at large industries such as oil companies is the construction of integrated information systems to control their projects, offering resources for the 3D visualization of their models with enough realism to be used for virtual prototyping, design review, change management systems, and training, among other activities. The engineering, design and review of CAD models are complex, collaborative activities, in particular when large-scale models are involved, as in the oil platform industry.

The use of advanced computer graphics and virtual environments *per se* has sparked a digital revolution in many activities, thanks to the novel visualization and manipulation possibilities they provide. Ironically, engineering teams still regard the usage of some of these systems as laborious and complex, and it hasn't been until recently that collaborative virtual environments have finally started to move out from research labs into the industry.

In order to gather information about usage scenarios, task analysis, user profiles and context, we conducted several meetings with researchers and engineers at a large oil platform company. We complemented this analysis with research literature results. We obtained a lot of useful data, and filtered out the most relevant issues to design a novel user interface aimed at supporting the engineering design and review activities.

In a review session, engineers manipulate 3D engineering objects, creating annotations and performing measurements. 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 maintenance or intervention operations in a process plant. Comments attached to objects can also be used as recommendations for project management. Figure 1 (a screenshot taken from of the desktop-based software currently being used by the engineering team) shows a measurement made 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.

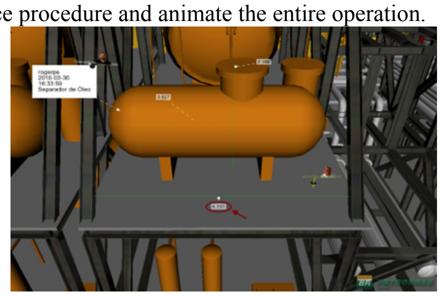

Figure 1: The desktop-based software currently being used by the engineering team to review and annotate the oil.

3.2 System Design

Our system was designed in order to allow multiple tablets (iPads) to communicate synchronously according to changes being per-formed in the 3D CAD models and therefore it was based on a Wi-Fi and Bluetooth communication framework to achieve a sound solution. The NivevehGL (www.nineveh.gl) framework was used for 3D visualization of models and achieved a very good performance, especially if we take into account the device's limited memory and processing power. In fact, the 3D models used by the oil industry company are very large as they are typically used in a powerful cluster of interconnected PC's [7].

Figure 2: The multitouch-only interface uses two "joysticks" to allow the engineer to navigate through the oil platform model.

There are two variants of the CEDAR mobile user interface: mul-titouch-only and multitouch coupled with accelerometer-based input. Figure 2 illustrates the multitouch-only user interface. It uses two "joysticks" (the circular images underneath the user's fingers), which are used to navigate through the 3D platform. The left button is used to control the displacement along the Z-axis (i.e., moving forward or backwards), the right button is used to simultaneously control the X and Y position of the camera (i.e. where the user is looking at).

In the second version, we replaced the right "joystick" button with accelerometer-based input, so that users can move forward or backwards using the left button, but can simply tilt the tablet device left/right or up/down in order to control where they are looking at. Figure 3 illustrates this.

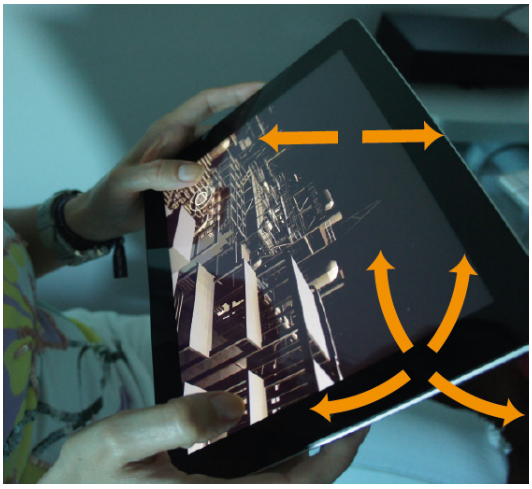

Figure 3: The multitouch + accelerometer-based interface uses the same "joystick" at the left side of the screen, but uses the accelerometer to control where the user is looking.

3.3 User Evaluation

3.3.1 Experimental Setup

In order to compare the two different conditions (multitouch-only and multitouch coupled with accelerometer-based input), we con-ducted an experiment with eleven participants (three female users), all civil engineering final year students. Participants were 21-32 years old and only one was left-handed. The testing began after an initial briefing session of about fifteen minutes.

We used a within-subjects experimental design where the partici-pants performed two tasks (T1 and T2, described below), under two different conditions: multitouch-only and multitouch coupled with the accelerometer-based input. For the sake of brevity we will refer to these two conditions (our independent variables) as MT and MT+A. In a random order, half of the participants performed the tasks under MT and then under MT+A, the other half performed the tasks under MT+A and afterwards under MT-only. Every participant started out with Task 1 (simpler than Task 2) and then moved on to perform Task 2. Both tasks were specifically designed in close cooperation with engineers and researchers at a very large oil industry company, with the specific goal of attaining task cases that would constitute a representative sample of the type of activities faced in the real world quotidian endeavors of oil platform engineers. In other words, our project's demonstrator sub-team validated them.

For each trial session, we measured the task completion time, the number of errors and the answers to a 5-point Likert scale survey about the two different user interfaces. Therefore, the experiment was a 2 x 2 repeated measures design with 2 user interfaces (MT and MT+A) and 2 tasks, T1 and T2.

3.3.2 Task 1: Navigating through a path

Participants started out by performing this task, which is simpler than task 2. In this task, all the participants need to do is simply navigate through a path that is highlighted on the virtual floor of the platform, until they reach a certain spot. The task is obviously considered complete when they reach that spot.

3.3.3 Task 2: Placing a new device

In this task, an engineer is going through the decision-making process of placing a new device in the oil platform and choosing the best location to place it in the platform. He has to navigate through the platform taking measurements and then analyze several possible locations to find the best spot to place the new device. The task ends when the user indicates the chosen spot.

3.3.4 Task Completion Times

As mentioned before, task completion times were measured and Figure 4 shows the obtained results for the average completion times in the different conditions and tasks.

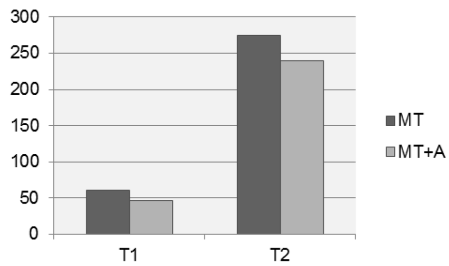

Figure 4: Average task completion times in seconds.

In order to determine the statistical significance of these differences, we performed a two-way ANOVA with α=95%. The main effect for the user interface (MT versus MT+A) was found to be significant with $F_{1,10} = 5.8$, $p < .05$. Under the MT condition, par-ticipants took 167.5s to complete the tasks whereas under the MT+A condition they took 143.1s.

As expected, the average completion time for task 1 was lower than task 2 (53.7 seconds versus 256.8 seconds).

Therefore we concluded that the average task completion time was significantly lower in the MT+A condition. This is inline with the following results and suggests that the accelerometer input is a good solution to couple with the "move forward/backward" touch-based joystick.

3.3.5 Number of Errors

For this experiment, we defined the number of errors committed by participants as (i) the number of times the user deviated from the pre-defined path along the oil platform, for Task 1; and (ii) the number of times the user deviated from his/her desired path along the platform when trying to find a spot for placing the device, plus the number of times the user moved backwards beyond a certain threshold. This number was measured for each condition, and the results are illustrated in Figure 5.

We performed a one-tailed t-test to assess whether or not the MT+A condition produced significantly fewer errors than the

MT-only condition, at a confidence level of 95%, and we obtained t(10)=1.72, p=0.147 for Task 1.

For Task 2, we obtained t(10)=2.08, p=0.012. Therefore, we con-clude that the differences in the mean number of errors were not statistically significant for the first task, but were significant at 95% confidence for the second task.

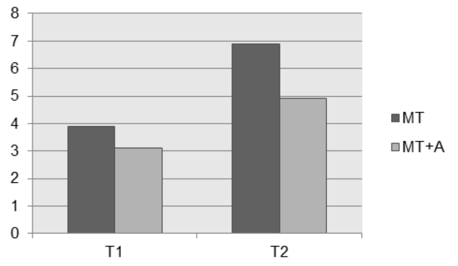

Figure 5: Average number of errors per participant.

3.3.6 *Survey*

After the testing phase, participants were asked to fill in a short survey with 7-point Likert scales with four questions:

1. The interaction style was easy to understand.
2. The interaction style was perceived as fast.
3. The interaction style was easy to use.
4. The interaction style was perceived as accurate.

The resulting qualitative data is shown in Figure 6. In general, participants perceived the MT+A condition as being easier to understand and easier to use than the "joystick"-based multitouch-only user interface. However, the MM-only condition was per-ceived as being more accurate than the MT+A. With the regard to the perception of how fast a given interaction style is, we observed that the difference is very small.

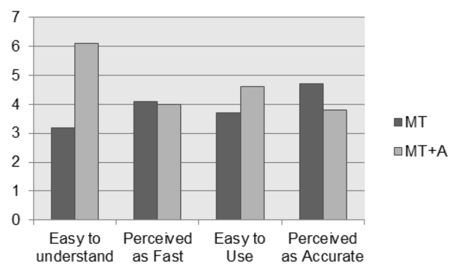

Figure 6: Qualitative data from the survey.

4. CONCLUSIONS AND FUTURE WORK

We presented a novel multimodal user interface specifically conceived for supporting design and review of large engineering models at oil platform industries. We evaluated two different conditions: using multitouch-only input, and using multitouch coupled with accelerometer-based input. Statistical analysis of quantitative data suggests that the second condition is faster and less error-prone than simply using multitouch input. Additionally, qualitative data showed that users perceive the multitouch-only interface as being more accurate, but more difficult to understand, and to use.

The main limitation of our study is related to being performed in a controlled laboratorial setting. More research effort should be concentrated into the real world usage of such a system. However, the feedback from the research and engineering team at the oil industry is very positive regarding this solution, especially as it allows the navigation and annotation of the platform model in a mobile context, without loss of performance and in a collaborative way, using both Bluetooth and Wi-Fi communication protocols.

As for future work, we are implementing and evaluating multi-modal annotations to the 3D oil platform model as a way to improve the reviewing engineering process. Sketches, camera-based and audio-based input could be used to achieve interesting solutions that better support the needs of offshore engineering teams.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Bolt, R. (1980). Put-that-there: Voice and gesture at the graphics interface. In Proceedings of SIGGRAPH 1980, pp. 262-270.

[2] McMahan, R., Alon, A., Lazem, S., Beaton, R., Machaj, D., Schaefer, M., Silva, M., Leal, A., Hagan, R. and Bowman, D. (2010). Evaluating natural interaction techniques in video games. In Proceedings of the 2010 IEEE Symposium on 3D User Interfaces (3DUI'10). IEEE Computer Society, Washington, DC, USA, pp. 11-14.

[3] Baxter, W. V., Sud, A., Govindaraju, N. K., and Manocha, D. (2002). GigaWalk: interactive walkthrough of complex environments. In Proceedings of the 13th Eurographics Workshop on Rendering, ACM International Conference Proceeding Series, vol. 28. Eurographics Association, pp. 203-214.

[4] Shou, L., Chionh, J., Huang, Z., Ruan, Y., and Tan, K.L. (2001). Walking through a very large virtual environment in real-time. In VLDB'01: Proceedings of the 27th International Conference on Very Large Data Bases, pp. 401–410.

[5] Robertson, B. F. and Radcliffe, D. F. (2009). Impact of CAD tools on creative problem solving in engineering design. Computer Aided Design. 41, 3 (Mar. 2009), pp. 136-146.

[6] Brown, M., Newsome, S. and Glinert, E. (1989). An experiment into the use of auditory cues to reduce visual workload. In Proceedings of the SIGCHI conference on Human factors in computing systems (CHI'89), no. May, pp. 339-346, 1989.

[7] Santos, I., Soares, L., Carvalho, F. and Raposo, A. (2011). A collaborative VR visualization environment for offshore engineering projects. In Proceedings of the 10th International Conference on Virtual Reality Continuum and Its Applications in Industry (VRCAI'11). ACM, New York, NY, USA, pp. 179-186.

[8] Santos, I.H.F., Raposo, Gattass, M. (2006). A Service Oriented Architecture for a Collaborative Engineering Environment in Petroleum Engineering. Research in Interactive Design, Vol. 2, Springer-Verlag, 2006, pp. 106.

[9] Evans, F., Volz, W. et al. (2002). Future trends in Oil and Gas Visualization. In Proceedings of the IEEE Visualization 2002, pp. 567-569