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USER ACTIVITY PROFILES WITH THE CO-STAR IMMERSIVE DESIGN SYSTEM

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ABSTRACT: *This paper describes the analysis of user activity during the evaluation of Co-Star, a demonstration immersive stereoscopic design system for cable harness design. Ten participants completed a harness design task and user activity during the task was profiled into five major activity classes: Design, Information, System Operation, Navigation, and Process Integration. The results provide a compelling visualisation of the nature of user activity during the task.*

Keywords: Immersive Design, Task Analysis, Cable Harness

1. Introduction

Engineering design is usually supported by computer-aided design (CAD) systems, which can bring significant benefits through improved quality of the design output or improved efficiency of the design process. However, further improvements to current CAD tools may be possible, for example, by providing more intuitive user interfaces that support the natural work flow of the user, or through the appropriate use of new technologies. In order to ensure that such developments are worthwhile it is necessary to understand how users interact with and use design systems so that opportunities for improvements can be properly identified and quantified. A challenge to doing this is that design is a complex activity involving problem solving and it can be difficult to investigate specific elements without fundamentally changing the nature of the activity.

This paper presents the user activity distribution obtained from analysing user interaction data for a cable harness design task during the evaluation of an immersive design system for cable harness design , Co-Star (figure 1) [1].

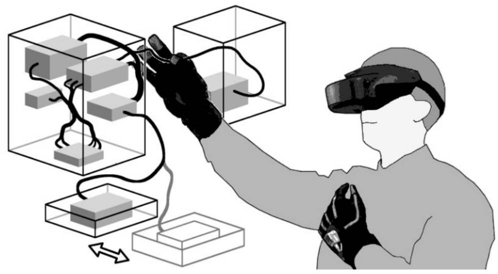

Figure 1 *Immersive Design*

A cable harness is an assembly of wires, connectors, fasteners and other components that provides electrical interconnectivity between different modules within a larger electromechanical product such as an ATM, vehicle or aeroplane. Cable harnesses can follow complex 3D routes within a product and developing a harness design that fulfils all the electrical, mechanical and assembly be immersed in the 3D product model and requirements of the product can present many challenges to the engineers involved. The Co-Star system allows an engineer to be immersed in the design model and use normal upper body motions to create and edit the cable harness design directly within the model (figure 2).

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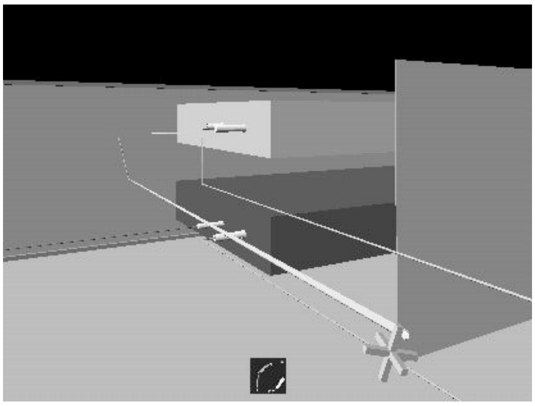
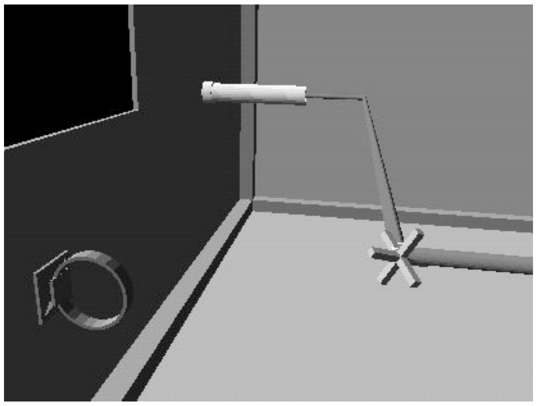
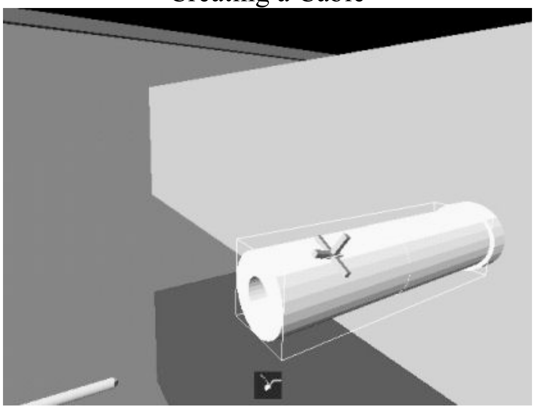


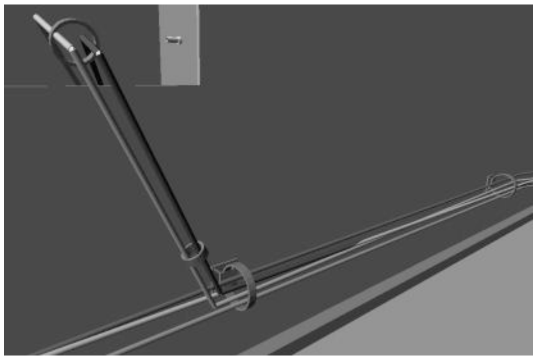
Creating a Cable



Editing a Cable (Drag & Drop)



Selecting a Connector



Harness Model Detail

Figure 2 *Co-Star Screen Images*

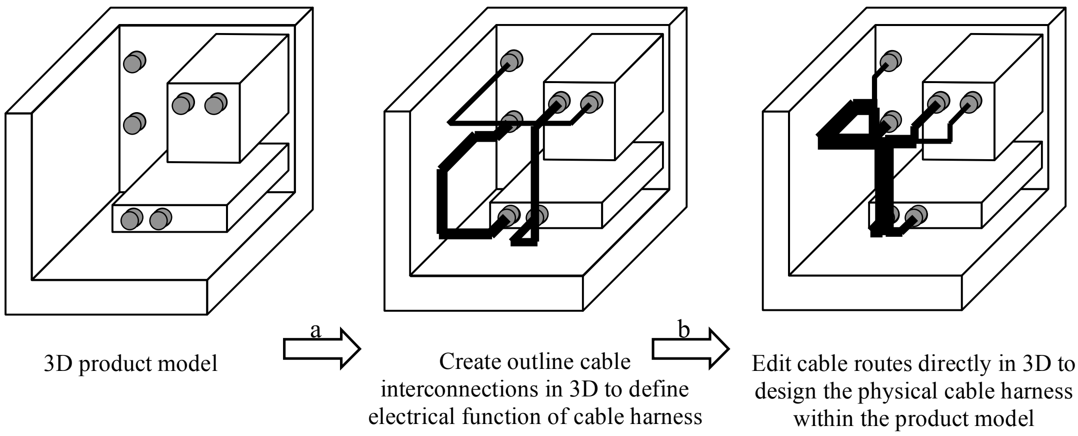


Figure 3 *Cable Harness Design*

Designing a cable harness using Co-Star is a two stage process (figure 3). Firstly, the electrical connections are defined by creating outline cables between connectors within the model (a). Secondly the physical cables routes in the product are detailed using direct interaction with the model to complete the harness design (b).

3. System Evaluation

System evaluation involved ten participants who each used it to complete three cable harness design tasks. Each task took approximately 20 – 30 minutes to complete and represented a stage of a cable harness design. All of the tasks took place in the same model with only the state of the harness model changing between them. The first task involved the creation of some outline cables to define the harness connectivity; the second involved detailing the routes of some outline cables in a model to complete a harness design; whilst the third involved making some revisions to a completed harness design. Participants completed each task at a different session and the results presented in this paper were all obtained from the third task. This task had five main sub-tasks:

1. Add Cable 1.
2. Delete Cable 2.
3. Find and fix cable harness error.
4. Export Documentation.
5. Exit System.

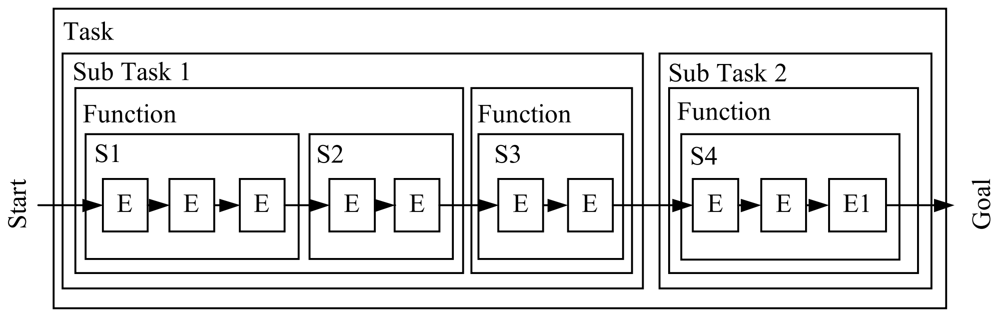
Each session began with a briefing using a summary of the task goals and a desktop VRML viewer displaying the model environment. The briefing was used to ensure that the participant understood the objectives of the task and any constraints but at no stage was a solution suggested to them.

The immersive design session followed during which the participant completed the design exercise using the head-mounted display and motion tracked gesture interface. During this session details of all the user's interactions with the system were unobtrusively recorded in a comprehensive time-stamped log-file. It is the data from these log files that has been analysed to produce the activity distribution profiles. The immersive session was immediately followed by a questionnaire and interview session; the results of which are not included in this paper.

4. Design Categorisation

During analysis the task activity was broken down into meaningful sequences of actions using functional decomposition using the principle that larger activities (sub-tasks) are made up of composite groups of actions (functions), which are in turn made up from smaller sequences of actions and individual interface events (figure 4). Functional decomposition is a standard engineering approach the basics of which are described in any good engineering design textbook [e.g. 2,3].

However, the specific methods must be developed for the application being investigated and those described here were appropriate for the Co-Star system evaluation, although they are also applicable to the analysis of design and design systems in general.



S: Action Sequence, E: Event

Figure 4 *Principle of task decomposition into units of activity*

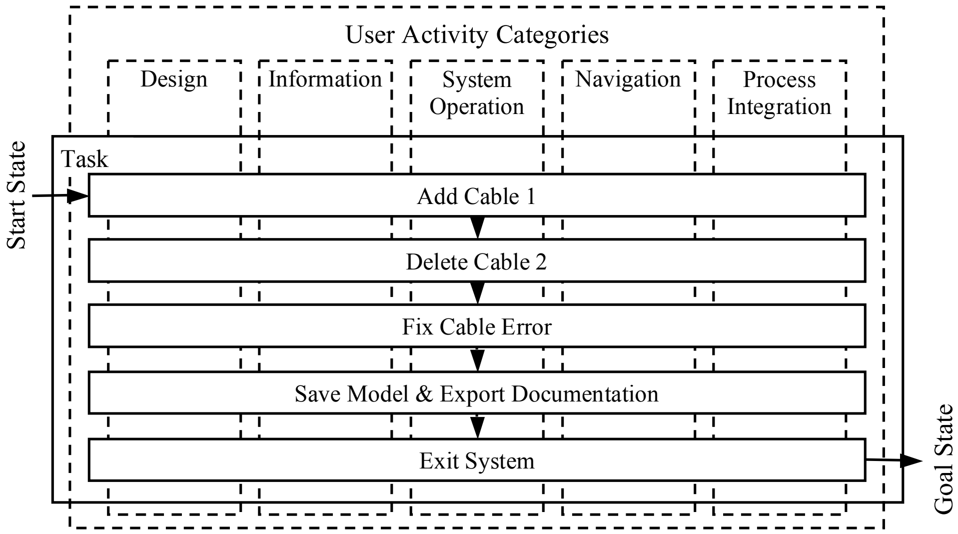


Figure 5 *Task categorisation*

Function: A composite sequence of user activity that achieves a single purpose within the system. Typically functions correlated with items on the menu system, and the use of several functions would be required to complete each sub-task.

Action Sequence: A single sequence of user activity that produces a single identifiable action or operation within the system. Typically several action sequences would be required to complete a function.

Interface Event: A single user input.

An analogy with the language constructs 'letter', 'syllable', 'word', 'sentence', is useful to illustrate the relationship between these different activity descriptions. In language the simplest words are one syllable long and contain one letter e.g. 'a' or 'I', but words can also be more complex with many syllables and letters and may also include the letters 'a' and 'i'. At a higher level groups of words are used to produce sentences that convey a specific meaning or purpose. Similar relationships apply to 'action sequences', 'interface events', and 'functions' which exist in different combinations to deliver the purpose of the user's current sequence of activity.

After task decomposition, the identified action sequences were grouped according to their purpose to determine for how long or how often a particular type of activity had occurred during the task. All action sequences were considered to belong to one of five classes (figure 5).

Design: All activity that causes the design model or documentation to be changed under the control of the user

Information: All activity relating to the user obtaining information from a text screen.

System Operation: All activity needed to operate the system but which does not usually change the model

Navigation: All activity leading to a change in the user's viewpoint but which does not usually change the model

Process Integration: All activity that interfaced with the wider product development process. In this case 'save' and 'export' design data.

Design is the core system function and this category was sub-divided into three additional categories to obtain more specific detail regarding this aspect of system operation:

Design - Goal : Actions that produce an immediate change in the design model and which advance the design towards the goal state (complete design).

Design – Support: Actions that do not produce an immediate a change in the design model but enable the user to subsequently carry out a design goal activity

Drag & Drop (Position Edit): The action of moving an object from one location to another by direct interaction with it in the model environment

System operation includes all interactions that are required to operate the system but which would not necessarily be needed to complete the design if a different system was used. This included all menu activity except setting library part parameters which was classified as a design support. Design support activity only included activity that directly allowed a subsequent design goal activity and did not include any activity that was only needed to support the operation of the system. 'Drag & drop' point editing was used to move the location of cable points and modify the cable paths in the model, this action often involved concurrently navigating within the model and is classed as design because moving the point changes the design model. However, any navigation that occurred in between moving points was classed as navigation. Finally, two additional classifications were used as relative measures of operational performance during the task and in the seven activity categories outlined.

Unproductive Activity: All activity from any category that can be removed from the process without affecting the outcome of the task, i.e. any activity that did not add-value to the design process.

Sequence Breaks: Pauses in activity between the end of one discrete action sequence and the next.

The overall objective of the analysis was to determine the activity distribution for the participant group during the task and to develop an average profile for a typical user based on both time and number of action sequences. This profiling was used to investigate user activity for the overall task, different sub-tasks, and during the operation of specific design functions and model interactions, although only the task level results are reported in this paper.

5. Results

Results from the participant group are reported as the mean and standard deviation (St dev) using both time (seconds) and a count of the number of action sequences. Pie charts of the mean result for the group are also included to illustrate the typical distribution of user activity obtained for the task.

In table 1 '% Task' is the percentage of the mean total task that was allocated to each activity category, e.g. for design goal 129s is 10% of the 1256s mean task time and 35 action sequences is 15% of the mean task total of 224 sequences.

In table 2 '% Un P' is the percentage of the mean unproductive activity allocated to each activity category, whilst '% Cat' is the percentage of each activity category that was unproductive, e.g. for design goal 11s is 12% of the unproductive activity total of 89s and 9% of the mean design goal category time of 129s.

In table 3 '% Seq B' is the percentage of the mean total inter-sequence time allocated to each activity category, whilst '% Cat' is the percentage of each category formed by sequence breaks e.g. for design goal 36s is 10% of the total sequence breaks of 356s and 28% of the category total of 129s.

6. Discussion and Conclusion

All of the ten participants completed the evaluation task and the mean task completion time for the group was 1256s (std dev 326), the fastest individual time was 693s and the longest 1881s. The participants had been given the task of completing a cable harness design task using the system, having been told the design goals but not what the design should be or how to go about producing it.

Table 1

Participant	1	2	3	4	5	6	7	8	9	10
Task Time (s)	1307	1433	1242	1271	1881	1125	693	1099	1549	963
No. Sequences	323	276	306	227	215	179	160	142	229	179

Distribution by Time (s)				Distribution by Action Sequence Count			
Mean	1256	St dev	326	Mean	224	St dev	62

	Design		Information		System Operation		Navigation		Process Integration	
	Time (s)	count	Ti	Co	Ti	Co	Ti	Co	Ti	Co
Mean	343	55	106	18	293	55	509	94	5	2
S dev	164	14	36	6	76	16	160	36	2	1
% T	27	25	9	8	23	24	41	42	0	1

	Design Goal		Design Support		Drag & Drop	
	Ti	Co	Ti	Co	Ti	Co
Mean	129	35	57	10	157	10
S dev	53	12	21	3	130	7
% T	10	15	5	5	12	5

Distribution of task (T) time (Ti) & count (Co) data into the activity categories

Table 2

Unproductive Activity by Time (s)							Unproductive Activity by Sequence Count							
Mean	89		St dev		64		Mean		20		St dev		12	
% T	7						% Task		9					
	Design Goal		Design Support		Drag & Drop		Information		System Operation		Navigation		Process Integration	
	Ti	Co	Ti	Co	Ti	Co	Ti	Co	Ti	Co	Ti	Co	Ti	Co
Mean	11	3	5	1	0	0	2	2	70	14	1	0	0	0
S dev	14	3	7	1	0	0	3	2	47	8	3	1	0	0
% up	12	14	6	3	0	0	2	8	79	73	1	2	0	0
% cat	9	8	9	7	0	0	2	9	24	26	0	0	0	0

Distribution of unproductive task (up) activity into the activity categories

Table 3

Total Sequence Breaks by Time (s)				Total Sequence Breaks by Count			
Mean	356	St dev	110	Mean	180	St dev	53
% T	28						
	Design Goal	Design Support	Drag & Drop	Information	System	Navigation	Process Integration
	time	time	time	time	time	time	time
Mean	36	23	10	6	48	229	3
S dev	17	12	8	6	17	85	2
% ISB	10	6	3	2	14	64	1
% cat	28	40	6	6	16	45	70

Distribution of task inter-sequence breaks (ISB) into the activity categories (cat) by time

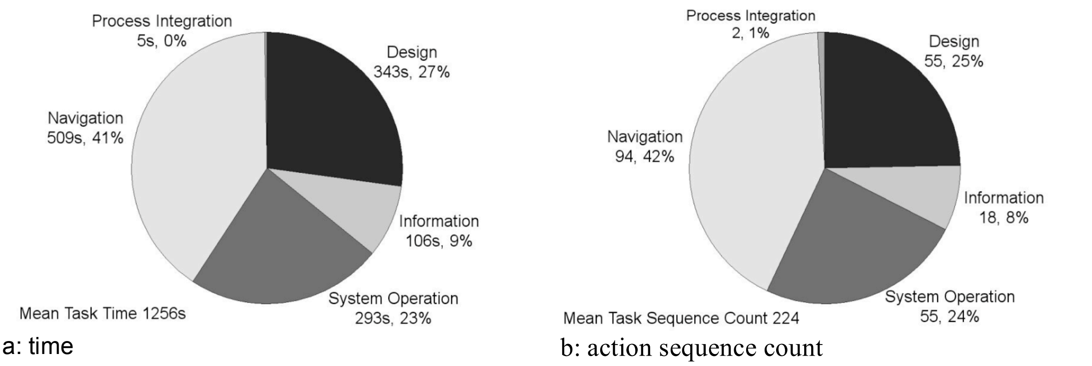


Figure 6: *Mean task activity distributed into the main activity categories*

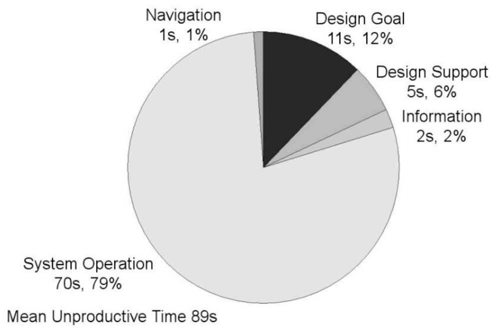


Figure 7: *Distributed of mean unproductive activity by time*

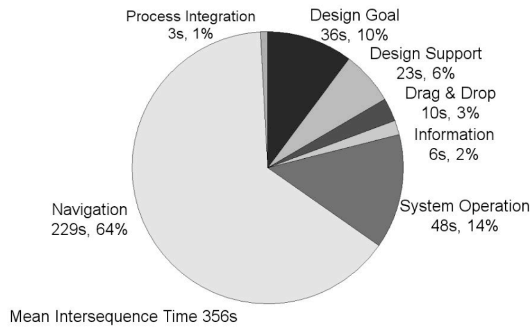


Figure 8: *Distribution of mean inter-sequence time*

However, the task goals were quite specific and participants were guided towards a solution by the inclusion of appropriate design cues in the model, although there was some variation in the solution produced and the methods used by different participants. This freedom for the participants to work normally was central to the evaluation. The system log files were a complete time stamped record of every user interaction with the system including all gestures, menu interactions, functions used, object interactions, and navigation around the environment. These files contained all of the data needed to reconstruct the activity undertaken during the design session and were used to identify specific action sequences that had been used to generate the design, operate the Co-Star system, obtain information, or navigate the model. These smaller units of activity were common across all users regardless of how they had undertaken the overall task and it is the analysis of these smaller sequences that has enabled the task profiling presented in this paper.

Distribution of the average activity for the group during the design task shows that the largest use of activity was navigation (41% time, 43% count), followed by design (27% time, 25% count) and system operation (23% time, 24% count) and finally obtaining task information (9% time, 8% count). The generation of design data was the core purpose of the user within the system and fact that this only accounted for a quarter of all activity was quite surprising considering a similar amount was devoted to operating the system and rather more was spent simply moving around the model. It may be deduced from this that the system would benefit from developments to increase the efficiency of model navigation and system operations so that less time is spent on these activities.

Unproductive activity was any sequence of actions that could be removed from the design process without changing the outcome. Typical examples include opening and closing the menu system or a text screen without using it, activating a design function and exiting it without using it, inserting a wrong part and having to delete it, or setting one of the system parameters to its current value. (Navigation was only counted as unproductive if it occurred within an erroneous sequence of activity). On average unproductive activity accounted for 7% by time (9% by count) of task activity. Distributing this into the activity categories shows that the majority of this unproductive activity was due to unnecessary system operations (79% of unproductive time, 73% count) and that overall 24% of system operations by time (26% by count) were unnecessary.

Individual action sequences are discrete series of actions and there is often a short pause between the end of one and the start of the next. These pauses have been called sequence breaks and on average there were 180 pauses in the task accounting for 28% (356s) of task time (mean break 2.0s (std dev: 0.6s)). Distributing this between the activity categories shows that 64% of this break time occurred during navigation and that this accounted for 45% of the total navigation time. Whilst this also includes time looking around from a static location it also suggests that the system would benefit from developments to improve the flow of the navigation activity.

In general, the participants reported positively on the experience of immersive design using the Co-Star system and it received a good evaluation. The user activity profiling presented in this paper has been extremely useful in linking the subjective user feedback gathered during the interview sessions and actual performance and use of different aspects of the system. In particular the profiling technique has clearly identified and quantified the opportunity to improve future systems by targeting research and development effort in a number of key areas, namely system operation and navigation, and also shows that efforts to improve other areas of the system are unlikely to yield similar improvements in operational performance.

7. Acknowledgements

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8. References

1 Holt POB, Ritchie JM, Day PN, et al.: Immersive Virtual Reality in Manufacturing: Design Metaphors and Cognitive Ergonomics. Journal of Computing and Information Science in Engineering, 2004, 4(3):161-170

2 Cross N.: Engineering Design Methods, 1989, John Wiley, ISBN 0-471-92215-3

3 Otto K., Wood K.: Product Design, 2001, Prentice Hall, ISBN 0-13-021271-7