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AUTOMATED KNOWLEDGE CAPTURE IN 2D AND 3D DESIGN ENVIRONMENTS

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Abstract

In Life Cycle Engineering, it is vital that the engineering knowledge for the product is captured throughout its life cycle in a formal and structured manner. This will allow the information to be referred to in the future by engineers who did not work on the original design but are wanting to understand the reasons that certain design decisions were made. In the past, attempts were made to try to capture this knowledge by having the engineer record the knowledge manually during a design session. However, this is not only time-consuming but is also disruptive to the creative process. Therefore, the research presented in this paper is concerned with capturing design knowledge automatically using a traditional 2D design environment and also an immersive 3D design environment. The design knowledge is captured by continuously and non-intrusively logging the user during a design session and then storing this output in a structured eXtensible Markup Language (XML) format. Next, the XML data is analysed and the design processes that are involved can be visualised by the automatic generation of IDEF0 diagrams. Using this captured knowledge, it forms the basis of an interactive online assistance system to aid future users who are carrying out a similar design task.

Keywords: Knowledge Capture, Virtual Reality, User Logging, Computer-Aided Design (CAD), Knowledge Management, IDEF0 Diagrams

1 Introduction

Computer-aided design (CAD) systems are now the main tool used by engineers to create and capture the final design solution to a particular problem. However, CAD systems are not as adept at capturing the design knowledge that is accrued by the engineer during the design session and the reasons when certain decisions are made are not recorded. Therefore, if the original engineer that created the design was not available anymore, anyone else who needs to understand how the design was created would find it very difficult. Therefore, having the ability to capture this knowledge would be extremely beneficial for future reference. Instead of having the designer manually recording this information, which would be time-consuming and disruptive to the creative process, all the designer's actions can be logged automatically, and unobtrusively, in the background so there is no extra workload for the designer. Once the design knowledge is acquired, it can then be embedded into a design rationale log or a product life-cycle management (PLM) system.

The research has focussed its attentions on logging users who are carrying out a design task in a traditional 2D CAD-like environment, as well as a 3D immersive virtual reality (VR)

environment. Section 2 of the paper will discuss the background, experimental procedure, results and analysis for the VR experiments. Next, section 3 will present details on the theory, experiments, results and analysis for the experiments carried out in the 2D design environment, before ending with conclusions.

2 3D Design Environment

2.1 Virtual Reality

As virtual reality (VR) becomes more cost-effective, due to the price reduction of the associated hardware and the possibility of running a VR system on a cheaper PC-based computer, it will become utilised more during the design of engineering solutions. Therefore, engineering information will be created throughout the whole product development process.

Unlike a traditional 2D CAD system, a designer who uses the 3D immersive system can have many aspects logged. For example, all of the user's head and hand positions, changes made to the model and all interaction with the menu system are recorded in a log file. In addition, there are timestamps next to each user action and the log file can be post-processed afterwards to extract more information from it (Ritchie *et al*, 2006). Early work that involved analysing log files to automatically generate assembly sequence plans was detailed in (Ritchie *et al*, 1999), but more recent work (Ritchie *et al*, 2007) has shown that user activities can now also be detailed.

2.2 User Logging and Knowledge Capture

The main aim of this paper is to attempt to automatically capture the knowledge of an engineer, generated during a design session, by logging every action that is performed. Not only will this make it more time and cost-effective when compared with manual methods, but it will also allow this knowledge to be embedded into a PLM system or design rationale log, for example. This formalised storage of knowledge can then be applied in many applications to aid other users. For example, if a subsequent user were to carry out a particular design task, the system would interrogate the knowledge store to ascertain whether any of the information in it would be useful to the user. If relevant information is found, it can then be 'pushed' to the user, who can then decide whether to use that information, or not. By logging the user unobtrusively in the background, the engineer is not interrupted and their creative process will not be disrupted.

There has already been some research in the area of user logging and knowledge capture. In the paper by (Wyatt *et al*, 1999), users who are carrying out a soil mechanics experiment in a VR environment are logged. By analysing the log files, an interactive help tool is attempted to be created that will aid the user in design tasks. Similarly, (Brough *et al*, 2006) uses the data that is logged, generated while users are performing an assembly task in a 3D immersive environment, so 'hints' can be generated to help subsequent users.

Compared with the papers just mentioned, the innovative feature of the research presented in this paper is that the design knowledge hints are automatically 'pushed' to the user, rather than requiring them to manually request to view a hint.

2.3 Apparatus and Methodology

The name of the experimental platform used in this research is called COSTAR (Cable Organisation System Through Alternative Reality), and it runs on an SGI® Octane2™ workstation. The user wears a Virtual Research V8 head-mounted display and Pinch® Gloves to operate the system. To track the user's movements, an Ascension Flock of Birds® magnetic tracking system is utilised with a motion sensor on the user's hands and head. Finally, the application was developed using SENSE8®'s WorldToolKit® release 9.

To select any one of the numerous cable design functions available in the hierarchical ring menu system (Figure 1), glove pinch gestures are performed by the user.

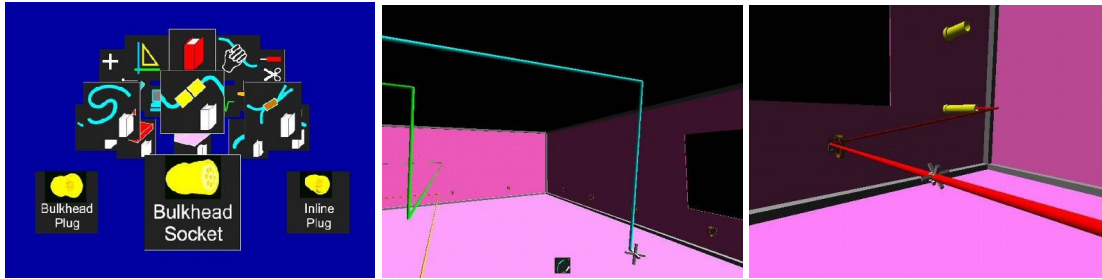


Figure 1 - Hierarchical Ring Menu and System in Use

As a design task is carried out by the user, all the user's actions are logged and output to both a text file as well as an XML file. The logged user actions include the menu options that are selected, the changes made to the design and also the user's head and hand positions. Figure 2 shows an example of two logged activities; one is 'cable drag and drop' where a cable is moved from one place to another and the other activity is 'create connector'. By attempting to identify repeating patterns of behaviour, indicated by repeating patterns of XML sequences, it is hoped that this will enable the design activities to be analysed and formalised.

```

<?xml version="1.0" encoding="UTF-8" ?>
- <costar_events>
- <cable_drag-drop>
  <pick_cable>1</pick_cable>
  <drag_cable>1</drag_cable>
  <release_cable>1</release_cable>
  <cablepointname>A01H01C01S01P02</cablepointname>
  <cable_move_reason>ThermalInterference</cable_move_reason>
</cable_drag-drop>
</costar_events>

<?xml version="1.0" encoding="UTF-8" ?>
- <costar_events>
- <create_connector>
  <activate_connector_menu>1</activate_connector_menu>
  <select_connector>1</select_connector>
  <position_connector>1</position_connector>
  <connector_name>A01B18</connector_name>
  <connector_position_x>-374.971</connector_position_x>
  <connector_position_y>-611.53</connector_position_y>
  <connector_position_z>889.296</connector_position_z>
</create_connector>
</costar_events>

```

Figure 2 - XML Representations of "Cable Drag & Drop" (left) and "Create Connector" Design Activities (right)

2.4 Experimental Procedure and Analysis

To evaluate the VR system and to gather experimental data, a trial was set up which involved getting 10 users to each perform three tasks using the system (Robinson *et al*, 2007). The tasks required the users to carry out several cable design activities such as bundling, routing, cable modification and choosing connectors. By automatic parsing of the log file, each user action was categorised and assigned to certain design activities, as well as having a process flow diagram being automatically plotted (see Ritchie *et al*, 2008). By analysing the process flow diagram, an engineer can determine the key steps that were performed to solve a design problem and, furthermore, the data can also be stored in a PLM system so subsequent users can access the information, as well.

GROUP OF ACTIVITIES	NAME OF ACTIVITY	SYMBOL	COLOR
1 EFFECTIVE ORIENTATION	LINE	U	PURPLE
	ASSEMBLE	#	VIOLET
	ENGAGEABLE	#	LIGHT VIOLET
2 MANIPULATION OR VISUAL IDENTIFICATION	SEARCH	◁▷	BLACK
	FIND	◁▷	GREY
	SELECT	→	LIGHT GREY
	INSPECT	○	SLURRY GREY
3 CONTROL ACTIVITY	DRAW	∩	RED
	RELEASE LOAD	∩	GAMMA RED
	HOLD	∩	GOLD GREY
4 PRECISION MOVEMENTS	POSITION	9	BLUE
	PRE-POSITION	8	PALER BLUE
5 GENERAL MOVEMENTS	TRANSPORT LOAD	∩	GREEN
	TRANSPORT EMPTY	∩	OLIVE GREEN
6 DELAY	PLAN	P	BROWN
	REST FOR UNPREDICTABLE DELAY	R	ORANGE
	UNAVOIDABLE DELAY	∩	YELLOW
	AVOIDABLE DELAY	L.D	LEMON YELLOW

Figure 3 - Gilbreth's Therblig Symbols (courtesy of Johnson & Ogilvie, 1972)

As well as measuring how much time was being spent on each activity, another way to identify inefficiencies in the user interface would be to analyse the user's body motions. It was noticed that when a user was carrying out a design activity in the VR environment, the motions were similar to an operator who was carrying out an assembly operation. Therefore, after searching for a tool that could be used to analyse assembly tasks, a solution was found in the form of *therbligs*. Therbligs was developed by Frank Gilbreth (Johnson and Ogilvie, 1972; Price 1989) during the early 20th century to study assembly motions. It consists of a set of symbols that represent the mental and physical processes that are involved during an assembly task, as shown Figure 3, and these symbols are mapped onto each individual operation task.

By studying the resulting sequence of therbligs, any inefficiency in the system can be easily identified through visual inspection. For example, if there are numerous 'delay' therbligs associated with a particular assembly operation, then it means that the efficiency for that specific task will have to be improved.

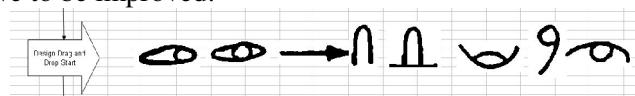


Figure 4 - Cable Drag and Drop Therblig Sequence

In Figure 4, the example shows the therbligs that are automatically generated by the spreadsheet macro for a 'cable drag and drop' operation. From left to right, the symbols signify that to complete the task, the engineer will be required to 'search' and then 'find' the relevant cable. Next, the cable is 'selected', 'grasped' and then 'held'. Finally, the cable is 'transported' to the required location, 'positioned' in the required position and is then 'released'. This automated mapping of therblig symbols is performed for all other cable design operations and, by parsing the log files and identifying sequences that regularly occur, this can help determine what the best practice is for performing a particular design task.

Another motion study technique devised by Gilbreth is *chronocyclegraphs* (Price, 1989). The method traditionally involved attaching a light source to the hands of a person performing an assembly task. By taking a long-exposure photograph of the whole assembly process, a result like the one shown in Figure 5 is obtained. This result displays the path, known as the chronocyclegraph, that the user's hands have moved through during the assembly task and helps identify areas of inefficient movement by the user. By letting the light source flash at a known frequency, it can also help determine the velocity and acceleration of the hand movements.

Since the log files for the VR cable design sessions contain the positions of the hands and head positions, a 3D chronocyclegraph can be easily constructed, as illustrated in Figure 5. This shows the path that the left hand has moved through during a cable design session and the colours of the path signify the different activity categories, which were defined earlier. If the velocity and acceleration of the head or hand motion is required, this can easily be calculated because a timestamp is associated with each user action. By knowing the velocity and acceleration, this information can be used as a confidence gauge for the designer based on the amount of deviation in the user's movements and also on the speed of the movement.

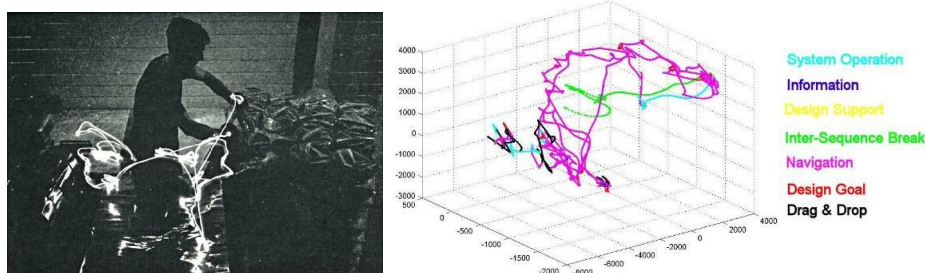


Figure 5 – Original Gilbreth Chronocyclegraph (left) and VR Chronocyclegraph (right)

2.5 Interactive Online Help

As has been mentioned previously, another key benefit of the log file analysis in this work was the potential to push information at the user as they carried out an activity during a design process. By using the therblig sequences to identify the repeating patterns for specific tasks within the XML log, a library of XML patterns can be created and stored in a database. The system has now been set up such that when the user performs an identifiable part of the design activity that matches a activity pattern in the database, it relates this to a part of a particular design task and offers or ‘pushes’ assistance to the user by displaying context-related instructions, as illustrated by the example in Figure 6.

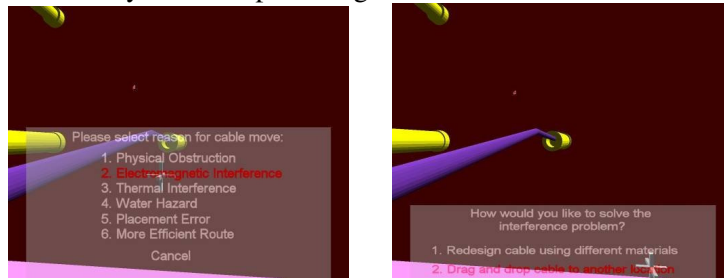


Figure 6 - Online help system

In the example, the user is moving a cable for a particular design reason, e.g. avoiding a thermal interference. On identifying in real time the task pattern associated with amending the cable, i.e. drag-and-drop, the user is prompted with a list of reasons for a possible design change. Once this is chosen, the text associated with the change is embedded within the XML log file for subsequent analysis. The menu system has been designed such that the interaction and associated task interruption for the user is quick and therefore does not affect the cognitive process associated with the task (Clark, 2006). Another key output from this logged activity is English-syntax instructions about the design change and the reasoning behind it, as shown in Table 1.

Table 1 - English Syntax Describing Design Change Reasoning

XML file section	Post-processed English syntax
<pre> <?xml version="1.0" encoding="UTF-8" ?> <costar_events> - <cable_drag-drop> <pick_cable>1</pick_cable> <drag_cable>1</drag_cable> <release_cable>1</release_cable> <cablepointname>A01H01C01S01P02</cablepointname> <cable_move_reason>ThermalInterference</cable_move_reason> </cable_drag-drop> </costar_events> </pre>	<p>Select cable point A01H01C01S01P02 and drag & drop. The reason for the moving the cable is due to thermal interference</p>

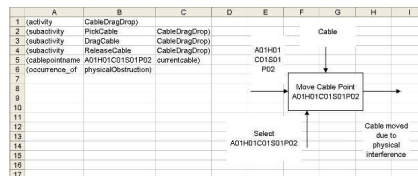


Figure 7 - Cable drag and drop IDEF0 representation

Post-task analysis also enables the XML log files to be converted into IDEF (Integrated DEFINITION Methods) diagrams (Anon, 2008) so that an overview of the decision-making process can be viewed (Figure 7). At present, when a user is identified by the system to be creating a new connector or beginning an assembly planning task, an IDEF0 diagram of the respective process is displayed to the user as a form of help. Diagrams such as these can also be easily be placed into a PLM system along with the English syntax description of design changes for future reference; demonstrating the considerable potential for the capture of design rationale

and intent using these methods. Therefore, the combination of the XML output and IDEF0 diagrams have been used to generate an ontology for cable harness design.

3 2D Design Environment

The next step in the research was to apply the knowledge capture techniques from the previous chapter to a design environment that resembled a traditional 2D CAD system. However, due to the difficulties in gaining the required access to the CAD software code to add the user-logging functionality, due to security and intellectual property issues, an alternative solution was required. This solution was a design environment called BAMZOOKi which allows the participant to design, build and test, just like in traditional CAD software. See Rea *et al*, 2007 for a detailed description of the design environment.

3.1 BAMZOOKi

BAMZOOKi is a design environment created by Gameware Development LTD, aimed at children, which allows the user to design, build and test virtual mechanical creatures called Zooks. To measure the effectiveness of the design, the Zook can be tested in trials which involves measuring how fast it can run (**sprint trial**), how far it can push a block in a certain time (**block push trial**) and how quickly it can run a hurdles course (**hurdle trial**).

3.2 Methodology

In the experiment, each participant was given a ‘Baseline Zook’, which had to be improved to meet specific performance targets. For example, one target is for the Zook to achieve more than 40cm/s in the sprint trial. The participant then begins to modify and test the Zook until the performance targets are met.

The log file that is generated for each design session is in an XML (Extensible Markup Language) format which allows the data to be easily shared, viewed and processed using various applications. Another advantage is that the data is both human and machine-readable. All user actions during the design session are logged together with all the trial results. See Rea *et al*, 2007 for more information on the log file structure.

After setting up user trials at two science exhibitions, nearly 800 user log files were obtained and after analysis, it was found that the average time spent in design activities were similar to those in the COSTAR trials. See Rea *et al*, 2007 for more details on the experiments and analysis.

3.3 Colour-coded Analysis of Log Files

After performing the statistical analysis in the previous section, the next stage of the analysis involved identifying the elements that are required to produce a successful design.

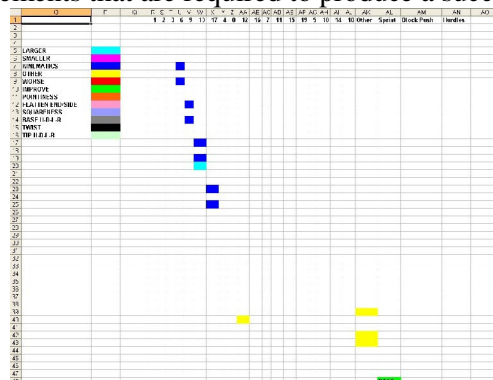


Figure 8 - Colour-Coded Representation of Log File

Therefore, a colour-coded representation of each design activity logged was devised to aid in determining which user actions occurs the most often before a successful trial result was obtained. In Figure 8, an example of the colour-coded representation is illustrated which was generated automatically using a spreadsheet macro that parses the log file.

The example shows a short design session where several actions were performed just before achieving a successful sprint trial result. Each colour represents a different design change that is made to the Zook so, for example, the blue cells in the spreadsheet represent a kinematic change, which in this case is a modification of an IK point on the Zook’s legs. The rows run from top to bottom in chronological order and each column represents one body part on the Zook. In the example, a blue cell appears in columns 6, 9, 13 and 17 which signifies that a kinematic change has been made to the body parts of the same number, which in this case are the legs. To represent a successful trial result, a green cell with ‘pass’ in it appears at the bottom of the spreadsheet. After generating a colour-coded representation for a selection of log files in which a successful trial result occurred, certain user actions were observed that lead to successful trial results and this is summarised in Table 2.

Table 2 - User Actions Required for Successful Trial

Trial	User Action Required For Successful Trial
Sprint	1. Modify IK points to lengthen stride pattern. 2. Increase length of legs
Block Push	1. Increase size of body 2. Modify IK points to lengthen stride pattern
Hurdles	1. Modify IK points to lengthen stride pattern. 2. Increase length of legs

Having obtained the information in the table, an information push system to aid a user during a design task was created in which the hints displayed to the user are based on this information. More details on the information push system is presented in Section 3.5

3.4 Alternative Design Process Representations

Even though the colour-coded representation proved useful in identifying common user actions required to achieve a good design, it was more difficult to extract the design knowledge in a form that is more structured and formalised. Therefore, a new representation in the form of an XML file is shown below:

```
<?xml version="1.0" encoding="UTF-8" ?>
- <bamzooki_event>
  <change_leg_size>13</change_leg_size>
  <change_body_size>1</change_body_size>
  <change_ik_point>3</change_ik_point>
  <change_ik_point>2</change_ik_point>
  <change_ik_point>4</change_ik_point>
</bamzooki_event>
```

To generate this XML data, a log file monitor, written using C#, was created that monitors the BAMZOOKi log file in **real-time** during the design session and as each design change is made to the Zook, an XML representation of the user action is output to a separate log file.

Due to the structured format of the XML fragment, a database of all these fragments can be created. Then, as the user creates a design, the system attempts to match the XML fragments that are output in **real-time** to the ones in the database. If a match is found, the system can then **predict** what design activity the user is about to carry out and any relevant information can be **pushed** to the user as a form of assistance. Based on this principle, a prototype information push system is presented in section 3.5.

An alternative representation that allows design processes during a design task to be visualised are IDEF0 (Integrated computer-aided manufacturing DEFinitions) diagrams (Anon, 2008). Once again, a spreadsheet macro was written that could parse a log file and automatically generate an IDEF0 representation of the design activities, as shown in Figure 9.

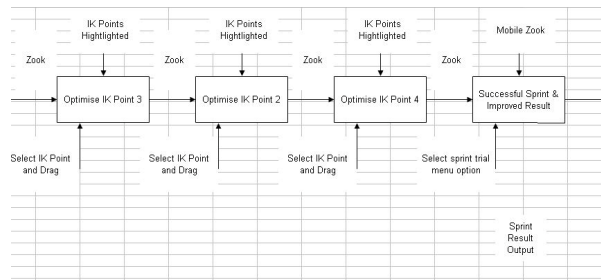


Figure 9 - BAMZOOKi IDEF0 Diagram

The main benefit of the IDEF0 diagram is that it allows the exact steps that were taken to arrive at the final design solution to be quickly identified by visual inspection. This would be beneficial in applications such as training new users on how to achieve the optimum design or in PLM systems where the design knowledge can be stored and can be accessed by many users.

To make it even easier for new users to understand and replicate the design knowledge, plain-English syntax instructions can be generated automatically by parsing the log file and outputting step-by-step instructions on how to achieve a successful design. An example of these instructions is shown below:

- Move bottom left IK point on right back leg 4 unit(s) left from origin
- Move bottom right IK point on right back leg 8 unit(s) right from origin
- Move bottom left IK point on right second-back leg 4 unit(s) left from origin
- Move bottom right IK point on right second-back leg 7 unit(s) right from origin
- Move bottom right IK point on right second-front leg 6 unit(s) right from origin
- Move bottom left IK point on right second-front leg 5 unit(s) left from origin
- Change right second-front leg to the following dimensions (WxHxL): 2 2 9.28
- Move bottom left IK point on right front leg 1 unit(s) up from origin
- Move bottom right IK point on right front leg 7 unit(s) right from origin
- Change bodypart 26 (unknown part) to the following dimensions (WxHxL): 8.56 9.08 2.48
- Change bodypart 26 (unknown part) to the following dimensions (WxHxL): 8.76 9.08 2.48

By following these simple-to-follow instructions, it can aid in accelerating the learning process for new users and, as new improved design solutions are found, the existing design knowledge can be correspondingly updated.

3.5 Information Push System

By utilising the extracted design knowledge obtained from the analysis in Section 3.3, this information can be ‘pushed’ to new users if it is relevant to the design task that they are working on.

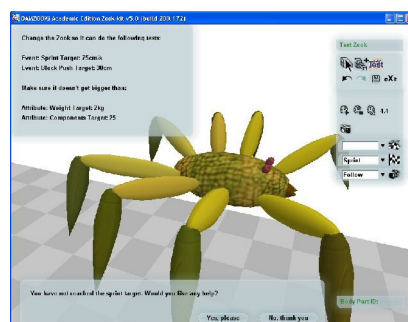


Figure 10 - Sprint Online Help

The current prototype online-help system involves using a C# application that runs in the background to continuously monitor the user log file for specific events happening. In the example shown in Figure 10, if the user fails a sprint test more than once, a dialogue box will appear to ask if any assistance is required. At this point, the user can accept or reject the request by selecting the corresponding button in the dialogue box. If assistance is required, a webpage

will appear which will contain instructions on how to modify their Zook to improve its sprint performance. Correspondingly, if the user were to fail the block push or hurdles trials more than once, assistance relating to block push and hurdles will be presented to the user.

From the analysis of the log files presented in the Section 3.3, it was found that changes in leg size usually occurred before a sprint trial and changes in body size occurred before a block push trial. Therefore, when a user changes the leg or body size for the first time in a design session, a dialogue box will appear to ask if any assistance is required in improving the sprint or block push, respectively.

Many improvements are still to be implemented in this prototype information push system but it already demonstrates the ability to automatically push information to the user in real-time through the use of logging. One possible improvement to the system might include superimposing the help information on top of the Zook, rather than having the user to look at a separate help page. Eventually, it may be possible to have the system analyse the Zook in real-time, during a design session, and for it to display what changes need to be made to improve its performance. Moreover, the changes could be implemented automatically by the system on behalf of the user, if required. What this means is that the system can, potentially, capture and suggest design knowledge in real-time to aid the user during a design task.

4 Conclusions

This paper has presented a prototype system for automatically capturing design knowledge by unobtrusively logging the user during a design session and then analysing the log files to extract the design knowledge. This design knowledge has then been utilised in an information push system that offers assistance to new users and this has been demonstrated in both a 3D VR cable harness design environment and a 2D mechanical creature design environment. Furthermore, the logged design activities from both design environments have been automatically grouped into specific design categories to aid the analysis of the data.

Two time and motion study techniques called *therbligs* and *chronocyclegraphs* have been utilised to gain a better understanding of the design processes that occur during a cable harness design session. The techniques can also be used to help identify inefficiencies in the design of the user interface and once the changes have been implemented, the system can be benchmarked using the design categorisation scheme to gauge the amount of efficiency improvement in the user interface. It is also envisaged that a user's 'thinking time' can be identified by looking for pauses that appear in the *therbligs* or *chronocyclegraphs*, which may indicate when the user is thinking about the design or about to make a design decision.

As with the 3D cable design environment, XML was used as the log file data format for the 2D design environment because it is well-structured and straightforward to import to other systems. IDEF0 diagrams were also automatically generated in both design environments to allow the design processes to be easily visualised.

Further analysis will be performed on the log files in the attempt to extract more design knowledge and the information push system will be further enhanced. Based on the encouraging results obtained in this research, future work will involve extending the current work into analysing tasks that are carried out in real-world applications and industrial-based designs. Eventually, it is hoped that the design knowledge capture and information push system can be integrated into industrial CAD applications.

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