A TECHNOLOGY SELECTION PROCESS FOR THE OPTIMAL CAPTURE OF DESIGN INFORMATION

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There is currently a lack of good practice guidance and commonly accepted standards for empirical design researchers in terms of (a) the amount of information to capture and (b) the appropriateness (what is captured, and in what form). For example, it is common for researchers to default to video capture. This is often costly to implement and generates large datasets that are difficult and time consuming to analyse. This paper thus attempts to provide practical guidance to the researcher on what technologies are optimal for capturing various common design situations.

Keywords: Empirical Research, Observational Studies, Technology, Guidance.

1. INTRODUCTION

Empirical studies form an important part of engineering design research. Researchers frequently undertake this activity using a variety of capture and monitoring technology. This paper focuses on the issue of the lack of practical guidance on such technology used for observational studies in empirical design research (EDR). A range of off-the-shelf technologies have been used to monitor a wide range of design work, including audio-visual information, written information and computer-based activities. These technologies were evaluated through a series of participant-observer style studies consisting of a researcher undertaking three design tasks, whilst capturing as much data as possible. The tasks were chosen to provide a cross section of design situations at different stages of the design process. Each study utilised multiple technologies in various combinations, such that each of the technologies was trialled thoroughly during the design tasks.

Each of the technologies tested was then evaluated against a range of metrics, including the cost of deployment, ease of use, amount of 'post-processing' required and ease of analysis. The output from the technologies was also evaluated for the 'richness' of capture, in terms of basic contextual information (such as dates, locations and sources), as well as the level of insight that could be gained into the designers' activities.

The contribution of this paper is a detailed technology assessment and a pragmatic process to guide researchers through the selection of technology with regard to their research question. The process first asks the researcher to abstract the core aspects of the research question in terms of the type of activity under investigation. Next, these core aspects are used to highlight the technologies that may best suit the researchers needs via a flowchart. Finally the process guides the refinement and detailed assessment of the selected technologies.

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2. BACKGROUND — EMPIRICAL DESIGN RESEARCH

In order to develop a holistic view of the design process, it is important to validate theory through empirical study. This can take many different forms including fieldwork, scenarios and games. These three major empirical paradigms have evolved indirectly from pre-existing empirical ideas such as ethnography and field research and share many techniques and technologies. There is however an ever-increasing variety of purposes to which empirical techniques are being put in design research. These include various lab and industry based studies examining many diverse aspects of both the individual designer and the design process.

This proliferation of approaches, techniques and the technologies employed has developed from the expanding scope of design research. This has included the introduction of sociological, psychological and other factors in addition to the core of traditional design research [1]. In addition, a range of approaches for the generation, analysis, storage and re-use of data derived from observational-type studies have been developed (see, for example, [2, 3]. These have combined to give an increasing complex research environment, where clearly defined boundaries or metrics are often lacking. The increasing availability and complexity of capture technologies has also given rise the possibility of generating vast quantities of data from even the smallest design task, although this potential volume of data and subsequently time-consuming analysis may actually discourage such studies [1].

Although there is an increasing awareness of the need for guidance on what constitutes quality and validity in EDR, little attention has been paid to the optimisation of technological approaches to capture data from observational studies. This is especially marked when the level of activity surrounding guidance on methodological approaches is considered [see, e.g., 4]. Thus, it is clear that in order to expand the scope of empirical design research, whilst also maximising the possible advantages of new or existing technologies, it is necessary to consider both the *methodological* and *technological* aspects of observational studies. In addition, there is a distinct lack of pragmatic guidance on what, how or when technologies should be used in order to produce contextually rich and reusable information, whilst avoiding capture or analysis overload.

3. METHODOLOGY

The overall research question to be answered by this work is "*how can design researchers be guided to select the most appropriate or optimal tools/technologies to record data for a given research question?*" The specific objectives of this work were to (i) Establish the potential for various existing and novel information capture tools and technologies to effectively capture observational data from various common design situations, and (ii) Investigate the potential for subsequent re-use of this information for design researchers, embodying these findings in a pragmatic guide for researchers to use when selecting information gathering technologies for a given research question. To address these two objectives, participant-observer style experiments in the form of three, week-long design exercises were undertaken by a researcher, in conjunction with trainee-engineers working on existing industrially-sponsored design projects, described below.

The first was a feasibility study into various manufacturing methods available for made-to-measure orthotics. The report covered pros & cons of the manufacturing methods, availability of resources and production of a cost estimate.

The second project investigated the feasibility of the design and manufacture of personalised shin pads. This included investigation of materials suited for body impact protection, a bio-mechanical study of the human lower limb and investigation of manufacturing processes suitable for shin pad materials.

The final project was a product-design task to design an insert to fit into bottles to provide a 'drizzle' function for condiments & syrups etc. This involved liaising with the manufacturer, reviewing past designs, and creating and evaluating concepts. The final design was prototyped and a presentation made.

Table 1. Tools and Technologies Evaluated.

Category	Tool/Technology
Audio-visual	Pocket video camera, Video camera, Webcam, Mobile ‘phone, Video Conference (VC) Facility, Skype [6]
Text-based	LiveScribe Pen [5], Microsoft OneNote [7], Keyword search, Tablet PC,
Computer-based Activity	ManicTime [8], Xobni [9]

Table 2. Summary of Projects.

Description of Project	Hours Captured	Volume of Data (Gb)	Hardware Used	Software Used
Feasibility study	23.5	6.61	LiveScribe pen, Pocket video camera, Video camera	ManicTime, Xobni
Feasibility & materials	24.0	4.96	LiveScribe pen, Pocket video camera, Video camera, mobile ‘phone	OneNote, ManicTime, Xobni, Keyword search
Product design	21.2	2.90	LiveScribe pen, Tablet PC, Webcam, VC	OneNote, ManicTime, Xobni, Keyword search, Skype

For each week-long episode, a range of different off-the-shelf capture technologies (both hardware and software-based) were used and evaluated by the researcher in multiple situations. These included ‘traditional’ tools such as video cameras, as well as newer innovations such as the LiveScribe pen [5], which records written information and associated audio. The data captured represented over 68 hours of design-related activity totalling over 14Gb. The tools and technologies used are listed in Table 3.1., and the project characteristics summarised in Table 4.1.:

The tools and technologies were then evaluated using a range of metrics in three categories:

Practical Aspects, such as ease of use, processing required, ease of subsequent analysis, capture and storage cost.

Basic Information, such as whether decisions, rationale, sources of information and basic contextual information (times, locations and dates etc.) were apparent.

Insight into Designer Activities, such as whether they were working on product or process-related aspects, or whether they were searching for solutions, evaluating alternatives etc.

In order to reduce researcher bias, each of these metrics was assessed in a quantitative and unambiguous manner wherever possible. These metrics are presented in full in Table 3. For example, the *practical aspects* of ‘processing required’ was assessed using the number of individual processes required

Table 3. Criteria Used for Scoring Practical Aspects.

	CRITERIA			
SCORE	Ease of Gathering/ Autonomy	Processing Required	Ease of Analysis	Capture & Storage cost
1	Complex — requires researcher presence	4+ processes	Complex, subjective	•500+
2	.	3+	.	•101–500
3	Some intervention	2+	Straightforward	•50–100
4	.	1+	.	•0–50
5	Instant — ‘fit and forget’	Instant/no processing required	Instant, un-ambiguous, no training needed	•0–Free

(such as downloading, converting, or transforming into a graph etc.) to obtain the data in a usable format. The researcher also used a grounded approach, with no preconceived ideas of the usefulness of the technologies under test. Finally, results from multiple instances of use were considered for each technology, with most technologies being used over 20 times during the three projects.

For the *basic information* category, each tool/technology was assigned a score based on whether that aspect was impossible to determine (scored 0), or represented implicitly (scored 0.5) or explicitly (scored 1). For example, if the captured information was time-stamped or included e.g. company and project information, its ‘basic context’ was judged to be explicitly represented and scored 1. The results are presented in full in Table 5.

Finally, *the insight into designer activities* was assessed by coding a sample of the captured information from the video camera and corresponding written notes to determine what aspects of designer activities could be determined from the data. (e.g. whether the work related to the product or process, problem solving and communication activities etc.) The schema for the coding of these aspects was taken from [10], who applied successfully in the analysis of emails and [11] who applied it to engineering logbooks.

4. TECHNOLOGY EVALUATION RESULTS

This section presents the results of the evaluation, showing how the technologies perform against multiple criteria. First, the scores for practical aspects of each tool or technology are scored from 1 to 5, according to the criteria shown in Table 3, overleaf.

The full scores for each technology are now presented in Table 4.

Table 4. Practical Aspects of Tools/Technologies Evaluated (Top four highlighted in grey).

Tool/Technology	Ease of Gathering/ Autonomy	Processing Required	Ease of Analysis	Capture & Storage cost	Total
Pocket video camera	3	3	3	3	12
Video camera	4	3	3	2	12
Webcam	4	4	4	4	**16**
Mobile ‘Phone	5	3	2	2	12
Video Conference	2	1	2	1	6
Skype	2	2	3	1	8
LiveScribe Pen	4	3	4	2	**13**
Microsoft OneNote	2	3	4	3	12
Keyword search	4	5	4	5	**18**
Tablet PC	3	2	4	1	10
ManicTime	5	2	2	5	**14**
Xobni	4	2	2	2	10

Moving onto the metrics for basic information, Table 5 now shows what basic information was discernable from the information captured by each technology. These scores were arrived at by analysing sections of the recoded information for the presence of basic context (such as times, dates, projects etc.), the sources used (i.e. from what information the activity was based) and evidence of decisions or rationale. If these were impossible to determine, 0 was awarded. If they were implicit (i.e. were evident indirectly, in combination with other knowledge) half a point was given. If the aspect was represented explicitally, a score of 1 was given:

Finally, for assessing the insight that may be gained into designer activities, two segments of information from the same hour-long event (a meeting discussing to clarify the first project brief) were

Table 5. Basic Information Contained Within Captured Information (Top three in grey).

Tool/Technology	Basic Context	Sources	Decisions	Rationale	Total
Pocket video camera	0.5	0.5	0.5	0.5	2
Video camera	0.5	0.5	0.5	0.5	2
Webcam	0.5	0.5	0.5	0.5	2
Mobile 'Phone	0.5	0.5	0.5	0.5	2
Video Conference	1	0.5	0.5	0.5	**2.5**
Skype	1	0	0.5	0.5	2
LiveScribe Pen	1	0.5	1	1	**3.5**
Microsoft OneNote	0.5	0.5	1	1	2
Keyword search	1	0.5	0.5	0	2
Tablet PC	1	1	0.5	0.5	**3**
ManicTime	0	0.5	0	0	0.5
Xobni	1	0.5	0.5	0	2

Table 6. Coding scheme Used for Comparison of Video and Text (see [10] for definitions).

Problem solving	Communication processes	Communicative acts	Project/ Process-related	Product-related
Goal setting	Clarifying	Agreeing	Planning	Cost
Constraining	Debating	Disagreeing	Time	Materials
Solving	Informing	Opinions		Function
Evaluating	Exploring	Orientation		Performance
Decision making	Digressing	Gives Suggestion		
	Managing	Shows antagonism		
		Shows solidarity		
		Shows tension		
		Shows tension release		

analysed by a neutral 3rd party using the coding scheme adapted from [10] and shown in Table 6. For example, '*constraining*' is defined as '*Imposing boundaries with requirements and desirables*'. The use of neutral 3rd party for coding ensured that no bias was introduced by the coder using their personal knowledge of the work to interpret too heavily the information.

The top-level results from the coded video and corresponding written notes are shown below.

Although the sample is small and should be expanded in future work (see Section 5.2), it can be seen that — as one would expect — it should be possible to extract more information about problem solving activities (18 occurrences vs. 6) and also many more occurrences of communication of some sort, compared to what may be extracted from the written notes alone.

Table 7. Comparison of activities evident from video and corresponding written notes.

	Problem Solving	Communication processes	Communicative acts	Project/process related	Product related
Video	18	23	7	6	13
Written Notes	6	11	0	5	6

5. DISCUSSION

The section above presented the results of an evaluation of numerous technologies used for information capture, analysing them with a range of metrics, including their potential to provide information and insight useful to design researchers.

However, the scores by themselves offer little guidance as to what technology is most appropriate to capture different design situations. For example, that the pocket video camera scores very highly overall, does not necessarily mean it is the most appropriate way to capture all types of situation, as despite the camera capturing considerable amounts of information it is often unfocused and time-consuming to analyse.

This sections therefore aims to offer a pragmatic guide to how best to use the information presented in Section 4, before discussing limitations and further work.

5.1. A Pragmatic Guide for Design Researchers

As noted above, for any guide to select an appropriate tool/technology successfully, it must be tailored to specific design situations. Therefore, each captured 'event' was described, and these descriptions synthesised into five common scenarios: (i) Co-located meetings/verbal collaboration, (ii) Written communication, (iii) Non co-located work, (iv) Individual design work and (v) Other peripheral activities (Not design-related, e.g. project management, administration, etc.) The suggested strategy consists of three steps:

1. **Deconstruct the research question to identify the situation** — the researcher must identify the situation and activity/aspect to be studied. It is important to note that when a researcher uses these guides, they should have an existing research question which has been abstracted, rather than using the flowchart to formulate the question.
2. **Select the optimum technology using the flowchart in Figure 1 —** following the flow path will lead to the first and second choice technology for the given situation:
3. **Refine the technology choice —** the researcher should then study the detailed analysis tables presented in Section 4 to refine their choice of information capture technology according to the parameters of the research question.

As an example of how to use this guide, two example research questions (RQ's) are given below:

RQ1: *What proportion of a design engineer's working time is wasted on non work-related tasks on the internet?*

Here, the situation is individual work, and the aspect to be studied is time spent using the internet. From the flowchart, OneNote and ManicTime are suggested as the optimal tools for studying individual work. From Table 3.1., ManicTime is categorised as a tool for recording computer-based activities (such as internet use) and is therefore most suitable. Not only does it work autonomously without intervention from researcher or participant, but is free and require little or no training to use (Table 4).

RQ2: *Do actions arising in meetings go unrecorded in personal notes?*

Here the situation is a co-located meeting, which the flow chart suggests either a video camera or LiveScribe pen to capture. As the objective is to compare actions arising during verbal exchanges vs. written notes, the researcher could opt to use either the LiveScribe pen or both. However, if they know the information must be gathered cheaply or with little intervention from the researcher, Table 4 rates the LiveScribe Pen more highly in these categories. On the other hand, if the researcher's definition or proposed coding scheme for actions meant that a greater level of interpretation was required, Table 7 indicates that a major feature of video is its rich output, especially with respect to communication activities. In this case, the researcher may select both the LiveScribe pen and Video Recoding, or carry out a pilot study to ensure the LiveScribe pen output is suitable for analysis with their coding scheme.

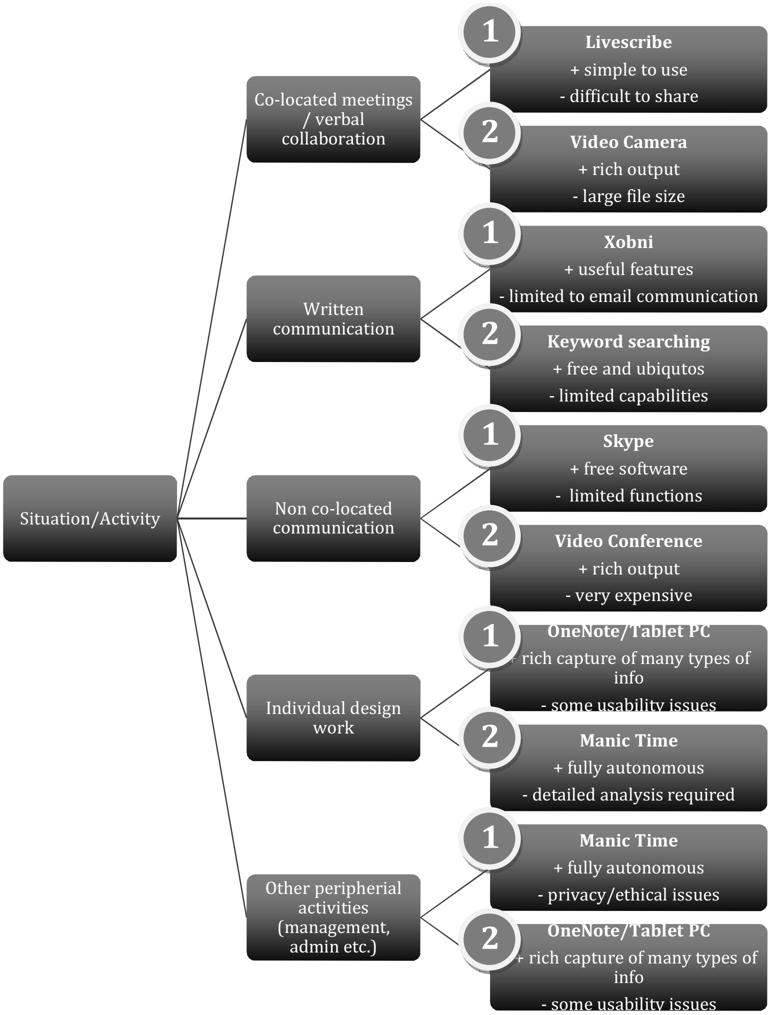

Figure 1. Preferred Tool/technology Choices for Optimal Capture.

5.2. Limitations

However, there are limitations which fall into two broad areas — Firstly, the example RQ's given above are relatively simple and not all types of RQ will benefit from this guidance. The focus has been on capturing data from observable/recordable phenomena. The guidance would be of little use if, for example, the RQ involved investigating how trust in customer-supplier relationships affects collaboration. Further, [1] also contends that multiple methods must always be used to give a clear picture of the process — this paper only seeks to give guidance on how to conduct observational studies for a given RQ, not whether the RQ will yield interesting or useful knowledge, what other types of research may be required to achieve a full understanding, or how to best analyse the resulting data (although there are many existing analysis protocols for some types of data — most notably video & audio).

Secondly, the study reported here — although of a reasonable size — has shortcomings in terms of inter-coder reliability and practicality in industry, with respect to privacy and legal issues etc. Moreover, the suitability of each tool/technology with regards to producing data that may be easily and comprehensively re-used by other researchers in the future has not been fully addressed.

To this end, the work reported in this paper is currently being used as the basis for a larger series of empirical studies in industry and corresponding lab studies. These will build on the existing data to give insights into the difference been longitudinal, discreet and lab-based studies, as well as offering more detailed information on the performance characteristics of the different technologies in these situations. In addition to addressing the industrial limitations, this further work will afford development of a more refined guide for researchers. It will offer improved resolution, reliability and validity in a wider range of situations (e.g. when studying more complex behavioural aspects of designers) and give guidance as to how such methods integrate with the wider methodology being employed.

6. CONCLUSIONS

This paper argues that there is a lack of pragmatic guidance for the optimal use of technology in empirical studies, potentially leading to the sub-optimal type or quantity of information (too much or too little) being captured. The aim of this research was therefore to develop a basic, pragmatic guide to aid the selection of capture technologies.

In order to do this, participant-observer experiments were carried out, with a researcher using a wide range of off-the-shelf technology to record all aspects of their activities in three week-long design projects. The resulting dataset comprised over 68 hours and 14 Gb of data. The technologies were then assessed for both the possible insights they could provide into design activities and also pragmatic issues such as ease of use, cost of storage, difficulty of analysis. Based on this, a pragmatic guide was developed with the aim of allowing a researcher to quickly and effectively narrow their capture technology choices, before drilling-down into the technical information provided by the assessment to refine their choice.

However, it is clear that this work represents only a first step. As such, two broad areas that require further work have been discussed. These notwithstanding, it is argued that this problem is both relevant and important to the community, and the pragmatic guide outlined in this paper offers not only useful basic guidance, but will hopefully also serve to highlight cheap, easy-to-use and novel technologies such as [5] and [8] that are seldom used in design research at present, possibly because of a lack of awareness of their existence.

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