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A REVIEW OF STATE-OF-THE-ART TECHNOLOGIES FOR SUPPORTING A DESIGNER'S ELECTRONIC LOGBOOK

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1. Introduction

It is common practice for designers to keep a personal record of their work. In general such records are contained within paper based logbooks and take the form of a notebook or ring-binder of sheets. These records represent a large amount of design information and design related information that may not be recorded by other formal means, such as technical reports and meeting minutes. This information may include:

- Fundamental design knowledge
- A rich source of design information and rationale that supports decision making
- Information for design audit purposes and a legal record for accountability and Intellectual Property issues.
- The results of analysis and modelling. This many also include failure as well as success.
- Informal information regarding suppliers and customers, including contact details and performance assessments.
- The outcome of discussions with experts and colleagues.

Clearly, the ability to access this wealth of potentially valuable information is highly desirable. However, this is all but prevented by current paper logbooks which severely restrict access, sharing and organisation of content. Many of these issues could be overcome through the creation and adoption of an electronic designer's logbook. Such a technology could provide both the designer and the wider organisation with:

- A more complete understanding of previous design issues and how they were resolved
- Information describing lessons learned and important background or contextual information
- A single accessible location for ideas, sketches and notes relating to a given project or design, improving the 'collective memory' of an organisation
- Better support for concurrent and distributed design activities

According to Blemel [1989], "Automation of engineering notebooks should be simple and easy", so why - 17 years later - do paper logbooks still dominate? In order to provide some insight into this and provide important direction on how the next generation of electronic logbooks could be configured to be more effective than a paper based logbook, current state-of-the technologies for handling personal notes are reviewed. This review discusses each technology and evaluates its ability to support a range of key functions of the designer's logbook. Using the findings of the review, a hybrid technology strategy is proposed which forms the technical platform for an electronic designer's logbook.

2. State-of-the-art technologies

Over the past decade a number of technologies for recording and managing written notes have been developed. Myers [2003] provides a useful summary. They can be broadly split into i) enhanced or augmented paper-based logbooks, ii) computers with pen based input and iii) keyboard- or web-based logbooks. The following overview and discussion is not intended to be exhaustive, but instead focuses on more recent implementations and represents a broad cross-section of these classes.

2.1 Augmented paper systems

Several technologies have been developed that provide for the electronic capture of handwriting as it is written on to paper. These 'pen based' technologies track and record their own movements as digital coordinates via a sensor placed under a pad of paper [Acecad, 2004]. This basic approach is also taken by the a-book project [Mackay et al, 2002], but is particularly novel, as it uses a combination of paper placed on a sensor and a small Personal Digital Assistant (PDA). The PDA acts as an 'interaction lens' when placed on the notebook, providing links to other pages, dynamic content such as computer models or video, and even physical objects by tagging them.

Another approach to augmented paper systems is to use Anoto functionality [Anoto, 2005], which is a combination of a digital pen and special paper. It is unique as the sensor and recording technology are integrated into the pen itself, which must be used in conjunction with paper printed with a fine grid pattern. The grid pattern allows the pen to identify not only its position on a page, but the page number as well. The system has a limited paper-based interface to, for example, classify notes or indicate the note is to be emailed when downloaded from the pen. Current implementations of the Anoto system include not only conventional notebooks, but, for example, Post-it notes and diaries.

2.2 Pen computing

Personal Digital Assistants (PDAs) and other pen-based computers are an increasingly common method of recording personal notes. As well as the general feature-set (drawing, typing, diary, email and web browser), they have audio and video functionality. Some can also communicate via wireless networking (WiFi) or Bluetooth. There are two main examples of specialist logbook software designed for PDAs and pen-based computers:

Dynomite [Wilcox et al, 1997] incorporates unstructured pen input, linking of recorded audio to written notes, classification via tags (such as 'to-do', 'contact' or 'URL') and search facilities. The Electronic Engineering Notebook, or EEN [Gwizdka et al, 1998] is another pen-based computer or PDA based logbook, but aimed specifically at engineers. It allows the input of unstructured text via a pen, with post-classification and searching based on engineering ontologies.

More recently, Microsoft has released OneNote™ for Tablet PCs [Microsoft corp., 2005]. In addition to the features of Dynomite, Tablet PCs also provides handwriting, speech recognition and collaborative tools in a much more powerful notebook-sized device. OneNote also allows the insertion of image files and other attachments. Although not aimed specifically at engineers, OneNote has been demonstrated in an engineering environment.

2.3 Keyboard and web-based notebooks

Research Notebook™ [Knowligent, 2002] and Electronic Laboratory Notebook (ELN) of Myers [2003] are both server-based logbooks, accessed through a web-browser. The primary input mode is via a keyboard, although images can be inserted and dynamic links created between files. Both attempt to bridge the gap between personal and enterprise-level records management by providing data security and authentication features such as digital signatures and limited structuring of information through the use of templates.

3. Evaluation and appraisal

In order to evaluate and appraise the capability of the previously discussed technologies to support an electronic designer's logbook the key functions of the logbook need to be understood. These functions were identified in previous research [Hicks et al, 2005] from a study of over 50 engineers and a detailed audit of sixteen engineering logbooks. The survey and analysis revealed five main classes of activity:

- **Creating/recording** – How information is recorded, and what form it takes. For example, there were thirteen classes of information (such as written notes and sketches, annotated CAD drawings, calculations and Post-It notes etc)
- **Classifying** - Marking or structuring information to aid understanding and re-use
- **Browsing/navigating** – Reading or reviewing logbooks contents (flicking through pages etc)
- **Searching** – Structured way of locating a particular piece of information
- **Sharing/collaborating** - Sharing means a person sending information, or making it available if requested whilst collaborating is the synchronous or asynchronous creation or editing of content by two or more individuals.

As well as these activities, a number of practical requirements were also identified, including portability, survivability, degree of autonomy, start-up time, readability and input rate.

Each state-of-the-art technology is evaluated with respect to these activities and requirements. The results are presented in table 1 and discussed in the following sections. In order to aid the comparison, existing paper based logbooks are also included in table 1.

3.1 Creating/Recording

None of the technologies reviewed can support all thirteen classes of information identified from previous work without additional effort to convert types into a suitable format. Arguably though, the benefits of being able to embed or link to actual models, instead of representations of a single viewpoint outweigh the inconvenience of having to digitise the small amount of paper-based information. However, support for single viewpoints is essential as they often illustrate particular points being made, which would not be apparent from the model alone.

Wilcox et al [1997] point out that "freeform input, spatial layout and even doodles (for their visual cues) are an integral part of the note-taking process", which was confirmed by observation during the previous analysis presented in Hicks et al [2005]. This is why logbooks that do not allow free-form input seem to be less appropriate for engineering logbooks which are largely used by an individual, although there is still clearly a balance to be found between freedom of input and ease of reuse.

The retention of paper as the recording medium holds several key advantages over other technologies as it retains the well documented affordances of paper such as reminding by physical presence [Sellen and Harper, 2002] whilst allowing electronic backup, distribution and searching. However, such systems do have potential drawbacks, such as their inability to include dynamic content such as hyperlinks or video and difficulties keeping the paper and electronic copies synchronised. The 'interaction lens' of the a-book [Mackay et al, 2002] offers an interesting solution, although requires adaptation of existing systems and methods of work to support it.

A key area that has apparently received little attention is the finding by Sellen and Harper [2002] and supported by analysis of existing logbooks [Hicks et al, 2005] is that reading and writing occurs simultaneously over 50% of the time. Given that many of these technologies are designed to overcome the difficulties of switching between paper and electronic formats, this activity is poorly supported. In addition, most of the technologies are not engineering specific, meaning integration with common engineering data types (e.g. CAD, analysis software etc) is not complete.

One area where all the technologies provide a clear benefit over existing paper-based books is in the automatic recording of time, data, author etc. This information was often found to be missing from paper logbooks. Automatic recording of this information lowers the burden on the author and also provides useful information for searching.

3.2 Classifying

Classification of some sort is necessary to support searching and reuse. Most of the technologies described here allow classification by 'tagging' elements such as lines of text or sketches. In the case of EEN [Gwizdka at al, 1998], these tags are based on engineering ontologies and provide a way of providing detailed and structured information for storage and retrieval, without constraining the user too heavily at the time of input. Other technologies, such as Microsoft OneNote allow users to define custom sets of tags.

Research into different levels of data structuring [Gwizdka et al, 1998] supports the view that a free-form interface, with structuring occurring after note-taking is preferable, whilst analysis of previous logbooks [Hicks et al, 2005] reveals authors use symbols such as stars or bold words to tag entries, suggesting engineers would find classification by tagging fairly easy and natural. The thirteen classes identified in previous work, plus custom tags, could form the basis for a schema which would allow classification by type of information as well as content.

Again, there is a need to investigate further the balance between ease of creation and ease of reuse in the engineering domain, although 'lightweight' structuring via tags does appear appropriate for engineering logbooks.

3.3 Browsing/Navigating

Previous research [Hicks et al, 2005] has highlighted the importance of this activity, with a majority of engineers accessing their current logbooks on a daily basis and 'browsing to remind'. Paper is well suited to this task by providing subtle visual and tactile cues gained from turning pages.

Clearly, augmented paper-based approaches have an advantage in this area, but the user is then required to switch between two views (paper and electronic) to see all the information (e.g. links or attached files). By the nature of their interfaces, computer-based logbooks do not provide the same level of support for browsing in this way. Being able to access recent information quickly and 'browsing to remind' are key activities for engineers and if a pen-computing or web-based logbook is to be used, more regard must be paid to supporting this activity.

3.4 Searching

All the technologies reviewed provide some search capability, either by searching tags or - in the case of web-based logbooks - a keyword search. In addition, previous research [Hicks et al, 2005; Wilcox et al, 1997] revealed that engineering logbooks are almost always arranged chronologically. Many of the technologies reviewed provide automatic recording of information such as time, date and author, which would be of significant benefit to the engineer. Many engineers rely on memory and browsing, which is more difficult if this information is missing, as is commonly the case with engineering logbooks.

The ability to search logbooks is one of the greatest advantages that electronic logbooks could provide over their paper equivalents. Although the search methods could clearly be improved upon by using more sophisticated handwriting recognition and contextual or semantic search techniques, search facilities should provide a major and immediate benefit for engineers. Previous research has revealed that whilst engineers typically access their current logbooks on a daily basis, nearly 20% did not retain past logbooks, with a further 42% referring to them for specific events only [Hicks et al, 2005]. Whilst it could be argued that this is because they contain little of value, this is not borne out by either the comments of engineers in the previous research [Hicks et al, 2005], or findings that the respondents were "generally dissatisfied" by the note-taking process [Wilcox et al, 1997].

Despite the capabilities of electronic searching, sketches or other visual objects which make up a significant amount of the typical engineer's logbook [Hicks et al, 2005] are still not easily searchable. It is suggested that using a schema for tagging information elements based on the previous research into the thirteen classes of information engineering logbooks contain may overcome this to some extent. This would be an important capability given the special importance of sketches and other graphical representations in engineering.

3.5 Sharing/Collaborating

Given that a significant proportion of design is now undertaken in distributed teams, support for sharing and collaboration is particularly important.

Web-based notebooks such as ELN [Myers, 2003] have an obvious advantage for sharing, as notes are held centrally on a network. The relatively structured form of these tools may also make reuse easier compared to free-form, unstructured text. However, other types of electronic logbooks also make sharing easier than existing paper-based logbooks by their very nature and there is no reason why the files from other logbooks could not be held centrally to facilitate sharing.

Turning to collaboration, lots of free-form annotation of multiple document types (Images, CAD drawings and the use of Post-It notes to add comments) has been observed in existing engineering logbooks [Hicks et al, 2005] and is clearly of importance to engineers. As these annotations often made little sense to anyone but the authors, the voice recording facilities of Dynomite [Wilcox et al, 1997] and OneNote [Microsoft corp., 2005] could be very useful. However, these systems don't effectively support collaboration in all situations (e.g. face-to-face and distributed).

For example, one area of particular importance in collaborating and annotating is identifying multiple authors. Web-based logbooks such as ELN [Myers, 2003] are good at identifying and authenticating authors, as is the Anoto system, as each pen has a unique ID, although the issue of combining data from multiple pens has not yet been tackled. This is another area where improvements over paper could provide real and immediate benefits to both the individual engineer and wider organisation.

3.6 Practical Considerations

Previous research [Hicks et al, 2005] showed that engineers typically use their logbooks for a variety of tasks in multiple locations, such as taking notes at their desk, during meetings or at a client's site. It is therefore suggested that logbooks that rely on always-on network connections are unlikely to be suitable for the majority of engineers. *Portability, survivability and degree of autonomy* (e.g. battery life) are therefore also key issues. They do not appear to be explicitly addressed by existing technologies, although augmented paper-based books tend to have lower power consumption than full pen-computing based logbooks.

Other ergonomic considerations such as *start-up time* (a major drawback in this author's use of Tablet PCs) and *readability* of the screen/interface in a variety of conditions also need to be considered if the logbooks are to be successful, as does *input rate*. Research Notebook [Knowligent, 2002] which suggests typing input rates are 40-100% greater than writing for most people. However, these figures fail to takes into account start-up time (up to two minutes for a Tablet or desktop PC) which becomes significant when recording short notes, time taken recreating spatial layouts, formatting and tables, and time taken to digitise sketches and diagrams, all of which are commonly observed in existing logbooks [Hicks et al, 2005].

4. Discussion

Paper logbooks continue to dominate, and for good reason. None of the technologies reviewed can easily support the full range of information recorded by engineers in paper based logbooks and are particularly poor at supporting browsing. In addition, existing attempts have not generally paid sufficient regard to how paper logbooks are used, or the well documented affordances of paper, such as simultaneous reading and writing and reminding through physical presence [Sellen & Harper, 2002]. Augmented paper-based systems are better in this regard, although have their disadvantages, the primary one being synchronising paper and electronic instances.

In general the technologies reviewed herein were not specifically designed for engineering and as such do not provide comprehensive support for the full range of essential engineering tasks, such as free-form sketching and annotating external documents (e.g. CAD drawings). Other more routine but important practical requirements such as portability, survivability and start-up time may also prove to be fundamental barriers to the uptake of an electronic logbook.

In order to overcome the information handling limitations - in particular organising and browsing - a classification based on information types could be adopted. For example, a schema based on the thirteen classes of information identified in previous research [Hicks et al, 2005], combined with custom tags may provide the basis of a strategy for facilitating the reuse of types of information not easily searched by conventional means, such as sketches and annotations.

More generally, electronic logbooks have the potential to offer the engineer immediate and substantial advantages for specific tasks, particularly the embedding of complete computer models, large data sets and dynamic content, more effective searching, and better support for multiple authors and sharing/collaboration in a distributed environment.

Table 1. Classification of Logbook Technology

Class	Paper	Augmented paper			Pen-based computing			Web/keyboard based	
Name	**Existing Paper**	**Digimemo**	**'a-book'**	**Anoto system**	**Electronic Engineering Notebook (EEN)**	**Dynomite**	**Microsoft OneNote (Tablet PC)**	**Electronic Laboratory Notebook (ELN)**	**Research Notebook™**
Reference	N/A	Acecad [2004]	Mackay et al [2002]	Anoto [2005]	Gwizdka et al [1998]	Wilcox et al [1997]	Microsoft [2005]	Myers [2003]	Knowligent [2004]
Support for: Creating & Recording	Pen, external documents	Free-form Pen	Free-form pen, external documents and linking to physical objects	Free-form pen	Free-form Stylus	Free-form Stylus, Audio	Free-form Stylus, Audio, Importing of other data types	Keyboard and mouse, Importing of other data types	Keyboard and mouse, Importing of other data types
Classifying	Visual marks only (e.g. highlighting)	No in-built facilities, Grouping downloaded files on computer only	Linking to other pages and physical objects, Indexing via PDA	Allocation of notes to folders when downloaded (e.g. project A, B etc)	Tagging and linking of elements based on engineering ontology	Tagging elements with properties, Tagging pages with keywords	Custom tagging of elements (e.g. sketch, 'To-Do' etc)	Attach metadata to elements (description, author etc)	Templates to guide note-taking
Navigating	Browsing through pages	Browsing book, Scrolling through files on computer, grouped by title, date etc.	Browsing book, Scrolling through index on 'Interaction Lens'	Browsing book, scrolling through files on computer, grouped by title, date etc.	Scrolling through pages, Semantic index, Semantic links	Scrolling pages, Browsing contents page, Dynamically created views	Scrolling through pages Dynamically created views	Scrolling through pages or contents page	Scrolling through pages or contents page
Searching	Visual scanning only, through pages or contents page	Browsing book, Browsing files on computer, grouped by title, date etc.	Unknown	Page name and properties, Keyword (via handwriting recognition)	Semantic index	By tags, keywords attached to pages and page properties	Tags, Page title, Keyword (via handwriting recognition)	Keyword, User entered metadata (description, author, date etc)	Keyword, Attachment names, User entered metadata, (description, author, date etc)
Sharing & Collaborating	Need to make physical copies, Co-located collaborating only	Can send electronic files, No support for multiple authors	Can send electronic files, Unknown support for collaboration	Can send electronic files, Some support for multiple authors	Can send electronic files, No support for collaboration	Can send electronic files, Unknown collaboration support	Can send electronic files or store in a shared workspace	Can send electronic files, Shared workspace with access control.	Can send electronic files, Shared workspace with access control
Other notes		Paper and electronic versions hard to synchronise	Not portable	Paper and electronic versions hard to synchronise	PDA and Java version for Desktop PCs available			Secure authentication of notes	Secure authentication and multiple author support

5. Conclusion

This paper has reviewed a number of technologies that could support an electronic designer's logbook. The study reveals that for an electronic logbook to be successful in the engineering domain, there is a need to combine the best and most appropriate aspects of the various approaches (personal note-taking vs. organisational record-keeping) whilst not neglecting basic practical requirements such as speed of use, portability and autonomy.

Of the technologies reviewed, solutions based on the Anoto digital pen and Tablet PC technology appear to have real potential to replace the ubiquitous paper-based engineering logbook. For example, Tablet PCs would benefit from better support for multiple authors, browsing and simultaneous reading and writing, whilst Anoto pen solutions could be developed to allow customised sets of 'tags' to be used for classification. However, the suitability of these solutions is somewhat contingent on the task being performed. For example, a design engineer may spend most of their time in an indoor environment at their desk or at on-site meetings and may benefit most from a pen-based computing solution which allows embedded dynamic content and seamless integration with other common software applications such as web-browsers and CAD/analysis software, as well as immediate sharing with no further hardware (unlike augmented paper systems). Where greater portability and autonomy are required (such as for a maintenance engineer), an augmented paper-based approach using an Anoto digital pen to combine the affordances of existing paper logbooks with better support for searching, sharing and collaborating offers the most promising solution.

As a consequence of the findings, and given current technologies, the most feasible solution is to integrate tablet PC and digital pen technologies. Such a hybrid solution has the potential to offer enhanced functionality and improved performance across all of the key functions of the designer's logbook, whilst also satisfying important practical considerations. This hybrid scheme is currently being investigated by the authors. The overall approach involves the creation of a strategy for capturing, classifying, organising, synchronising and presenting all design information. Furthermore, a critical element to the successful creation of an electronic designer's logbook is that the information content is managed such that it is complementary to other information sources such as PLM, electronic documents and customer relationship management systems. To support this, a strategy for semi-automated classification and referencing of information elements is also being developed. Achieving such a solution would ensure that all recorded design information and knowledge was available and accessible to the entire organisation - a situation that is rarely achieved by any engineering organisation regardless of sector or size.

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