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A REVIEW OF STATE OF THE ART AND EMERGING INTERACTION TECHNOLOGIES AND THEIR IMPACT ON DESIGN AND DESIGNING IN THE FUTURE

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1. Introduction

Engineering design generates a large quantity of digital and physical information in a wide variety of formats, which can be challenging to manage effectively. With designers increasingly having to consider a product's entire lifecycle and potentially coordinate the activities of an internationally distributed supply and manufacturing network this is only becoming more difficult. Issues with fragmented information, integrating physical and digital information and productivity all contribute to these difficulties. Digital information has several distinct management advantages over physical information (such as paper documents) including indexing, searching, editing and replicating. Whilst certain design activities and their associated information can be readily digitised the process of doing so often leads to a loss in the intrinsic value of the original format. Furthermore, performing the same task on a computer can hinder the activity, such as sketching and making personal notes [McAlpine 2010]. This suggests that the process of interacting with the information is a key issue that needs to be addressed to help bridge the physical-digital divide.

Interaction technologies have developed substantially over recent years including gesture control with the Kinect and multi-touch screens, driven by increased focus placed on usability by consumer electronics companies. These emerging and state of the art interaction technologies offer the potential to improve the way designers interact with digital information in a number of ways; existing digital interactions can be improved by replacing ill-suited modalities (interaction communication paths: vision, sensory and auditory [Karray et al. 2008]) with more natural and intuitive interfaces; physical interactions can be digitised; information from capturing interaction can be used to generate knowledge about how designers work, for example; the divide between digital and physical information can be reduced through for example AR; introduce new ways of working. This paper reviews these technologies giving examples of how they are currently used and how they could be introduced into the design process. The review is not intended to be exhaustive but provides suggestions for further research as to how the interaction technologies could be used to support design in the future. Comments will be made on the quality of existing interaction modalities and how the *"designer-computer interface"* is moving towards a *bi-directional modality* future where users input and output information from computers simultaneously in multiple ways.

2. The state of the art

This section examines the state of the art in interaction technologies for inputting and outputting digital information. Key modalities are identified and subsequently interaction technologies are examined for each modality.

2.1 Modalities

In engineering design, information can be considered to be anything that provides data within a context [Hicks et al. 2002]. Digital information might be in the form of emails or CAD whilst physical information may be markings on a prototype, post-it notes or a whiteboard. Engineering designers constantly interact with information, transferring it between formal and informal states in a process of either inputting or outputting information. The paths by which digital information is transferred are called modalities and can be grouped into three broad categories [Karray et al. 2008]:

- Vision-based
- Sensor-based (touch etc)
- Auditory-based

The existing modalities for manipulating digital information are highly prescriptive and are not always the most natural or intuitive [Oh and Stuerzlinger 2005], [MacKenzie and Sellen 1991]. Within engineering design whether a modality is primarily used for inputting or outputting information is normally well established. Vision as a modality is almost exclusively used for outputting digital information, usually via a graphical display. Sensors are predominantly used for inputting digital information, most commonly by a mouse and keyboard. Audio modalities remain relatively undeveloped within engineering design and do not experience the same ubiquity as a means of inputting or outputting digital information.

2.2 State of the art interaction technologies

Over the past decade consumer electronics manufacturers have placed a greater emphasis on how users interact with their products. This has substantially reduced the cost and improved the capabilities of interaction technologies to the extent that many are becoming more widely adopted. This section gives an outline of these state of the art and emerging interaction technologies and briefly describes their current applications. All technologies are commercially available (unless stated). The technologies have been selected on the basis of their potential benefit to design practitioners.

Table 1. Vision-based interaction technologies

Technology	Description	Examples
3D Display	Generation of scene through stereoscopic vision or volumetric display to give perception of depth	CAVE is a total immersion system where a user is placed inside a room. Each wall surface has a rear 3D projected image displayed. This allows the user to be situated 'inside' of a 3D projection. [Mechdyne 2011]
Augmented Reality (AR)	Enhancement of physical scene with digital information either through direct projection or graphical overlay on an intermediary screen	AR glasses combine head mounted stereoscopic displays with stereoscopic video capture. The cameras feed directly to the screens giving the illusion of transparency but the ability to overlay information. Compatible with Autodesk. [Vuzix 2011]
Eye Tracking	Capture of gaze with respect to a frame of reference	Eye tracking devices allow for accurate positioning of the eye either through a set of wearable glasses or a desktop appliance. This indicates where the attention of the user is focused. [Tobii 2011]
Gesture Control	Cameras able to detect depth combined with software allow for markerless tracking of the human body. Body gestures can be used as commands.	Xbox Kinect controller has an official SDK to develop and exploit industrial uses of the gesture control device originally designed for computer games. [Microsoft 2011]

The technologies in Tables 1, 2 and 3 are all commercially available, however, their integration into the design process is limited.

Table 2. Sensor-based interaction technologies

Technology	Description	Examples
Touch Display	Visual display where graphics can be directly manipulated by touching the screen	Perceptive Pixel touch displays are large screens (up to 160”) capable of high fidelity intuitive control with unlimited contact points. [Perceptive Pixel 2011]
Data Glove	A wearable device that captures precise positional data of each finger as well as flexure extent.	Data gloves are used for creating physiologically accurate animations of digital hands. [5th Dimension Technologies 2011]
Haptic Device	Haptic device is a generic term for any device capable of recreating the sensation of touch either through the simulation of surface texture or force feedback.	The Phantom Omni is a stylus attached to a boom with six degrees of freedom that can introduce an element of force feedback. Varying the force feedback vector can create the perception of probing a physical object with the stylus.[SensAble 2011]
Wearable Haptic Device	A wearable device, such as a glove that aims to recreate the sensation of touch either through the simulation of surface texture or force feedback.	CyberGrasp constrains the extent by which fingers can flex giving the illusion of the user grasping a physical object. The glove is also capable of providing finger and hand positional data to the computer. [Cyberglove Systems 2011]

Table 3. Auditory-based interaction technologies

Technology	Description	Examples
Speech Recognition	Software that is able to understand speech and either convert to text or interpret commands.	Speech recognition software integrated into mobile phones can analyse a user’s speech and interpret the context and meaning of the request allowing the user to speak in a more natural way rather than use specific voice commands. [Apple Inc. 2011]

3. Applications of state of the art interaction technologies within design

This section examines where each of these technologies have already been applied within engineering design and discusses their possible future applications for an increasingly digitised design process.

3.1 Engineering design activities

Based on a synthesis of design process models [Hales 1991], [Ullman 2002], [Pahl et al. 2007] and review of the design research literature a number of common design activities have been identified. These are well established in the literature and each form the basis for a distinct branch of design research as well as being independently identified in numerous studies of the design process such as Hales [1991]. Table 4 outlines each of these activities and gives a brief description as well as a number of exemplar references. With these general activities established it is possible to begin the process of identifying which interaction technologies are used where and subsequently where future research/technological development should be directed.

Table 4. Engineering design work activities

Work Activity		Description
1	Information seeking	Searching for, requesting, synthesizing, evaluating and linking information including searching, interrogation of records and making notes on found data e.g. [Hertzum and Pejtersen 2000], [King et al. 1994]
2	Conceptual design	Ideation and concept development tasks including sketching, collaboration, mind mapping, idea selection and concept exploration e.g. [Philip Cash et al. 2011], [Kuijt-Evers et al. 2009], [Tang et al. 2011]

3	Design development	Development of a design once a final concept has been selected including costing, function mapping, DFMA, design refinement and problem solving e.g. [Carrizosa and Sheppard 2000], [Luck 2007], [Kim and Maher 2008]
4	Design review	Reviewing existing work or future planning including review meetings and reflection on current designs e.g. [D'Astous et al. 2004], [Huet et al. 2007], [Bergström et al. 2005]
5	Embodiment/ Detailed design	Technical layouts, CAD configurations and material selection including CAD, prototyping and configuration e.g. [Scaravetti and Sebastian 2009], [Chenouard et al. 2007]
6	Product testing	Running, setting up or dismantling test hardware or software including virtual or physical testing and user testing activities e.g. conducting CFD analysis
7	Project reporting	Formal collation and dissemination of structured reports including lessons learned, structured reports, product metrics and formal presentations of findings e.g. [Wild et al. 2005], [Haas et al. 2000]
8	Dissemination	Informal distribution of decisions, work plans or progress including informal email, interpersonal conversations and shared workspaces e.g. [McAlpine 2010], [McAlpine et al. 2011]
9	Miscellaneous work	Any work related tasks which are explicitly not administrative work but do not include work on an engineering design project e.g. office organization, tidying, sorting of components
10	Administration	Work relating to administration inc. personnel management, internal processes and organization of emails and filing e.g. organization of filing system and personnel review meetings

Some of these engineering work activities have already been widely digitised whilst others are still largely conducted using physical media. Hence there is an opportunity to not only improve current digital interactions, but also digitise physical activities and bridge the digital-physical divide. The following section describes how interaction technologies are currently being used and considers where design activities could benefit from them being implemented. Miscellaneous and administrative work will not be considered.

Information seeking

- Augmented reality is an approach to outputting information that has the potential to increase the effectiveness of information searching by allowing it to integrate into other design activities. For example, a designer creating concepts as part of an ideation activity could call upon information, such as past solutions or alternate principles that would be directly projected on their workspace, to support the process.
- Effective information searching relies heavily on using specific keywords. Speech recognition capable of interpreting the meaning of voice searches and incorporating an element of context can help users find information in a more intuitive way [Guha et al. 2003].
- Eye tracking can be used to build up a profile of what a user finds useful whilst information searching. Future searches could then be improved by applying the knowledge of the user's information preferences to rank search results in order of likely value [Campbell et al. 2007].

Concept design

- Design with vision is a collaborative project exploring the application of eye tracking whilst sketching during ideation. Eye tracking is used to recognise areas of a sketch that a designer finds interesting and then suggest alternative forms exploiting the ambiguity of sketching [Jowers et al. 2011].
- Touch displays with styluses are already used by the creative industry for sketching and detailing. Sketching in this manner affords some of the physicality of a pen and paper but the advantages of a digital medium including greater ability to replicate and edit work.
- Sketching is a useful tool in the design process for visualising ideas. Augmented reality could increase realism, recall and rendering in sketches by projecting construction lines, vanishing points, perspective grids or even add an element of shading to aid the communication of ideas [Tang et al. 2011].

- EyeWriter is an open-source art project to bring low-cost eye tracking solutions to paraplegic patients. The EyeWriter uses the movement of the eye to control a cursor on screen that is used to sketch. This could be used as a control interface for marking up physical prototypes with a combination of augmented reality [EyeWriter Initiative 2011].

Design development

- Quality Function Deployment (QFD) matrices are often difficult to interpret as they contain large amounts of information. An augmented reality version of the 'house of quality' could aid with the ease of reading the matrix by visually highlighting relationships such as information about the customer and the design requirements.

Design review

- Code Space is a research project by Microsoft where gesture control and touch screens (amongst other interaction technologies) are used to facilitate review meetings for software code. A chairman leads the review meeting on a touch screen where portions of code are displayed. Participants at the meeting are able to suggest alterations from their seats by using gestures detected by Microsoft's Kinect controller. Using mobile phones members of the meeting can also wirelessly send code excerpts to the presenter who can review them and decide whether to accept or reject the segments [Bragdon et al. 2011].
- Speech tracking during design review meetings can be used to automate the process of recording design changes for version control. Context and additional supporting information from conversations could be included in the version history to provide information on the rationale behind previous decisions [Bracewell et al. 2009].

Embodiment and detail design

- The process of creating CAD data can be considered to be the translation of a conceptual 3D model into a digital 3D model. However, the modality for inputting the conceptual into the digital is entirely 2D, a mouse and display screen. 3D displays combined with data gloves or gesture control affords the opportunity for CAD geometry to be inputted in 3D making the interaction more natural [Kela et al. 2005].
- Using schematics for layout design can omit interference between elements on planes not represented by the viewport. Augmented Reality through head mounted displays is already used during factory planning where an object marker, representing a 3D model of a piece of equipment, can be placed on the real factory floor or a scale model. The user looking through the AR glasses sees the normal factory surroundings but where the object marker is located a 3D model representing the machinery is placed. AR glasses track the user's location so the wearer can move around the factory floor whilst the system adjusts the view of any 3D model for the correct perspective [Vuzix 2011]. For moving components any interference over the full dynamic range can quickly be spotted as the AR systems have the ability to animate 3D models [Azuma 1997]. As object markers are small pieces of card they are readily repositioned.
- ClayTools by SensAble uses their Phantom Omni haptic device as the input method for digital sculpting. The force feedback on the stylus is controlled to simulate the sensation of sculpting clay away from a solid block of material. Complex surfaces can be made and controlled in a more intuitive way instead of describing and manipulating CAD geometry [SensAble 2011].
- Speech Recognition can be used within CAD environments as a simple command call up function reducing physical repetition of actions.

Testing

- 3D display devices are powerful tools for visualising complex computer simulations such as CFD. Fluid flow is a 3D problem that can be difficult to visualise in 2D. Using CAVE or through a head mounted display it is possible to run fluid flow analyses and create a virtual flow environment [Mechdyne 2011].
- The CyberForce haptic glove can create force feedback for hand and wrist movements simulating the sensation of mass and grasping an object within a CAD environment. The

system can be used to digitally test a user's ability to assemble components or to perform functions such as pulling levers [Cyberglove Systems 2011].

- In the design of instrumentation displays and interfaces eye tracking devices can be used during testing to highlight areas the user focuses on. A greater understanding of what information the user is paying attention to can then be fed back into the design [Tobii 2011].
- Augmented Reality can be used to project high quality surface finishes onto rapid prototyped models through a technique known as Spatial Augmented Reality (SAR). Physically producing "automotive finishes" on prototypes for consumer testing is time consuming and expensive. Projecting the required surface finish provides a readily adaptable model that is significantly cheaper to produce [Marner et al. 2011].

Project reporting

- Speech recognition during meetings can be used for the automatic production of minutes. The technology could also be used to transcribe verbal reports for purpose of searching and reuse. This would aid in the capture of design rationale during the design process [Bracewell et al. 2009].

Dissemination

- Speech recognition during conversations and meetings could be used to automatically detect when a decision has been made, and by who, and then automatically disseminate the decision on the basis of pre-defined rules. For example, a supply order authorisation could be given verbally but have an automatically generated digital record.
- The process of converting informal information into formal information can be time consuming and expensive. The ability for speech recognition software to understand the context and summarise the content of a conversation could be used to automate this process [Loftus et al. 2008].

4. Discussion

This section considers how state of the art interactive technologies may impact on the designer and design process in the future and then provides an insight into the barriers for adopting these technologies.

4.1 The future effect of state of the art interaction technologies on designers and design

The quantity of information that engineering designers can be expected to deal with is certain to increase. For this to remain manageable engineering designers must move beyond using each modality for only inputting or outputting information at any time. Seven key areas in need of further research have been identified regarding how state of the art interaction technologies will affect design.

4.1.1 Bi-directional modalities

Bi-directional modalities can be considered as two-way information interaction pathways through the *same* modality. They offer the potential to improve information interaction by increasing the quality, richness and efficiency of the interaction without requiring the user to change their behaviour. For example, a bi-directional touch screen would allow a user to navigate a model via touch but would additionally provide sensory feedback in the form of surface texture, material type etc through the screen. Several examples of bi-directional interaction devices have been noted with systems capable of adapting to a user's interaction intuitively based upon their use to improve the quality, richness and efficiency of the interaction. A device indicative of this trend is the eyeBook, which integrates eye tracking with a digital reader to create an adaptive system that highlights key words based on the users reading speed i.e. whether they are scanning a document or reading carefully [Biedert et al. 2009]. Further research is required to understand how best to introduce bi-directional modalities into engineering design, specifically how a system or a device should respond to a user's interaction.

4.1.2 Information creation

The interaction technologies in this paper have the potential to fundamentally change how designers work. It is unclear if having more intuitive, natural interfaces for computers will improve the quality of information creation or only increase the speed and ease of doing so. Current interfaces require users to work in a prescribed way and this may have some intrinsic advantages by guiding designers to produce information in a set manner. For instance, verbal reporting and written reporting are very different in style. The adoption of new interface technologies is likely to change not only the modalities of inputting information but also the cognitive process of doing so. Introducing new interaction technologies may also have the effect of merging design activities. For instance, ideation and embodiment may seamlessly merge as a digital sketch is used to create the technical layout of an artefact [Prieto 2011].

4.1.3 Information finding

Compared to physical media computers have several distinct advantages in terms of creating, editing, replicating, and searching for information. The use of new interaction technologies to help digitise the remaining physical design activities, partially or completely, will increase the quantity, availability and ability to capture information. The possibility of using this information from digitised design activities to record and visualise information paths has the potential to increase the effectiveness of the designer through retrospection. Determining what information generated by new interaction technologies is valuable and should be captured requires further research.

4.1.4 Information sense making

New modalities in engineering design provide an opportunity for designers to rethink how they make sense of information. By fully, or even partially, digitising design activities the possibility of linking data across the design process exists. Understanding how and what to link and the best ways to make use of this information remains to be addressed. Further, technologies such as eye-tracking could be used to record what can be thought of as sense-making plots through information sets.

4.1.5 Artefact interaction

New interface technologies offer the possibility of enhanced interaction with digital and physical artefacts. With increased capabilities for interacting with digital models the prospect of greater functional, ergonometric and aesthetic testing emerges. Whilst this might make testing quicker and easier the question of quality of interaction and understanding generated is again raised. An improved understanding as to whether there is a trade off between digital and physical artefact interaction is required.

4.1.6 Virtual collaboration

Digitising engineering design activities through the introduction of new interaction technologies brings ubiquitous virtual collaboration closer to reality. This could include virtual worlds made possible with interaction technologies such as gesture control, eye tracking and speech recognition. Designer practices and behaviour could change in unpredictable ways as a consequence of this with the potential to affect creativity, innovation and productivity. As such, existing business models for such a work environment may no longer be applicable.

4.1.7 Multimodal design records

The interaction technologies discussed in this paper have the ability to substantially expand the capabilities of recording the design process by capturing different modes and types of information on a much larger scale. Richer multimodal records of the design process could be used to optimise the process reducing things such as repetition of work as well as provide a more complete record.

4.2 Barriers to widespread introduction

This section identifies and discusses five key barriers to the adoption of interaction technologies within the design process.

4.2.1 Miniaturisation of hardware and integration

Computers and digital design activities require engineering designers to work in a prescribed manner e.g. in a specific location in a specific way. The new interaction technologies could allow users to work in more intuitive and adaptable ways but they often have technical limitations that require a specific environment or intrusive equipment. Miniaturisation and integration into existing computers and electronic devices will allow engineering designers to work where and when they desire, addressing this issue. Progress towards this is already being made with some of the interaction technologies such as the Senseg touch screens with responsive tactile surfaces [Senseg 2011].

4.2.2 Interface standardisation and software integration

For the full potential of interaction technologies to be achieved the software they work with needs to be designed with new interfaces in mind. Control standardisation is a key part of achieving wide scale adoption and interaction technologies that have established this, such as touch screens, are extensively used. For the same to occur for the remaining interaction technologies more research is required into how engineering designers are best suited to use the interaction technologies to manipulate digital information.

4.2.3 User barriers and appropriate application to engineering work

Engineers are used to thinking functionally and working with existing modalities such as a mouse and keyboard. The introduction of new interaction technologies, such as gesture driven environments, will radically change how existing engineering designers work. Compliance in adopting these new interaction technologies and ways of working will be a factor in their success. Where and how to apply interaction technologies is poorly understood and needs further investigation in order to add meaningful value to engineering design work. Hence there is a need to more fully understand engineering work and in particular the work tasks associated with information interactions in order to develop interface systems that enhance interactions and productivity.

Personal privacy is also of concern as interaction technologies, particularly speech recognition, have significant issues that need to be resolved prior to widespread deployment. Again, understanding where and how to implement these technologies is key.

4.2.4 New ways of working

In contrast to alignment of multimodal interaction technologies with current process and workflows there exists the opportunity to create totally new ways of working. The interaction technologies reviewed in this paper could promote work practices not in keeping with existing business structures in unpredictable ways.

5. Conclusions

This paper has reviewed nine interaction technologies that could be applied to the engineering design process. From this review seven areas have been identified where these technologies could have a significant effect on the engineering design process. However, four barriers have become apparent that could limit the uptake and possible effectiveness of interaction technologies.

This review highlights the changing technological environment of engineering and the potential for radically new ways of working within the design process. Based on common trends in the development of the reviewed technologies the authors contest that a key aspect of future interaction technologies in the design process will be the move form linear to bi-directional information exchange. This is characterised by concurrent input and output information through the same modality.

In order to realise the potential benefits of the reviewed technologies further work is required to answer the following research questions:

- The need to understand the extent to which the engineering design process can be digitised and where digitisation would have the greatest impact.
- Further to this there is a subsequent need to understand the implications of changing modalities for inputting and outputting information in terms of quality and working process.

In addition to these research issues uptake of new technology is unlikely to become widespread until a dominant technology emerges for each modality and clear benefits are demonstrated within the engineering design domain.

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