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Human factors considerations for the application of augmented reality in an operational railway environment

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Abstract

Railways are recognized the world over for the vital social and economic role they play. However, in recent years their financial and economic performance has been criticized because of inefficiencies and increasing operating costs. In order to keep pace with changing business paradigms, railways across the world need more and better technology, higher capacity, better punctuality and reliability and more sustainable asset management to improve efficiency and reduce cost.Augmented Reality (AR) is a technology that could ease execution of complex operations, and assist railways in meeting their business objectives. AR mixes virtual and actual reality by supplementing a view of the real world with added computer generated sensory inputs in the form of graphics, video, sound and location data. AR provides the user with new tools to improve efficiency in the transfer of knowledge for several processes, from multiple sources and in several environments[1]. Technological developments such as AR generate the need for thorough investigation of human factors throughout the lifecycle of the system. Design, implementation and operation of any new systems in the railway environment will generate a host of new human-related problems and successes that will require fundamental and applied understanding [2]. Therefore, in order to fully understand the human factors risks associated with using AR in the operational railway environment, a set of Human-Computer Interaction (HCI) design frameworks for railway AR applications was established.

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1. Introduction

In order toinvestigate technology in the railway industry, especially in asset management and maintenance operations, a prototype AR proof of concept (POC) application for railway asset management was developed. It transpired that AR technology could improve efficiencies in asset management and maintenance operations by overcoming complexity barriers, particularly dispersion. Fast transfer of asset information via handheld mobile computing devices (HMCDs)—such as smart phones and tablets—directly to track workers on location makes it easier and more efficient to manage assets dispersed along the long narrow corridors of rail networks [3].

Industry experts and senior business leaders were interviewed, as were frontline maintainers and operational staff, from railways and related organizations in the UK and Asia. Thisenabled the development of a vision statement, which provided a definitive target and a clear route to determine what capabilities the AR system would need to deliver. It also formed the foundation for the first step in the Systems Engineering (SE) process.

Adopting a holistic SE approach for POC development allowed the authors to: (1) clearly understand project scope, define the system boundary and identify system stakeholders and system interfaces; (2) develop and capture functional requirements, whilst considering system dependability, maintainability, technical risk, commercial risk and safety risk; (3) decompose functional requirements; (4) map functions onto a physical hierarchy to define how the system is to be implemented in terms of its architecture.The SE approach provided a mechanism to understand the problem space and drive the development of innovative technology, while verifying that the solution met the original requirements before moving to the next phase in the development lifecycle.

A review of the AR POC SEdevelopment approach showed a close association between Human Factors Engineering (HFE), safety engineering and risk management and that all three disciplines needed to be used to mitigate the many risks associated with integratingAR Apps into complex operational railway environments.

The purposes of this paper are 1) to highlight the significance of the HFESE discipline when designing complex socio-technical systems for the railway and 2) to provide an overview of HF risks associated with using AR in operational railways, and 3) to establish a set of HCI design principles for railway HMCD AR applications. These principles will recognize the specifics of the railway environment and address perceptual issues in AR such as alignment and registration of information in different work environments and at different times of the day.

2. Background

Augmented Reality (AR) is a technology that could considerably ease execution of complex operations. AR mixes virtual and actual reality by supplementing a view of the real world by added computer generated sensory inputs in the form of graphics, video, sound and location data from GPS (Global Positioning Systems), to enhance the user’s perception. AR provides the user new tools to ensure efficiency in the transfer of knowledge for several processes, from multiple sources and in several environments[4].

At present the majority of AR applications are focused on entertainment, marketing and retail. However, as the technology matures it is likely to be more readily adopted for industrial applications. On the railway and elsewhere, numerous potential benefits of AR to enhance customer service and the customer experience of travel have been identified [3], but these are not the subject of this paper, which will focus on asset management, in which field AR tools offer improvements and new perspectives in the way that railway asset management operations are conducted. Table 1 below provides an overview of different types of augmented reality.

A number of authors have investigated AR for procedural tasks in maintenance and repair [6][7][8]. Tang et al. [9] experimented and tested the effectiveness of AR instructions provided through a HMD for assembly tasks. AR significantly reduced task error rates and reduced mental effort.

Rail as a transportation mode and system is dynamically complex, which occasionally results in unpredictable and emergent behavior. To effectively operate rail as a mode of transport, the factors that give rise to its complexity need to be analyzed to develop an understanding of its natural characteristics. According to Schmid[10] there are four main factors that drive this complexity, namely, diversity, variability, dispersion and interdependence.

Table 1.Types of augmented reality and their application.

Augmented reality type	Description	Augmented reality application
Projection	This type of augmented reality uses virtual imagery to augment what the user sees. It allows users to interact with presented virtual imagery.	Virtual signage or posters: overlay virtual information on surfaces.
		Collaboration: allow multiple users to view and interact with virtual imagery.
Recognition	Recognises objects, patterns or markers in the real world to provide supplementary real-time virtual information to the user.	3D visualization: overlay of 3D information relative to a particular object in the environment.
		Virtual demo: display 3D representation of a product prior to completion of its manufacture.
		In situ: used to visualize virtual object placed in an environment relative to an object, marker or pattern.
Location	Location based augmented reality utilizes detailed inputs from triangulation technology to provide the user with relevant directional information by precisely overlaying real-time virtual information over a view of the real world presented to the user by the device camera.	Location layers: overlay of virtual information onto the real world relative to the user's location, to provide data about object or new places.
		Points of interest: provide virtual markersto indicate points of interest to the user, conveying information such as direction, distance, altitude etc.
		In situ: used to visualize virtual objects placed in an environment relative to coordinates and/or a marker beacon (iBeacon).
Outline	This type of augmented reality merges the outline of a person's body or of an object with virtual information, which allows the user to pick up and manipulate objects that do not exist in the real world.	Training and education: can provide hands-on experience with complex equipment or work scenarios.
		Understanding systems: use of augmented reality for internal or exploded views of complex objects.

Managing the railway complexity, particularly in terms of creating and managing information about the infrastructure is made significantly more difficult by its structure. This is because the railway is effectively a diverse range of long-life assets dispersed along the infrastructure in a very unpredictable environment, with high levels of interdependence between the different systems and subsystems. Most academics and practitioners would agree that interdependence is one of the most important concepts in defining complexity.This characteristic of the railway requires management people and equipment across long and narrow corridors of extended networks, sometimes involving contracts between multiple parties. This results in complicated logistics and high operational costs.

AR technology has the potential to overcome some of these complexity barriers, particularly dispersion. This is because mobile ARenables a much faster transfer of asset information directly to track workers at the point at which information is required.

3. Railway augmented reality application development

The AR App development process started with the classical V-model[13]. The V-model was adopted to provide a structuredSElifecycle approach to:(1) Identify functional requirements; (2) design solutions for those requirements; (3) manufacture / construct the solutions; (4) verify that the solutions meet the original requirements; and (5) to manageacceptance of the solutions by the User and other relevant stakeholders.

In the V-model, the left branch represents the requirements elicitation and design activities. It reflects the breakdown of requirements from a functional level down to a component and sub-system level. The point of the V represents the development phase. The right branch represents the testing and validation phase, including a step-by-step realisation and evaluation of the product, starting at component and sub-system level up to overall system level. The right branch concludes with the acceptance and handover phase.Designing an integrated system takes place on the left-hand side of the V-model. Implementing this integrated system takes place on the right-hand side of the V-model. This includes the validation phase, in which successful system integration is demonstrated.

The firststep was to interview industry experts and senior business leaders, frontline maintainers and operational staff, from railways and organisations in UK and Asia. Their outputled to the development of a vision statement.

With the vision statement in place, a high level MODAF OV-1a operational concept graphic (ConOps Graphic)[11] was developed(Fig. 1) to show what the system [architecture] is addressing, and its constituent parts and operations. Its main use was to aid communication in developing requirements. With the ConOps Graphic complete, the system was named Integrated Enterprise Asset Management System (IEAMS).

For the IEAMS system architecture, the author used Sparx Systems Enterprise Architecture (EA) UML software with a custom TRAK architecture framework add-in to create an architecture description [14].This led to the identification solution functions required in orderto deliver the desired User capabilities. The derived functional requirements were used to develop the prototype iPad AR App as proof of concept.

As part of the verification process the App was tested while performing its different functions to verify that the functional requirements had been fulfilled before progressing to the next phase in the SE lifecycle. In order to compare the output from the Concept Design Phase to the requirements, verification evidence was captured in the form of screenshots taken from the App. Examples are shown in Fig. 2.

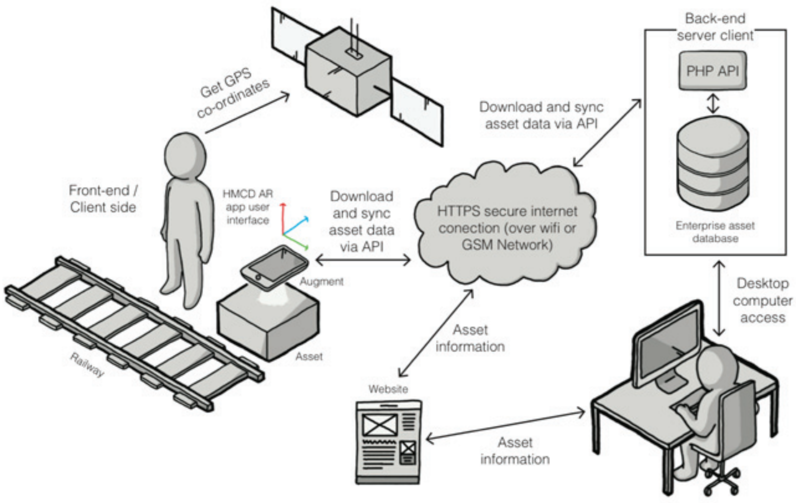

Fig. 1.MODAF OV-1a perspective ConOps graphic of the IEAMS.

Fig. 2. (a) verification of interaction with point of interest; (b) verification of filtering function.

4. Human factors engineering and railway mobile augmented reality applications

It became clear as the POC was being developed that an iterative incremental development approach [12], which integrates human factor considerations in all phases of the SE lifecycle process, would be appropriate. Previous research and summaries have identified HFE as critical to the success of AR applications [15].

In order to address human factors, two main tools were developed: an interaction framework for Mobile AR (MAR) applications within a rail environment, and a HFE activity and lifecycle model to guide application development. These two tools will be discussed below.

To understand the two HFE tools we should recap the present state of the HF literature in both MAR applications and the provision of railway information in a mobile computing environment.

HF considerations are important for MAR applications for the following reasons:

Match between AR functionality and user needs[16]: AR applications, and in particular MAR applications must deliver content that is relevant to the task. AR clearlysuits tasks such as navigation, but is not so obvious a choice for skill-based tasks such as assembling or disassembling machinery, where the need for extra information is limited. User needs can be identified and analyzed using HF design methods.

Perceptual issues in AR[17]: Correspondence between the augmented information and the real world is a key element of successful AR applications, and can help to prevent confusion and human errors when interacting with the scene. Human perception can be taken into account during the design stages.

Management and structuring of context-aware information[18]: There are a number of challenges within this group, such as discoverability, salience, and learnability.

Object selection and manipulation[19]: MAR applications in particular may present interactive information and objects on a small touchscreen. A HFE focus can help to address issues associated with object size and occlusion.

The requirement to provide AR applications for non-technical audiences[20]: As AR applications move beyond research and POC demonstrators there will be a need to ensure that applications can be easily used by most or all of the target participant group. This may involve considering the preferences and expectations of users with different levels of technical knowledge and computer familiarity.

Handheld computers and the provision of mobile information has been a developing theme within the UK rail industry for a number of years [21][22]. Dadashi et al [21] conducted a review of the user interfaces of a number of different mobile / handheld computers being used at the time within the UK Network Rail (NR) track infrastructure. They conclude that the purpose and design intent of a railway mobile application is an important factor, and a main determinant in providing information technology tools that are both 'usable' and 'easy to use'. Bye [22] reports on an initiative within Network Rail called ORBIS that aims to improve the provision of railway asset information on HMCDs. Given that these factors are likely to be critical to the success of any AR application, and in particular any MAR application, HF considerations have been recognized being important to the next steps in the development of the IEAMS. This research has been summarized in an interaction framework that is presented below.

4.1. Rail industry mobile augmented reality interaction framework

An interaction framework[23] is a representation of the flow of control and information, and the transformations on that information, that are inherent with a particular application when used in a particular context. The main benefit of an interaction framework is that it provides a concise summary of the salient factors where users are interacting with technology. This information can then be used to structure and guide the development of the application, as the framework highlights concerns important to this particular context.In this case, an Interaction Framework has been used to capture the important aspects of interacting with MAR applications in a railway industry context. This framework was subsequently used to derive a sequence of HFE activities.

Based on the previous research, Fig.3 shows the interaction framework that was developed for this project.This framework was subsequently used to derive a sequence of HFE activities.

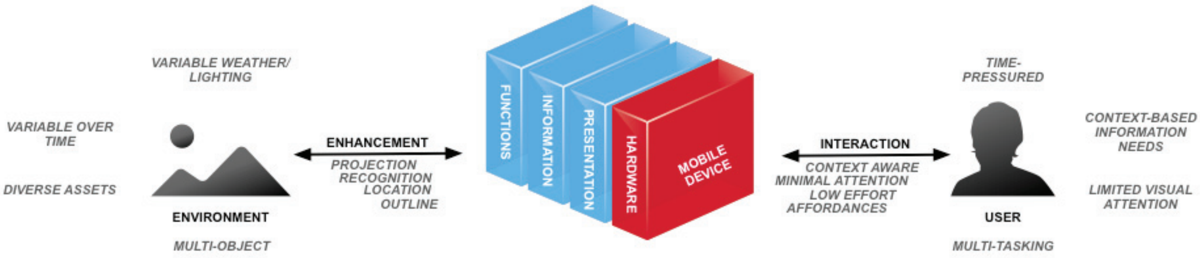

Fig. 3.Railway industry mobile augmented reality interaction framework.

There are properties and characteristics of the User that are important for MAR applications. According to research [24], and supported by the interviews conducted during the POC phase[3], railway MAR end-users are likely to be under time-pressure (because the railway is a time-critical system), require information that is context-specific and may also be dynamic, have limited visual attention, and be multi-tasking or have multiple priorities at any one time. These properties are specific to mobile applications, as reflected in previous studies of the provision of railway asset information onto mobile devices[22][24].

A novel aspect of AR applications is that they are intended to augment or enhance the environment and context of the user. This is in contrast to purely mobile applications, where the intention would be to monitor or potentially control aspects of the environment. These enhancements act upon the railway environment, which in itself also has special characteristics, as captured in the model of railway complexity[10].Aspects of the railway environment that are relevant to MAR applications include the following:

*Variable weather / lighting:*The railway trackside environment includes open sections (in both urban and countryside settings) and tunnels. The variability of lighting levels, sources, and types is great. MAR applications within a railway context will need to be able to cope with this variability in weather and lighting.Light intensity and occlusion are often difficulties with optical see-through HMDs [15].

*Variable over time:*The railway environment changes over time. This is especially the case on work sites, where construction activity may mean that the environment changes in unanticipated ways (removal of track, installation of temporary works, etc.). This can often be the case as different teams may be responsible for different parts of a project. MAR applications will need to deal with the evolving and dynamic nature of railway infrastructure.

*Diverse assets:*In a trackside railway environment a number of different assets and services exist, such as electrical power, train detection and signaling equipment, and communications equipment.

Multi-object: A visual scene may contain many potential targets. The application will need to be able to identify and isolate the topic of the user's interest.

The interaction framework was then used to refine a set of design principles and to structure these principles around an appropriate HFE lifecycle that would be integrated with the main SE project phases.

4.2. HFE development activities to support railway mobile augmented reality

Given that the literature review and interaction framework emphasize that the provision of relevant information and functionality is of critical importance to MAR applications, it follows that a systematic approachto the integration of human factor concerns into the development of the application is necessary.

Hix et al [25] describe a user interface design and evaluation process for a MAR application. This process involves activities such as work domain analysis, expert usability evaluations, and formative and summative usability evaluations. However, this process is not fully integrated with a structured SE lifecycle approach(such as a V-model, for example).

To overcome this shortfall, the HFE process of Hix et al [25] was adapted and mapped onto the classical SE V-model being used by the project (Fig. 4.). Fig. 4. also shows the MAR HF design principles to be addressed by each lifecycle stage. While a number of generic HF guidelines exist, specific MAR HF guidelines have been found to be more appropriate [20], as standard guidelines do not fully apply to 3D visualizations and interactions [26].

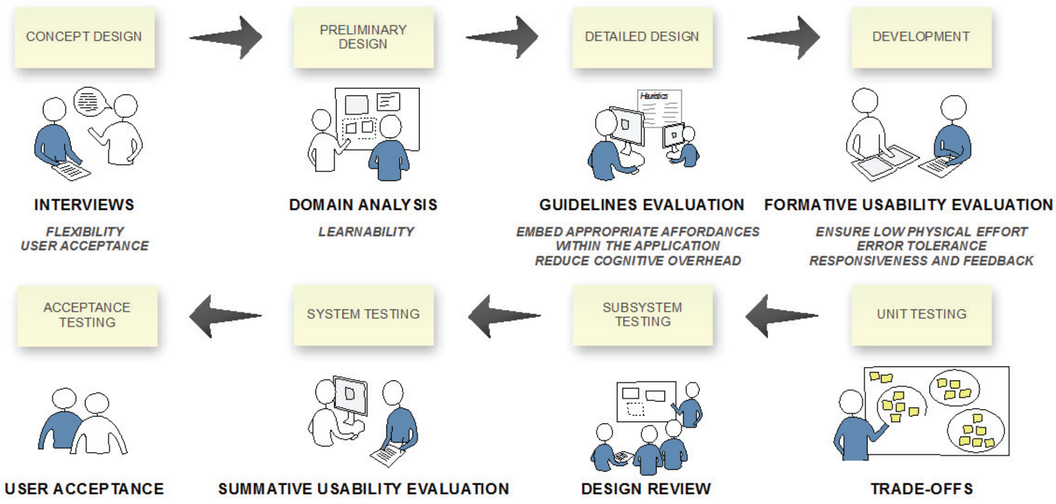

Fig. 4.Mobile augmented reality HFE development activities.

Concept Design was conducted as part of the POC. The remaining HFE activities are described below:

Preliminary Design: This stage should involve domain analysis. This is the process of capturing and describing the tasks, constraints, and context of use associated with particular activities. Field studies to collect this type of data are important but not often conducted during MAR development. During this activity, the principle of learnability can be addressed. Learnability concerns the match between the concepts, structures, conventions, and terminology within the application and those that are held or can be acquired by the target audience.

Detailed Design: In accordance with the process reported by Hix et al [25], a guidelines evaluation should compare the emerging application design against good practice principles, helping to ensure that basic usability principles are met before evaluations with end-users occur. HF principles such as the usage of clear and appropriate affordances, and reducing cognitive workload, can also be addressed via the application of guidelines evaluation.

Development: During the development phase formative usability evaluations can be used. This style of usability evaluation is intended to contribute to the application development and design. As such, it can often involve low fidelity or partial prototypes. Principles such as error tolerance can be investigated during these activities.

Testing: As developed functionality become available it is possible to conductusability evaluations to test if the design meets measurable criteria such as performance times, extent of task completion, and end user satisfaction.

The MAR HFE development activities presented above is intended to guide the development of the next stages in the project. Together with the interaction framework it is believed that this provides a good basis for integrating relevant human factor considerations into the wider development of the application.

5. Conclusions

Application of AR technology can help overcome complexity barriers, particularly dispersion, by allowing a much faster transfer of asset information directly to track workers wherever they are, which makes management of assets dispersed along the extended rail networks easier and results in improved railway efficiency.

In order to achieve this benefit, we have shown how HF considerations, in the context of systems engineering practices, have been applied to the on-going development of an AR application.

Based on this case study we can conclude that it is possible to combine good practices in HFE MAR development activities with a V-lifecycle approach to application development. We have also shown how it is possible to use HFE activities to address MAR HF design principles at appropriate stages within the development lifecycle.

In particular, the case study highlights the need for consideration of HF principles especially at the early stages of application development, in order to determine the functionality and concept design of the MAR app. In this way user information needs, and factors in the railway environment, can be identified and accounted for.

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Fig. 4 contains elements from UX Stencil © Todd Zazelenchuk& Elizabeth Boling. Available from http://www.userfocus.co.uk/uxstencil/.

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