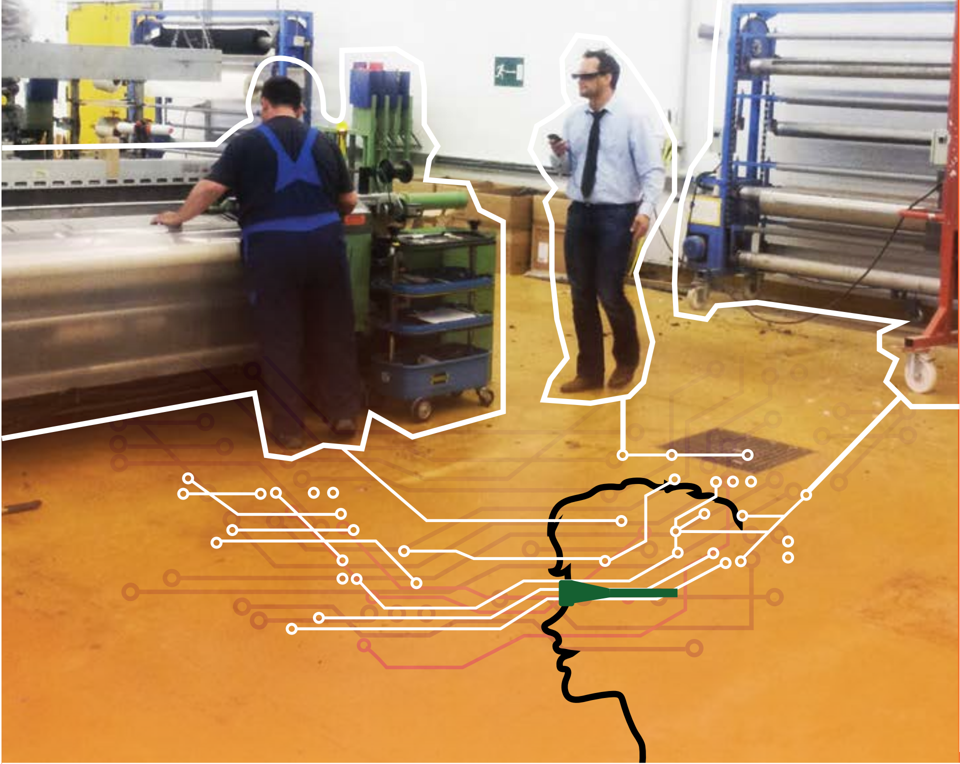

Mini-Proceedings of the Workshop on

Advanced Manufacturing with Augmented Reality

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Paul Davies, Patrick Ryan

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edited by

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Advanced manufacturing with augmented reality

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While there is potential for improving the quality of human-assisted processes, manufacturing research focuses heavily on the use of robotics. This further increases demands on humans needed to setup, configure, and operate highly sophisticated manufacturing systems. Augmented Reality has the potential to significantly increase operational efficiency, add value, and reduce error in manufacturing. AR in manufacturing is of interest across many sectors and businesses, with more and more successful case studies being reported.

There is great diversity in manufacturing. As a result, the requirements for precision and potential for automation and guided reproduction vary widely.

Unfortunately, there is little or no opportunity for those who are working independently at the cutting edge of the field to share their views with others. As a result of the absence of a central group or committee to provide a status report, there is no holistic, detailed and current view.

This workshop on Advanced Manufacturing with AR is a first attempt to resolve this shortcoming. It thereby addresses three key themes:

- Technical Data Delivery: We will hear from experts and participants will engage in discussion to develop agreement on what constitutes the state of the art for use of AR to deliver technical data in 2014.
- The Shop Floor Environment: We will hear from experts and participants will engage in discussion to develop agreement on what constitutes the state of the art for use of AR to map value streams and increase value, to avoid waste and increase sustainability, and to reduce risk and prevent human error on the shop floor in 2014.
- Quality Inspection: We will hear from experts and participants will engage in discussion to develop agreement on what constitutes the state of the art for use of AR to inspect manufactured goods in 2014.

This workshop helps increase awareness of the current state of the art in industry on the three highlighted themes and develop the most advanced research agenda for AR in manufacturing. Experts and participants will document the current state of the art and propose research areas that can become the basis for academic and public/private partnership-funded research projects. Those who participate in the workshop will be best placed to develop groundbreaking research projects based on the most challenging problems. By developing agreement among those in the field, the workshop will help to focus funding and other resources on the short and long term research topics.

Functional requirements for AR field service repair: a case study

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Research suggests that the assembly and maintenance of equipment in the field are two areas with the highest potential impact on Augmented Reality (AR) for industry [1]. These are two areas that have already received some of the most attention from researchers. Early research demonstrated the ability of AR techniques to reduce task completion times and reduce errors for assembly tasks [2]. Feiner and Henderson demonstrated that AR can help users move between maintenance tasks more quickly and remain more visually focused on the task at hand [3]. Follow on studies also showed that AR can reduce errors in the so- called phychomotor phase of procedural tasks [4]. With so much of the benefit of AR for these manufacturing related tasks already assumed, the specifics of how to effectively delivery these results should not be overlooked. Many User Experience (UX) issues remain to be addressed before AR applications can penetrate the industrial space.

Our company recently developed a maintenance and repair application for phone and tablet devices that highlights a number of techniques we have developed to address mobile AR application UX issues. The users of this hand-held AR application are anticipated to be highly skilled repair personnel who have not been trained specifically on the equipment in question. To address the needs of these users 3 specific types of information are available through the app; diagnostic information, traditional bill-of-materials part lookup and operational animations to illustrate the behavior of the system. The following features were applied to the application:

AR/3D transitions

While hand-held mobile devices greatly facilitate the introduction of AR applications into the industrial space, they introduce usability issues because they occupy at least one hand. In order to make these applications more flexible, it is our position that the significant upfront investment in an AR application demands that it also be usable in a strictly 3D mode. Not all assembly and repair tasks benefit immediately from the AR form factor. As a result, we utilize an AR to 3D transition in all of our assembly and maintenance applications. We utilize information not about AR marker visibility but instead about the visibility of the equipment to trigger the transition to 3D mode. Once in 3D mode, a typical multi- touch gesture interface allows the user to rotate and zoom around a 3D pivot point. Selecting individual parts adjusts that pivot point. Facilitating a 3D mode does require a model of the equipment.

AR transparent part isolations

Part isolations are an important part of the dynamic presentation of equipment. In a strictly 3D mode, surrounding parts can be exploded along various vectors, cut- away or given transparency to allow for users to understand parts in their context.

We feel that AR applications need to be able to deliver these same rendering techniques onto physical equipment. Typical cutaway views require using the current state of the device and its associated 3D model to mask out parts of the 3D rendering. Techniques are required to diminish the appearance of content that may remain visible in the video feed and would otherwise confound the illusion of part cutaways. Achieving a transparent view of a physical device has more complex requirements. Since the content behind the device is unknown to the camera under most conditions, the backside of the device is the most appropriate canvas onto which other transparent parts should be rendered. We expect to supplement this process with diminished reality video techniques soon [5]. When parts the background canvas do not require rendering (e.g. they are already visible and un-occluded) they need to be masked out of the rendering process through stenciling. We have formalized the processing of incoming CAD models in order to achieve these rendering techniques without customization.

AR part manipulations and animations

A corollary to part isolations is the illustration of alternate device configurations (e.g. part removal, part movement). The presentation of AR part manipulations and animations in our system requires that parts be labeled as *transparent*, *invisible*, *static* or *moving* at any state in the application. Invisible parts are not rendered in 3D mode but require a diminishing technique in AR mode. Transparent parts require our background canvas technique in both modes. Static parts are rendered in 3D mode but masked out in AR mode. Moving parts are also rendered in 3D mode but require the management of diminishing techniques, masking and 3D rendering. Assembly, repair and functional illustration all require some ability to animate part replacement and movement. We use Activity Diagrams to describe high-level assembly tasks. However, some animations require complex authoring that is not part of assembly instructions. For these we use a lower level authoring system that makes automates the restoration of part locations and visibility when moving between different device states (e.g. brewing, moving to grind, etc.).

Dynamic part labeling

An important part of making any mobile or AR-enabled mobile application useful is improving on the type of equipment documentation that users typically use. For many technicians doing repair work, a black and white line-drawn schematic with part labeled bill-of-materials (BOM) is the de facto standard. Giving users the ability to identify parts accurately and, more importantly, to order those parts accurately is an important part of providing usable assembly and repair related information. Presenting part labels and BOM in a dynamic 3D and AR environment requires dynamic part labeling techniques. An important part of providing dynamic labeling is identifying the parts of the visual scene that they cannot occlude. The most important parts typically are other UI elements and parts (physical or virtual) of the device in question that need to remain in view.

We have based our initial work on published dynamic labeling techniques like those developed by Bell, et al. [5]. We have extended those techniques to handle placing labels around arbitrarily contoured objects with known 3D models. We employ a GPU-based method to allow us to simultaneously calculate multiple levels of label avoidance detail (e.g. whole device, individual parts).

Hybrid online and offline usage modes

Practical field service applications require that offline use be an option. However, these applications also need the flexibility to download new and modified data when connected to networks. The development of complex AR applications that utilize dynamically loaded content is a challenge. One approach that shows promise involves deploying the base application with each functional template implemented so that all dynamic date becomes only a problem of parameterization. One drawback of languages such as X3D/VRML that define assets along with low-level nodes, their parameters and their routing has been that complex graphical assets are not easily optimized for simultaneous portability and high-fidelity. We base our software stack on the Unity Game Engine for optimal rendering fidelity and speed on mobile devices. Unity Game Engine has facilities built-in for packaging and delivering assets and their parameters through asset bundles. Our system uses a hybrid approach where scripting describes the placement and state of objects in the scene but where complex application state transitions, animations and other parameterized behaviors can be downloaded separately in through asset bundles.

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Quality inspection in shipbuilding

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Newport News Shipbuilding (NNS) has used three dimensional (3D) product models for designing, visualizing, and manufacturing complex construction projects for over two decades. These models are typically stored and displayed on desktop or laptop computers, and are the foundation for drawing and work instruction production for our high-variability, low production rate manufacturing. By using augmented reality (AR) technologies on mobile computing devices, industrial engineers or craftsmen can overlay the 3D product model at full scale, in-situ, on the actual objects being built. NNS effectively uses AR for inspection and workflow management with this technique. We will present our perspective on the technology readiness, technical approach, and recommended academic investment, and discuss lessons learned on user factors and practical needs.

NNS uses mobile devices and multiple targets to deliver product model information when and where it is needed. For the accuracy and stability needed, one or more planar 2D fiducial markers are typically necessary. These can be fixed in a horizontal or vertical plane giving the viewer at most single or bi-directional targeting. SLAM-based technology can be used in certain cases, but is still not widely adopted on mobile platforms with production level models. NNS will discuss technological limitations experienced for inspection and workflow management projects in both tracking and overlay. NNS will provide comments on the benefits and necessity of the mobile hardware form factor, and provide some perspective on laptop-based or head-mounted computing.

At NNS, AR products are handed to end users, not in the hands of the developers or expert level AR users. Consequently, the need for a solid and stable user experience is critical. Craftsmen under tremendous time and budget pressures have no tolerance for unstable or fragile applications. Depth cueing, occlusion, and well-designed user-interfaces are critical to a solid AR experience and, by extension, user adoption. NNS will discuss some of our perspectives on these practical issues.

Process models for augmented reality

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Augmented reality (AR) is a developing technology that is very suitable for technical data delivery, mostly because it allows providing the relevant information in time spatially registered at the appropriate place. This way it has the potential to exceed current analogue and digital documentations by reducing mental as well as physical effort for the user. The support of manual assembly, error diagnosis and repair processes by AR in production environments seems very promising and has already been successfully researched, e.g. within the research projects ARVIKA and AVILUS. But to support these kinds of processes, AR based documentations must fully incorporate their structure to lead and follow a user through the completion of a process.

To the best of the authors' knowledge so far no survey of process models proposed for use in AR applications has been conducted. Thus this paper systematically summarizes the literature on process models for AR and how these models are defined. Although we are interested in models which are suitable for AR based technical documentation, we do not only collect the models which were suggested for this very purpose but aim to get a broader view. We focus on extracting the core concepts of the process models and leave out details of the implementation or the user interaction.

As we are interested in AR based documentation we identified several properties of the models which have influence on if and how assembly, error diagnosis and repair processes can be modeled:

- Many models extend a *basic model*, e.g. activity diagrams or task models, and by this define the underlying structure of the model. E.g. when a task model is used, a process is represented as a hierarchy of tasks and subtasks. When an activity diagram is used the same process is represented as a series of steps where one step leads to the next.
- The *transitions* between the single steps can be distinguished into user and system triggered. To disburden the user, a model should incorporate a concept for automatic system triggers but also allow user triggered transitions. E.g. when one step of a process is to add a part, either the system can automatically detect the new part or the user can confirm the addition by a manual action to go to the next step.
- *Branching* becomes necessary when different steps need to be executed based on the current conditions. E.g. when a malfunctioning component of a device is identified in a diagnosis step, the subprocess for its exchange must be executed. Again, we distinguish between user and system triggered. To disburden the user, case discriminations should be possible without manual input.

- *Parallel steps* are necessary to model processes which give the user extended freedom when going through the process. This becomes relevant when a user wants to switch between two or more steps, e.g. because he is waiting for some replacement parts and during this time wants to work on another task.
- The number of *AR objects per step* can range from one to arbitrarily many. More than one object may be needed when it comes to e.g. complex assemblies or quality checks. It is also interesting which kinds of objects are included, which roles the objects have and how the relations between the steps and the objects are defined.
- The inclusion of *memory* in a process model is necessary when multiple ways can lead to a certain step and the next transition depends on the previously executed steps. E.g. when different parts of a product are first assembled and later joined, their virtual representations have to be saved to be later recalled. Memory can have multiple forms, e.g. stacks or named variables.
- Inclusion of *dynamic information* which is not yet available at the time of authoring is relevant for diagnosis purposes, e.g. during quality testing. An example for this is the inclusion of an oscilloscope graph of an electrical signal.
- It is desirable to have *reusable components* to reduce the effort for authoring. When e.g. multiple models of one product are produced which all share the same housing, the subprocess to assemble the housing should be reusable for every model.

The surveyed models are classified into different categories which each contain models with a similar structure in terms of basic model, behavior and the previously presented properties. Overall the following categories can be identified:

- *Linear process models* have in common that they define processes as a linear sequence of steps. They don't include branching into subprocesses, parallel steps or memory.
- *Assembly oriented models* have in common that they have one object which in each step is extended by a second object. When the second object itself is not an atomic object but has to be assembled, the process is called recursively for the second object.
- *Task based models* have in common that task models are used as the underlying structure. The basic idea behind them is that a task can be decomposed into smaller subtasks until the subtasks have a sufficiently low complexity. This way they form a tree with the overall task as the root.
- *Activity based models* are based on activity diagrams, e.g. UML Activity Diagrams, or the very similar flowcharts to model the process flow. They are either used to model AR processes or AR software that incorporates processes.
- *State based models* have in common that a process is modeled as a set of states which are connected by transitions. It is important to note that the formalisms used to define these models are very similar to the ones used for activity based models. In fact, the main difference is the semantics and the view on the process. While activity based models

represent a view on a process which consists of actions that lead to other actions, state based models represent a view where the process is in a state and actions cause it to go into another state.

- *Dependency resolving models* are based on the fact that most but not all steps depend on other steps that have to be completed before they can be executed. Thus only the final step is selected for execution and all the steps that have to be executed prior to it are automatically determined. The result is a linear process which can then be completed. So far this category only contains one model.

Still none of the models in the different categories includes all the priory established properties in a desired way. Even though some activity and state based models contain most of them, a lot of effort is needed for authoring, e.g. due to bad reusability. Opposed to that the one model of the type dependency resolving models allows minimal authoring effort but only supports linear execution. Thus future research needs to be done on process models that are able to cover multiple models of a product with minimal redundancy, support memory for dis- and reassembly, parallel steps, branching and dynamic information. On top of that they must be easily utilizable by authors of technical documentations.

Case Studies in Aerospace, Defense, and Energy

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Augmented reality (AR) is beginning to connect human workers on the manufacturing floor with real-time sensor data, industrial control systems, and automated machinery that leverage 'big data'. Early adopters of AR are excited by the potential for improving access to the right information so crucial decisions can be made in real-time. However, a divide between early adopters, often found in R&D teams within large organizations, and pragmatists, often found in day-to-day operational teams, still exists. This presents a significant barrier to wide scale deployment of AR in manufacturing environments.

To build the support needed to bring AR into an organization, early adopters often find themselves in a position where the support of key pragmatic decision makers and influencers is needed. As with the introduction of any potentially 'disruptive' technology, early adopters are on the lookout for tangible evidence and case studies that show the ground-level benefits that AR brings: (1) a sound business case articulating positive return on investment (ROI) and total cost of ownership (TCO), (2) assurance that the technology can be made to work reliably under operating conditions on the shop floor, and (3) confirmation that the technology can be deployed in a scalable way that ensures its acceptance by shift workers who will be the end beneficiaries of the technology.

To illustrate these challenges and some insight into how they are being addressed, we will present three case studies that showcase how AR is envisioned to be used in manufacturing settings within aerospace, defence, and energy. These case studies will showcase some of the business, technical, and organizational considerations that are important to real-world success, as well as opportunities for future research into how AR systems can be designed, built, and positioned for long-term success.

Augmented Reality and the Shop Floor Environment

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To wit, an advisor once told me: "All models are wrong but some models are useful." Three common component technologies are frequently used in AR: recognition, tracking, and rendering. This model, while useful most of the time, isn't useful to addressing broader adoption or implementation for manufacturing or industry. Industry is not concerned with the answers to "what" or "how". Rather, promoting broader adoption within manufacturing and industry only requires answering "why".

Industrial and manufacturing operations have spent tremendous resources to optimize existing processes through conventional or traditional means. Attacking 'value-added' operations with tools sets from 'time-studies' to LEAN Programs has been the norm. Every technology required for AR to create transformative impacts to existing business processes exist today. AR technologies, for the first time, allow companies to address activities that were previously considered 'necessary-non-value-added'. This 'undiscovered territory' requires collaborative exploration from the Academic, AR Tools and Solutions Providers and Industry Beneficiaries communities.

To this end, research going forward should be focused on business case analyses centering on the challenges to current implementations. Specifically, these areas are mobile device barriers to shop-floor entry, company returns on investments, and challenges (and opportunities) surrounding integrating mobile AR tools into existing processes.

Augmented reality job performance aids for the shop floor

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This workshop contribution describes augmented reality application scenarios for supporting knowledge-intensive and skill-building activities on the shop floor, applying a novel learning process model (eMeMO, see [1]).

The TELLME project investigates how to improve training in manufacturing environments of small and medium enterprises with state-of-the-art technology-enhanced training and learning methods. The process methodology eMeMO optimises, personalises and customises training content to individual needs of workers in a manner aware of context and individual learning profile.

There are three uses cases in TellMe that include hybrid applications.

The first one, *AgustaWestland (AW)*, is an Anglo-Italian helicopter manufacturer and training provider. In TELLME, AW uses AR to provide efficient training at the work place for increasing the maintenance technician's skills. In particular, two issues are addressed:

- New maintenance tasks are usually described in a service bulletin. This document is released by the aircraft manufacturer for correcting issues or improving efficiency of systems within the aircraft. AR can effectively reduce technical misunderstand-ings related to the use of new maintenance documentation by enriching textual descriptions with augmented and multimedia content to foster better understanding.
- When technicians have to deal with infrequent or complex

problem situations, they may need additional and refreshment training. AR can augment helpful information using audio-visual instruction via optical head-mounted displays for guiding the technicians through the maintenance sequence. This reduces the technician's learning time by providing all required knowledge and resolving issues directly where needed.

The second one, *AIDIMA*, is a non-for-profit private research association aiming on enhancing the competi-tiveness of the furniture, wood, packaging, and related industries in Spain, serving more than 700 companies.

- AR is used in TELLME for supporting workers during the first time assembly and installation of customised and complex furniture with a drive-through procedure. This helps to avoid mounting problems and errors that can lead to damaged parts. Moreover, it is aimed to save time in resolving issues.

Finally, the *Quality Group* is a German textile factory network that provides fashion and work wear garments as well as functional fabrics. AR in TELLME for the Quality Group sup-ports two business activities:

- The quality inspection of the finished fabric. In order to train employees to detect and identify fabric defects of several types, AR is used to enhance their peripheral vision, helping to train the recognition, classification and fixing of defects.
- Machinery set-up in the weaving mill is a knowledge and

time-intensive activity as there is a broad variety of raw materials and as the processing settings are often complex with a large number of dependencies. AR facilitates the process by displaying values for specific settings and by guiding through the overall set-up process.

Following a brief introduction of the eMeMo methodology, the contribution shows how each of these AR pilot scenarios are integrated. Furthermore, specific expected benefits will highlighted, as well as the chosen evaluation methodology.

As the first wave of validation pilots are currently under way, there are no evaluation results yet available to clearly identify possible challenges or obstacles. Corresponding suggestions will form part of a later article about this contribution.

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