Towards Augmented Reality in Quality Assurance Processes

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ABSTRACT

Augmented reality (AR) has gained exceptional importance in supporting task performance. Particularly, in quality assurance (QA) processes in the automotive sector AR offers a diversity of use cases. In this paper we propose an interface design which projects information as a *digital canvas* on the surface of vehicle components. Based on a requirement analysis, we discuss design aspects and describe our application in applying the quality assurance process of a luxury automaker. The application includes a personal view on spatial information embedded in a guided interaction process as a design solution that can be applied to enhance QA processes.

CCS CONCEPTS

• **Human-centered computing** → *Interaction paradigms*; *Information visualization*; Mixed / augmented reality;

KEYWORDS

Augmented Reality, Hand-held Devices, Concept and Implementation, Design Decisions

ACM Reference Format:
Natalie Hube, Mathias Müller, Jan Wojdziak, Franziska Hannß, and Rainer Groh. 2018. Towards Augmented Reality in Quality Assurance Processes. In *MMVE'18: 10th International Workshop on Immersive Mixed and Virtual Environment Systems, June 12–15, 2018, Amsterdam, Netherlands.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3210438.3210442

1 INTRODUCTION

An increasing global competition has forced automotive companies to improve quality and efficiency. The foundation of a quality inspection and component qualification is always determined by customers' as well as stakeholders' requirements [32]. Therefore, the foundation of audit procedures and auditors, as assessors of quality, are decisive to enhance quality processes. By applying tools and technologies, companies can improve their performances and subsequently increase customer satisfaction and gain market shares. In this never-ending pursuit of perfection, manufacturers have started to explore the benefits of AR in an industrial environment. Various approaches deal with augmentation of information in the context of navigation, health care and education. Concepts and applications exist for showing spatial and temporal information, yet approaches, which utilize the actual space and objects in the automotive context are missing. In cooperation with a luxury automaker, we propose a visual design of an AR tool for quality assurance (QA) in the automotive industry which projects essential information directly onto the car components. This *digital canvas* allows auditors to focus on the task at hand and ensures each part is made perfectly (cf. Fig. 1).

The conceptual model, based on [14] and depicted in Figure 2, shows the relation between the real world or object space (4), its virtual projection (3) on the tablet screen forming a frame of interest (2) and the users' view on the whole system (1). In contrast to a entirely virtual environment the user is not limited to the virtual space, but able to perceive both environments at the same time. These four main design aspects emerged during conception phase. The derived design decisions address challenges in presentation as well as interaction that can also be applied in a large scale to derive rules for AR applications.

2 RELATED WORK

In AR applications, the interaction model provides a lot of opportunities to re-think the traditional interaction approaches. Above all,

Figure 1: Screenshot of the resulting AR application.

MMVE'18, June 12–15, 2018, Amsterdam, Netherlands

ACM ISBN 978-1-4503-5771-5/18/06...$15.00
https://doi.org/10.1145/3210438.3210442

the users' position and orientation as well as the resulting viewing behavior have to be directly considered when creating user interfaces for AR-based human-computer-interaction. We concentrate on four core design aspects which derive from our understanding, on how the user interacts with an AR application in the given scenario.

2.1 Visualization Context (1)

A characteristic of tablet-based AR is to interact directly with a real-world object through the display. Suitable visualization methods are needed to display all required information. Concurrently, it is required that content should be highly accurate, fast to use and be conform to industrial standards and practices [23]. At the same time, the application should support context-awareness [15] as this factor is crucial for its usefulness, while [8] also emphasizes the relevance of content and discusses the visualization of real versus abstract. Furthermore, both highlight to better understand depth to benefit the visual context.

Due to the connection between the real environment and the virtual content, the context plays an important role: the view on the real object should be unobstructed to keep a cognitive relation as a link between both worlds, since information visualization as a context-sensitive element depends on the observed object [2]. In this conjunction, [21] discusses the importance of reducing visual clutter. Further, clustering can be partially eased by spatial and semantic attributes to reduce information overload [30]. This allows users to stay focused at their actual task, since clutter impacts task performance [25]. When rendering many targets, objects can be encapsulated to reduce visual clutter and content occlusion [13]. To resolve visual clutter for data which is part of more complex or semantic structures, level-of-detail concepts using depth-based layers as a Zoomable UI (ZUI) techniques can be used [27].

2.2 Viewport Interaction (2)

While working on a real object, it may be necessary to physically move it. The camera limit the minimum distance to the object. The emerging issues can be prevented by freezing interaction when adding annotations [19]. As the user can move freely, task performance is more accurate [5]. [4] found that freeze interaction was useful to support authoring processes and reduce jitter issues. [1] also implemented a pinch-to-zoom gesture to support manipulation, while [12] proposes to freeze while constraining panning interaction to a part of the scene for collaborative purposes in order to view the real and virtual objects side-by-side and pass the current view to other attendees or screen-sharing the viewport. [29] refers to view independence in co-located work as it supports task performance as well. As the user is not keeping context when freezing the display image at a certain spatial angle and position, it is crucial to allow switching between frozen and live view.

2.3 Guided Interaction (3)

Due to limited viewport size, not all information can be displayed. Thus, support of object localization outside the viewport is crucial. [16] compared moving objects to determine their off-screen position, resulting in better results for less cluttered visualizations regarding accuracy. [26] compared a 2D mini-map and 3D spatial arrows to visualize an off-screen position and discovered better efficacy of the spatial variant. By displaying off-screen objects, a new challenge in mapping objects following a particular order emerges. [7] implies the user is following a narrative and is significantly involved in how the application and thus, the content, responds. This narrative may also reflect the underlying business processes in the given scenario. [28] describes the importance of human-computer-context interaction, thus implying the relevance of content. In our case, it consists of successively processed complaints asserted by auditors in a QA process (see Sec. 3), that should be facilitated by an AR visualization. [24] suggested calculating the shortest path interactively to offer the optimal route, while Faro3D provides a step-by-step checklist [10] to keep track of information elements. Nevertheless, [7] signifies that one of the key features of AR is the ability to explore content openly. Therefore, the user's freedom of movement should not be limited by interface design decisions.

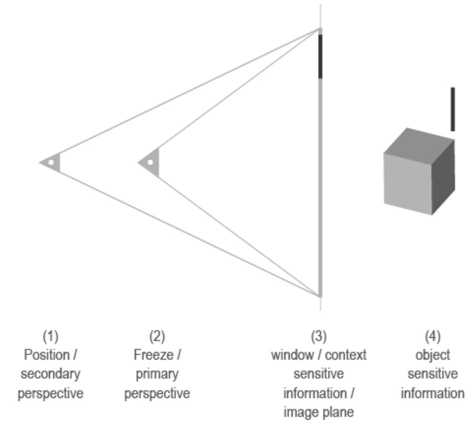

Figure 2: Model of relationships between the user (1) and both real and virtual objects (4) using a touch-enabled handheld device (2 and 3).

2.4 Spatial Data Visualization (4)

Spatial relations play a significant role in guided navigation, which is primarily about perception. Disparity planes, depth cues and dimensionality thereby need to be considered [9], whereas the latter may reflect in different facets [7]. [21] propose to use user-perspective rendering to prevent disparity of viewing planes to overcome cognitive barriers between the real and virtual world. Another design issue is where and how to place information in the spatial layout in the view plane, specifically when rendering 2D labels associated with a 3D counterpart [3]. It is important to address different issues of AR, which arise mainly from spatiality, such as registration errors [18]. Perspectivity issues are important to minimize cognitive barriers between the real and virtual world in handheld AR: [20] identified ordinal-scaled objects are more efficient in registering distances than constantly scaled objects. [11] points out perceptual phenomena to oppose ambiguity of depth perception by displaying 3D content on a 2D surface. With textual presentations, [31] suggests text should not be rendered screen-aligned, rather through spatially-registered text to keep users immersed.

3 ADAPTION OF QUALITY ASSURANCE

During the pre-series production of a vehicle, car elements, sheet metal parts and electronic components are tested, harmonized and qualified for series production. Therefore, engineers of the luxury automaker measure exact positions and proportions of parts like body panels and taillights, to make sure they're within the automaker's strict limits. So far, the engineers use handwritten markings to log conducted measurements and record subjective assessments by color-coded stickers. The aim was to design and develop an AR system which supports this process by visualizing measurements and complaints to facilitate the evaluation procedure on how the luxury automaker decides which car components of its vehicles pass the Quality Assurance (QA) in pre-series production.

Our requirement analysis was a two-step process. In an initial step, we used elements of a facilitator's toolbox to enhance scoping and ideation processes of QA engineers. These processes are guided by the World Café method [6]. Within four incremental sessions of structured debates, the QA engineers were encouraged to write and draw key ideas on paper and handicraft elements, following the basics of Low-Fi prototyping. Every session provided a different perspective on UI aspects, thus allowing the QA engineers to analyze requirements and identify specifications. In this way, a smooth progression from an abstract point of view to concrete requirements was realized [22].

Afterwards, we conducted individual, face-to-face, semi-structured interviews to complement the requirement analysis. Five engineers with different backgrounds were interviewed. In a predefined, standardized QA process, the engineers are observed and interviewed when working on specific tasks. The interviews combined specific questions and open-ended questions [17]. The results were:

- Markerless detection of vehicle parts: On the production floor, engineers need a one-fits-all robust and accurate tracking solution. The system should register spatial attributes of vehicle parts in real-time without preparation. The detection of complaints as well as the valuation of an uncovered vehicle part can be ensured by markerless vehicle parts.
- Information about joints and gaps as well as surface quality: Engineers should instantly gauge whether parts are interfering with each other, if the surface finish meets specifications, and other potential issues with all the components in position. The presentation of cross-part information is necessary to carry out a cause analysis.

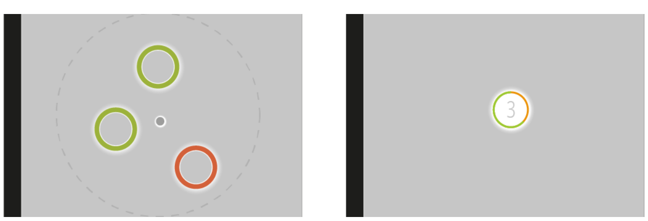

Figure 3: Collapsed (left) and grouped elements with preview of number of contained elements and element type distribution (right).

- Quality Management: QA is mainly focused on processes, by which both employees and suppliers are involved. It must be guaranteed that processes are monitored and constantly fulfilled by the system to ensure greater efficiency and cost-effectiveness.
- Usability: the application should be tablet-based to support the documentation process (input) as well as the presentation of information directly on the surface of the vehicle part (output). The interface design should be intuitively understandable without a need to read a complex manual.

Our preparatory considerations and requirement analysis led to the following design goals:

(a) Augmented presentation: individual and user-centered depiction of information that prevent cognitive overload and amplifies users' perception
(b) Process-based interactions: methods to overcome limitations of a representation, facing large datasets in a guided and audited process
(c) Depiction of complaints: base visualization of complaints and their locations, including severities as well as surface deviation, directly on the vehicle

4 INTERFACE DESIGN

During the design process, requirements regarding the Augmented presentation where addressed in the visualization context: free, unobstructed view on the object by minimal UI and reducing visual clutter by employing ZUI-concepts. Additional issues related to the augmented part of the visualized car component and the (collaborative) interaction with these augmentations determined several decisions connected with the viewport interaction. To facilitate the process-based approach, we introduced different approaches for guided interaction. The depiction of complaints and the visualization of measurement data needed to reason about possible error sources and actions to solve these issues were part of the considerations about spatial data visualizations.

4.1 Visualization Context (1)

The consequence from the hand-held AR-scenario, is that both the real object and its virtual, augmented counterpart are visible at the same time. The tablet works as a lens, which adds an additional layer of information over the real object. The application design allows the user to approach the object of interest and choose a specific perspective from which the desired information is visible at best, persist this perspective (cf. **following section**) and quickly change the viewpoint. Therefore, the user can assess an overview over the data connected to the whole component and then choose a more detailed view on the subject by changing the viewpoint and concentrate on details in a specific area, or a specific issue marked on the component. This allows to directly access information by naturally interacting with the real object.

After the first design iteration we noticed, that the amount of available data leads to visual clutter and information overload. We therefore added ZUI concepts to the augmentation: Depending on the viewing distance, overlays show different levels of detail and labels on the component surface are clustered depending on the viewing distance (cf. Fig. 3), similar to the approach employed

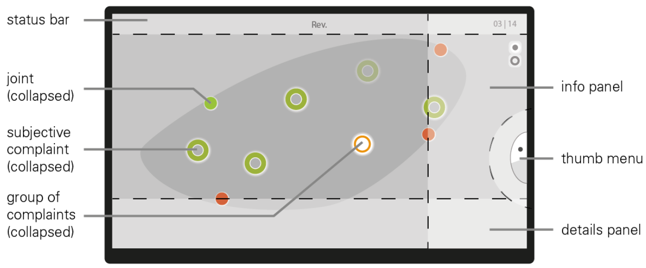

Figure 4: Screen layout of the application.

in [30] and [27]. The collapsed group visualization previews the number of contained elements and the distribution of element types (in our scenario: distribution of error ratings). These groups can be expanded and collapsed via touch, by decreasing distance or zooming into the image when frozen. The idea of direct interaction is also reflected by the chosen screen layout and placement of interactive elements. Basically, the screen is completely blank from UI elements, except a minimized version of the thumb menu on the lower left side. Depending on the current application state, additional panels are displayed (cf. Fig. 4).

Due to ergonomic considerations, the menu is not placed in the center, but with a moderate offset downwards, to be better accessible in the common tablet hold position. The thumb menu works as the main menu for triggering actions such as displaying additional documents or information, switch application modes or editing items. As the original component is of special interest in the application scenario, one key requirement is to preserve an unobstructed view on the original object. The option to preserve the current view allows interaction with both the virtual content and the real component to facilitate interaction.

4.2 Viewport Interaction (2)

During the design of the application, we observed the requirement to "freeze" the current AR image to discuss the current issue in more detail. Although, the idea to decouple the visualization from the real object partially breaks with the idea of AR, this feature quickly became a key requirement for the application. This works similar to the "Freeze-Set-Go" approach from [19], but was extended with the option to adjust the viewport afterwards by implementing zoom and pan capabilities.

Benefits of this approach are manifold: The user can change the working distance to the real object, which is useful especially in the interior of a car (approach the component, take a snapshot and then discuss in a more convenient position without hiding the original), the ergonomics of touch and stylus input are improved as well as the image is more stable, and collaboration is simplified, e.g. when the tablet can be passed around.

Another interaction is made possible with freezing the viewport: augmented view and original component can be viewed side-by-side, e.g. to compare details, show overlays or color maps of the surface to depict surface anomalies. However, several issues arise, when switching back to live tracking mode: Continuation of tracking presents an issue, especially, when the object gets out of the camera view. Furthermore, especially in case of large objects, the user may be surprised or temporary lose the orientation, when the current viewpoint changes significantly.

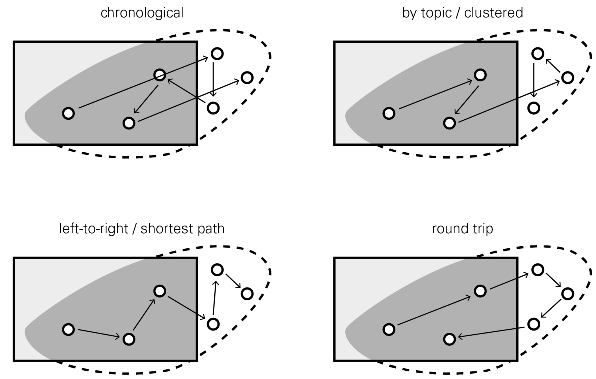

Figure 5: Different options for navigation paths.

4.3 Guided Interaction (3)

One strength of a virtual workflow representation is the opportunity to track the progress and give feedback about open issues or missed elements. The given use-case features a significant amount of data and different views, leading to many context changes, different material displayed in rapid succession and different viewpoints on the real object. It is therefore easy to lose track of the current progress. Additionally, off-screen elements are easy to omit. In the design process, we therefore defined the following goals:

- Interaction follows underlying processes and reflects traditional process steps.
- Feedback about number of complaints to be discussed and remaining elements
- Special treatment of off-screen elements

To facilitate these goals, we implemented a guided interaction, which allows the user to go through all complaints of a component in a special order. However, complaints were usually accessed in a chronological order in the past, which leads to large positional changes over the whole component and even beyond the current viewport. Using a virtual guide through the single elements offers the opportunity to choose between different layouts (cf. Fig. 5): semantic (chronological, ordered by topic) and spatial (shortest path, from left to right, "round-trip") path layouts are possible.

During the design process, the display of off-screen elements represented a versatile issue. Relating to guided interaction, our first approach was to only guide through elements visible in the current viewport. However, this bears the risk of overlooking elements outside the viewport in discussion with the supplier, and induces the need to completely recalculate the navigation path when the viewport changes. This claim also prevented us from displaying off-screen elements while obeying them from the guided interaction. The final decision was to calculate a navigation path that covers the whole component and iterates over all items in the desired order. When an element is positioned off-screen it is displayed at the nearest display border, otherwise it is not visible. This decision was made to minimize visual clutter, but also makes it necessary to choose a navigation path which prevents frequent changes of the viewport, meaning that navigation should use a shortest path algorithm.

4.4 Spatial Data Visualization (4)

Visualizing planar data in a 3D environment represents a major issue, most often in terms of readability, comparability, visualization of spatial relationships and perspective-related issues such as occlusion and relative size. To deal with these issues, we had to consider whether spatial or semantic structure have more relevance. In our application, annotations and overlays are mainly used to visualize data. Whereas overlays align to the object rendered in perspective camera-space, in terms of annotations, readability and comparability were dominant requirements (cf. Fig. 6 (left)).

Therefore, we chose a parallel projection approach for rendering annotations (only the visualization, not the position). This results in constant sized objects and ensures the same readability for all elements (cf. Fig. 6 (right)). Additionally, all augmented elements are aligned to the camera to prevent distortions and increase readability. This hybrid perspective approach results in minimal conflicts regarding spatial positioning relative to the augmented model.

An alternative approach was the clipping of elements according to their distance/size, but this was no viable solution as the viewing angle on joints and the surface parts sometimes is rather steep. To address occlusion in our scenario, the aforementioned grouping mechanism is employed and collapsed groups are provided with an offset to their original position. In case of measurement values correct positioning is crucial, so measurement points do not have an offset but can be collapsed and expanded separately.

5 LESSONS LEARNED

From these design aspects key challenges for the design of AR applications arise:

Hand-held AR: In some cases, it might be necessary to break with the core AR ideas to facilitate the working process, by decoupling the virtual from the real space. This not only relates to spatial limitations or improvement of ergonomics, but also offers potential for collaboration and side-by-side comparisons. Observations show, that freezing the viewport facilitates collaboration between users. However, issues regarding focus and orientation loss need to be considered, as well as fast methods to recover specific views / perspectives. In the given application, the fast rescan of the selected car part provided to be a viable solution to repositioning.

Zoomable UI: To prevent information overload one useful approach is to use semantic zoom-techniques. However, balancing the amount of details is not trivial. To further structure information, dynamic grouping may be necessary. A large amount of data associated with a rather small object leads to a very short or inconvenient work distance. In this case, a virtual zoom represents a viable solution. In terms of virtual zoom, issues arise regarding quality of the live camera images. A possible solution could be to employ a high resolution photo instead of a snapshot of the video frame as frozen view. Another issue occurs with many differently distributed objects on a rather small surface: dynamic grouping may introduce some additional visual movement and - depending

Figure 6: Perspective projection of UI elements with distance-dependent visual size (left). Drawing overlays and annotations as parallel projection results in equally sized interface elements (right).

on the viewing position - items which repeatedly jump between different groups.

Navigation: A guided interaction reflects the nature of business processes and prevents orientation issues. Differences between spatial and semantic structure of displayed elements must be considered, as the order of elements may change. Depending on the use case, process and visualized data set, semantic or spatial/topological structure are more important. Possible issues arise when comparing data sets, which contain different elements and therefore result in divergent navigation paths. On the other hand, guided interaction should always be optional, as one of the biggest strengths of AR is the opportunity to move freely and explore without constraints.

Hybrid perspective: Data visualization in AR often represents a trade-off between exact spatial mapping and correct perception of the visualization. When visualizing quantitative or qualitative data, linear perspective and camera distortions highly influence the interpretation, especially when comparing values. A hybrid perspective - parallel projection for visualization, perspective projection for placement - can facilitate readability and perceptual correctness. However, some drawbacks, such as a reduced spatial consistency due to conflicting depth cues such as relative size may occur.

6 CONCLUSION AND FUTURE WORK

To draw an analogy, it took web developers many years to develop reliable, practical design rules for getting a website to fit on screens of different shapes. And yet that seems like a simple task compared to adaptive AR design, which needs to work across a mind-boggling range of arbitrary environments spanning three dimensions, rather than just a handful of common 2D screen sizes. It is necessary to describe rules and methodologies to design adaptive AR applications which utilize the actual space and objects around us.

We presented a novel design for QA in automotive industry that incorporates complaints in a guided QA process. The major challenge was to create a design that is intuitively understandable while using the benefits of AR. In general, the resulting design motivates to communicate information to the users in an appropriate way. We learned that user, hand-held interface as well as objects (real and virtual) have to be considered while designing AR applications. This includes many design choices and a large number of evaluations despite the possibility to build upon a broad variety of AR applications. Using a touch device to interact with a video-see-through AR-visualization features very different design decisions compared to the use of an optical-see-through solution. The duplication of the real world may present an issue regarding mapping and orientation but also offers additional value e.g. when using it for side-by-side comparisons. Especially in the given context, the AR-visualization is used often in combination with the detailed view on the original car component. This reflects the duality in our system: The tablet-based visualization serves as additional information layer, which is used to explain flaws or issues observed on the real object. Both stand side-by-side (e.g. bumps can be felt when touching the real component and the AR visualization delivers objective measurements to support the subjective feeling).

Observations of test users also show the potential of replacing real labels on the physical component with virtual augmentations: virtual elements do not get lost or unreadable, allow for switching between different views, visualizations and versions. At the same time the unobstructed view on the original component is important for subjective judgements. Freezing viewports allows to pass the device around and could enhance collaborative tasks. Guided interaction allows to follow the process closely and prevent omitting items. the hybrid perspective serves the purpose to optimize readability of text annotations and measurement visualizations.

We want to extend the mentioned techniques, especially regarding ZUI techniques which offer a wide range of opportunities in the context of AR, and also take a deeper look on the collaborative use of the frozen viewport in an AR-application.

Future challenges include a refinement of information visualization of measurement data, with the goal of enhancement of readability and quick assessment. One approach could be to extend the current ZUI techniques and employ glyph-based techniques. Tracking issues represent another issue regarding image stability, persistence of viewport and positioning. Finally, we have to evaluate our final design in study that show the benefits for auditors.

ACKNOWLEDGMENTS

On behalf of Natalie Hube and Mathias Müller, this research (project no. 100271686) has been funded by the European Social Fund and the Free State of Saxony.

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