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Augmented and Virtual Reality for Inspection and Maintenance Processes in the Aviation Industry

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Abstract

Maturity of augmented and virtual reality devices has considerably grown recently. As processes in the aviation industry are error prone and time consuming, efforts are made to implement these technologies to support human workers during inspection and maintenance. Nevertheless, varying process and device characteristics impede the selection of a suitable technology. A concept is presented to evaluate the potential of inspection and maintenance processes in the aviation industry regarding the use of mixed reality systems. Four different use cases are discussed applying augmented or virtual reality devices in an industrial context.

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Keywords: Augmented Reality; Virtual Reality; Mixed Reality; Inspection; Maintenance, Aviation Industry

1. Introduction

Technical advancement has led to the availability of powerful and reasonably low priced augmented (AR) and virtual reality (VR) devices for the consumer market. Moreover, AR and VR devices also have great potential for industrial applications. For instance, efforts are being made to implement AR based support systems for employee

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training, remote maintenance or inspection and assembly processes [1–3]. Due to a high degree of worker centered processes, cognitive support systems in the aviation industry will continue to be particularly important in the future. Although studies show that the potential of AR and VR technologies is promising, an a priori assessment of the potential benefits for a concrete industrial process is difficult. Therefore, concepts for a methodological assessment of the potential are needed.

2. Background

AR and VR both are part of a wider field of technology called mixed reality (MR). MR describes different technologies blending the physical world with the digital world and exists between the extrema of completely real and virtual environments (See Fig. 1) [4]. In addition, MR visualization produces visual stimuli with a higher level of similarity to real-world stimuli compared to standard displays. This allows the user to make use of the abilities learned in the real world, e.g. detection of meaningful patterns, or qualitative judgement [5].

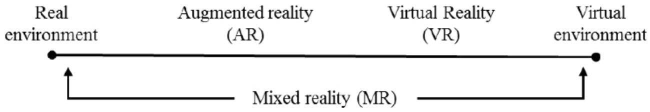


Fig. 1. Mixed reality continuum [4].

A variety of devices exist in the field of MR, such as AR tablets, Cave Automatic Virtual Environments (CAVE), head mounted displays (HMD), or AR projectors. These devices usually provide MR visualization as well as other basic functionalities especially for user interaction. In addition, tracked controllers, object recognition and tracking (e.g. hands) or haptic feedback can be integrated to support intuitive usability. By combining improved control and visualization, MR leads to optimized human-computer interaction.

Regarding the aviation industry, inspection and maintenance processes are characterized by a high percentage of manual work steps [6], small lot sizes, a great variety of handled components and a considerable effort for documentation in combination with the need to reduce inspection and cycle times [7].

The possible application of different MR technologies as cognitive support systems especially for maintenance has been thoroughly investigated [5, 8–13]. Although these studies contribute to the general understanding of applying MR technologies industrially, an a priori assessment of the potential benefit for a concrete industrial process is difficult to determine.

Elia has proposed a performance indicator for the application of AR devices in manufacturing based on technological and organizational criteria [14]. This expert based tool, however, allows only a feasibility study and no a priori estimation of potentials. In addition, the proposed tool does not help in the selection process of a specific MR device.

It is therefore inevitable to further detail methodologies that support the estimation of potential benefits when planning to apply MR technologies for a specific process in order to facilitate human integration in future inspection and maintenance processes.

3. Concept

To estimate the potential of MR systems for inspection and maintenance processes, we propose to classify all involved components into three groups: *object*, *model and human*. *Objects* are all non-human real-world assets (e.g. workpieces, tools, and environment). The *model* contains all virtual assets (e.g. process model, documentation and design drawings). The *human* is the human worker to be supported by the support system. As described, MR provides an enhanced interface between digital data and *human*, due to improved visualization and controls. Therefore, we propose that time and effort for the interaction between *model* and *human* can be used as a measure of the MR potential. Time and effort for these interactions are separated into three levels: little, medium and high. Little interaction takes place when there is no or just a rudimentary *model*. In this case, interacting with this model takes little to no time. Consequently, standard tools can be used instead. The medium level interaction consists of a bidirectional flow of *model* data, which is not directly apparent on the real world *object*. Still, the data is in direct relation to the process and of relatively low complexity so that an experienced worker could assess it without a support system. Therefore, it is also important to take interaction into account that does not occur immediately during the process but has happened before (e.g. training or continuous learning of a work sequence). The highest level of interaction with the *model* is assigned to processes in which the model contains essential information that cannot be substituted with experience or additional training.

Since different MR technologies are classified according to the degree of reality they allow and the degree of virtuality they can display, the suitability of different MR technologies can be determined by means of analyzing the interaction between *human* and *object*. Analogous to the model interaction we propose the distinction of three levels: little, medium and high. Little interaction means there is no change in the physical status of the object itself and only observations take place (unidirectional data flow). The medium level contains processes in which the physical status of the *object* is altered between predefined states. Consequently, modifying the *object* in previously undefined states means a high level of interaction between *human* and *object*.

As shown in Fig. 2, the potential of a technology characterized by a high degree of reality (AR) increases with higher effort for the interaction with the *object*. With little to none interaction between *human* and *object*, AR potential basically does not exist. Simultaneously, the potential of a technology characterized by a high degree of virtuality (VR) decreases with higher effort needed for the interaction with the *object*. If a lot of interaction with non-human real-world assets is needed, VR technology is not suitable.

In this case, effort describes not only the time complexity or the quantity of the interaction but also the quality of the representation required for the execution of the process. For example, a video see through display, that does limit the view of the object, is not suitable for a task for which all real world stimuli are needed.

In some cases, the potential for the use of MR can be further increased by enriching the model with additional data e.g. from additional sensors. This may be the case when the extension of the model allows the implementation of support functions, which replace or considerably accelerate an existing interaction with the object.

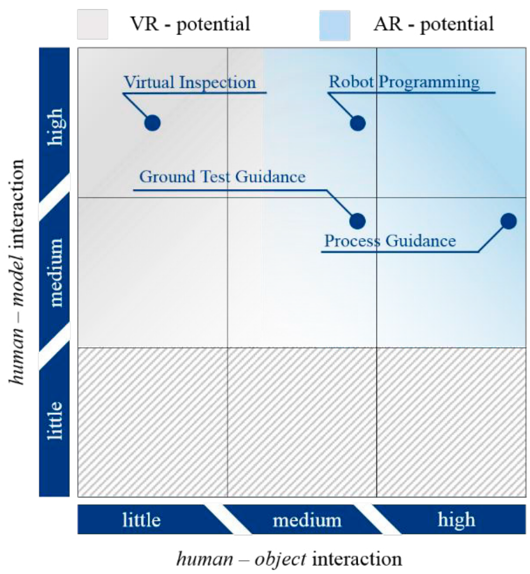


Fig. 2. Potential of AR and VR as a function of the efforts for the interaction between *human* and *model* as well as *human* and *object*, as well as four use-cases (Section 4).

4. Usecases

4.1. Virtual Inspection

The detection of cracks is of major importance in the maintenance of aircraft engines. Domaschke et al. developed an automated crack detection system for combustion chamber components as an alternative to manual Fluorescent Penetrant Inspection (FPI). The system uses robot guided white light interferometry (WLI) to digitize the complete surface of the component. The resulting high resolution 3D point clouds are used for automatic crack detection. The outcome of the measurements and image processing still have to be assessed manually in order to find false positive results in the data set [15]. For this purpose, the automatically generated boundaries of the detected cracks are compared with the point cloud data describing the local surface of the component. The result of the assessment is documented in the digital *model* for each crack.

For the evaluation of each identified crack, a scaling of the respective point cloud and a change of the point of view are often necessary in order to distinguish cracks from e.g. scratches. Therefore, this task is the most time consuming step in the process and the effort for the interaction with the *model* can be considered as high.

According to the presented concept, this high effort suggests a high potential for the implementation of a MR system. Since the entire process is carried out based on the model and no human-object interaction takes place, a technology from the MR continuum that is characterized by a high degree of virtuality should be used (Fig. 2). These findings are consistent with the results of various studies that have demonstrated higher processing speeds and lower error rates for the judgement of spatial data due to the use of VR [1, 16–18].

In the first use case, an immersive virtual environment based on Oculus Rift, OpenGL and the Oculus SDK was developed for the implementation of the task in VR (Fig. 3, 4). The main component of the software is the visualization of the point cloud data. Due to the size of about one billion points and the high performance requirements for visualization in VR, a complete visualization of the point cloud data is not possible with the latest graphic cards. In order to generate immersion and maintain the reference to the real component, a level of detail algorithm (LOD) was implemented. LOD enables the continuous calculation of suitable sub-samples of the point cloud depending on the point of view of the user in the virtual environment. A game controller is used for control of motion, as well as for selecting the crack model and the submission of the assessment results.

This environment was used to compare speed and error rate in VR with a conventional desktop environment in a controlled study. In this study, no significant advantages of the VR implementation were found. However, an interview with the participants and an analysis of the application indicate that this result is mainly attributable to inadequate control. It is expected that by further optimizing the digitization and implementing improved control, practical advantages can be provided. First attempts with tracked controllers as input devices have yielded promising results.

Fig. 3. Virtual inspection of a combustion chamber.

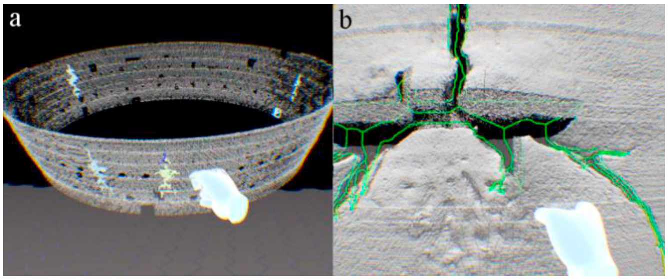


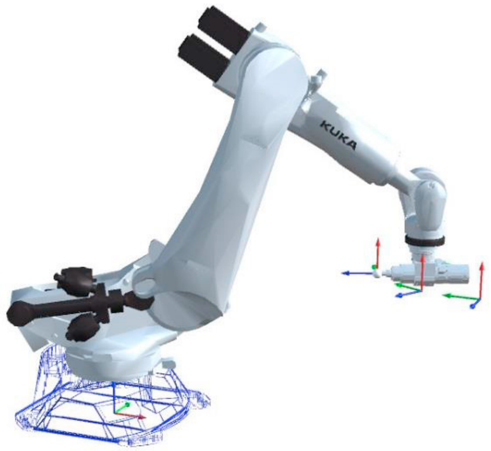
Fig. 4. (a) Visualization of a data set; (b) Visualization of a crack area.

4.2. AR Supported Robot Programming

There are different approaches to robot programming. The key concepts can be divided into two main categories: online (including lead-through and teach method) and offline programming [19]. All approaches have a number of disadvantages [3]. Regarding online programming, these are for example safety concerns and economic reasons. Offline programming on the other hand is less intuitive and an exact model of the real environment is needed to prevent excessive rework on the programs when applied in the real production environment [20]. Especially when no or only outdated CAD data of the parts to be inspected or machined is available (e.g. in the field of aircraft maintenance) and lot sizes are small, existing approaches of robot programming are ineffective.

In accordance with the presented concept, the interaction between *human* and *model* as well as between *human* and *object* suggests using an augmented reality solution (Fig. 2). So-called AR supported robot programming is a combination of both standard approaches but overcomes their specific disadvantages [3, 21].

In the second use case, this approach is applied in an inspection process. A holographic robot model for the initial, AR supported path planning in a robot-based inspection process is implemented (Fig. 5). The interactive robot model can be positioned in the real production environment. In this exemplary implementation, the virtual and real robot is a KUKA KR300 R2500 ultra and the utilized AR device a Microsoft HoloLens. The virtual robot model can be manipulated by virtual lead-through. Similar concepts can be applied when using portable robotic systems for inspection or maintenance processes. The positioning of these systems can be verified and validated on site using AR based robot models before the physical system is actually positioned. Furthermore, safety is an advantage when interacting with a virtual instead of a real robot [22]. Recent research also suggests that augmented AR interfaces can enrich and therefore facilitate the interaction between *human* and robot [2, 22].



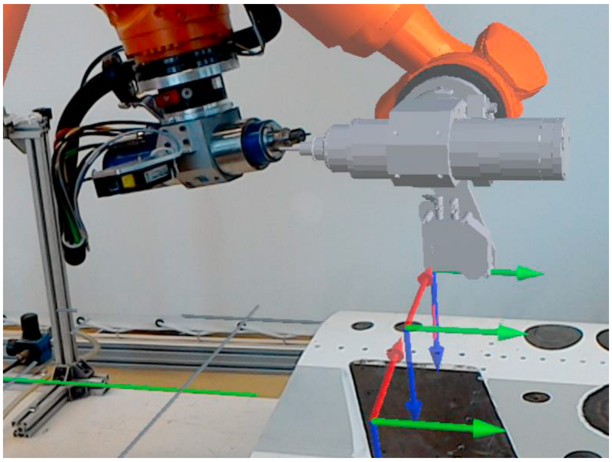


Fig. 5. Virtual robot model (left); Initial robot path planning for an inspection process using the robot model (right)

4.3. Ground Test Guidance

The ground test is the final test of all aircraft systems in aircraft production and is carried out simultaneously with the final assembly. During the tests, a substantial number of manual operations is performed, e.g. operation of switches or reading of displays in the cockpit. The test procedure is described in so-called ground test instructions (GTI). A total of over a thousand different control elements are located in the cockpit, which are referenced in the GTIs by means of identification numbers and the control panel on which they are located. The equipment of the cockpit with these control elements differs for each type of aircraft and airline.

During the test execution, test instructions from the GTIs are processed in sequence and the results are documented in the GTIs after each step. Accordingly, the ground test is characterized by a constant exchange of information between the *human* and the *model* (GTIs). Due to the high amount of different control elements and GTIs as well as the unintuitive referencing, the identification of control elements in the cockpit involves considerable effort, particularly for inexperienced workers. Since the effort decreases with the increasing experience of the worker the total effort for the interaction with the model can be considered as medium to high. According to the presented concept, this indicates a medium to high potential for the implementation of a MR system. Due to the continuous interaction of the worker with the physical *object*, as well as the spatial allocation of the GTI data within the cockpit, a technology from the MR continuum that is characterized by a high degree of reality should be used (Fig. 2).

The ground test has some significant similarities to assembly processes. For those processes, a large AR potential has been identified using the example of different use cases. As the ground test, assembly processes are defined by a specific and predetermined sequence, the documentation of workflows in assembly plans and the necessity to identify certain work objects [23–25].

Therefore, an AR system for ground test guidance is implemented using a Microsoft HoloLens and an existing AR framework (Unity). The implementation is based on a model of the cockpit, containing all control elements with the associated identification numbers as well as their spatial position. Referencing of the HMD is realized via a marker placed in the cockpit. On this basis, textual test instructions can be visualized directly at the location of the corresponding control elements in the field of view of the worker (Fig. 6). The inaccuracies of the tracking system are compensated by showing an area around the control element instead of its exact position. In addition, the head tracking of the HMD and arrows displayed in the worker's field of view are used to indicate the position of the next control element. The test results can be documented within the AR application using the gesture control provided by the HMD. After the transmission of the test result, the next test instruction is shown automatically, so that the worker is intuitively guided through the ground test.

4.4. Process Guidance

As maintenance processes are characterized by a high percentage of manual work steps and small lot sizes, manually guided, semi-automatic machines are often a reasonable alternative to fully automated systems. An example for this is a semi-automatic, mobile machine for the milling of scarf profiles during repair of fiber composite parts. The worker manually moves the machine in a plane parallel to the damaged surface (Fig. 6). Depending on the position in this plane and the reference geometry, the infeed of the milling tool is controlled automatically [26]. During the process, information such as optimal processing strategies or machine parameters are displayed to the worker.

In this case, extensive bidirectional communication takes place between the human worker and the physical system, resulting in a high level of interaction between *human* and *object*: the worker manually moves the physical system and gets information about the process by monitoring it and by receiving feedback through process forces. Additionally, there is a high effort for the interaction between *human* and *model* as the machine control informs the worker about the optimal processing strategy, whether the speed of the manual movement is appropriate, about areas yet to machine etc. On the other hand, the human confirms when a process step is terminated.

According to the presented concept this relatively high effort for the interaction between human and model shows that there is a great potential for the use of MR. Since communication takes place between the *human* and the *model* as well as between the *human* and the *object*, an AR system is needed (Fig. 2). This allows the worker to monitor the process and to move the physical system as well as to get additional information from the model.

In the fourth use-case, such a support system is implemented using a Microsoft HoloLens and Unity. It assists the user during positioning of the mobile physical system as well as during the process itself. The referencing of the HMD to the real, physical system is realized by a marker. This AR system allows the user to interact with the model without having to avert his gaze from the physical system which is particularly useful when informing the user about the optimal processing strategy during milling.

A future study will have to show whether the use of this technology leads to a measurable increase in productivity compared to a conventional human-machine interface using a tablet PC.

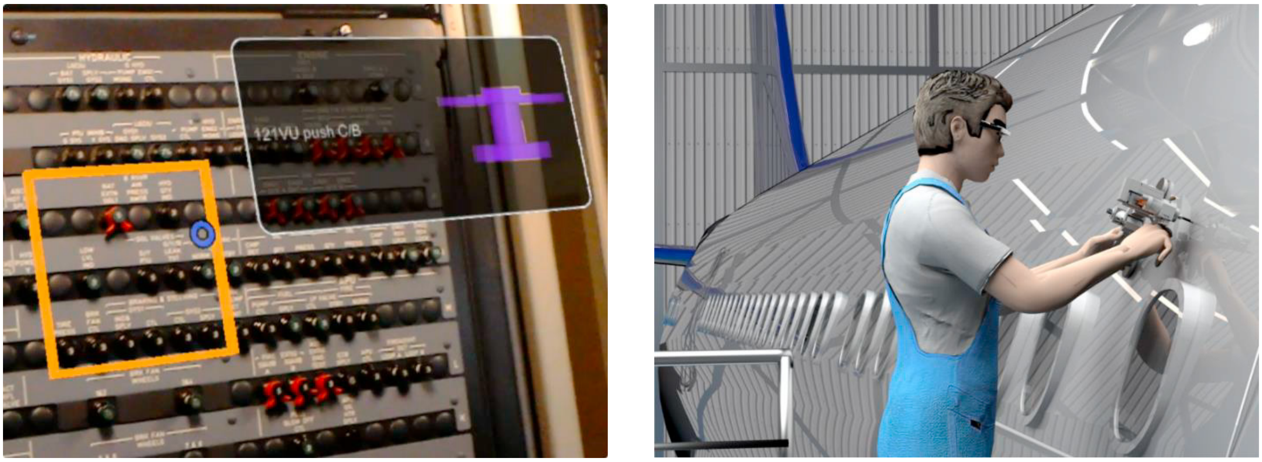


Fig. 6. Groundcheck guidance using AR system (left); Worker with semi-automatic, mobile machine and AR system. (right)

5. Conclusion

In this paper, a concept was presented that simplifies the assessment of the potentials of MR technologies. Furthermore, the concept simplifies the selection of a suitable technology for a specific use case. Time and effort for the interaction between the data basis and the worker have been proposed as a measure for the general potential of MR support systems. The classification of interactions between operator and the non-human real-world assets facilitates the selection of an appropriate technology, AR or VR.

The presented concept was applied to four different use cases in the field of inspection and maintenance in the aviation industry. This shows that the concept is generally applicable to a variety of applications. The *model* is used to classify and analyze the use cases and shows the possible assessment of MR potential as well as the selection of the most suitable technology. Further studies have to be conducted to elaborate the presented use cases. One crucial aspect is the comparison of productivity of the different processes with and without additional support systems. Thi support the verification of the estimation of MR potentials and suitability of a certain technology. Applying the concept to further use cases will ultimately contribute to further detail the levels of interaction.

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