Towards Remote Analytics in Nondestructive Testing

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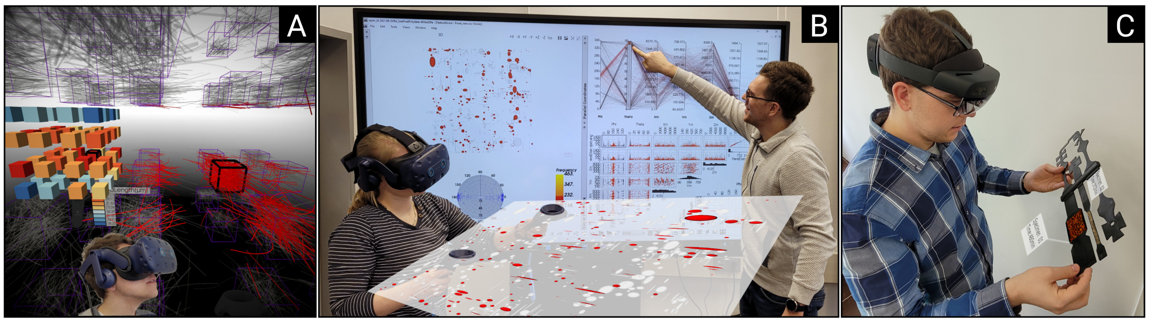

Fig. 1. Cross-virtuality (XV) transition between our NDT applications in virtual reality (VR) [12] (A), between a VR and desktop collaboration [11] (B), and augmented reality (AR) (C)

In materials science, the inspection and characterization of safety-critical components through non destructive testing (NDT) is essential. Especially inspections outside the expert's workplace involve high travel, accommodation and testing costs. Remote Analytics and collaborative material characterization by cross-virtuality (XV) approaches offer a comprehensive and efficient way of analysis independent of the expert's location. By using immersive technologies such as augmented reality (AR), it is possible to display embedded visualizations on the real object, thus extending the multidimensional analysis through physical context and interaction. More complex analysis can be continued in an immersive workspace with correct spatial representation using virtual reality (VR). Through a remote connection and appropriate transitions between the different interfaces on the reality-virtuality continuum (RVC), the advantages of the systems can be exploited in a collaborative setting. In this paper we present ideas and concepts along the RVC from current research in NDT.

CCS Concepts: • **Human-centered computing** → **Visual analytics**; **Collaborative and social computing**.

Additional Key Words and Phrases: cross virtuality analytics, remote analytics, situated representations, collaboration, materials science

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1 INTRODUCTION

Composite materials are extensively used for safety-critical parts, e.g., in aerospace but also other application areas, making them one of the most promising and demanding materials of the century [22]. In the field of materials and component testing, non-destructive testing (NDT) techniques, such as ultrasonic testing (UT) and X-ray computed tomography (XCT) are essential [13–15]. Especially XCT generates large volumetric datasets (i.e., primary data) and derived thereof high-dimensional quantitative data (i.e., secondary data) based on the individual characteristics of the scanned materials (e.g., length of fibers, dimensions of pores). Understanding and interpreting spatial NDT data together with derived non-spatial data is critical to ensure the mechanical integrity of a component. Techniques along the reality-virtuality continuum (RVC) [19] offer the possibility of immersion in a truly spatial representation (VR) as well as direct interaction and augmentation of physical objects (AR). The transition between these areas allows for the combination of their advantages and facilitates a collaborative analysis [10]. Newly emerged opportunities also feature remote collaboration between a remote expert and an on-site AR user [5, 18, 20, 25]. Remote analytics thus generates large cost reductions by eliminating the need for experts being on-site, and it contributes to climate change mitigation. The concurrent or sequential usage of different points on the continuum supports experts in material characterization, and can directly lead to cost reduction, efficiency improvement, increased flexibility and quality. To achieve this, we used well-established approaches from visual analytics to enable an efficient and precise analysis on 2D desktop systems. We then developed a novel visualization system which offers material experts an immersive exploration of multidimensional secondary data of composites in VR. Finally, we combined these two approaches to enable a collaborative analysis between the frameworks: a fluid and natural embodied exploration in VR coupled with the familiar 2D diagrams and efficient input of parameters through a desktop application. The next steps extending this analysis should enable a direct interaction with the inspected objects, as well as situated visualizations in AR. The use of AR also enables the development of a remote analytics platform that supports natural collaboration between external experts and users in the field.

2 RELATED WORK

To get an overview on the developments in the field of immersive analytics of NDT data, we introduce the most relevant studies from this domain in the following paragraphs. Amza et al. [1] introduced an application for training operators in using ultrasonic equipment for NDT of pipework. The system significantly lowered the steep learning curve of ultrasonic testing for NDT applications and thus decreased the costs of traditional training. In the study of Schickert et al. [24] the authors visualized NDT and computer aided design (CAD) data on physical objects by smartphone AR visualizations. The system of Utzig et al. [25] uses digital twins to superimpose damage information on the physical aircraft components. By collaborating on the real object and remotely on the CAD model, the efficiency of aircraft inspection tasks could be improved.

The areas of our prior research (gray circles indicated with A1-A4), as well as the current focus of our ongoing work (red circle indicated with A5) are indicated in the illustration in Figure 2. A broad overview of the material analysis from the field of visual analytics to immersive analysis and collaboration has already been provided by Gall et al. [10] (**A1**). The study of Gall et al. [9] (**A2**) focused on immersive visualization of multidimensional volumetric data from material science. In the ImNDT framework [12] by the same authors (**A3**), experts are supported in the time-consuming and cognitively demanding task of analyzing complex fiber-reinforced polymers (FRPs). The tool allows a natural embodied navigation and interaction and showed benefits in discovering structural patterns and similarities through the spatial

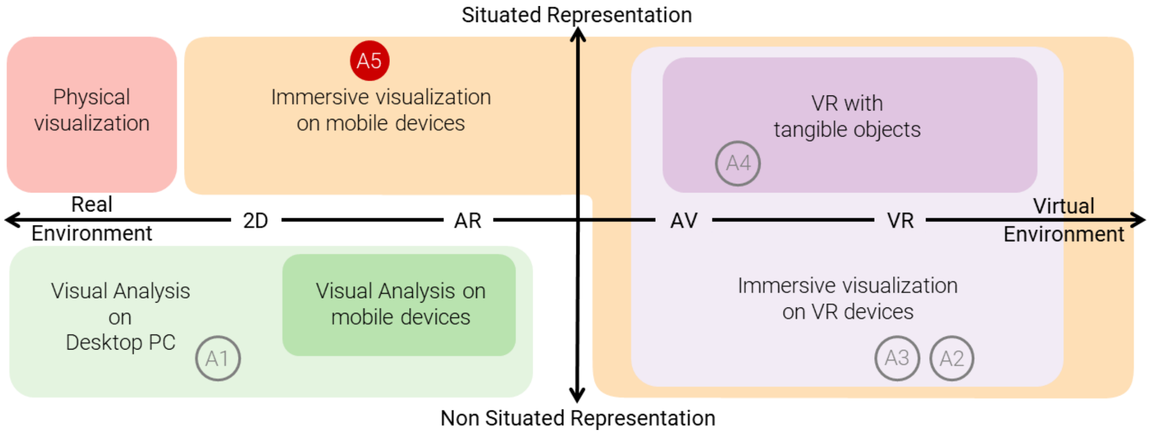

Fig. 2. Overview of the data representations in material analysis across the situated reality-virtuality continuum. Circles A1-A4 indicate points of our research in the continuum. The red circle A5 represents our current situated AR research.

representations (see Figure 1 A). The Cross-Virtuality-Analytics tool (**A4**) by Gall et al. [11] combines desktop-based analyses with explorations in VR (see Figure 1 B). The demonstrated system allows several experts analyzing a dataset on a large multi-touch screen to collaborate with an expert using a VR head-mounted display (HMD), in order to perform a collaborative material analysis. Using the cameras on the HMD, the collaboration can be enhanced further by including the real environment and teammates. By transitioning between a detailed numerical analysis on a 2D device to embodied exploration in a spatial domain visualization, the particular advantages at each of the points on the RVC can be exploited.

The main challenge but also an outstanding opportunity in material characterization will be to enable a spatial analysis, which is simple, effective, and after all possible, at any time and any place. Our next prototype (**A5**) will therefore deal with AR to enhance the previous analysis and make it independent of location (see Figure 1 C). The possibility of combining all this with other interfaces across the RVC and thus enabling an intuitive and collaborative analysis offers unexpected opportunities, like more engaging explorations and natural interactions, for a wide range of domains.

3 CONCEPTS ON IMMERSIVE ANALYTICS

In this chapter, we introduce examples of future concepts (C1-C3) such as situated data representations, remote analysis, and cross-virtuality (XV) analysis, which will become core relevant for upcoming research in the field of materials analysis.

Situated Analytics (C1) is concerned with non-situated and situated representation, where situated representations can be either embedded or non-embedded. Situated representations aim at displaying information in the environment of its data referent (i.e., the real world object entity or space the data refers to), while embedded representations overlay the information on the physical data referent [4, 7, 27]. Whitlock et al. [26] presented a visualization system in the field using mobile overviews and situated AR visualizations. Their work showed that on-site data collection and analysis can improve field work by providing quick overviews and detailed analysis that includes physical context. The system of Prouzeau et al. [21] uses a digital twins approach to author 3D models and spatially embedded visualizations in VR which can be viewed on site through an AR HMD. An example of a situated physicalization was shown by Danyluk et al. [6]. They compared physical and VR versions of simple data visualizations. Their study demonstrated the benefits of interacting with tangible objects and the value of virtual annotation tools for data analysis.

Remote analytics (**C2**) approaches focus on long-distance communication and collaboration. Immersive visualizations and interactions facilitate these activities and improve the visual data exploration [2, 16]. Chen et al. [5] demonstrate a remote collaboration between a single HMD user and external users who can see and annotate the space from the HMD user's point of view. CoVAR by Piumsomboon et al. [20] enables the remote collaboration of an AR user and a VR user. Through interactions such as eye-gaze, head-gaze, and hand gestures in the shared world, a collaboration is facilitated.

Cross-virtuality analysis (**C3**) finally provides the opportunity to leverage the different strengths of each interface by transitioning between systems with different levels of virtuality [8, 23]. The MagicBook by Billinghurst et al. [3] provides users with a collaborative environment in which they can switch between reality, spatial AR, and VR through a handheld display and a real book. MARVIS by Langner et al. [17] enables data analysis from 2D visualizations on tablets with 3D augmentation by AR HMDs.

4 SITUATED ANALYTICS ACROSS DISTANCES

In the following section, we will present indicative scenarios from materials science for which the introduced concepts will be of interest. We focus in particular on the field of material characterization and quality control. We will further relate the previously outlined concepts and our applications to the respective scenarios and situations presented.

Indicative Scenario 1: We start our first scenario with an incident-based NDT of a damaged component at a distant airport. Remote analytics using AR devices can eliminate the need for on-site inspection by NDT experts, as on-site staff can be guided through the analysis (**C2**). Avoiding the need for experts to travel and stay on-site can reduce costs and prevent high grounding expenses. The remote experts can see the object to be inspected on standard desktop devices through the video transmission of the AR HMD and the superimposed UT and XCT data using AR visualizations adapted to the respective situation (**C1, A5**). With the help of annotations and existing CAD models, the personnel on site can be guided and further testing can be initiated. For more complex analysis, the expert can switch to a VR HMD and collaborate through special interactions such as gestures and gaze, and view a virtual reconstruction of the environment (**C3, A4**).

Indicative Scenario 2: More complex tests, such as in-situ tests or high-resolution scans, can also be facilitated directly at the experts' testing site through immersive analyses. With the help of AR, it is possible to interact directly with the object under investigation and its secondary data (**C1, A5**). This enables more natural interactions and immediate spatial interconnection with the object under inspection. In addition, other devices at the workplace such as standard desktops, tablets, or smartphones can be combined for collaborative analysis (**C3, A4**). The 2D representations can be extended by the respective immersive device through fluid transitions. The data obtained in this process can then be sent to external mobile devices to continue an on-site analysis (**C2, A3**).

5 CONCLUSION

Immersive technologies offer the possibility to visualize data in the world around us and augment physical objects with context-specific information. There is immense potential for materials testing through remote collaboration that saves travel costs and time, as well as contributing to climate change mitigation. The collaboration between the systems on the reality-virtuality continuum, described in this paper, also significantly changes the way we interact and analyze materials, as analysis becomes possible at any time and place, with any device and in a collaborative manner.

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