Augmented Reality for Forming Technology – Visualisation of Simulation Results and Component Measurement

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Abstract. In sheet and bulk forming, numerical simulation has become established over the last 20 years as an indispensable tool for research and industrial practice. The numerical calculation of forming processes supports a time- and cost-efficient development in the context of a virtual product evaluation. Currently, simulation and measurement results are mainly displayed on conventional screens. However, this approach has several disadvantages. On the one hand, only cut-outs can be displayed, especially in the case of large components. A visualisation of entire components in real size is often not possible. On the other hand, no direct comparison with the real components is possible. Augmented Reality is a promising approach to solve the challenges outlined above. As part of the contribution, an innovative approach for component validation based on Augmented Reality technology will be introduced. Thereby, the visualisation using different Augmented Reality devices and the feasibility of a measurement task with Augmented Reality devices will be presented.

1. Introduction
Nowadays, digital tools in production engineering are still gaining in importance for manufacturing processes. One component of computer-aided engineering, CAE (computer-aided engineering), is process simulation in manufacturing technology. Simulation is an indispensable tool for designing and optimizing increasingly complex manufacturing processes. For example, in forming technology manufacturing processes are almost invariably calculated using the widely used finite element method (FEM) [1]. The finite element calculation is a numerical method for solving complex physical problems, which is used for the investigation and design of forming processes. Modern simulation programs for sheet metal and bulk forming enable the implementation of new manufacturing techniques for lightweight body construction on the basis of the FEM [2]. The simulative process design enables high-strength materials to be processed by forming technology and new production methods to be used. The use of FEM software also contributes to the realization of modern design features, e.g. narrow radii and sharp edges. The information gained through the use of simulations depends crucially on the quality of the simulation validation and the simulation evaluation. The validation of the simulation model is usually done by comparing the virtual model with a real model. Both sub-processes of the simulation and the entire virtual model are compared with model tests and prototypes. The simulation model is then calibrated on the basis of the experimental results. Besides the forming simulation itself, the postprocessing of the results is a major topic to enhance results and efficiency. In this context mobile devices offer enormous advantages by offering a tailored user...
experience with innovative features in an Augmented Reality (AR). Augmented Reality differs from Virtual Reality (VR) by integrating the physical reality (Figure 1).

![Figure 1. Augmented, Mixed and Virtual Reality][3]

2. Augmented Reality devices and fields of application

In the beginning of AR technology only devices specifically made for this application could be used to visualize holograms within the real world. Today, other commercial digital devices, such as smartphones and tablet computers can be used as well. Although AR devices are much more expensive while having only limited possible applications, they still have their raison d'être due to the performance of those devices. There are various devices on the market, the most common devices for AR applications are presented in Figure 2. Besides the Microsoft HoloLens (Figure 2 left) and the Meta 2 (Figure 2 middle), Canon developed an MR-solution for industrial applications and Magic Leap is working on a promising MR-project. Since the operating system iOS 12 was introduced by Apple, applications are supported on smartphones and tablets (Figure 2 right).

Within the framework of the scientific analysis, the suitability of different systems for the use of augmented reality in forming technology was investigated. Preliminary work has proven in this context that the technology is particularly suited for the presentation of simulation results in order to generate a direct benefit for the design of forming processes [4]. Prerequisite for a reliable and convincing presentation of the simulation results as well as for a robust positioning of the components in the room is a holistic assessment of the environment. For the analysis of the environment, only the camera images of the smartphone are used. This approach differs significantly from AR-glasses. In contrast to smartphones AR-glasses are equipped with advanced depth camera, which allow a complete three-dimensional digitization of the environment. Consequently, a positioning of objects is possible in the complete available room. In contrast, most smartphones are still equipped with conventional cameras. Therefore, a complete three-dimensional digitization of the environment is not possible. Rather, sophisticated and complex pattern recognition algorithms are necessary in order to provide a spatial orientation. For the approach, the methods of Bauer et al. [5] and Schreiner et al. [6] were enhanced for detecting flat surfaces.

![Figure 2. Augmented Reality devices][3]
2.1. Augmented Reality glasses
AR-devices which are connected to a network or WiFi are referred to as Connected-Wearables and belong to devices for the Internet of Things (IoT). These devices provide additional information for the user or can collect data from the environment of the user depending on the application.
The Microsoft HoloLens is a well-established AR-device and an independent computer operating on Windows 10 [3]. The HoloLens mainly consists of optics and the headband, which contains the computer hardware, the sensors, speakers and the rechargeable battery. The Meta 2 offers some advantages with regard to the performance due to the connection to an external computer, thus the flexibility is restricted. Therefore, this investigation focusses on the Microsoft HoloLens.

2.2. Smartphone and tablet computer
Recently, also smartphones and tablet computer can be used for augmented reality applications. In contrast to special AR-devices like the HoloLens, smartphones are equipped with more simple cameras and a lower computational power. Moreover, the user does directly see the environment, but only a representation on the screen of the smartphone or tablet. Besides the hardware, a sophisticated software and operations system is necessary in order to process the large amount of data. Apple has at the moment a leading role in the area of augmented reality. The technology is based on the development of the German company metaio, which was acquired by Apple a few years ago. Afterwards, large parts of the technology were integrated in the operations System iOS and released in 2018 [7].

3. Visualisation of forming simulation results using Augmented Reality
Due to the increasing importance of numerical analysis within the field of forming technology, the importance of an efficient and user-friendly utilization of the gained results also increases. In this chapter the visualization of simulation results is exemplarily shown for the Microsoft HoloLens as well as for Apple iPhone and iPad. The biggest challenge in the visualization of simulation results lies in the presentation of high-resolution polygon meshes. In finite element analysis, simulation objects are discretized by very small elements for reasons of accuracy. In the optical measurement of components even a much higher element density is achieved. However, the large number of elements of the mesh leads to performance problems when displayed on the HoloLens. To achieve optimal visualization of these simulation models, the original FE mesh must be transformed into a polygon mesh with a reduced number of elements.

3.1. Visualisation of simulation results with Microsoft HoloLens
The visualization of simulation results as a hologram is challenging especially due to the amount and the structure of the data to be converted. A main challenge is the class design. A prefab is used as a placeholder for the simulation results and the corresponding legend. The prefab determines the properties of the objects as well as their interdependencies. Initially the geometry, the colors and the resulting values are extracted from the numerical model. Based on this information a mesh is generated, which is then transformed in a mesh of triangles by the game engine Unity. The 16-bit network allows 65,536 nodes, for a higher number the mesh has to be divided into several sub-meshes. The object is then equipped with a Box Collider for hit queries. For an adequate visualization a shader renders both sides of a surface to prevent them to occur transparent when looked at in the direction of the normal vector of this surface. The corresponding legend is necessary to classify the qualitative depiction of the simulation results. Thus, the legend is oriented towards the user. [4] The transformation of the simulation results to holograms enables a location-independent visualization and thereby, a comparison of the numerical data and experimental component right after the manufacturing operation, as shown in Figure 3 a). Figure 3 b) presents the point of view from the user. The result of the numerical simulation with the corresponding legend is displayed next to the experimental part, creating an Augmented Reality.
3.2. **Visualization of simulation results with Apple iPhone and iPad**

The conversion of the simulation results is a complicated multi-step process. For this purpose, first the position of the object is overwhelmed from the coordinates of the mesh and each mesh element has to be additionally assigned with a barycentric coordinate function. [8] Depending on the size of the mesh, it may furthermore be necessary to perform a grid reduction in order to ensure a real time processing of the data. [9] After the new orientation and transformation the results of the forming simulation have to be assigned to the elements. In dependency of the grid reduction and the application of the barycentric coordinate transformation, the results can be calculated for the single elements. For the visualization on smartphones, in addition, a legend has to be integrated in the geometric file. Thereby, the highest x-coordinate of the geometry is identified and the legend is positioned accordingly. Within the scientific investigations the representation of different color themes was solved by the development of color templates as .jpg files. The visualization of simulation results using an iPad is presented in Figure 4 a). Of course, the developed methodology can also be used to visualize CAD data, as shown in Figure 4 b).

The positioning of the simulation results requires not only sophisticated algorithms but also an enhanced computing power in order to ensure real-time process and localization of objects. In the framework of the fundamental scientific investigations, the time needed to obtain sufficient information about the environment and thus to enable a location-fixed representation of the simulation results in real size was analysed. Table 1 shows the results of the Tracking Times, which were necessary in order to gain and process the data of the cameras. For the investigations, different processors of the company Apple were used. Since the A11 Bionic chip a processing in less than 1 second is possible.
Table 1. Experimental analysis of tracking time for Apple devices

| Device   | System   | Processor | Tracking time |
|----------|----------|-----------|---------------|
| iPhone SE | iOS 12.1.2 | A9 SoC   | 10 s          |
| iPhone 6s | iOS 12.1.2 | A9 SoC   | 8 s           |
| iPhone 7  | iOS 12.1.2 | A10 Fusion | 3 s          |
| iPhone 8  | iOS 12.1.2 | A11 Bionic | 2 s          |
| iPhone X  | iOS 12.1.3 | A11 Bionic | < 1 s        |
| iPhone XR | iOS 12.1.3 | A12 Bionic | < 1 s        |
| iPhone XS | iOS 12.1.3 | A12 Bionic | < 1 s        |
| iPad Pro  | iOS 12.1.3 | A12 Bionic | < 1 s        |

4. Measurement of geometrical part properties with Augmented Reality

With the above described procedure not only a realistic localization of the simulations objects in the environment is possible. Rather additional information about the real object such as the forming part can be generated. In this context, a methodology was developed in order to obtain geometric properties of the sheet metal semi-finished products with the help of the information from the cameras. Significant advantage in contrast to conventional measuring approaches is that not additional measurement set-up is necessary. With the help of HoloLens, on the one hand, a three-dimensional grid of component geometry can be derived directly from the so-called WorldMap. However, the quality is currently not good enough to achieve the necessary accuracy for the forming technology. Therefore, within the scientific investigations markers for sheet metal processing were developed and used, as presented in Figure 5. In order to allow easy positioning on the component, they were provided with magnets, and can therefore be mounted directly on the steel sheet. As part of the methodological approach, the patterns must first be unambiguously identified with the markers, which differ significantly from the sheet structure. Within the algorithm the markers are enlarged to plane $E_1$ und $E_2$. Finally, the distance can be easily calculated with the canonical normal. The method has a lot of advantages in comparison to a conventional procedure. Without any additional the measurement equipment a geometric validation of simulation results directly at the forming part is possible.

![Figure 5. Measurement of height difference between planes with HoloLens](image)

In order to analyze the measurement quality the measurements of the HoloLens were compared with a tactile measurement. With the HoloLens the height of part was identified with a mean value of
39.8 mm. The height measured with the height gauge is 40.6 mm, as shown in Figure 6. Consequently, the deviation of 0.8 mm has to be considered in the evaluation of part properties. Nevertheless, the methodology can be transferred onto parts manufactured in bulk forming operations as well.

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Figure 6. Quality of distance measurement with AR-device
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5. Conclusion and outlook

In this work, a new approach for simulation validation and simulation evaluation was developed. The developed method creates the necessary prerequisites for the application of augmented reality technology for the visualization of simulation results of sheet metal and massive forming. The application-oriented approach enables the holographic representation of simulation results of sheet metal and massive forming on the HoloLens, Microsoft's AR glasses as well as every iPhone and iPad. With the application of markers, even a measurement of the real part is possible. Within further investigations, the methodology will be further enhanced. Thereby, it will even be possible to measure the angle between to planes and use the data for the analysis of springback.

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