Augmented reality for supporting manual non-destructive ultrasonic testing of metal pipes and plates

Robert Deppe*, Oliver Nemitz†, Jens Herder*

* Hochschule Düsseldorf
Münsterstraße 156
40476 Düsseldorf
Tel.: +49 211 4351-3268
robert.deppe@study.hs-duesseldorf.de
jens.herder@hs-duesseldorf.de

† Salzgitter Mannesmann Forschung GmbH
Ehinger Straße 200
47259 Duisburg
+49 203 999-3299
o.nemitz@du.szmf.de

Abstract: We describe an application of augmented reality technology for non-destructive testing of products in the metal-industry. The prototype is created with hard- and software, that is usually employed in the gaming industry, and delivers positions for creating ultrasonic material scans (C-scans). Using a stereo camera in combination with an HMD enables realtime visualisation of the probes path, as well as the setting of virtual markers on the specimen. As a part of the implementation the downhill simplex optimization algorithm is implemented to fit the specimen to a cloud of recorded surface points. The accuracy is statistically tested and evaluated with the result, that the tracking system is accurate up to ca. 1-2 millimeters in well set-up conditions. This paper is of interest not only for research institutes of the metal-industry, but also for any areas of work, in which the enhancement with augmented reality is possible and a precice tracking is necessary.

Keywords: Nondestructive Testing, Ultrasonic, Augmented Reality, Tracking, Stereo camera, head mounted display, NDT, AR

1 Introduction

In the field of nondestructive testing of steel products, the ultrasonic (US) inspection is a frequently used method to assure given safety requirements [DPD+10] [MBH+04] [AKMN14]. For heavy plates and large diameter pipes the manual US testing is often applied as a follow-up inspection. Here, a US probe is moved by hand on the surface of the specimen (Figure 1). While moving and possibly rotating the probe, the operator monitors the US signal on a screen. Usually, in case of an imperfection in the material, the US signal exhibits a higher amplitude and the position of the imperfection can be marked on the specimen. However, the exact position and orientation of the probe are not captured during the manual inspection. Hence, generating an objective report with for example a map of color coded US amplitudes onto probe positions (a so-called C-scan, cf. Figure 2) is not directly possible. Furthermore, those parts of the specimen surface that have already been inspected are usually not tracked and visualized. There is especially no control if there is a gap in the inspection path.

The aim of our system is therefore to track the position and orientation of the US probe during the inspection and assign them to the corresponding US signals. This tracking is done with standard AR/VR components of an *HTC VIVE* system. The probe is attached to a *VIVE* tracker and the global coordinates of the probe are converted to coordinates in a local coordinate system on the specimen. These local coordinates are sent to a US inspection software which generates a C-scan of the specimen. With the help of a *ZEDmini* stereo camera it is possible to view the inspection in AR and visualize certain virtual elements; for example the pathes of already inspected areas.
In this work only plate products have been considered, i.e. specimen with planar surfaces. In a subsequent step it is planned to extend this work to pipes, i.e. cylinder shaped specimen.

Figure 1: Left: A longitudinally welded large diameter pipe in a pipe mill. Right: Manual ultrasonic testing of the weld seam.

2 Related Research

In a 2015 *Olympus* patented the procedure of enhancing the manual inspection with AR-glasses, which help to trace a predefined inspection-plan path. The patent describes details like tolerated deviation from the inspection path. However, the patent mentions no logging to log specific points or the traced path on the probe [LLSLH15]. *Walter et al.* describe a system, which uses a stereo camera and active markers to determine the probes position and orientation on a possibly curved surface of plane components [WBA^{+}17]. A system similar to our described AR-application, supporting the cleaning of surfaces is presented in an article by *Bonasio*. It describes the advantages of using AR-technology, like a DRAW or HYBRID system (section 4.3), can have on quality assurance in the commercial cleaning industry [Bon17]. *Fadzil et al.* describe a manipulator based system to track the position and orientation of B-scans in a medical application of ultrasonic inspection to create three dimensional voxels of the measurement values [FFS^{+}15].

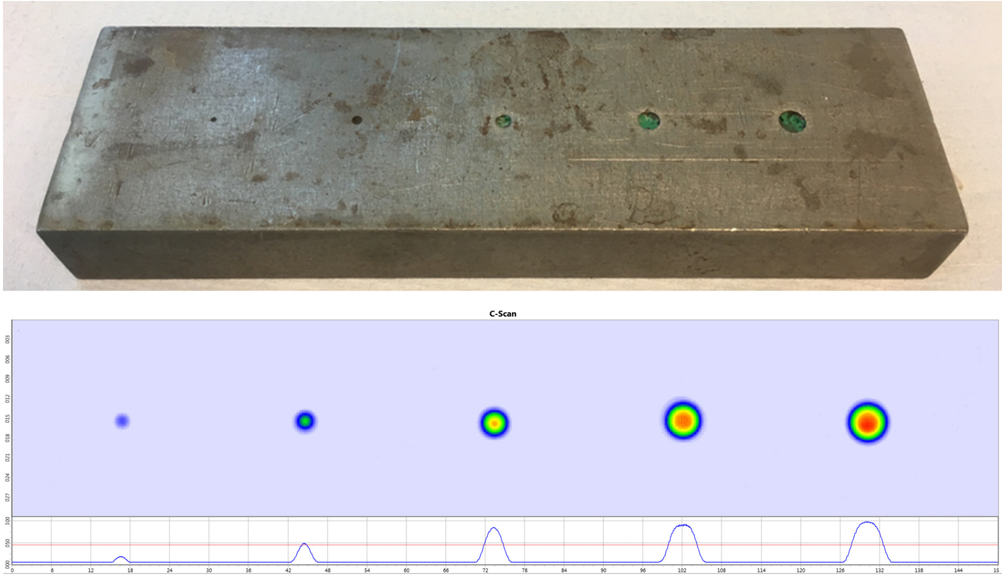

Figure 2: Example of a C-Scan: A plate specimen (top) with multiple flat-bottom holes of different diameters has been inspected with a 5 MHz probe which was moved along a rectangular grid across the back side. At each grid position an amplitude value is extracted from the US signal and converted into a color. The resulting image on the grid is the so-called C-scan which can be seen at the bottom. In this case a rectangular grid with a fine resolution of 0,1 mm has been used.

3 Description of the AR–application

The AR-application supports manual US testing in two ways. First, the operator is able to see the already inspected path and identify gaps through a VIDEO-HMD. Futhermore, it is possible to visualize the local coordinate systems axes on the specimen as well. For this AR visualization, a stereo camera is used to create a VIDEO-HMD and to create a depth mask [DBGJ13]. Second, the position and rotation of the probe are sent to the ultrasonic scanning computer. There, the data is combined with the measurements received by the probe and a C-scan can be generated.

4 Implementation

The AR-application was implemented in the game engine Unity. The application takes care of defining the local coordinate system of the specimen, receiving global coordinates from the *VIVE* basestations and converting them into local coordinates. These local coordinates are transferred via TCP/IP to a US inspection software written by SZMF. The US inspection software combines them with the US signals that have been received at the same time. The US signals can be further processed into a C-scan or other result types. The whole setup is illustrated in Figure 3.

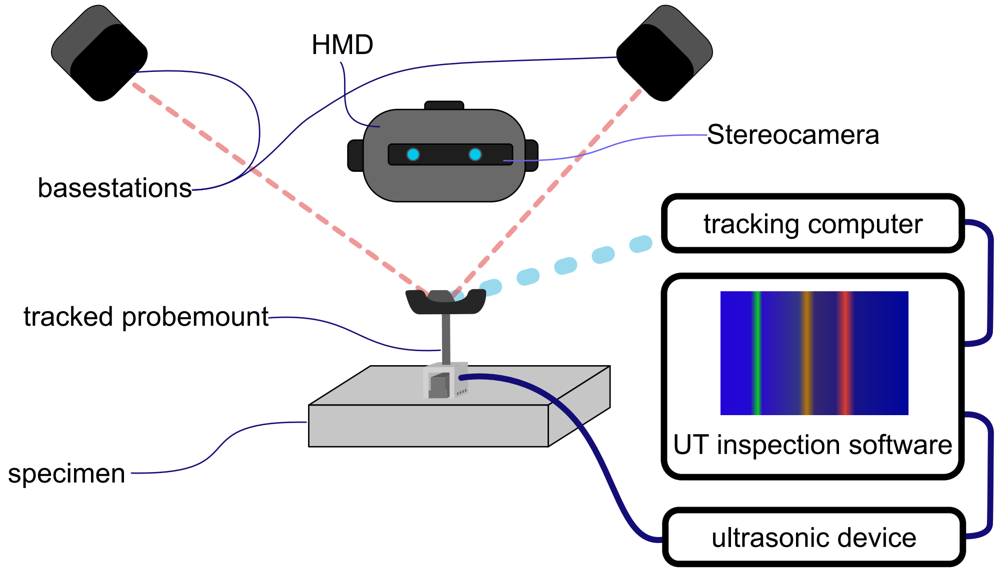

Figure 3: Setup of the described AR-application.

4.1 Tracking of the ultrasonic probe

The ultrasonic probe is tracked with the help of an attachable tracked *VIVE*-tracker. This tracker is attached to a mount, in which the ultrasonic probe is fixed with screws (Figure 6). The offset and orientation between the tracker and probe is applied in the *Unity* engine by setting the virtual probe as a child transform of the tracker.

4.2 Detection of the coordinate system in worldspace

The local coordinate system of the surface to be measured is defined in two steps: first a point cloud of the surface is created by moving the tracked probe across it. Next, a plane is fitted into this point cloud using the Downhill-Simplex optimization by Nelder and Mead. For the planar specimen considered in this work a simple plane computation based on three measured points would be sufficient. Nevertheless, the fitting algorithm is used, as it is more flexible for future, more complex applications like pipes or other geometries.
In a second step the local coordinate system is determined by defining its origin and the direction of the x-Axis. The y-Axis in the fitted plane is then automatically chosen orthogonally to the x-axis and the z-axis is the vector product of the x- and y-axis. In the application, the origin and the direction of the x-axis are chosen by pressing the setup button.

4.3 Visualization of the tracking-data

To visualize the already traced path, a visual feedback is given to the operator. The feedback can be implemented in multiple ways, depending on the application. The path can either be drawn on the surface (Draw), erased from a pre-colored area (Erase), or be drawn onto a pre-colored area (Hybrid) (Figure 4). The main purpose of this visualization is to show

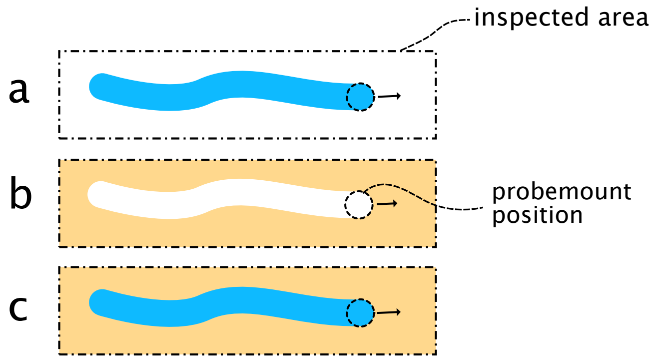

Figure 4: Different methods to mark covered area. (a) Draw (b) Erase (c) Hybrid

possible gaps in the inspection, or to follow a predefined inspection-path. In the case of SZMF, there is usually no specific inspection-plan that can give a pattern to erase, therefore DRAW was implemented. The AR-view of the application can be seen in Figure 5. The patches in the surface, where no color can be seen, can be explained by a lack in accuracy of the depth image, generated by the used stereo camera.

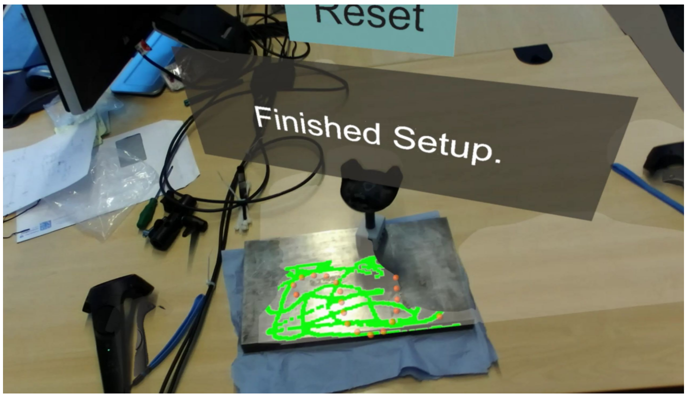

Figure 5: AR-view of the application. The green marking shows the path the probe has taken.

4.4 Continuous and singular logging of position

The application allows the continuous logging of the probes position. This protocol can be useful for documenting exactly which path was taken, and where exactly the imperfections were detected. In addition to that, it is possible to log singular spots and store them for later use.

4.5 Results

A part of the final setup of the supported manual US inspection system is shown in Figure 6. The probe which is mounted to the tracker is placed on a steel plate and connected

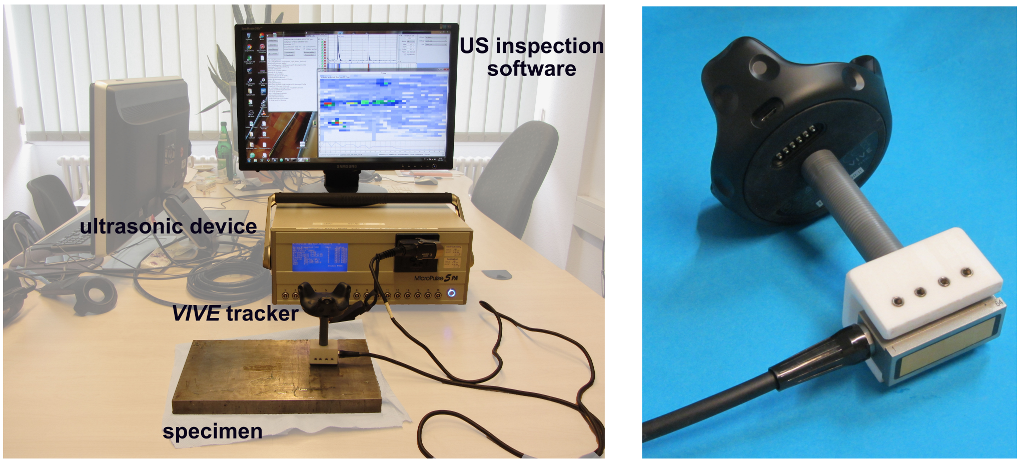

Figure 6: Left: Setup of the system with live generated C-scan visible on the monitor. Right: Probemount used in the setup.

with a US device (Micropulse 5 from PeakNDT). A monitor on the US device shows the US inspection software which displays US signals in the correct position on the specimen (C-scan). In Figure 7 another example of a C-scan can be seen. The specimen contains two flat bottom holes of 10 mm diameter which can be clearly recognized in the C-scan below. The grid resolution of the C-scan is 3 mm.

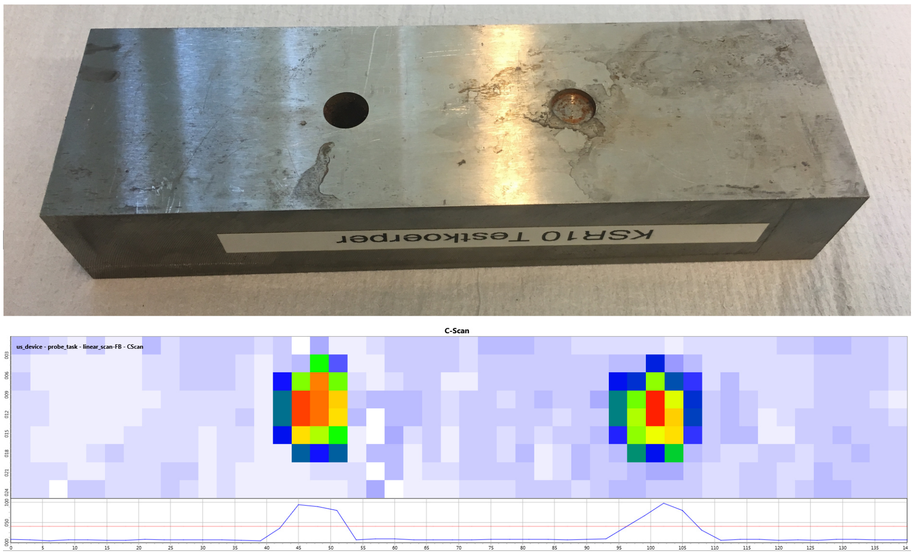

Figure 7: C-scan generated with the *VIVE*–tracking system.

5 Evaluation of the *VIVE*-tracker accuracy

The accuracy of the *VIVE*-tracker was determined in an experiment using an automated x-y-scanner, which has a nominal accuracy of about 0.01 mm. Both *VIVE* basestations were positioned on opposite corners of the scanner, though one at a greater distance (Figure 8).

The tracker was screwed to the moving head of the scanner and moved in a comb structure over a surface of 400 mm x 800 mm. During the process, the position of the tracker and absolute time was continuously logged. In the beginning and end of each comb tine the movement was paused by 2 s to identify the corresponding positions in the log-file. Thereby it was possible to compute differences of the mean position of the *VIVE*-tracker coordinates at these predefined positions and their nominal coordinates. The whole comb measurement has in turn been repeated multiple times to compute mean values of these differences. The

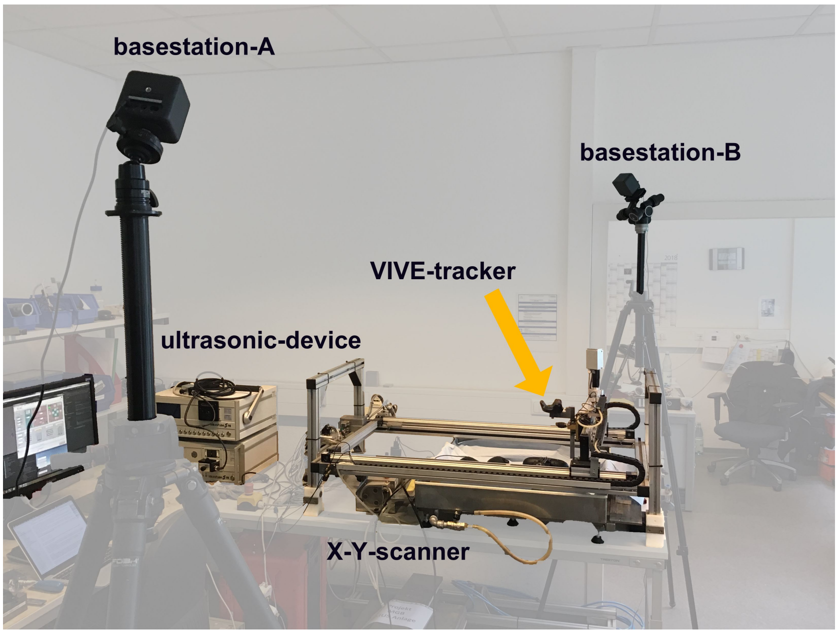

Figure 8: Setup for the evaluation of the *VIVE*-Precision.

accuracy results show a decline in quality as these positions get closer to the closer basestation (basestation-B in Figure 8) with an error up to 18 mm. In the opposite corner the values had an expected quality of about 1-2 mm. We assume, that basestation-B was located too close to the scanner such that one corner of the comb was shadowed. However, we plan to repeat this trial with more optimal basestation positions.

6 Conclusion

We have used a VR-Tracking system, which is usually used for HMD applications, for tracking an ultrasonic sensor. We showed that the accuracy for generating ultrasonic volume images is good enough (Figure 7), enabling cost effective systems. The HMD system was modified with a stereo camera for building an AR Video-HMD system. AR was used to show the manual scanned surface to an operator. The developed registration procedure for the test object allows multiple measurements on different occasions. In the application field an object will be tested, modified and repaired, and finally tested again. The final test will be done for the same measurement area, which can be found through the registration method. The developed prototype is not mobile and robust enough to be used in the field, but with the advances in AR displays and mobile tracking, improved nondestructive testing procedures for advanced product quality can be developed.

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