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Touch-based Augmented Reality Marking Techniques on Production Parts

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Abstract

In the machining of production parts, the quality of the surface is subject to a variety of influences. Tool wear, thermal effects and vibrations can affect the surface quality of the machined object drastically. Some of those effects on the surface, like marks from vibrations, can be seen by machining experts directly on the object without measurement hardware or metrology systems. Those pieces of information held by the experts are valuable to the surface finishing staff, the metrology staff and data scientists, who could use them to improve both the product and the process. However, to enable this exchange of information, the relevant data needs to be indicated in a spatially resolved and machine-readable format. Additionally, the experts need to be able to mark the areas for all kinds of different requirements in a fast and suitable manner without possibly damaging the part itself. Our approach for this task is using a touch-based Augmented Reality system that allows the users to mark these areas of interest on the production part digitally without touching the production part itself. Therefore, we propose two different marking techniques - *Shift&Freeze Marking* and *Relative Marking* - based on literature from pointing tasks. We performed user trials to evaluate the usability, task load and overall performance of those techniques showing a general suitability for touch-based AR marking of relevant regions on productions parts.

Keywords: Augmented Reality; Data Augmentation; Data Preprocessing; Industry 4.0

1. Introduction

In modern production, milling at high speeds is a common and prominent technology for machining processes. During the high-speed milling, a variety of effects take place and result also in inaccuracies compared to the planned result and problems with the surface quality. Such surface quality issues can arise by the combination of flexible cutting tools, workpiece material and process parameters. A typical effect, that can also be seen by machining and process experts without additional metrology systems, are marks, introduced by vibrations of the workpiece during the machining process. Those vibrations and the resulting marks directly impact the workpiece quality requiring additional surface finishing steps or can even lead to a surface quality beyond repair. Further, those vibrations change the forces that are taking effect on the milling tools which then results in higher tool wear. [1]

At the same time, new analysis tools from the computer science and data science arise taking benefit from the process and sensor data to gain insight. In the last years, many more Machine Learning applications have been created and applied in the field of manufacturing. For most of those Machine Learning models, well-described data sets are required as the data quality directly impacts the model quality. In the milling process, the data set needs the information where on the workpiece surface quality issues like the marks from vibrations are located. Only with this information, data scientists can relate the (location-based) surface quality to the (time-series) sensor data from the machining process. By that, marking areas of interest (i.e., bad quality surface) of a workpiece is crucial for

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enabling useful and understandable Machine Learning models targeting the milling process in manufacturing. [2,3]

The usage of Augmented Reality (AR) for tasks and challenges in production became a major trend in research and industry in the last decade. Popular applications include training [14], remote support [15] and context-sensitive instructions. [16] Recently, also a research framework of Augmented Reality for metrology purposes was presented (named the Immersive Metrology). [17] The Immersive Metrology concept aims for validation of assemblies and provide step-by-step guidance for the workers. None of those related works deal with marking techniques for production parts including the export of the markings for later analysis.

In this paper, we present techniques to perform this marking task on a known workpiece with the help of Handheld Augmented Reality (HAR), focusing on the usability and accuracy of the interaction. Existing tools for marking in HAR, like Vuforia Chalk [13], lack the functionality of registering markings in the local coordinate system of a workpiece. We overcome this challenge in our proposed solution by aligning the workpiece using a set of fiducial markers.

In the next section, we will describe some existing techniques for selecting and pointing in HAR, that served as a basis for our marking techniques we describe in detail in Section 3. We briefly present the technical implementation in Section 4 before presenting the setup we used in our user study in Section 5. After the results of our study are presented in Section 6, we conclude our work in Section 7.

2. Selecting and Pointing in HAR

Marking is a task not a commonly researched in handheld augmented reality, so the base for this kind of interaction is built by the task of selecting and pointing. To overlay the virtual contents on the real environments for the users, the concept of HAR is similar to the concept of Magic Lens by Bier et al. [4], who describe the intuitive metaphor for a window to another world. Users see the real environment in front of their device on its display, as the device's camera records it. In addition, this real environment shown on the display is augmented with virtual elements. Adding interactivity is most intuitively accommodated by allowing users to use their fingers for touch control. They could simply touch the points of interest on the display, but in comparison with traditional mouse controls, the rate of selection errors rises significantly. One central reason for this is that the fingers being used for selection are obscuring the desired touch point, especially for precise selections and smaller regions. [5]

To tackle this problem in the interaction, different selection and pointing techniques were proposed by researchers. Boring et al. [6] added a *zoom* feature to enlarge small objects making the selection easier and decreasing the occlusion effect. Further, they proposed using a *freeze* feature, where the scene of the augmented reality is frozen to enable the user to interact without changes of the scene due to movements or shaking. While in their studies the *zoom* was best for selecting regions, the *freeze* feature performed best in manipulation tasks.

Another approach to avoid the occlusion problem is using a screen-centered crosshair pointer on the display. By this, moving the device allows users to point to regions without need to have their fingers near the target on screen. Still, studies found it unintuitive to move the body for a selection on a device and also this was uncomfortable to some of their participants. [7]

Another approach developed by Vogel et al. is the *shift* technique, where users try to select an object but due to the occlusion the selection is ambiguous. To counteract, their system shows the region below the finger shifted above it, allowing the user to move the finger towards the target object while seeing the area around the current selection. The authors also suggest adding a zoom to the shifted area, to further increase fidelity. [8]

Vincent et al. [9] developed additional techniques combining concepts. Their *Shift&Freeze Pointing* uses the *freeze* feature and adds the *shift* feature. When selecting, the *freeze* freezes the image, stabilizing the viewport, and the *shift* allows better selection on that view. Further, they proposed *Relative Pointing*, where the users have a crosshair on the screen, allowing movements by moving the device, while in addition the users can move the crosshair on the screen by moving the fingers anywhere on the screen and linking the movement of the finger to the crosshair.

3. The HAR Marking Design

As described in the previous section, there are numerous approaches for handling the selection and pointing tasks in the handheld augmented reality. As our use-case targets the marking of areas on a workpiece, the selection and pointing tasks have similar challenges, like the finger occlusion problem, but must be extended for marking tasks. Therefore, we use the concepts and results from the selection and marking developments as our base and propose two marking techniques for handheld augmented reality suitable for marking areas on a production workpiece and storing the area information accordingly.

3.1. Shift&Freeze for Marking

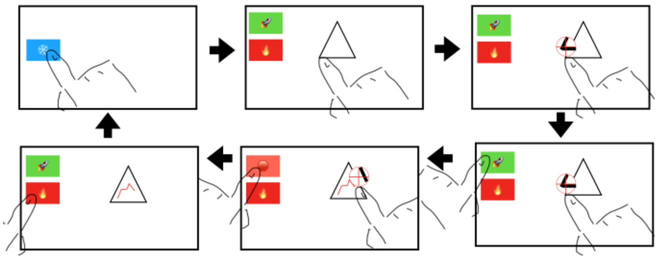

Figure 1 The *Shift&Freeze Marking* technique. Users can freeze the view; point using the *shift* method and start the marking mode. After that they unfreeze the view again.

The first proposal is the *Shift&Freeze Marking* technique and bases on the *Shift&Freeze* technique for selection and marking. The interaction concept is shown in Figure 1. The users start by freezing their current view (top left) and can go on to selecting the starting point for the marking procedure. For this, the shift method is provided enabling precise selection in this step (top center and top right). After this, the user starts the marking mode by touching the mode selection button on the top left. This can be done for example with the other hand as the button is arranged near the device edge (bottom right). While the marking mode is active, any movement of the crosshair results in extending a line drawing on the current view and can be finished by tapping the mode button again (bottom center). This drawing is shown to the user and stored in the app, to convert the location information later accordingly. Tapping the De-Freeze button, the view gets back to a live view of the scene allowing the user to start the next procedure.

3.2. Relative Marking

The second proposal is the *Relative Marking* technique, which is based on the *Relative Pointing* technique. A crosshair is present the whole time on the screen for the user. This is shown in detail in Figure 2. The crosshair is placed on the screen with a live view through the camera of the device, allowing the user to target the real object by moving the device. In addition, the crosshair can be moved by moving a finger anywhere on the screen (top row sketches). When the finger movement is used, the image is frozen to increase image stability. By tapping the mode selection button, a new line drawing starts at the exact crosshair position (bottom right). The crosshair can be moved by device movement or finger-based movement anywhere on the screen as before and extends the line drawing accordingly (bottom center). By tapping the mode switch again, the drawing of the line stops and the view returns to its original state (bottom left).

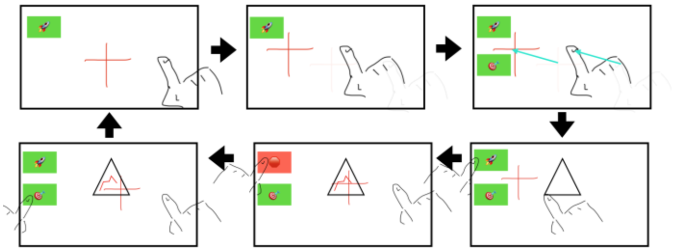
Figure 2 Using the Relative Marking, users can control a crosshair on the screen by device movement or their finger movement including a freeze feature for image stability.

Both of the proposed techniques are suitable to perform markings using a handheld augmented reality device. As the use-case is a workpiece from milling, the model of the workpiece is also integrated into the app. It is registered to the physical workpiece using fiducial markers. By this, the markings on the surface of the object can be located using ray casting inside the viewport of the app. This allows the markings to be rendered on the surface of the part and to export and show them on the 3D/CAD representation of the workpiece.

4. Implementation

Both techniques were developed for Apple iOS using the ARKit framework. To register the location of the physical part, we place it on a breadboard in precisely measured distances to fiducial markers that are detected using the ArUco framework. This allows us to render the workpiece's CAD model in the exact same location as the physical part is located. To not occlude the workpiece, only the outline of the CAD model is rendered to allow the user to confirm that the registration was successful.

When the user touches the screen, the touchpoint is converted into a ray, that is intersected with the CAD model to determine the precise location the user wants to mark in workpiece coordinates. This process is repeated every frame until the screen is released. Consecutive markings are connected by line segments and rendered using ARKit functionality. In addition, the points in workpiece coordinates are written to a file for further processing.

5. Study Setup

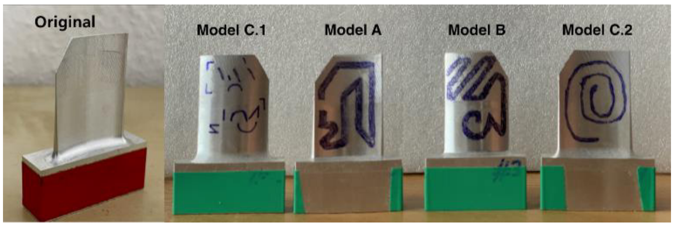

Figure 3 The machined workpiece blade part. The original (left) shows the curvy shape and vibration marks. The pieces on the right show the models for the studies providing a variety of shapes, thicknesses, and locations.

Having the two proposed techniques for marking areas on machined workpieces, a study was set up to examine the performance, usability, and acceptance of users for these. During the preparation and pre-studies, we faced slight disagreement on what areas of a workpiece with marks from vibrations should be marked. As this would impact the study by introducing additional variables and bias, we decided to create artificial areas on the work pieces to be marked by the participants. This results in the test objects shown in Figure 3 (right), where different models (A, B, C.1, C.2) are shown. The workpieces are made of aluminum, machined on a Alzmetall GS-1000 machine. The workpiece is a small blade part, with a height of 6cm and a smallest wall thickness below 0.3mm in a curvy and reflecting shape as can be seen in Figure 3 (left).

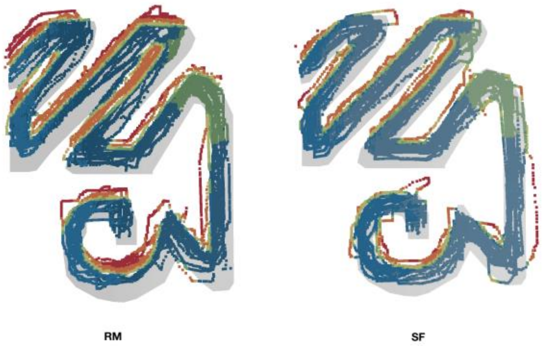

Figure 4 Markings from users on top of the reference traces for trial model B. Blue and Green areas are within the tolerance, while orange and red areas are outside the tolerance.

Using those models, and an implementation of the marking techniques for an iPad Air, the study aimed for different performance indicators which are collected in the app itself for technical parameters like the marking accuracy and time needed. For the non-technical indicators, we used questionnaires along with the System Usability Scale (SUS – standardized in ISO 9241_11 [10]) and the NASA Task Load Index (NASA TLX [11]).

The study was performed with more than twenty participants where all participants did not have prior knowledge to AR marking tasks. Also, all participants have been healthy right-handed persons. All participants had to mark the areas drawn in blue on the workpieces with the different techniques. We used pseudo-randomized trials (Latin Square) to deal with fatigue, learning and other effects during the study.

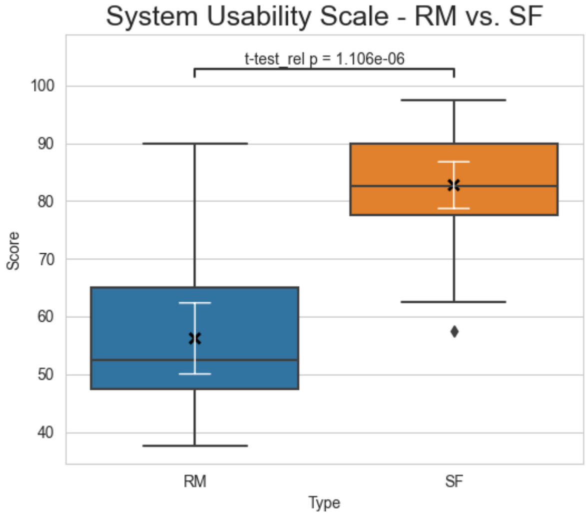

Figure 5 The System Usability Scale for Relative Marking (left) and Shift&Freeze Marking (right).

6. Study Results

The proposed techniques *Shift&Freeze Marking,* and *Relative Marking* are compared by the results of the study for the use-case of machined objects. By that we also focus the question, which of the presented marking techniques is suited best for a small workpiece marking task.

A central indicator for the performance in terms of accuracy of the marking is the distance of the markings of the users compared to the target trace. We use the success rate metric, which denotes the rate of markings being in a range of less than 0.375mm (tolerance) to the target trace. Throughout the trials, the success rate ranged from 50.9% to 100% for the Relative Marking (median: 53.6%), while the Shift&Freeze Marking achieved 53.6% to 100% (median: 91.4%). Testing those results using the Mann-Whitney U test, the results had a significant difference (p-value of 0.024). An example of the user markings displayed along the reference trace for the two techniques is shown for model B in Figure 4, where the blue and green areas denote markings being inside the tolerance.

Another indicator on the performance is the time needed by the users to fulfill the tasks. While the duration for the tasks for models A and B did not differ significantly between the techniques, a significant difference can be seen for the model C. While the task completion time for *Relative Marking* ranged from 2.49min to 9.64min (median: 4.81min), the time when using the *Shift&Freeze Marking* ranged from 1.83min to 7.77min (median: 3.68min). This is a significant difference in the task completion time with a p-value of 0.022.

Complementing the technical results for the performance, we also evaluated the usability indicators. The first indicator is the System Usability Scale, which is derived by a standardized questionnaire. The comparative results are shown in Figure 5. As the results show, the users scored the usability significantly higher (p-value 1.1e-06) for the *Shift&Freeze Marking* technique.

In the NASA TLX questionnaire results we also found significant difference in terms of raw frustration (p-value 0.0009) and raw performance (p-value 0.03) in favor for the *Shift&Freeze Marking*, which can also be seen in detail with the other subclasses in Figure 6. The NASA Task Load Index Overall Workload ranged from 7.7 to 89 for the *Relative Marking* (median: 64.3) and from 9.3 to 72.7 (median 39.2) for the *Shift&Freeze Marking* and by that resulting in a significant difference with a p-value of 0.02.

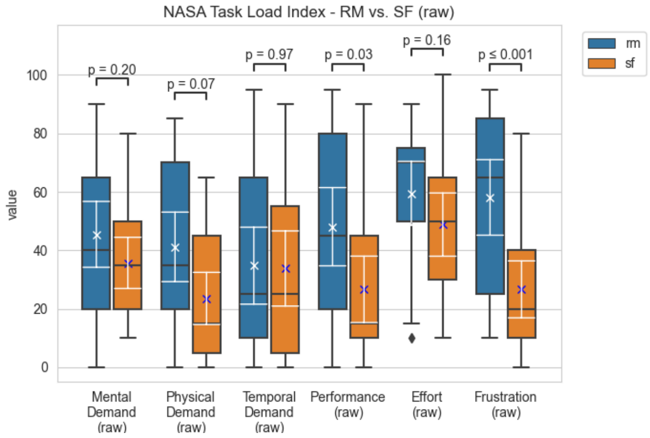

Figure 6 Results for the NASA Task Load Index for the different subclasses and the derived p-values.

7. Conclusion and Outlook

7.1. Conclusion

The results show several significant differences in the metrics and indicators from the user study. In general, all participants were able to fulfill the marking tasks with the *Relative Marking* and *Shift&Freeze Marking* techniques, showing the general effectiveness of those. For both cases, the accuracy ranges are wide from nearly 50% to 100% for tasks and user, while the majority performed significantly better with *Shift&Freeze Marking*, making this in general the better performing technique but still providing a high range of accuracy. Similar to this, the time needed for the tasks significantly favors the *Shift&Freeze Marking* method. By this, that method is shown to be better in terms of effectiveness and efficiency for this production workpiece marking use-case.

Usability tests like the System Usability Scale and the NASA TLX also show a favor for the *Shift&Freeze Marking* technique as the effective load and frustration is lower than for *Relative Marking*. SUS scores above 70 are considered “good”, scores above 80 “excellent”, which let us consider the *Shift&Freeze Marking* being a good to excellent technique for this task, while *Relative Marking* falls back behind that.

Taking all of this into account, we can conclude, that the two proposed techniques for the marking task of a small production part are effective, but the *Shift&Freeze Marking* should be used as it is outperforming *Relative Marking* in terms of efficiency, accuracy, and usability. The time needed for such markings is likely to be significantly lower with only some minutes in comparison to traditional metrology lab setups and measurement machines.

7.2. Outlook

In this paper, we have proposed two techniques for performing marking tasks in a production use-case to enable data augmentation in modern data-enabled production.

We used a specific use-case of a small production part including curvy and reflective surfaces. In terms of effectiveness other use-cases should be examined. Such use-cases could include other materials (e.g., non-reflective or transparent components) and sizes (e.g., large-scale production parts). Also, this setup relies on discrete production parts. A major challenge for a marking task is the transfer to a continuous process. This could result in sample-based marking or even an integration into the process itself to perform online-marking of relevant areas and link the data correctly to the moment of continuous production (e.g., continuous electrode coating process).

Towards the usability, a revisiting of the *Relative Marking* should be performed, searching for the reasons of the significant difference in the results and potential extensions to tackle those, if possible. As we focused on handheld augmented reality without additional tools, a comparison with techniques from other augmented reality systems or stylus-supported handhelds are of interest.

Finally, the marking data gathered using HAR methods should be assessed for its suitability in machine learning applications. Such applications could include the automatic detection of rattling marks using imaging systems or solely based on the machine data.

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