ARtifact: Tablet-Based Augmented Reality for Interactive Analysis of Cultural Artifacts

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***Abstract*—To ensure the preservation of cultural heritage, artifacts such as paintings must be analyzed to diagnose physical frailties that could result in permanent damage. Advancements in digital imaging techniques and computer-aided analysis have greatly aided in such diagnoses but can limit the ability to work directly with the artifact in the field. This paper presents the implementation and application of *ARtifact*, a tablet-based augmented reality system that enables on-site visual analysis of the artifact in question. Utilizing real-time tracking of the artifact under observation, a user interacting with the tablet can study various layers of data registered with the physical object in situ. Theses layers, representing data acquired through various imaging modalities such as infrared thermography and ultraviolet fluorescence, provide the user with an augmented view of the artifact to aid in on-site diagnosis and restoration. Intuitive interaction techniques further enable targeted analysis of artifact-related data. We present a case study utilizing our tablet system to analyze a 16th century Italian hall and highlight the benefits of our approach.**

***Keywords*-Augmented Reality; Cultural Heritage Diagnostics; Non-Invasive Analysis; Mobile Systems;**

I. Introduction

Cultural artifacts, whether they be sculptures, paintings, buildings, ruins, or otherwise, serve as priceless records of our history. Such artifacts must be carefully studied in order to diagnose any physical weaknesses or degradation and ensure their proper preservation. The field of cultural heritage diagnostics focuses on understanding the state of cultural artifacts through the use of various diagnostic technologies.

Cultural heritage diagnostics have benefited from recent advancements in digital imaging technologies and computer-aided analysis, enabling a noninvasive approach to artifact diagnosis. Several multispectral imaging techniques have proven useful for understanding artifacts such as paintings [1]. These diagnostic imaging techniques provide a wealth of information beyond what is visible with the naked eye. Unfortunately, current visualization methods limit the ability to correlate this information with the physical artifact, especially when working in the field. If the artifact cannot be moved from its location in the field, some form of information must be brought out to the field. A primitive solution might involve using paper printouts, but this can be awkward and inefficient if trying to work with multiple types of image data. More sophisticated solutions may utilize laptops or tablets loaded with the relevant data, providing better interactivity with the data. However, even these approaches present a disconnect between the data and the physical artifact, forcing a user to constantly shift their attention between the two.

For a new approach to interactive artifact analysis, we build off of recent advances in the functionality and performance of mobile devices such as tablets. Tablets equipped with multi-touch screens provide an intuitive means of interaction, and powerful dual-core processors and multi-megapixel cameras make a compelling platform for augmented reality (AR) applications. AR applications on tablets typically utilize a technique known as "video see-through" AR in which virtual objects are superimposed in real time onto a live video stream captured through the tablet's rear-facing camera. The virtual objects are registered with real world objects so that as the user operates and positions the tablet, the virtual objects appear to reside within the physical world. Video see-through AR presents an intuitive visual interface for associating additional information with real world artifacts. Combined with multi-touch interactions, such a system can serve as a powerful analytical tool.

This paper presents the implementation and application of *ARtifact*, a tablet-based AR system for on-site interactive analysis of cultural artifacts. Our tablet application tracks the artifact in question and superimposes various layers of diagnostic image data registered with the artifact, enabling a user to effectively "see what cannot be seen." This augmented see-through interface allows the user to explore artifacts *in situ* and always maintain focus directly on the artifact. By providing a direct mapping of data to the artifact, the user no longer needs to perform a side-by-side comparison between the artifact and another source of information, easing analysis and reducing cognitive load.

ARtifact leverages interaction metaphors broadly adopted for use with today's smartphone and tablet devices to explore artifacts and related media in new ways. The interactive multi-touch display of the tablet enables intuitive, targeted data analysis by allowing the user to "wipe through" to

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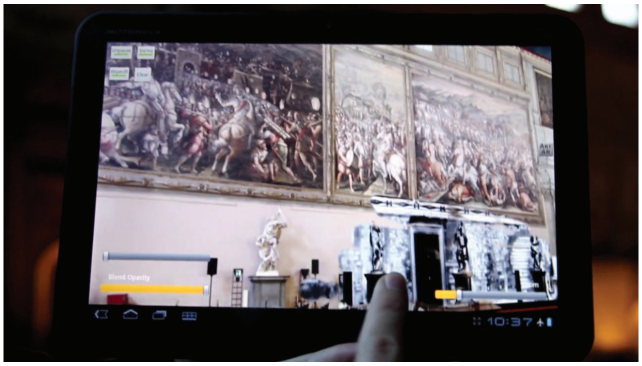


Figure 1: Wiping AR overlay to reveal thermal image data of the east wall of the Salone dei Cinquecento.

different data layers as seen in Figure 1. The interaction and analysis techniques made possible with ARtifact enable a holistic understanding of an artifact and allow exploration across both space and time as different spectra reveal multiple layers of an artifact's history.

ARtifact provides a powerful platform for on-site analysis but also lends itself to a range of other deployment possibilities involving digital representations of artifacts. Such digital artifacts can be found within various types of multimedia such as photos, videos, or even computer animations. The ability of ARtifact to work with these digital representations increases the versatility of the system and promotes additional analysis scenarios in a variety of environments.

We present our experience using ARtifact for on-site analysis within the *Salone dei Cinquecento* or "Hall of the 500" in Florence's Palazzo Vecchio. Specifically, we investigate the structural makeup of the east wall of the hall by visualizing previously captured infrared thermography data. Using this data we also analyze one of the frescoes on the east wall, Georgio Vasari's *Battle of Marciano*. We highlight the benefits of ARtifact when used for this on-site analysis.

II. Related Work

Augmented reality has seen a number of uses over the years including maintenance and repair [2], situational awareness [3], interactive story telling [4], and medical training and surgery among others [5]. Recently, the availability of increasingly powerful mobile devices has led to the development of hand-held AR solutions [6], [7]. The performance of AR systems continues to improve, providing a compelling approach for enhancing the way in which we interface with the physical world.

One of the fundamental concerns in AR applications is the correct alignment of the augmentation with the real world. One approach, used by the well known ARToolKit [8], involves tracking fiducial markers. Fiducial markers limit the general utility of AR as they require additional preparation around the artifact. Another approach, more suited to working directly with an artifact, involves natural feature tracking. Wagner et al. have presented a technique for real-time AR on mobile phones that involves tracking textured planar targets [7]. The tracking of reliably detectable features, extracted from an image of the target object, holds unique benefits if the algorithms are lighting and position invariant to at least some degree. ARtifact uses modified SIFT keys for feature tracking and artifact identification, which have proven reliable under a broad range of different conditions [9].

Various AR applications focusing on cultural heritage have emerged over the past decade, many of which provide some sort of museum or on-site tour guide [10], [11]. Other applications present digital recreations of artifacts at earlier points in history [6], [12]. While these applications can visualize interesting information associated with cultural artifacts and locations, they do not provide a compelling interface for assisting with the diagnosis of artifacts.

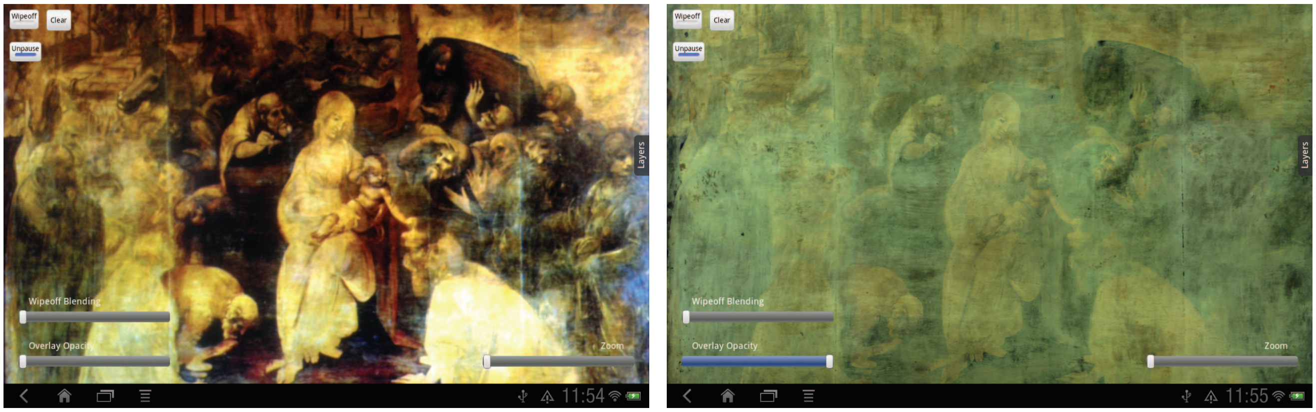
Outside the realm of augmented reality, other systems have emerged that specifically target cultural heritage diagnostics. For example, with *Wipe-Off*, Ponto et al. [13] build upon the power of multispectral imaging as a diagnostic tool [14]. Wipe-Off provides a multi-touch surface interface that enables intuitive and refined analysis of artifact data. However, the Wipe-Off system cannot feasibly be moved to field sites for direct assistance with preservation efforts. ARtifact addresses this issue by enabling users to perform similar interrogation methods with an artifact in situ.

III. Technical Approach

We targeted our development for Android-based tablets given the availability of a wide range of powerful devices and the accessibility of the operating system and development environment. Our system consists of an Android application and a simple file hierarchy stored on the tablet that contains high-resolution image files representing the various layers of data available for each artifact. Upon launching the application, the user is presented with a live camera view from the tablet's rear-facing camera and a minimal graphical user interface. When the user aims the camera at the desired artifact, the application recognizes the artifact and overlays one of the available layers of data. This overlay is positioned on the screen such that it precisely aligns with the current view of the artifact, as seen in Figure 2.

A. Data Preparation

Before using ARtifact in the field, some initial steps must be performed to prepare artifact-related data for use on the tablet. In order to perform natural feature tracking of an artifact, we use QUALCOMM's Vuforia library [9] to analyze a visible light photo of the artifact and extract a



(a) Overlay disabled, showing live view of the artifact.

(b) Overlay enabled, showing *ultraviolet fluorescence* layer.

Figure 2: The diagnostic AR overlay during an analysis of Leonardo da Vinci's mural, *Adoration of the Magi*.

feature description of the image using a modified version of the SIFT algorithm [15]. The feature description is stored within the tablet application and used during runtime to identify and track the artifact when it becomes visible within the live camera view.

Each layer of data available for an artifact is stored within the file hierarchy as a TIFF image file. To ensure the proper alignment of these layers when superimposed upon the artifact, preparation involves sizing and cropping each TIFF image so that it aligns with the photo used for generating the feature description.

B. System Overview

The ARtifact application consists of several components working together to process both camera and user input and render the desired augmentation (Figure 3).

1) Vuforia AR Library: The Vuforia AR library processes the live video stream from the tablet's rear-facing camera. To provide the "see-through" functionality of the interface, Vuforia renders the unmodified video stream as the background for subsequent augmentation rendering. Feature detection is then performed on the video stream using a modified SIFT algorithm and processed with the previously mentioned artifact feature description to provide artifact identification and tracking. Tracking results are passed along to the Graphics Renderer as a pose calculation. This pose calculation consists of a transformation matrix which specifies the camera's pose relative to the artifact.

2) UI Manager: The user interface (UI) of ARtifact consists of a set of standard Android UI elements which are managed by the UI Manager. Simple slider elements allow the user to adjust various parameters of the visualization, such as overlay opacity and camera zoom. The well-known multi-touch gestures of pinching and dragging can also be used to zoom the camera view and subsequently pan around the view. A pause button allows the user to freeze the current camera view and then modify other parameters of the visualization without having to hold the tablet in place.

On the right edge of the interface resides a "layers" handle which, upon dragging it out from the edge of the screen, reveals the list of data layers available for the artifact. The list contains a small preview of each layer along with its name; tapping a layer within the list signals to the Data Manager which image data it should load.

The multi-touch "wiping" mode is enabled through a UI toggle button. Once enabled, wiping the overlay with a finger causes the UI Manager to send touch events to the Graphics Renderer used for compositing the image data for the desired layers. To select the layer to reveal when wiping, a user must press and hold the desired layer within the layers list.

3) Data Manager: The Data Manager is responsible for managing the TIFF image files stored within the file hierarchy and loading the image data for the artifact layers. When a user selects a layer to view from the layers list, the Data Manager loads the corresponding image data as a texture and passes it along to the Graphics Renderer.

4) Graphics Renderer: The Graphics Renderer receives input from all of the other components in order to compose and render the desired augmentation. Given the pose calculation from the tracker, the Graphics Renderer aligns the AR overlay in place with the artifact and superimposes the image data provided by the Data Manager. The rendering may be translated or scaled based on the viewport transforms provided by the UI Manager. The UI Manager also provides the Graphics Renderer with various parameters that affect different aspects of the rendering such as the overlay opacity.

To achieve the wiping functionality, the Graphics Renderer processes the touch events from the UI Manager and composites the desired image data. Each of these touch events has a location in screen space corresponding to where the user touched the screen. The Graphics Renderer projects these screen space coordinates onto the AR overlay

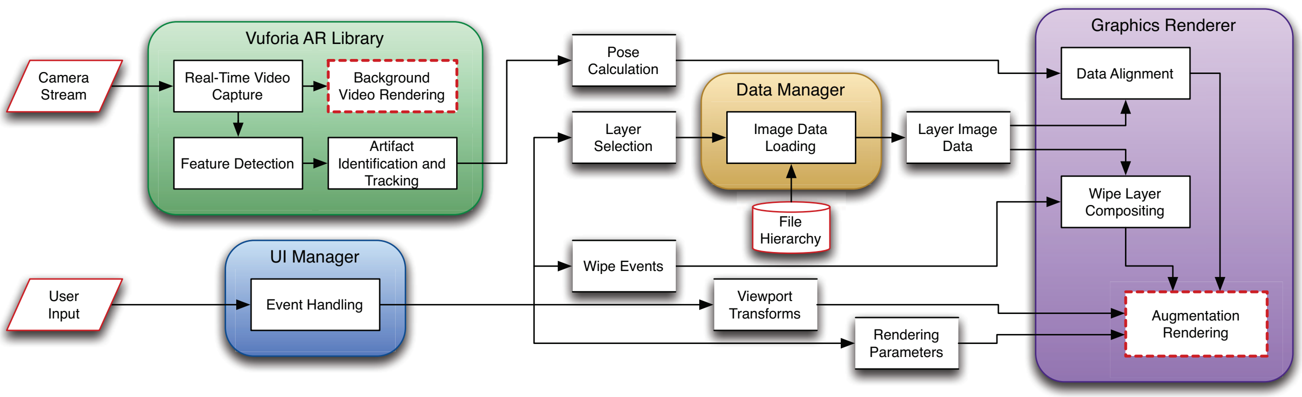


Figure 3: ARtifact system overview. Arrows represent data flow. Items with solid red outlines represent input sources. Items with dashed red outlines represent outputs.

by inverting the previously mentioned pose transformation matrix. The Renderer uses an OpenGL frame buffer object (FBO) to store the areas of the overlay that have been wiped. The FBO contains a rectangular texture that corresponds to the rectangular area of the overlay, and for each touch event, a circular blob is drawn onto this texture. We then use the FBO as a mask for blending the overlay layer data with the layer data to be revealed.

IV. Interaction and Analysis Techniques

ARtifact provides a versatile platform for artifact analysis through a variety of interaction techniques. The simplest of these techniques involves using the tablet as a filter through which to view an artifact. In a manner similar to the Magic Lens concept of Bier et al. [16], the tablet allows a user to alter their perception of the artifact by providing a viewport through which various filters can be applied. Here, the filters are the data layers available for the artifact, and viewing these allows a user to intuitively explore a wealth of data regarding an artifact.

By presenting data within a see-through viewport, a user need not shift their attention away from an artifact. Comparisons of the physical artifact with the related data can easily be accomplished by varying the opacity of the AR overlay using the UI slider. To get a closer look at the data, a user can simply pan and zoom with the standard multi-touch gestures.

Another powerful analysis technique involves the ability to wipe through to a certain layer in precisely defined locations (Figure 4). This technique enables refined investigation of an area without modifying the surrounding data, providing context for the wiped area. With the wiping mode enabled, wiping the overlay with a finger reveals the desired layer data at that location. Using the "wipeoff blending" UI slider, the untouched overlay data can fade out so that only the wiped area remains superimposed on the live camera view of the artifact.

Figure 4: The layers list on the right side of the screen shows the available layers. The "IR" layer is highlighted to indicate that it will be revealed when wiping. The wiped area reveals IR data superimposed upon the live view of the artifact.

While moving the tablet around an artifact provides an intuitive means of exploring data, it may also be desirable to focus on one specific area of the artifact. In this case, holding the tablet in place for extended periods of time can become tiresome and make it difficult to perform precise analysis. To ease this effort, enabling the pause toggle button will freeze the camera view while keeping the rest of the interface fully interactive. This feature can be especially useful when combined with the wiping technique by making it easier to inspect very precise areas.

A tablet-based approach also promotes collaborative analysis among multiple users. Rather than having users crowd around a single computer display, each user can operate their own tablet and have full control over what data to explore. Multiple collocated users can work together to simultaneously perform different analyses of the same artifact and easily compare different views or datasets.

Figure 5: Wiped area revealing hidden archway within the east wall of the Salone dei Cinquecento.

Figure 6: Viewing the *Battle of Marciano* fresco from afar. AR overlay highlights prominent crack regions.

V. Field Experience: Salone dei Cinquecento

Originally constructed in the late 15th century, the Salone dei Cinquecento stands as the largest hall within Palazzo Vecchio in Florence, Italy. During the middle of the 16th century, artist Georgio Vasari was commissioned to remodel and enlarge the hall. To get an idea of how the hall looked before the remodel, we brought ARtifact on site loaded with a thermal image of the east wall. Examining the thermal image reveals what appears to be an archway within the wall that has since been filled with bricks. Looking at the wall today with the naked eye shows no signs of any such archway. ARtifact provides an intuitive interface for understanding the relation of this archway to the present day hall. A user can go into the hall and wipe the AR overlay in the area where the archway resides, revealing just the archway superimposed upon the live view (Figure 5). Rather than sitting in front of a computer screen viewing this data, ARtifact enables the user to move around the physical artifact that this data represents, providing a truly immersive experience.

Upon the east and west walls of the Salone dei Cinquecento, Vasari and his helpers painted six large frescoes depicting various battle scenes honoring Florentine military victories. Examining these frescoes today reveals the poor condition they are in. To help find areas in need of restoration, we again utilized infrared thermography data with ARtifact. We specifically focused on one of the frescoes on the east wall depicting the *Battle of Marciano* (Figure 6). The thermal image contains many dark lines scattered throughout (Figure 7a), corresponding to cooler areas within the fresco. These cool areas result from air residing in cracks within the fresco, and it is these cracks that cause concern for the state of health of the fresco.

Using ARtifact, we could easily explore the thermography data of the fresco in situ to find damaged areas. Moving the tablet around the fresco let us intuitively inspect the data at any area. The wiping functionality proved extremely useful as it allowed us to highlight specific crack regions within the data and superimpose just these regions onto the live view of the fresco (Figure 7b). ARtifact provided a much more effective tool for aiding with analysis compared to the paper printouts that our collaborators were used to working with.

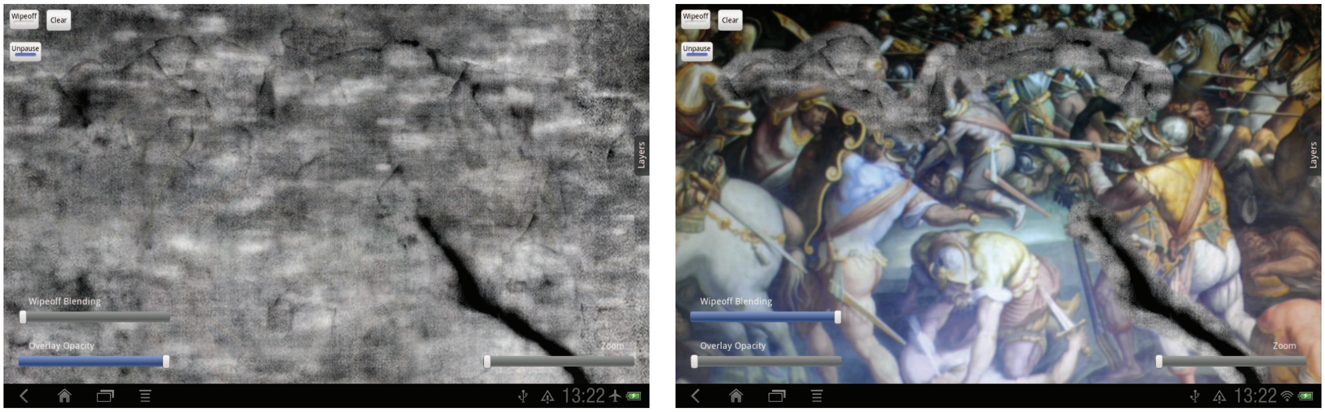
VI. Future Work

In its current state, ARtifact serves as a standalone visualization tool. We plan to develop the system so that it can more fully integrate with the workflow of our team for aiding with on-site cultural heritage diagnostics. Specifically, while studying an artifact, a user will have the ability to both view and input annotations (text, markers, drawings, etc.) correlated with specific areas of the artifact. These annotations will be stored in a shared team database so that users can reference them at any time.

Because of the AR library being used, ARtifact can currently only track planar targets. This limits our system so that it only works with two-dimensional artifacts or a single side of a three-dimensional artifact. We hope to extend the capabilities of ARtifact to support complete analysis of three-dimensional artifacts from any viewing angle.

VII. Conclusion

ARtifact provides a powerful platform for on-site interactive analysis of cultural artifacts. The augmented reality see-through interface allows users to maintain focus on an artifact while intuitively exploring related data, and the variety of possible interaction techniques provide the means for targeted analysis. With our system, cultural heritage diagnosticians can make decisions in the field rather than having to bring results from the lab. We experienced the intuitive analysis capabilities of ARtifact first-hand when studying the Salone dei Cinquecento in Florence. With further development, ARtifact can become an even greater asset within the diagnostic workflow.



(a) AR overlay showing thermal image with clearly visible cracks.

(b) Specific areas wiped to view cracks in relation to rest of fresco.

Figure 7: Analysis of cracks within the *Battle of Marciano* fresco.

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