Reference

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Virtual Recovery and Exhibition of Heritage

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Progress in computer technology has changed conventional archaeology and its exhibition. A project in which I am heavily involved fuses art and culture with computer technology in an effort to bring a world heritage—the Museum of the Terra Cotta Warriors and Horses in China—into cyberspace (see Figure 1). The statues unearthed in the excavation were created two thousand years ago in the Qin Dynasty. Three sites contain 8,000 terra cotta statues, most of them damaged in ancient times. Archaeologists have spent 20 years unearthing and recovering 3,000 of these statues. Using a laser range finder I developed makes it possible to precisely document unearthed objects as 3D models. For damaged pieces, my colleagues and I can use an advanced interface to recover the original shapes and colors in cyberspace, avoiding new damage to relics.

This virtual recovery framework lets us safely connect, move, and reconnect fragments many times in a virtual environment. The data examined in the virtual space can augment our imagined picture of the unearthed objects' original appearance and guide the physical restoration.

Figure 1. Virtual recovery of excavated relics makes multimedia exhibition of artifacts possible.
We could even leave the original fragments in their unearthed state for future generations to study. Moreover, we can put recovered relics into a virtual museum to show their now-lost original appearance based on archaeological facts—hard to achieve in a real situation, where relics must be carefully preserved in controlled environments, untouched. We can even simulate the past in a realistic scenario before we have completed digging out all the sites. A variety of data reduction approaches help us display the virtual scenes.

**Measuring 3D models of unearthed finds**

Our first step is to digitize the unearthed objects faithfully. I built a portable laser range finder to capture both the 3D shape and color of objects in the excavation site. A laser plane scans an object, and a camera flexibly mounted on the device moves with it. Image processing obtains the 3D position and color of each scanned point based on spatio-temporal analysis. We have made many different efforts to light the device because we move it from position to position while measuring.

One measurement takes two minutes and results in two images: a depth map (Figure 2) and a color map. The two display the range information and associated color of each point, respectively. Using these two maps, we generate 3D surfaces with colors mapped onto it (Figure 3). We need to retain a high resolution of the artifacts to maintain the value of the virtual models for reference and appreciation. So far we have measured 20 statues and unearthed objects in an excavation pit.

**Virtual recovery of excavated relics**

We want to virtually recover two things: damaged shape and missing color. Restoring real pieces is like solving a 3D jigsaw puzzle and requires tremendous work. Repainting pigments onto real relics is not considered. Further, archaeologists prefer to leave the original fragments in their unearthed state for future generations. If a virtual recovery succeeds, the recovery of real objects may even be omitted.

We recover broken pieces into a graphics space. By using our customized design interface, we can move graphics models of broken pieces within the space. We examine them and connect them into a complete model. Employing a 3D magnetic position sensor, we can move a relic fragment freely in the virtual space. On the other hand, because we have a large amount of data to handle, we put more computation power behind quick display of objects rather than on interaction.

We want to make the virtual recovery available on personal systems, either carried to excavation sites or joining the recovery from a remote site via the Internet. Mouse-based software lets us manipulate things manually in the virtual space. We show multiple windows to indicate differences in depth. Clicking an object triggers an auxiliary ball or box to control object rotation and translation. Moreover, we provide semiautomatic connection functions that transform pieces into a connected shape after selection of either one or three pairs of contact points.

Besides shape, we also recover the now-lost color painted on statues in ancient times. Pigments on statues fade when exposed to air. No approach so far can visualize the original colors of all the statues. Based on fragmentary pigment
samples, however, we can now reproduce the colors. Editing a measured color map manually and projecting it back onto the 3D model lets statues show their brilliance again.

In color recovery, we add color to surfaces that are mostly terra cotta color, but we keep the shading. The shading from the carved shape lets us easily line out regions of different materials, such as skin, loops, armor, and clothes. Based on the 10 to 20 colors archaeologists provided, we change the values of hue, saturation, contrast, and intensity in each region. The distribution of shading in the region remains.

Figure 4 shows color maps of two statues. Shape and color recovery are faithful to the archaeological facts.

**Virtual museum**

Crucial to virtual display is data compression. We use two types of compression to display models effectively: compressing models by reducing data at flat surfaces according to curvature and color there, and reducing resolution when objects are displayed in the distance. We prepare multiple models to realize visualization of the museum.

First, we compute surface curvature, surface discontinuity, and local contrast of surface color from the depth and color maps. The larger the value, the more detailed data should remain. Then, we have a program recursively divide large patches on a 3D model into subpatches so as to fit fine changes in shape and color. Starting with a large patch, our algorithm will not stop until either the patch is not divisable, or surface curvature and color in a patch satisfy predefined criteria. The color of a patch is the average from the area it covers. With such compression, we can reduce the data yet keep the visual features. For graphics rendering, we prepare models at several different levels of resolution. Depending on the observation distance, our system automatically selects a proper level of the model to display.

With the recovered models, we can now generate a virtual scene where the whole troop of terra cotta statues appears in front of an audience. Archaeologists have investigated the global scale of the site and figured out locations of the statues. They decided not to dig up all of them. In this situation, our work becomes very significant. Our troops can even show colored statues following color recovery, which archaeologists have long anticipated.

Figure 5 shows queues of warriors at the excavation site. Those in the back are truly virtual, as that part of the site hasn't been excavated. Visitors can walk through the troop and examine the relics from different angles in such a virtual museum. Beyond that, we plan to achieve a more virtual level of media exhibition. We will change materials on the bodies—editing costume color and reflection characteristics—to change statues to real warriors, arm the troop with excavated weapons, and even animate the troop in the near future—all in the virtual space.
Driven by the diffusion of multimedia technology and by the availability of effective electronic imaging tools, image-processing techniques have recently been applied to the analysis, preservation, and restoration of artworks. As tools for artwork restoration, image-processing techniques serve two purposes. They can be used as a guide to the actual restoration of the artwork (computer-guided restoration). Or, they can produce a digitally restored version of the work—which itself is valuable—although the restoration is only virtual and cannot be reproduced on the real piece of work (virtual restoration).

In this article, we present two applications of digital image processing for restoring artworks. The first belongs to the class of computer-guided restoration techniques, and the second represents an example of virtual artwork restoration.

The first example refers to cleaning dirty paintings. More specifically, we describe a technique that, by relying on cleaning a small patch of the painting, can foresee the final result when the same cleaning methodology is applied to the whole piece of work. Restorers can use it by applying a set of different cleaning methodologies to very small patches of the painting. They can then use the virtual cleaning software to determine which cleaning procedure is likely to give the best result, thus using digital image processing as a tool to guide the actual restoration of the artwork.

In our second example, we present a system for removing cracks from old paintings and frescos. In many cases, cracks severely deteriorate the aspect of paintings both because of their number and their heaviness. Thus, a system capable of removing them is of great interest, even if the removal is only virtual.

Cleaning dirty paintings

Let \( I(x, y) \) be the image representing the dirty painting and \( I_c \) an image representing the same painting after a small patch of the painting has been cleaned. We aim to find a transformation \( T \), such that in the cleaned area \( I' = T[I] \) is as close as possible to \( I_c \). According to the model we developed, \( T \) is a point operator that acts on each image pixel separately. In other words, we assume that the cleaning of a pixel does not depend on the neighboring pixels. Let, then, \( P = (P_r, P_g, P_b) \) represent the RGB coordinates of a generic pixel in \( I \), and \( R = (R_r, R_g, R_b) \) the coordinates of the corresponding point in \( I_c \). To model the cleaning of \( I \),