Visualization and Deformation Techniques for Entertainment and Training in Cultural Heritage

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***Abstract*—We think that state-of-the-art techniques in computer graphics and geometry processing can be leveraged in training and entertainment to make the topic of cultural heritage more accessible to a wider audience. In a cooperation with the "Antikensammlung" in Erlangen we produced five unique applications - all based around emperor Augustus - to visualize different scientific aspects for a big event targeted towards the general public. The applied methods include blending, geometric fitting, animation transfer and visualization techniques. Besides being entertaining, some of the presented applications are the foundation for more substantial research. (Please visit http://youtu.be/MJyC3RChQBA for our results video).**

I. Introduction

The conservation and analysis of cultural heritage is an important topic as the collected knowledge of our past shapes our understanding of history. Therefore, it is our responsibility to gain new insights and to preserve the gathered knowledge for future generations. For non-scientists this is best achieved by means of entertainment.

In our modern society, digital technology is ubiquitous, as it is applied to almost all aspects of our life. Using computer graphics in the Humanities and especially in the context of cultural heritage allows us to make the gathered information more accessible to the general public. In this paper, we describe five applications surrounding emperor Augustus that visualize different research and fun topics for a broad audience. The presented techniques are used to breath new life into the digitized versions of the emperor (see Figure 1) and create emerging and convincing illustrations that inspire the viewer and immerse him into an ancient time.

In the following sections we present the used methods back-to-back. For each of them, we start with a motivation, present the developed application as well as the technical challenges:

- Section II discusses how to augment real artefacts with virtual materials and illumination.
- Section III visualizes differences between busts using blending techniques.
- Section IV extracts the characteristics of the emperor Augusts and applies them to real people.
- Section V restores the facial geometry of statues.
- Section VI breathes live into a bust of Augustus and makes him speak again.

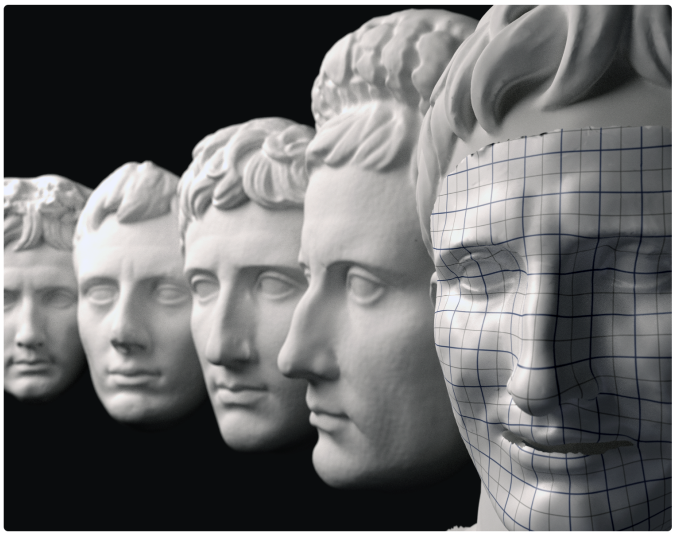

Fig. 1: 3D-Scans of emperor Augustus and a parametrized facial mask used in most of our applications.

We conclude in Section VII with a brief summary and try to give an outlook towards future developments in the field of entertainment and training in cultural heritage.

II. Virtual Painting

Most museums have a wide range of plaster casts which they present to the public. Those casts are not made from the same material as the originals and - in most cases - lack the proper texture. What the curators really would like to show the audience is a complete and authentic representation of the original - nicely painted and under the same illumination the statue was originally showcased.

We use modern computer graphic techniques for a presentation that allows us to virtually paint and illuminate white plaster casts by projecting a previously digitized and digitally textured version of the statue onto its surface (see Figure 2 or 3). This makes the experience in museums more engaging and can be used to provoke different moods. It is also a way to allow students to "play" with the look of the real world statues without damaging the originals.

In this application, we use a cast of an Augustus of Prima Porta statue and a corresponding high quality 3D-Scan. We want to visualize how the statue was originally painted (see Figure 3) and how it might have looked like with different paints and materials as well as under different illumination

Fig. 2: Photographs of a real world Augustus bust with different simulated materials: The leftmost image shows the statue without additional lighting from the projector. In the second image we simulated a spot-light illumination from directly above the emperors head. The last three images show different virtual materials (ceramic, silver and gold) that we applied.

conditions. However, in the scope of this paper we mostly show some experimental results of a smaller Augustus bust.

In our basic setup, we use an off-the-shelf projector to project a 3D-rendering onto the surface of the statue (see Figure 4 on the left). This allows us to augment the bust with virtual materials and illumination. Some examples of the implemented illumination conditions and materials can be found in Figure 2. The left most image is a photograph of the bust we used without any additional lighting applied (except a flash light). The second image shows a simulated lighting condition with a spot-light directly above the emperors head. In the last three images we applied different materials (ceramic, silver and gold) to the real world bust with realistic effects.

Fig. 3: Rendering of the digitally painted Augustus of Prima Porta (left). Photographs of the statue projected with three different materials (middle). Comparison of two Photographs showing the statue with a white and the painted texture (right).

The 3D-Scan of the full body statue was manually textured and painted by an expert in the field confirming to the current academic opinion as seen on the left statue in Figure 3. As a second visualization we choose a plain bronze material as well as an animation sequence highlighting different aspects of the painted statue. For researchers this may be used as an interactive alternative to typical handmade paintings merging real world tactile feedback with augmented information. The interaction with a real world object allows students to easily work in the digital realm without having to handle unintuitive 3D-Software. Following the ideas introduced in [1] we can show the effect different illuminations have on our perception of a statue. We achieve this by using environment maps to simulate the ambient light as well as artificial light sources.

A. *Technical Challenges*

In order to correctly simulate different materials and the virtual paint of statues we first need to obtain a 3D-Scan of the object we want to alter. To digitize our test bust we used a structured light scanner. The full statue was digitized by the Breuckmann GmbH. We use Blender to process the models and generate the images we project onto the real statue.

The virtual painting is performed using texture painting, which is a well known technique that is researched in great detail for example in [2]. However, simply projecting the rendering of the painted statue onto the white plaster cast produces visual errors that can be quite noticeable under different lighting situations.

The image displayed by the projector is subject to diffuse shading on the bust since the projector acts as the primary light source in our real world setup. The additional shading is especially noticeable when the virtual light source is not positioned in the focal point of the virtual camera which corresponds to the projector beam in the real world. The left image on the right in Figure 4 shows the statue lit by a white image from the projector. This approximately generates classic diffuse shading where surfaces with normals facing towards the projector are brightly illuminated while ones with a normal orthogonal to the projected light rays are not illuminated at all.

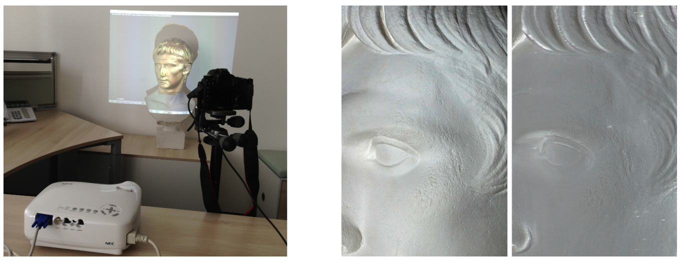

Fig. 4: Our low-cost hardware setup (left) and a comparison of the projection of a white image (right, left) and an image that compensates the real world shading (right, right)

The observed intensity I_{out} of an object lit by our projector is proportional to the dot product between the light direction $\vec{l}$ and the surface normal $\vec{n}$.

To compensate we add inverse diffuse shading to every projected pixel. This basically eliminates the lambertian reflectance. Together with the real world shading produced by the projector, most of the shading is canceled out. The result of our anti shading is displayed on the right side of Figure 4.

In order for the projection to work properly, we need to align it to the geometry we want to artificially illuminate. This alignment problem is well known from computer vision as described in [3] or [4]. If you compare the forehead, cheeks and eyes in the two images from Figure 4 (right) you should immediately notice the lack of shading. However you will also notice glowing artefacts around the nose and the hairline. Those are due to inaccuracies of our scan resulting in a mismatch of the calculated and real world geometry. In order to compensate for those artefacts a non-rigid calibration step might be required. Since we disposed of the real world shading,

Fig. 5: 3D-Rendering of our scans with regular and anti-shading (left) . A 3D-Rendering with custom material and projection to the real world bust (right).

we can now easily add virtual shading of any kind. Figure 5 (left) shows the anti-shading pass compared to a diffuse shaded bust. The middle statue is a rendering of our ceramic shader with the light source positioned on the bottom left of the image. Notice, that the image looks quite dark as our anti-shading is already applied. The image on the right is a photograph of the rendering projected onto the real world bust of emperor Augustus. The shading appears more like real ceramic on the real world statue as the hard bright contrast from the rendering is partially canceled out by the real world shading, resulting in a projection that is darker. Since our eyes adapt to changes in overall brightness this effect is barley noticeable compared to the advantages of removed real-world shading.

At the moment we are just using one projector, this results in a limited range of valid perspectives for the viewers, which is acceptable for our current application. Integrating more projectors to the systems is easily done, as we only need to adapt our anti-shading algorithm to consider different light sources with a known field of impact. R. Raskar discussed aligning and compensating multiple projectors in great depth in [5].

Another advantage of our statues is the fact, that they are diffuse white casts. Using other statues we may have to compensate for real world texture as well. A process for this is described in [6].

III. Visualizing Differences in Busts

Archaeologists often classify the characteristic developments between different archetypes of ancient rulers and interpret the found differences in facial geometry. This allows them to form an understanding of ancient times and infer changes in politics and society. To make the facial distinctions more apparent for archeologists and a wider audience, computer graphic techniques can be used to seamlessly blend between the busts of different periods.

Figure 6 shows two still frames of a blending sequence for emperor Augustus. In this example, the face of the bust on the left side seamlessly morphs between the faces of the busts in the wheel on the right. The statues on the wheel are ordered by age making this animation sequence a brief walk through the emperors life. The full animation can be found in the accompanying video.

We think that this form of presentation of facial differences is more immersive compared to showing multiple busts side by side, as noticing differences by comparing two still representations of the statues is more difficult to the human eye than spotting movements (which are in turn generated by the morphing between changing parts in the different versions).

A. Technical Challenges

We created high-quality 3D-Scans of 7 busts of the emperor Augustus from the “Antikensammlung” in Erlangen , one example can be seen in Figure 7. These scans are our foundation for the following steps. Blending between the geometry of multiple faces is a well known and studied problem in computer graphics and similar effects are frequently used in the movie industry for quite some time.

The main two ingredients for this morphing effect are a dense set of point-to-point correspondences between the 3D-Scans and a suitable interpolation technique. If inter-face correspondences are known, blending is an easy task and can be performed by interpolation techniques. Linearly blending the vertex positions is simple, but in general has problems with

Fig. 7: Digitized Statue: We reconstruct the 3D-Geometry of the statue on the left side using structured light scanning.

Fig. 6: Visualizing facial differences: The face on the left seamlessly morphs between the faces in the wheel on the right.

rotational components in the deformation. To compensate these artefacts, an interpolation based on the matrix exponential [7] can be leveraged. In our application, we can still use simple linear blending, as the difference between two faces is almost linear. Using the animation transplantation technique we retarget the morphed faces to a complete bust (see Section VI for details).

The difficult part of the blending problem is to establish the dense inter-scan correspondences. We use the two-level non-rigid registration approach [8] of Süßmuth et al. that is based on energy minimization to obtain the required correspondences. This algorithm is a non-rigid variant of the Iterative Closest Point (ICP) algorithm described in [9], [10].

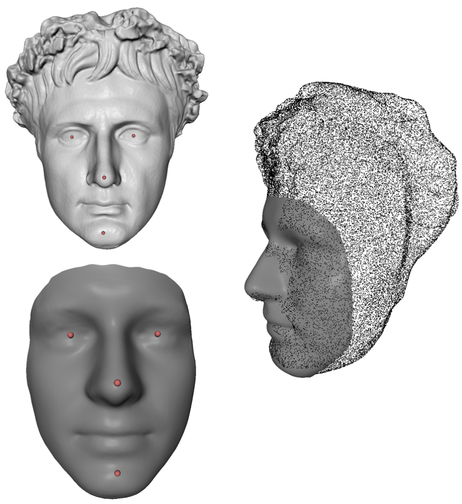

Fig. 8: Rigid Registration: The template mask on the bottom left is rigidly aligned to the 3D-Scan on the top left using a sparse set of manually placed markers (red).

We start by aligning a common template mask with the input 3D-Scans using a manually selected sparse set of markers by solving the Procrustes problem [11]. Figure 8 shows a 3D-Scan (top left) and the template mask (bottom left) both with the used set of markers in red. The image on the right shows the rigid registration of both the template mask and the scan. To exactly fit the mask to the input, we now compute a non-rigid warp between the template and the 3D-Scan. We use a reduced deformable model based on the deformation graph [12] to compute an approximate registration. This step is stable and can deal with huge geometrical differences between the template and the 3D-Scan, because it only optimizes a small number of degrees of freedom. The algorithm tries to minimize the distance to the target, which is measured using a continuous distance field based on hierarchically fitted radial basis functions [13], while trying to preserve local rigidity.

After this coarse registration step, the template is sufficiently close to the 3D-Scan and a fine scale optimization on vertex level can be performed. This optimization is based on the ARAP-deformation paradigm [14] and uses a point-to-point distance measure to exactly fit the template mask to the input data. A comparison between the rigid registration and the non-rigid warp can be seen in Figure 9.

IV. AUGUSTIFICATION

Archeologists know that the features of the facial shape of busts are influenced by the classical concept of beauty and god-like appearance as well as by the features of the real person and (to some degree) the family and ancestry. The goal of this section is to allow us to transfer the facial geometry of a real person onto the bust of the emperor Augustus. We not only replace the facial geometry of Augustus, but try to preserve the characteristic features of the statue. Figure 11 shows the results of our "Augustification" process. On the left, a 3D-Scan of a real person can be seen. We apply the properties

Fig. 9: Non Rigid Registration: The template mask (left) is non-rigidly warped such that it exactly matches the scan (right)

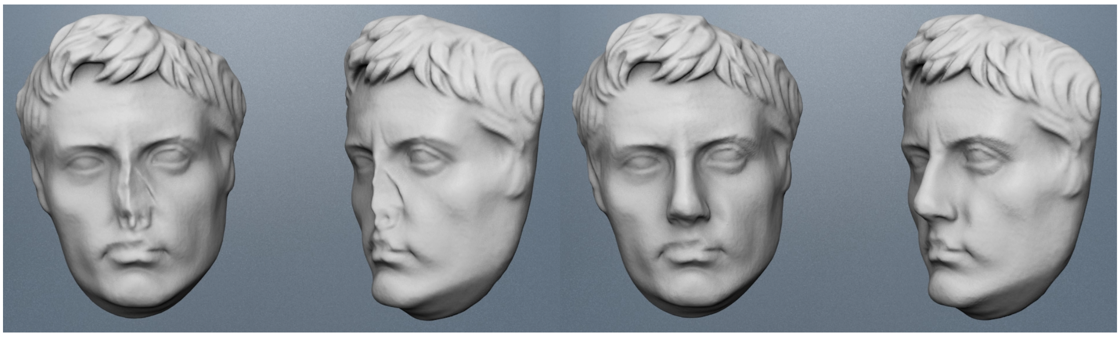

Fig. 10: Virtual Restoration: The damaged artefact has a broken nose (left), we use a fitting algorithm to repair the bust (right).

that differentiate the look of a statue from an average human face to the transferred person. The result is then transferred back onto the statue without any modifications except for some deformations around the border to generate a smooth transition between the new face and the rest of the bust.

The middle of Figure 11 shows the original statue. On the right is our "Augustification" result. One can still recognize the original face as well as some features of the statue like the pronounced eyes and an exaggerated chin and nose.

A. Technical Challenges

In order to compute the part of the facial shape that corresponds to the characteristic appearance of a bust of emperor Augustus, we require models for the intrinsic shape of the statue and the facial shape of real people. To build these models, we need dense correspondences between a huge number of 3D-Scans from real world humans. Those are computed using the algorithm described in Section III. Thereafter, we compute the mean face of the statues and the mean face of real people. We use 60 scans of humans to build the average face and 4 scans of busts of Augustus. We only use undamaged busts for this application. We apply the difference between the averages to a scan of a real person. Using the animation transplantation technique we retarget the face to the complete bust (see Section VI for details).

V. Virtual Restoration of Artefacts

Artefacts found at archeological excavations often are not well-preserved, as they have been damaged over time by atmospheric or other forces. A manual restoration of an artefact is not only a time consuming and expensive process, but might introduce new damages and most importantly destroys the original which has to be preserved for future generations. The created reconstruction also includes the subjective perception and artistic taste of the person creating the restoration. In contrast, a virtual restoration leaves the original intact, costs less and allows us to use objective and mathematical strategies to infer the look of the reconstructed object. In this application, we semi-automatically restore defective faces of busts of the emperor using only a minimal amount of user input and a database of undamaged busts to guide our prediction. Figure 10 shows the 3D-Scan of a damaged Augustus bust that we have repaired with our method. No artistic or otherwise subjective decisions had to be made to generate this reconstruction. In addition, we can seamlessly visualize the difference between the damaged and repaired bust.

Fig. 11: Augustification: Transferring a scanned face of a real person onto the statue.

A. Technical Challenges

To allow for a virtual restoration of a face, a database of the same person has to be created. Therefore, we have to once more acquire inter-scan correspondences as described in Section III. After that a statistical model of the faces is constructed [15]. This model can then be fitted to the damaged bust. The fitting is computed by minimizing an energy function. For the purpose of reconstructing certain parts of a statue, we exclude the damaged regions from the fitting energy using a manually painted binary mask that selects the undamaged regions. By solving a linear system of equations the best fit is computed. Once we found the best fitting representation of the non-defective parts, we seamlessly blend the computed replacement into the original defective geometry by using a smooth weight mask that has been constructed by applying heat diffusion to the painted stencil mask.

VI. Animation Retargeting

In all the busts of the famous emperor Augusts the facial expression always is neutral. Therefore, today nobody really has an idea about his spectrum of facial expressions. What was his facial expression while shouting at his host to get ready to march into battle? How did he look like when he was angry, amused or smiling?

In this section, we retarget several common expressions which have been captured by a real-time 3D-Scanner onto his face. This allows us to breath new life into the static ancient artefacts and make them speak again. Figure 12 shows

Fig. 12: Animated bust of the emperor Augusts: Neutral facial expression, letting the emperor shout, look angry, laugh and smile.

examples of an animated bust of Augustus. We let the emperor shout, look angry, laugh and smile. The whole animation sequence can be found in the accompanying video and was created to heighten interest in archeological content on an entertaining level.

A. Technical Challenges

In order to retarget animations captured by a real-time 3D-Scanner to a static target geometry, a consistent animation has to be extracted from the captured sequence of pointclouds as described in [16]. Thereafter, a dense set of correspondences between the animation and the target geometry has to be established. We compute those correspondences using the non-rigid registration algorithm we used in Section III. This allows us to deform the template mask such that it looks like the emperor and retarget the animation to this mask. Finally, the retargeted animation can be transplanted onto the original target geometry. This pipeline has been proposed by Süßmuth et al. [8]. The technical details can be found in the corresponding paper.

VII. Conclusion

We presented several applications of modern computer graphics techniques to make the presentation of cultural heritage in entertainment and training more accessible to a broader audience. This includes techniques for blending, animation, fitting and rendering. The accompanying videos have been used in a public presentation.

In our opinion, a increased awareness for our cultural heritage can only be created by making the presentation of our history more engaging. Thus in the future, we plan to apply other computer graphics and geometry processing techniques to the archeological context, to create more educational and entertaining material.

Acknowledgment

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References

[1] R. Raskar, G. Welch, K.-L. Low, and D. Bandyopadhyay, “Shader lamps: Animating real objects with image-based illumination,” in *Proceedings of the 12th Eurographics Workshop on Rendering Techniques*. London, UK, 2001, pp. 89–102.

[2] P. Hanrahan and P. Haeberli, “Direct wysiwyg painting and texturing on 3d shapes,” *SIGGRAPH Comput. Graph.*, vol. 24, no. 4, pp. 215–223, Sep. 1990.

[3] O. Faugeras, *Three-dimensional computer vision*. MIT press, 1993.

[4] O. Bimber, D. Iwai, G. Wetzstein, and A. Grundhöfer, “The visual computing of projector-camera systems,” in *Computer Graphics Forum*, vol. 27, no. 8. Wiley Online Library, 2008, pp. 2219–2245.

[5] R. Raskar, “Projector-based three dimensional graphics,” Ph.D. dissertation, Citeseer, 2002.

[6] S. Zollmann, T. Langlotz, and O. Bimber, “Passive-active geometric calibration for view-dependent projections onto arbitrary surfaces,” *JVRB - Journal of Virtual Reality and Broadcasting*, vol. 4(2007), no. 6, 2007.

[7] M. Alexa, “Linear combination of transformations,” *ACM Trans. Graph.*, vol. 21, no. 3, pp. 380–387, Jul. 2002.

[8] J. Süßmuth, M. Zollhöfer, and G. Greiner, “Animation transplantation,” *Journal of Visualization and Computer Animation*, vol. 21, no. 3-4, pp. 173–182, 2010.

[9] Y. Chen and G. Medioni, “Object modelling by registration of multiple range images,” *Image Vision Comput.*, vol. 10, no. 3, pp. 145–155, Apr. 1992.

[10] P. Besl and N. McKay, “A method for registration of 3-d shapes,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, no. 2, pp. 239–256, 1992.

[11] P. Schönemann, “A generalized solution of the orthogonal procrustes problem,” *Psychometrika*, vol. 31, no. 1, pp. 1–10, Mar. 1966. [Online]. Available: http://dx.doi.org/10.1007/bf02289451

[12] R. W. Sumner, J. Schmid, and M. Pauly, “Embedded deformation for shape manipulation,” in *ACM SIGGRAPH 2007 papers*, ser. SIGGRAPH ’07. New York, NY, USA: ACM, 2007.

[13] J. Süßmuth, Q. Meyer, and G. Greiner, “Surface reconstruction based on hierarchical floating radial basis functions,” *Computer Graphics Forum*, vol. 29, no. 6, pp. 1854–1864, 2010.

[14] O. Sorkine and M. Alexa, “As-rigid-as-possible surface modeling,” in *Proceedings of the fifth Eurographics symposium on Geometry processing*, ser. SGP ’07. Aire-la-Ville, Switzerland, Switzerland: Eurographics Association, 2007, pp. 109–116.

[15] V. Blanz and T. Vetter, “A morphable model for the synthesis of 3d faces,” in *SIGGRAPH*, 1999, pp. 187–194.

[16] J. Süßmuth, M. Winter, and G. Greiner, “Reconstructing animated meshes from time-varying point clouds,” *Computer Graphics Forum (Proceedings of SGP 2008)*, vol. 27, no. 5, pp. 1469–1476, 2008.

[17] A. B. Moreno and A. Sánchez, “GavabDB: A 3D Face Database,” Vigo, pp. 77–85, March 2004.