The Prototype Light Projection System for Cultural Heritage Reconstruction

Bartłomiej Specjalny*

Institute of Computer Graphics and Multimedia Systems
West Pomeranian University of Technology
Szczecin / Poland

Abstract

In this paper we present prototype of cultural heritage virtual reconstruction method by extracting three color pattern projected on object's surface. With rising accessibility to projecting devices and digital cameras new possibilities have risen. This paper focuses on automatizing active range scanner techniques with assumption to move pattern and not any of the scene elements including both object and devices. The goal was to acquire detailed point cloud for further reconstruction by determining shape of pattern lines. Results show that with the use of difference images, low-pass signal filters and line thinning methods a detailed high poly model can be obtained even without refining point cloud.

Keywords: virtual reconstruction of cultural heritage, 3D model acquisition, pattern projection, depth from photographs

1 Introduction

In the last years virtual reconstruction has been an essential problem in many practical applications. One of the applications is preserving and reconstructing cultural heritage in order to visualize catalogue or reconstruct actual historic objects of great value. The Wkryujście Altar presented in Figure 1, is one of the greatest cultural heritages both of the Polish and German nations in Western Pomeranian region. It is currently held in Szczecin National Museum, in Poland. Our goal is to create a technology to make a 3D geometrical reconstruction of the Altar. However, to protect the Altar against any damage all the test work were held on the test sculpture of the similar structure (see Figure 5) but relativly smaller.

The reconstruction is done by analyzing series of images. Each of images contains record of displayed light pattern. Each pattern consists of three lines with different colors. Colors used for the projection are main colors of the RGB color space both projected and recorded by camera. New Boolean images with extracted lines are created from three corresponding channels. Lines are filtered, posterized and thinned. The third dimension is extracted by lineform analysis. All gathered information are then extracted as the point cloud for further reconstruction.

In section 2 we provide information about the target object which is a piece of cultural heritage. Moreover, typical virtual reconstruction methods and previous work taken are described. Section 3 contains visualization concept and detailed information about implemented method. Section 4 documents results of the prototype reconstruction and presents encountered artifacts. Section 5 concludes the whole work and results. In this section we summarize final effect and propose future work.

In this paper we present prototype method for low cost virtual reconstruction. We adopt range scanning techniques to obtain high polygon surface of real object. We analyze set of images taken from one setup. We extract lines, and based on their shape we recreate point cloud.

2 Virtual reconstruction of cultural heritage

Target object - the Wkryujście Altar - is of the great cultural value despite the fact it was partially demolished. Because of its actual state it can not be rotated, moved or lifted. We would like to present its unique history and value.

2.1 The Wkryujscie Altar

The Wkryujście Altart is held in National Museum. It was founded about 1500 AC by prince Bogusław X for church in Wkryujście. Originally it consisted of eleven oak, polychrome reliefs and two figures of st. Paul and st. Peter. However, as the time passed the parts of Altar were damaged or lost (st. Paul figure is missing since 1900). It was during the Second World War when some of the reliefs were taken to Germany and four of them were confiscated by the Soviet Army. They were held in Kiel, Greifswald, Moscow and Riga. Most of the Altar parts were recovered by 2001 [2].

The Altar parts are currently in different conditions, due to the lack of conservation. This caused degradation of the wooden structure such as fractures and cracks, which gave

*bartlomiej.specjalny@gmail.com

Figure 1: The photograph of a sample plate of the Wkryujście Altar titled: Jesus Christ coronation with thorn.

the surface a specific structure. Mostly all of the paint fell of, and only small fragments were preserved. Also some of Altar parts were devastated by human hands: noses, hands and weapons fragments. The overall spatial shape of the subject is problematic because of complex surrounding fragments which are more likely sculptures attached to relief.

The object is unique and priceless testimony of medieval masters of wood-carving. That is why the National Museum wants to bring it back to public when most all of its parts are back. Even in its current shape it is worth seeing for medieval art connoisseurs. However, for ordinary man it looks like a regular wooden sculpture.

Due to the lack of information about the original shape of the Altar, the decision was made by the head restorer, to not change anything on the original Altar. This decision was made according to Venice Charter [1] and adequate Polish law. Instead, virtual reconstruction was held. Computer modelsnot only give museum or artists the ability to reconstruct paintings, but also missing parts of Altar without interfering with the original sculpture. Any attempts to recreate fragments of relief on the actual object would be considered devastating. This corresponds to ”primum non nocere” (in English ”First, do no harm”) maxim that all works on the object have to preserve original substance as well as the object's material and immaterial value. This means that only the minimum interference in the object is allowed. It makes from conservation, restoration and renovation a multidisciplinary subject, since it allows to preserve objects of great historical and cultural value.

2.2 Reconstruction techniques

In our work we focus on the automated and accurate geometric reconstruction of the museum's objects like sculptures and monuments. We take into consideration that our target object will be Wkryujście Altar.

There are a few projects like The Digital Michelangelo Project [4] or Scanning Monticello Project [6] which focus on the single laser projection and triangulation method. This method gives very good results but due to size of installation and costs it could not be used for Wkryujście Altar. Furthermore, fast laser scanning methods with hand devices could be difficult to perform because of large scanned surface, despite its great accuracy.

There are the real time model acquisitioning methods permitting to rotate object kept in hand and continuously updating its geometry, also filling missing holes in the fly [9]. Our object however can not be moved because of its poor condition.

The first attempt of the reconstruction of the Altar involved using stereophotogrammetric method in which geometric properties of objects are determined from images [5]. Only low detailed model was obtained. It was caused by the fact that model was reconstructed from a whole piece of the Altar and most of details were lost. But other multiple view geometry methods [8] with the detailed images of the Altar could give good results.

However, we want to focus on the high detailed reconstruction that can be done without any special equipment with single scene setup. That is why we based on conventional range scanning methods [3]. Taking into consideration the features of the Altar (poor condition and limited possibilities of moving the sculptures) and low budget of the project we propose method that uses ordinary and commonly available projector and camera. We wanted also to focus more on the actual data that can be extracted from images than the information that could be established on the knowledge of the position of the camera or projector.

3 Model acquisition technique

The measurement setup consists of the projector 3M^{TM} MP76401, Canon^{TM} EOS 10D digital camera with Canon^{TM} 17-40 mm f/40 L USM lens and the laptop with MATLAB^{TM} software (Figure 2). The projector is placed in front of the object. The camera is set on the same horizontal plane as the projector and their view directions form 45° angle. This way, the calculated depth is twice longer than a pixel horizontal shift from its base position (we assumed that the distance from the camera to the object is much longer than the depths). Both the projector and the camera are connected to the laptop to display line pattern and automatically take pictures of the object. To generate line pattern we use MATLAB^{TM} PsychoToolbox 3 [10]. The camera is controlled by Canon^{TM} SDK 2.5.2 and Canon^{TM} Remote Capture 2.7 software.

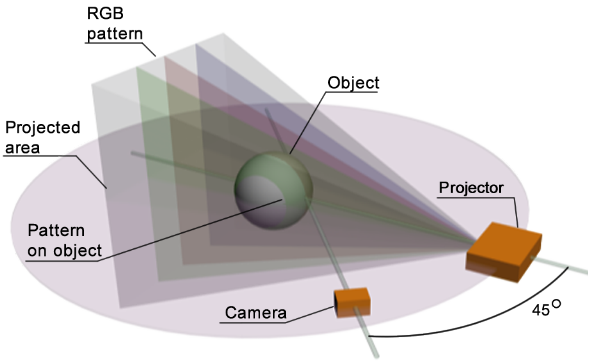

Figure 2: Model acquisition setup.

Before scanning, calibration takes place. Single dot is displayed in the middle to center the camera on the middle of projected area. Afterwards, we run line calibration to get indices of the two boundary lines enclosing the object. It allows to limit the number of required photographs and to estimate proper distance between the lines. Finally, a single shot of the object lighted by black image from the projector is taken (this image is called "base image Y"). This photograph will be used to reduce noise in the acquired data and extract color lines.

During scanning, the projector displays the vertical line pattern (Figure 4). The pattern is moved one pixel right after each photographs is taken (photograph is called "pattern image X"). The measurement is finished when the whole surface of the object is covered. The pattern consist of three vertical lines displayed simultaneously and set in constant range. This technique decreases by three times the number of required photographs without influencing the accuracy of the measurement.

The accuracy of reconstruction is limited by the projector resolution. It is desirable to project on the object as thin lines as possible. The lines should be sharp and the camera and the projector should be focused accurately.

After gathering all the input images, the workflow presented in the Figure 3 is executed. We compute the difference matrix XY for every pattern image X and base image Y. It helps to remove noise and highlights from the object. Then, difference matrices XYR, XYG and XYB are computed for each color channel. Additionally, a modifier can be used in the above equations to reduce exposition. We empirically found that this value should be set to 3, although, for less illuminated scenes it can be set to 1.

The low-pass Gaussian filter reduces noise and highlights. It also makes line smother and covers some of the missing parts. However, the filter kernel can not be too large because it could deform the lines. After Gaussian filtering, we posterize each channel to obtain the logical matrix containing information about lines (empirically determined thresholds are used). Since lines on logical matrix are a few pixels wide we reduce their thickness basing on the morphological operations algorithm [7].

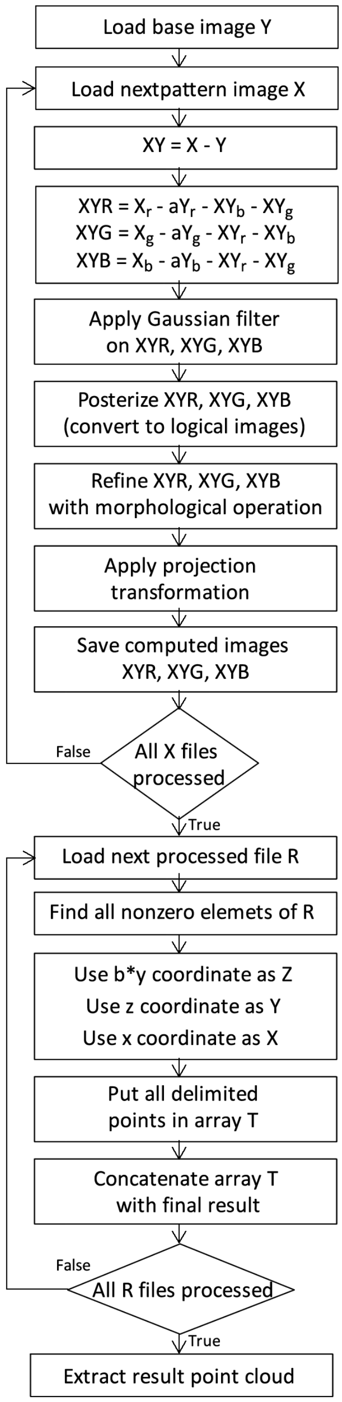

Figure 3: The flowchart of data processing, X,Y and XY represent all pixel from RGB image channels with values between 0 and 255, r,g and b stand for color channels index, XYR, XYB, XYG and R represent one channel images, additionally R is Boolean logical image, a is real modifier for image difference and $a > 1$, b is real modifier for horizontal distortion height correction and $b > 1$, T array contains all found vertexes that belong to a projected spline on the surface of the object.

Figure 4: The RGB light pattern projected on the object.

In the next step the projective transformation is conducted to reduce the perspective deformation of the object. Lines that are closer to camera are longer then the most distant ones. Their length should be reduced and the choice of what side to decrease/increase depends on which side of the projector the data is recorded.

Computed images XYR, XYG and XYB are saved maintaining number of line index. This way they are already sorted. After processing all files we reread them one by one as R matrix. Non-zero elements in R represent points in the point cloud. The coordinates of these points are computed basing on the position of the line and the pixel shift (see Figure 3). Height modifier b is applied to minimize flattening caused by taking picture from 45°. Extracted points are pushed into temporally array T. Before loading new sets of points T is concatenated with the final result array.

We export final point cloud to ASCII vertex file ($*.asc$). Mesh reconstruction is done in external software: Point Cloud 1.0 and Delaunay2_5D.

4 Results and discussion

In this section the results of the shape reconstruction of the object are presented. We tested our algorithm on the sculpture presented in Figure 5. It has similar structure to the Wkryujście Altar. The sculpture is also made of wood and has similar color as well as the surface texture.

The reconstructed mesh is presented in Figure 6. It consists of 403 317 triangles and was created basing on 203 672 points of the point cloud depicted in Figure 7. The points were gathered from 50 photographs of the light pattern and 1 base reference image.

Figure 7: The final raw point cloud acquired from a set of 50 RGB pattern photographs.

The shape of the object was preserved correctly with most of its details. The fidelity of reconstruction directly depends on the resolution of the projected pattern. For comparison, the mesh generated from lower number of input photographs (it means lower number of lines per the object surface) is presented in Figure 8. As it can be seen, less details were reconstructed in this mesh.

There are some artifacts in the final mesh. The main problem is a low scan resolution on surfaces parallel to the camera view direction (see the cheeks in Figure 6). This

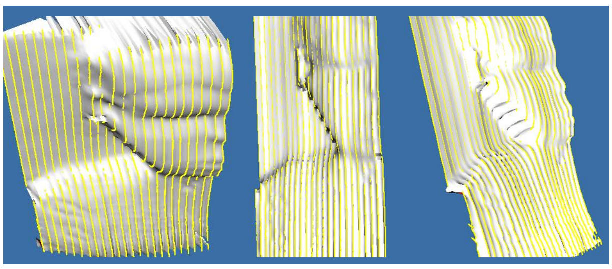

Figure 8: The mesh reconstructed with 8 RGB photographs. The yellow lines depict location of the projected lines.

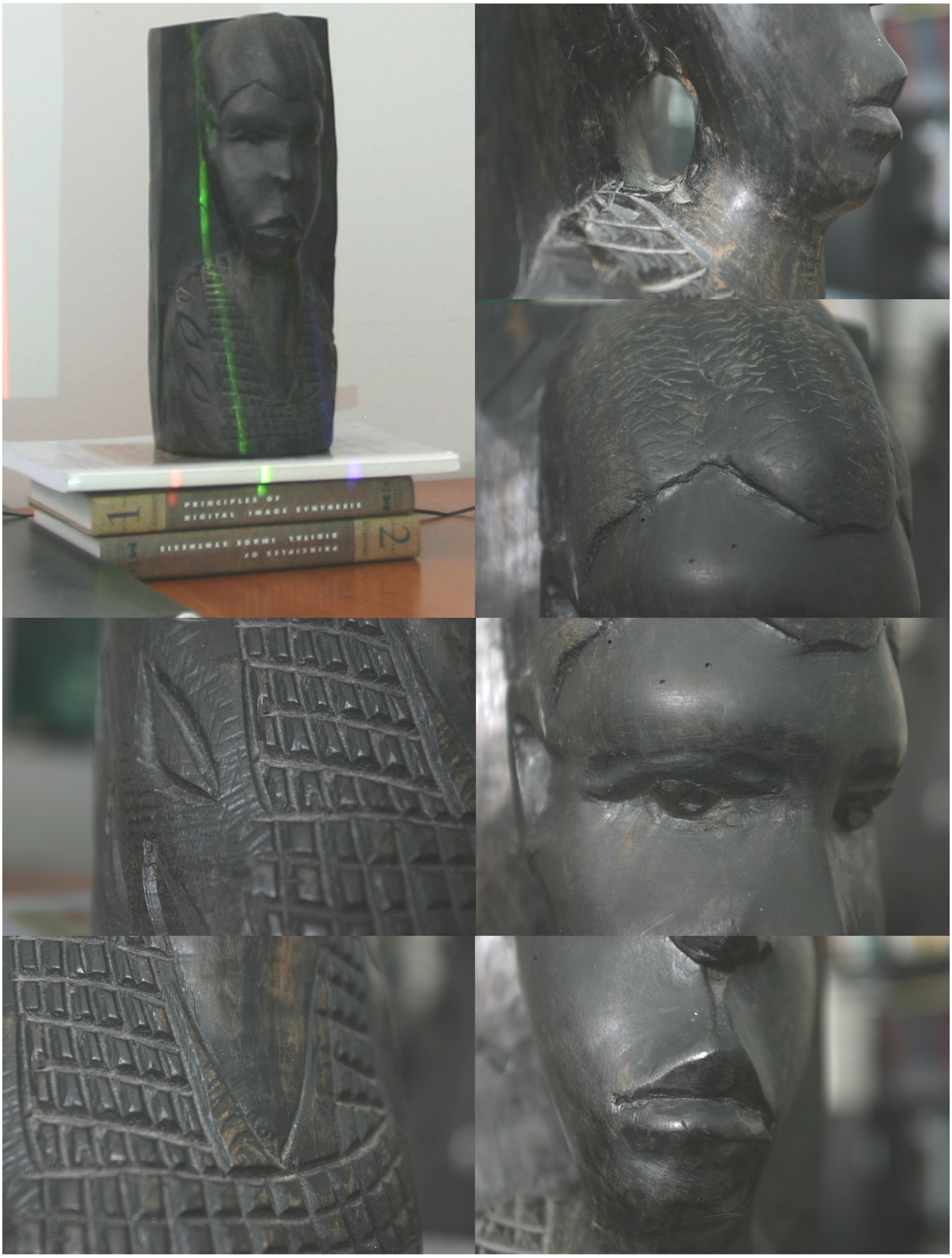

Figure 5: The test object used to prototype the reconstruction technique. We can not use the Wkryujscie Altar because of its actual condition and prototype method that is still developed.

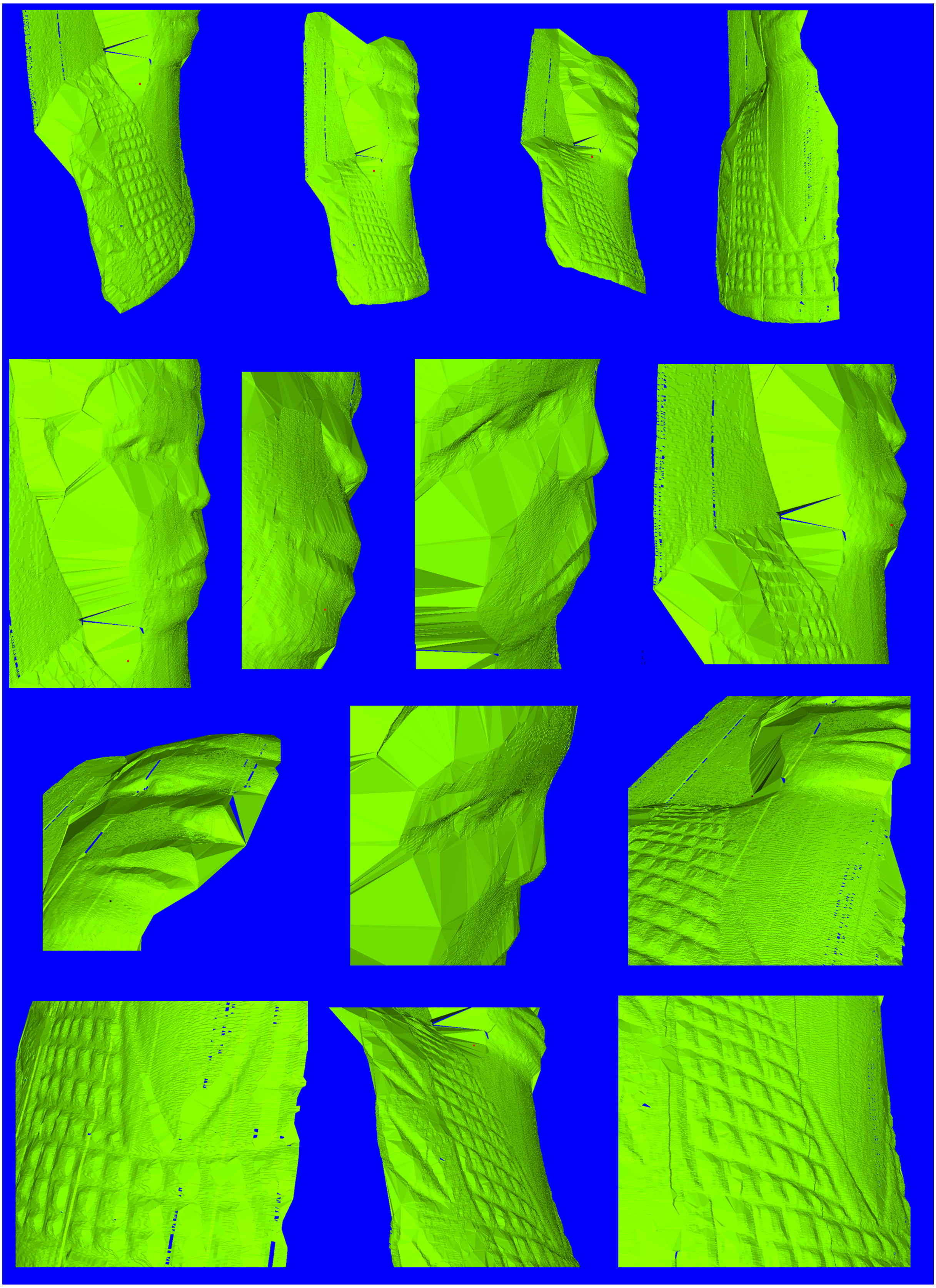

Figure 6: The final mesh reconstructed from the raw point cloud.

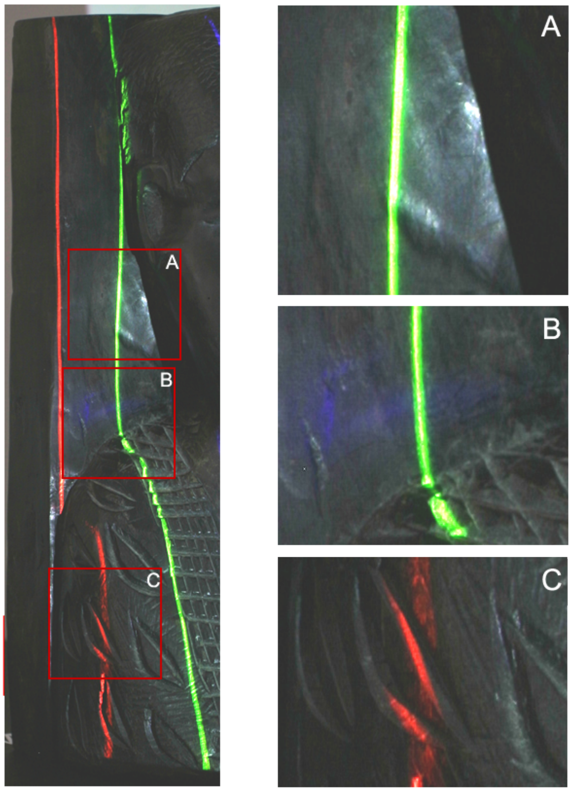

Figure 9: A sample close-ups of the light pattern projected on the object. A. The fluctuation of color caused by the highlight. B. The reflection of a blue line, this line is actually not visible in the presented image area. C. Red line splits into three separate lines.

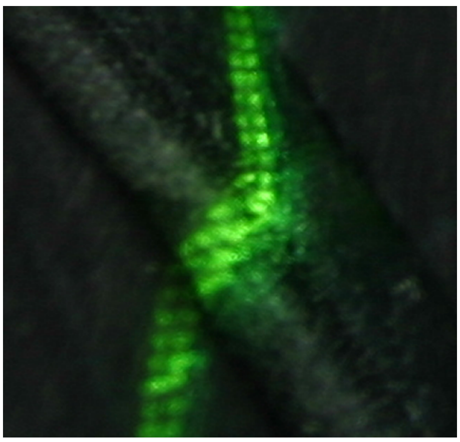

Figure 10: Magnified fragment of a green line. Its structure is distorted by the object surface. The visible green squares are effect of the projector resolution: every 1 pixel line consist of 2 projectors dots width. The projected lines has width from 1 to 3 millimeters.

drawback can be eliminated by mixing photographs taken from different directions. Some inaccuracies are caused by the material structure which splits a line into two or three (see Figure 9c). The lines have discontinuities and altering thickness (see Figures 9 and 10).

The results can be improved using advanced resampling and smoothing methods that would increase the fidelity of lines acquisition. What's more, more sophisticated the vertical perspective correction would correct the mesh proportions by making result model less flatten.

5 Conclusions and future work

In the paper we describe the prototype of the technique for the reconstrucion of object's shape. It is based on light pattern projection on the object surface. The photographs of the pattern deformed by the object irregularities are analyzed and virtual mesh of this object is reconstructed. We use inexpensive camera and projector but even with the use of this equipment high detailed elements can be correctly captured (see Figure 6). The missing regions can be filled by making another scan of the object from different camera position. We leave this issue for future work.

The presented technique is addressed for the Wkryujście Altar - the cultural heritage of the West Pomeranian Region. The shape and surface structure of the Altar is suitable for this type of scanning. After finishing the prototype phase we plan to make a scan of the whole Altar.

The accuracy of the reconstruction depends on the projector's resolution and its optical quality. We plan to use better projector for the actual scan. The using of the analog projector is also considered. Further improvement could be made by utilizing more sophisticated method of noise reduction and line acquisition.

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