INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 2/2024 (26): 131–138

ADVANCING FABRIC MATERIAL DIGITALIZATION THROUGH PHOTOMETRIC STEREO RECONSTRUCTION

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ABSTRACT

Photometric stereo reconstruction is a contemporary approach to digitizing fabric surfaces. By capturing multiple images of the surface illuminated from various angles and analyzing the resulting shadows, this method reconstructs the material's volume. It excels in capturing intricate texture details, particularly on surfaces with microscopic intricacies like fabric materials.

Key words: Photometric stereo reconstruction, textures, fabric surfaces, Adobe Substance Designer.

INTRODUCTION

Photometric stereo imaging represents the reconstruction of the volume of a two-dimensional image from information extracted from the shadows cast by its parts (Basri, R., Jacobs, D., Kemelmacher, I., 2007). When an object is illuminated from a certain angle with direct light, each of its parts casts a shadow on its adjacent surface or part of it. The longer the shadow, the higher the point that casts it is located in space. Thus, information about the height of the object's points can be derived (Grzegorz, B.).

Figure 1 shows an object illuminated from several different angles. It is clear that the shadows generated by this object are different from each other, but they represent the points that cast those shadows.

The principle of operation of photometric stereo imaging is as follows: The object is photographed orthogonally from above. In this way, each point of it can be represented by X and Y coordinates. These coordinates represent the base parallel to the shooting. The object is illuminated from different angles, and its shadows are studied. The longer the shadows, the higher the corresponding points that cast the shadow are. The more sides the object is illuminated from, the more information there will be for each point. This way, the third Z coordinate of each point can be determined.

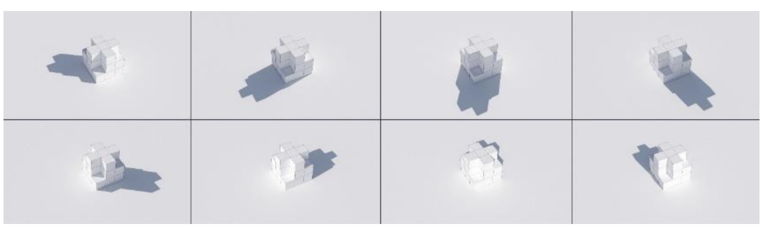

Figure 1: Perspective of an object and the shadows it cast when illuminated from different angles. Author's image, generated with 3DS Max software and Adobe Photoshop software.

Figure 2 shows the same object but photographed orthogonally. As seen under different illuminations, each point casts a shadow of a certain length corresponding to its height. Thus, after shooting, a 3D model of the respective object can be constructed.

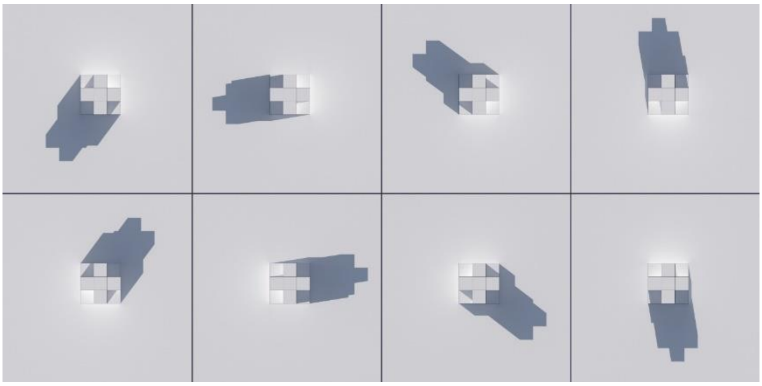

Figure 2: Top view of an object and the shadows it cast when illuminated from different angles. Author's image, generated with 3DS Max software and Adobe Photoshop software.

This method represents a two-dimensional capture of a given texture. It is illuminated from different directions, and based on the shadows, information is obtained about how deep and respectively protruding it is. This is a technique that interprets the height of each point on the object's surface by taking information from the shadow it casts.

Several pictures of the object are taken, and it is illuminated from several different angles. This way, there is more information about the geometry of the object itself. Through software, these shadows can be analyzed, and a texture can be constructed with accurate values of the offsets of each of its parts – the normal map.

THE AIM OF THE REPORT

The objective is to establish the principles of photometric stereo imaging, to structure the methodology during the capturing process, and to define best practices applicable in the digitization of textile materials.

METHODOLOGY

The entire process is divided into four main parts:

CAPTURING THE IMAGES

The object to be photographed is placed in a dark environment without any light. It must be illuminated from different sides and captured from precisely the same point. Typically, the object is placed in a specially made apparatus for capturing. It consists of a horizontal plane on which the object to be captured is placed, surrounding sides where the lighting fixtures are placed, and a camera directed perpendicular downwards towards the object. It is mandatory that the camera and the object do not move during the shots.

The lighting producing the shadows must be constant. Side lighting must be eliminated. This is necessary to accurately capture the shadows of the objects. The light should be white, approximately 6500 Kelvin, to capture the object's colour in its true colours. Ideally, the lighting should be flat rather than point-like. This means that the shadows will be parallel and will not converge at one point – the light source. The light should also be at a certain angle to obtain a good and readable shadow of the object. It is recommended that this shadow forms an angle with the base plane ranging from 15 degrees to 60 degrees. The flatter the object, the lower the angle should be used. The more angular the object, the higher the angle should be used. The optimal angle is 45 degrees (Grzegorz, B.).

Lighting can be point-like or linear. Point-like lighting produces sharper shadows but requires the light source to be further away for shadows to become parallel. Linear lighting produces softer shadows but can be placed closer to the object. Additionally, linear lighting has a lower intensity, and thus, any other external lighting must be eliminated.

To orient the software about the geometry, information from at least four images must be provided. These images should be taken with the object illuminated from four sides. For a more precise result, it is recommended to take eight images with lighting at a 45-degree angle. The more images taken, the more information there will be about the shadows, and the software will reconstruct the image more accurately. However, the more images there are, the more time and computational power the software will require to calculate the texture.

When objects are scanned in this way, a line can be left as an indicator of the subsequent distance measurement. Additionally, a template with colours can be left to verify if the respective colours have been correctly captured. If they have not, they can be corrected until the values from the template are reached.

When capturing a particular object, it must be considered how reflective its surface is. Although the camera is fixed, the light comes from different sources and can lead to errors in subsequent reconstruction. One way to eliminate unwanted reflections is through the "Bidirectional Reflectance Distribution Function" (BRDF). It represents a function of four real variables that determine how light is reflected from a given surface. With this approach, almost no light calibration is needed to achieve the desired results (Hertzmann, A., Seitz, Steven, M., 2003).

If an object with many reflections is being captured, the method of double polarization can also be used. This means that a polarizing filter is placed on the camera, and another polarizing filter rotated at a certain angle, is placed in front of the light. This eliminates any reflections because the photos are taken in a controlled environment with only one light source. The disadvantage of this technique in this case is that different polarizing filters must be placed at angles in front of each light source. This is necessary because the different light sources are at different angles relative to the camera. To avoid touching the camera and inadvertently moving it, the filters must be placed at specific angles relative to the filter placed on the camera. This further complicates the process and reduces the number of shots to be taken.

Figure 3 shows a device for performing photometric stereo imaging. It represents a closed space in the form of an octagonal prism. LED strips are placed on each of the walls, emitting white light. The lights on each of the walls can be turned on and off independently of each other. The placed object can be illuminated by eight different lights in this way, allowing the shadows of the object to be captured from eight different angles. The height of the walls must be adjusted to the focal length of the camera so that the camera can capture the maximum area of the bottom surface of the box without capturing the light sources from the walls (Riganelli, Dave.).

The lid of the box is also in the form of an octagon. It has a hole in its centre where the camera is placed, which will capture the images, each with different lighting. The entire box is made of foam board. This material is chosen because it is lightweight yet extremely durable and can withstand the weight of the camera. Additionally, when the camera is placed on the lid, it can be levelled so that it is precisely perpendicular to the surface being captured.

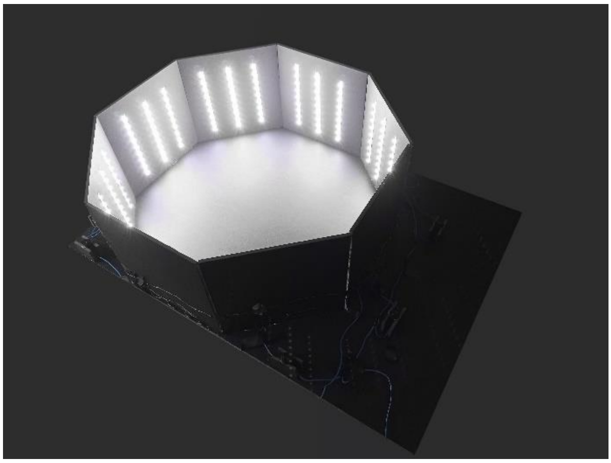

Figure 3: Shows the setup for capturing an object using the photometric stereo reconstruction method. Author's image.

The lid, walls, and bottom part of the device are black in colour on the surface. This is done to eliminate any reflected light from the surfaces of the device. Black absorbs all the light falling on it. This ensures that there will be no shadows in unwanted directions other than those from the directed lighting. Figure №4 shows the result of capturing the texture. Each image is taken with only one of the eight walls' lighting included. This way, eight images are obtained with the same position of the surface irregularities on the object but with different shadows they cast. This allows the software to subsequently reconstruct the height of individual points on the object by analyzing the shadow information.

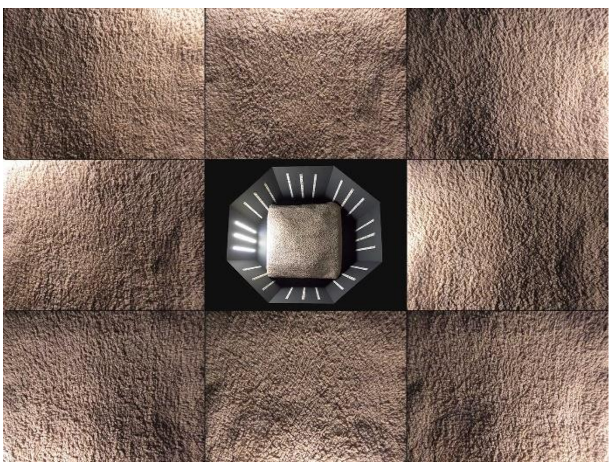

Figure 4: Shows the result of capturing the texture of the given object. Author's image.

INITIAL PROCESSING OF THE IMAGES

In this step, the quality of the images is checked. If necessary, the colour or contrast of the images is adjusted, the white balance is adjusted, the vignetting of the images is corrected, and it is ensured that there are no overly bright or dark areas in the picture. If such areas are found, they are corrected at this stage.

PHOTOMETRIC STEREO RECONSTRUCTION

At this stage, textures are generated based on the shadows of the objects. The images are imported into reconstruction software, and it generates textures for the base colour, surface irregularities, and heights accordingly. These textures are then exported in the desired resolutions. The higher the resolution at which the object is captured, the more information there will be for reconstruction, and the textures can be exported in larger resolutions. It should be noted that the larger the input files and the more numerous they are, the greater the computational power required by the software (Rens, A.).

Figure 5 shows the loading of the images into Adobe Substance Designer software and the necessary node system for generating the photometric stereo reconstruction from the captured images. At the end of this node system are the output data for generating the base colour texture, height texture, and normal texture.

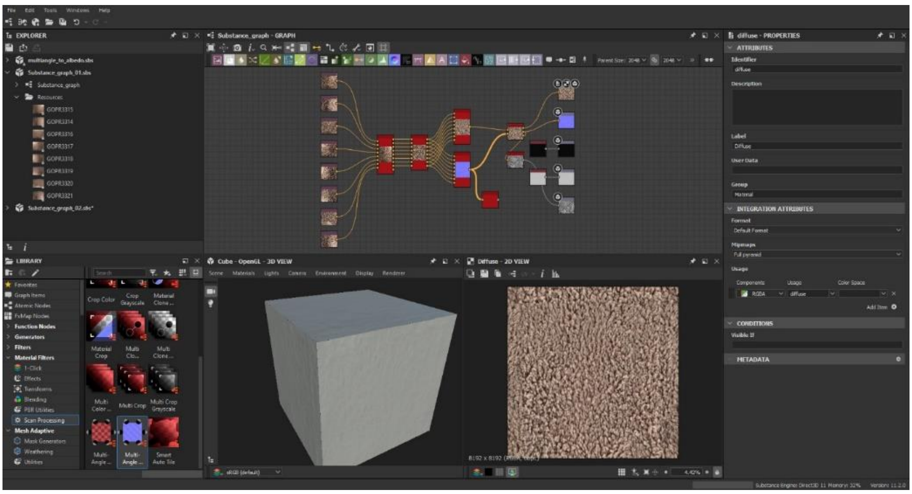

Figure 5: Shows the photometric stereo reconstruction of the captured texture in Adobe Substance Designer software. Author's image, generated with Adobe Substance Designer software.

FINAL PROCESSING OF THE TEXTURE

At this stage, final adjustments are made to the textures. Changes can be made to the base colour of the texture, for example. Additionally, areas of the texture where tiling effects occur may be corrected. Once the textures are ready, they are exported to their final directory with their final names.

Figure 6 shows a computer-generated image of a sphere with a material in which textures generated by the photometric stereo imaging method are loaded. The graph depicts the textures themselves from the process of their generation – the base colour texture, height texture, and normal texture.

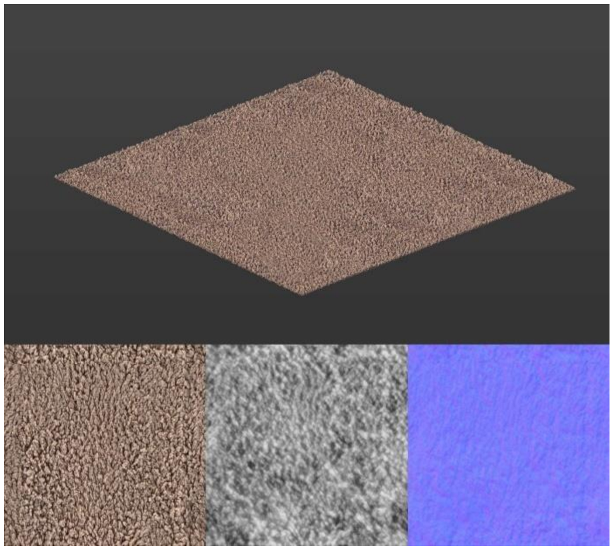

Figure 6: Computer-generated image of a plane with a fabric texture, captured and reconstructed using the photometric stereo imaging method, and generated textures based on the main color, heights, and normals. Author's image, generated with 3DS Max software and Adobe Photoshop software.

APPLICATION

Through this method, microscopic details of the surface of a given object can be captured most effectively. It is primarily used to capture details of fabrics and similar materials. This technique is applicable for scanning small objects or scanning a small part of an object. For larger objects, the results are not satisfactory.

Through this method, samples of various materials can be scanned very quickly. The generated textures in this way will be as close as possible to the samples provided to the designers.

When a designer prepares a project and has designed the interior space and wants to check which material would be most suitable for the corresponding interior space, they can scan a sample from the catalogue of a particular company and transfer it directly into the project. This way, it can be understood whether the given material is suitable for the interior space or not. If it's not, the process is repeated until the right solution is found. Subsequently, the designer can present to their client exactly how the project would look if the appropriate samples from the respective catalogue were used. When such scanned materials are applied to leather and textile products, an accurate and precise result is obtained.

In the creation of computer-generated images and virtual reality, it is of paramount importance that the models be extremely detailed. When this detail is made through geometry, they become with extremely many polygons, hence slow and difficult to process. This detail, especially the micro-detail, is best done with materials with detailed textures. When the method of photometric stereo imaging is used for digitization, the highest level of detail is obtained at the micro level in the texture. Exceptionally, photorealistic surfaces are obtained in the virtual space.

CONCLUSION AND FINDINGS

ADVANTAGES OF PHOTOMETRIC STEREO IMAGING

- Microscopic details of textures can be captured through this method.
- The imaging is precise as it is controlled by the environment of capture and the object being captured.
- Advantages of digitization through photogrammetric reconstruction:
  Primarily used for scanning surfaces of fabrics, leathers, and other materials with microscopic details. Only this method allows for accurate and precise capture of such materials. Photogrammetric imaging is not applicable because it requires information from surrounding spaces and objects for the software to orient itself regarding where the images were taken. When capturing such microscopic details, this is almost impossible. Even if the images were taken from a greater distance so that surrounding objects are present, it means that the captured object will occupy a smaller portion of the image. This will result in fewer pixels used by the camera, leading to a loss of information about the texture of the captured surface. Additionally, when capturing through photogrammetry, the focal length needs to be considered, leading to areas that will be out of focus. These areas practically lack information and would confuse the reconstruction software.
  In contrast to digitization through photogrammetric reconstruction, the method of photometric stereo reconstruction can reconstruct objects with much more detailed topography, even when their surfaces lack texture or are glossy.
- Advantages of digitization through a single captured image:
  The main advantage of reconstruction through photometric stereo imaging is that detailed information about the heights of parts of the surface is obtained. With reconstruction from a single image, there is information about the base colour of the surface, but there is a lack of information about the heights of the material. Consequently, it is almost impossible to derive accurate heights or normal textures. These two maps are extremely important when capturing materials with a high level of micro-detail.

DISADVANTAGES OF PHOTOMETRIC STEREO IMAGING

- Large objects cannot be captured. The larger the object, the larger the controlled space required for capture. Accordingly, the light sources must be specifically positioned to provide sharp and clear shadows. The larger the object, the larger the shadow it will cast, so the camera must be positioned at a greater height to capture both the object and all the shadows cast during illumination from different sides.
- The captured detail begins to degrade with larger forms. The larger the form, the more specialized camera must be used to capture the micro-details on the surface. The camera needs to have a higher resolution to capture the micro-details. Otherwise, there won't be enough pixels to record information about the surface.

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UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

2/2024

INNO vol. XIII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN
Science Journal
Vol. 13/ p. 1–142
Sofia 2/2024

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

Cover Design: Desislava Angelova

Printed by: INTEL ENTRANCE
Publisher address: UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
http://inno.ltu.bg
http://www.scjournal-inno.com/

THIS ISSUE CONTAINS PAPERS PRESENTED AT

TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE

INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN INNO 2024

7 – 9 October, Hotel Imperial Plovdiv, a member of Radisson Individuals, Plovdiv, Bulgaria

ORGANIZED BY FACULTY OF FOREST INDUSTRY, UNIVERSITY OF FORESTRY, SOFIA, BULGARIA

Twelfth International Scientific and Technical Conference
INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN INNO 2024,
is supported by the National Science Fund, Bulgaria
with co-financing agreement № КП-06-МНФ/40 of 13.08.2024

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