A VIRTUAL ENVIRONMENT FOR ARCHIVING MICRO-PRESENCE WITH IMAGE-BASED MODEL ACQUISITION

Masahiko Morita[1], Tastuya Saito[2] and Kenji Kohiyama[1]
[1]*Graduate School of Media and Governance, Keio University, 5322 Endoh, Fujisawa-shi, Kanagawa, Japan*

[2]*Tokyo National University of Fine-Arts and Music, 12-8 Ueno Kouen, Taito-ku, Tokyo, Japan*

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Abstract: Micro Archiving is a new method of photography that helps anybody digitally archive minute structures that existing capturing systems cannot deal with. For research use, it is an effective way to make high-fidelity virtual specimens of small objects that allow scholars to share the precious academic resources over the Internet in a digital format. For commercial use, the virtual models captured by the technology can be applied to computer graphics, games, digital cinemas and other digital entertainment media. Technically, our Micro Archiving technology enables easy and fast construction of high-quality and high-resolution textured virtual 3D models of small objects. Currently, application contents of Virtual Reality, Augmented Reality and other interactive media are dependent on the use of elaborate 3D models, which require expensive manual task. Micro Archiving technology provides automatic capturing process that can comprehensively handle a high-resolution all-focused imaging, 3-dimensional modeling and transparency capturing simultaneously. Micro Archiving is best suited for minute and complex objects such as machine parts, insects, plants and small archaeological materials.

1 INTRODUCTION

Invention of optical devices such as telescopes and microscopes widened the perceivable spectrum of the reality of the natural world by allowing us to see what is invisible to our naked eyes.

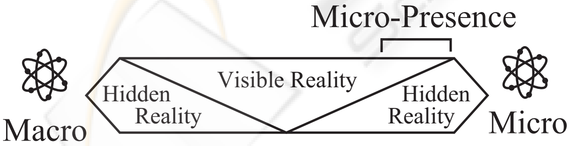

Figure 1: Micro Presence.

As well as revealing hidden aspect of the world, archiving it has been a challenge of importance in research fields where replicable duplication of specimens and samples plays a crucial role. For example, in biological studies on a small animals such as insects and microscopic organisms, a photography and hand-drawn sketches help researchers share scientific knowledge on invariable specimens. This applies to studies on artificial objects such as archaeological materials from the ancient time. In ancient sculptures and fossils, their fine surface structures are historical and cultural proofs that tell about how the objects are produced and how they are used. Archiving and investigating these proofs is an important element of a research task.

Here, the concept of Micro-Presence is introduced to mean a kind of reality that is too small to be directly experienced by our sensorial organs. A microscope is a good example of a device to unveil Micro-Presence by providing us with a way to observe microstructures of both natural and artificial objects.

Archiving Micro-Presence such as insects, plants, mineral substances and small-sized archaeological findings for research use is often useful in that it allows researchers and archaeologists to observe elaborate virtual samples to inspect physical features without having the actual samples. Use of virtual samples became a major technical topic as multimedia database technology has highly advanced in the last decade and the access to it has became extremely low-cost. This trend will be accelerated in the future as

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the bandwidth of the Internet increases and interface technology becomes easily accessible. Our project, Micro Archiving, aims at developing a technology to archive Micro-Presence in highquality. For research use, it is an effective way to make highfidelity virtual specimens that allow scholars to share academic resources over the Internet. For commercial use, the virtual models captured by our technology can be applied to computer graphics, games, digital cinemas and other entertainment media. The technical goal of this project was to build a new device for archiving small physical objects in digital form on these advancing future platform for helping researchers conduct research. The proposed imaging device needed to have specific features for this use and we designed the system to satisfy this goal. Our technique can scan 3-dimensional structure, all-focused color image, diffusion and transmission coefficients of a target object.

A small object often has very fine and minute structures that require a sophisticated optical device such as a microscope to be observed. For generating an all-focused image, where all the picture elements are focused, a con-focal microscope is one effective choice to scan a target object in high-resolution and high quality. However, it has a deficiency in that it cannot capture color information. Traditionally, for creating archives of small physical objects from archaeological sites,microscopic cameras and other 2-dimensional optical apparatus have been used. This kind of an image resource is a historical asset that provides cultural and scientific explanation on what our ancestors' life and technologies of those days were like. These replicable resources are one of the most important elements in conducting an archaeological research. However, the imaging technique is accompanied by loss of information that derives from transformation of 3-dimensional structure to the 2-dimensional medium. To solve this problem, 3-dimensional scanning technologies have been attracting attention in the research field. A 3-dimensional scanner is a device that can capture 3-dimensional structure of the target object often with color information.

There are varieties of 3-dimensional scanners for different uses. lazer-scanning technique is probably the most popular technique and there are a number of commercial products based on this technique. There is another technique that utilizes an active lighting. By projecting a certain pattern on a target object and recognizing the projected pattern, this technique analyzes the 3-dimensional surface shape of the target object. In these two methods, color-information are captured in a separate process often with a different imaging device. In Stereo camera method, corresponding two points in two images taken by a set of camera arranged in parallel are extracted to reconstruct 3-dimensional surface structure of a target object. This method is effective in scanning a large-scale object such as an architectural structure and a landscape(Levoy, 2000). However, they have deficiency in that they cannot deal with an extremely small object less than 5 cm.

2 SYSTEM DESIGN

Our Micro Archiving technology can comprehensively handle high-resolution all-focused imaging, 3-dimensional capturing and transparency capturing simultaneously. Constructing high-resolution 3D models is an expensive and time-consuming task. In often cases, 3-dimensional scanners and other image-based modeling methods are used to automate this process. However, existing systems had a trouble in case of a small object. This is the main issue that our newly proposed method solves. As we design the system, we examined required features and functions that satisfy our goal of providing researchers with an ultimate archiving system.

2.1 Depth Measurement

It was the primal objective that our system can capture 3-dimensional structure of a small object that existing technique cannot deal with. Small objects, especially in case of a natural object and small animals such as mineral materials and insects, have complex and minute structures of fine concavity and convexity.

Our system needed to capture these physical features. Our methodology is based on an existing image-based model acquisition method called ”Shape-from-focus”(Nayer and Nakagawa, 1994). In general, Shape-from-focus method is done in the following process. Firstly, a optical device, usually a camera, is focused onto a part of the target object. By slightly changing the focal length of the optical device, a sequence of images are taken each of these images contains different region in focus as shown in figure 2. In general, focusing depends on the distance from the camera to the target object. Therefore, by extracting focused pixels in each image, it is possible to measure the 3-dimensional surface shape of the target object.

However, the drawback of this method is that it is difficult to generalize the focus model. Especially in case of a complex object, pixels that are out of focus affect neighboring pixels and this effect is extremely complex to analyze. In general, a pixel becomes the

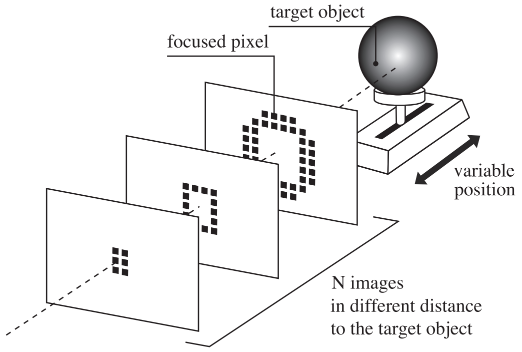


Figure 2: Shape from Focus.

brightest when it is in focus. The figure shows transition of brightness of a pixel in the captured sequence of images. The x-axis represents the distance from the camera to a part on the target object corresponding to the pixel. As can be seen, it is difficult to know at what position the pixel is focused(Figure 3 : normal lighting). This is largely because of complicated blur effect of neighboring pixels. This effect becomes more complex when measuring the 3-dimensional structure of a very complex object.

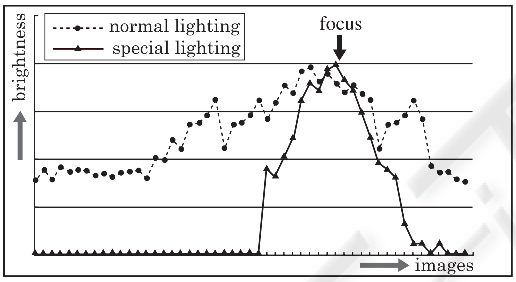


Figure 3: Transition of Brightness under our slit-lighting equipment... or a normal lighting equipment.

To simplify this complex blur effect, we designed a special slit lighting system as shown in figure 4. The lighting system and a digital camera is set up on a shock prevention table. The slit lighting system is composed of 8 illuminators which are attached to a ring plate with a hole in the middle. A target object goes through this hole when it is scanned. Each of the illuminator is connected to a light-box through an optical fiber cable. Light comes from the light-box and gathered and bundled to about 0.5 mm thick by a lens in the illuminator (Figure 5).

The slit-lighting system is arranged so that the beam of light goes parallel with the focal surface of the camera lens and it illuminates only the part of the target object that is located very near to the focused part. Therefore, a sequence of captured images contains mostly focused part radically eliminating the complex blur effect.

Under the slit lighting system, the transition of the brightness of each pixel becomes extremely simple and it also becomes easy to find focused pixels (Figure 3 : special lighting). We have not yet done an elaborated evaluation of the effectivity of this lighting system. However, with the proposed hardware preoperation utilizing the slit-lighting, a set of technical problems in case of analyzing a structure of a small complex object can be resolved.

As mentioned, our technique is based on Shape from focus method. In our proposed method, a target object is moved instead of changing the focal-length of the camera lens. Our system has an object manipulation arm that is attached on the shock prevention table and moves a target object in high precision with a built-in precision stepping motor. For a target object in 2.0 cm to 5.0 cm length, the manipulation arm is set to move in 0.1 mm pitch. For an object smaller than 2.0 cm, it is set to move even in smaller pitch of 0.05 mm.

2.2 Resolution and Image Quality

To archive a target object in great detail, the capturing device needs to be able to deal with high-resolution imaging. As we used a high-end digital camera, the resulting image can be as high-resolution as what the image sensor can handle. However, in conventional photography, it has been impossible to focus onto the whole part of the target object at once because of tight depth-of-field especially in case of capturing a minute object. This problem becomes even more critical in a microscope. We solved this problem by utilizing the depth data that is already captured by the system. To capture the target object in natural color, the system takes a sequence of pictures under a flash lighting. Since we already know what part is in what depth parameter meaning that it is possible to extract pixels in focus from the image sequence.

The sequence of images is taken under 4 stroboscopic lighting devices (TWINKLE FII by COMET) with a set of diffusers. With these lighting devices, a target object is uniformly illuminated. As is mentioned in the following chapter, this lighting does not necessarily have to be in this way and it can be any kind of lighting condition as is used in various kinds of existing active stereo 3D scanning methods.

This synthesizing technique makes it possible to take images of the target object under various kinds of lighting condition. Therefore, our method can be extended to support other image-based modeling technique. One of these modeling techniques is extraction of reflection model. It is often that physical object is composed of many different materials with different physical characteristics. For example, a shell surface of insects in a distinctive structure called structural

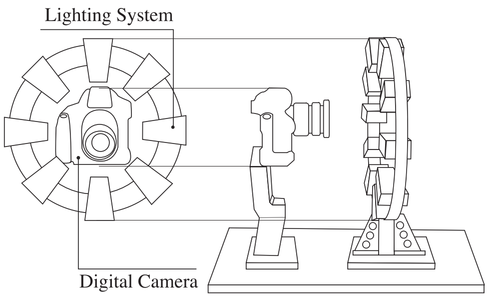


Figure 4: Slit Lighting.

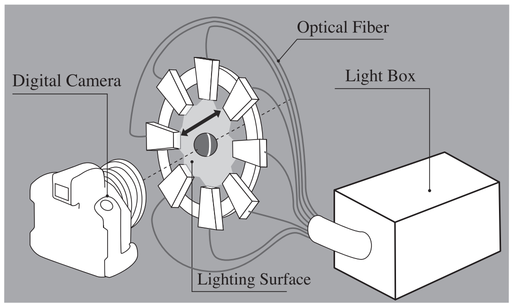


Figure 5: Slit Lighting structure.

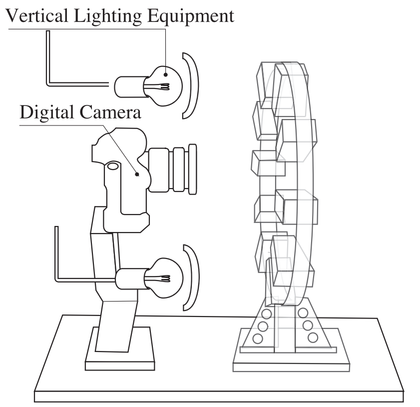


Figure 6: Transition of Brightness under our slit-lighting equipment.

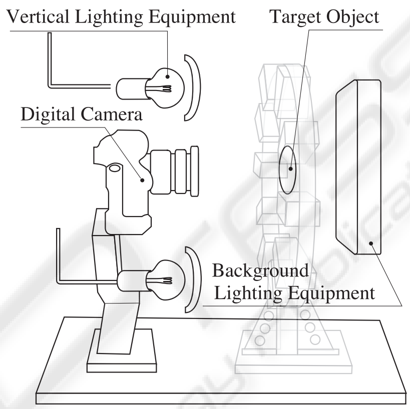


Figure 7: Transition of Brightness under our slit-lighting equipment.

color. The surface emits various colors depending on the lighting condition. Being able to manipulate the lighting condition allows modeling this kind of reflection pattern. Another example is transparency of the target material. We in fact designed a lighting system and transparency scanning technique using it to capture diffusion and transmission coefficients. This is discussed in the following chapter.

We used a high-end consumer digital camera (Canon EOS-1Ds Mark II) and SIGMA MACRO 50 mm F2.8 EX DG lens. The camera resolution is 5000 x 3400 pixels and the resulting depth data is also in this resolution, which is almost unattainable in existing 3-dimensional scanners. Our system does not depend on a specific function of a certain digital camera. The current camera can be replaced by any kind of a new product with higher resolution imaging capability.

2.3 Capturing Other Physical Features

The lighting condition a sequence of images for generating all-focused image can be in any form for measuring other physical features. By designing a proprietary background illuminator, our system can also capture transparency of the target object. This is an element that did not exist in the conventional photography.

In the natural world, there are semi-transparent materials such as a glass, feather of insects. To represent these semi-transparent objects in computer graphics, it is indispensable to take into account transmission, refraction and diffusive reflection. To deal with these optical characteristics of semi-transparency in photography, it is needed to check the materiality of the object corresponding to each pixel of an image. However, it is time-consuming, expensive and practically difficult. In existing research, there are several methodologies proposed that uses blue-screen to measure semi-transparency. In fact, even with these methods, semi-transparency is assigned to a virtual object in computer graphics by empirical assessment of an engineer and an artist. Also, diffusion effect, where a background image gets blurred in accordance with the distance between the background object and a foreground semi-transparent object, is hardly considered. In case of need, an object is modeled so that it appears to have a diffusion effect. In this research, we propose a new methodology to capture two characteristics of transmission and diffusion effect of a thin semi-transparent object from a series of photographic images and represent them in computer graphics.

In general, transparency means the ratio of how a foreground object is mixed with a background object. Diffusivity means how the background object gets blurred as the distance between the foreground object and the background object increases. In the current state of the industry, assigning these parameters to 3-dimensional models for use in films and computer graphics is empirically done and never seriously considered. We succeeded in developing a system to capture these parameters from a real object.

On top of this, the resulting scanned model is in general 3D computer graphics format. Therefore, it can be edited on various kinds of commercial 3DCG software and also shown on general viewers such as a regular 3D viewer software and Web3D viewer for observation. Using a general format allows other structural features such as internal structure captured by X-ray inspector to be easily added to the captured model.

3 SCANNING PROCESS

Our Micro Archiving scanning process is mainly composed of three parts in shown figure 8: scanning, image processing and postprocessing. In the scanning process, sequences of images are captured by our proposed system. In the image processing, the sequences of images are processed to extract 3-dimensional surface shape, an all-focused image and a transparency map. Finally, in the post-processing, these data are

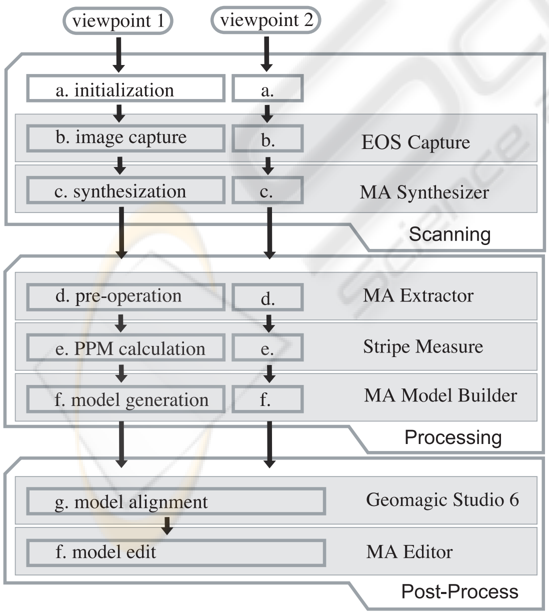


Figure 8: Transition of Brightness under our slit-lighting equipment.

combined together to output a 360 degree model and texture data. Also the model data is converted into a generic 3D model data format and also Web3D format for rendering.

3.1 Initialization

Firstly the target object is set on the moving arm and all the mechanical parts are set to be at the initial position. The slitlighting is set to illuminate the top of the target object. The lens of the digital camera is also set to focus on the illuminated part.

Camera parameter is also critical and it affects the quality of the resulting model data. It needs to be fine-tuned depending on what the target object is. However, we heuristically know that the following parameters are the best as default settings for an average target object.

Table 1: Camera parameters.

For slit-lighting condition	
Exposure	1.00 [sec]
Lens Aperture	F/5.6
ISO	400
Shutter Speed	1.00 [sec]
Aperture	F5.6

For strobo lighting condition	
Exposure	1/160 [sec]
Lens Aperture	F/8.0
ISO	100
Shutter Speed	1/160 [sec]
Aperture	F8.0

After the initial calibration, all the steps of capturing and processing are done by an automated script program.

3.2 High-Resolution 3-dimensional Imaging

Because focusing depends on the distance from the camera to the corresponding part in the image, it is possible to calculate how far from the camera each pixel in a taken image is.

$Img(x,y)$	: a pixel at the coordinate(x,y)
$Img(x,y)$	: a pixel at the coordinate(x,y)
$\|Img(x,y)\|$	: brightness of the pixel at the coordinate (x,y)
$ImgAF$	: all-focused image
$ImgD$	: depth image
$ImgS_{Index}$	: $Index_{th}$image taken under the slit lighting.
$ImgC_{Index}$	: $Index_{th}$image taken under the flash lighting.

For measuring 3D structure, the following process is automatically done.

$$|ImgD(x,y)| = Index$$

where,

$$|ImgS_{Index}(x,y)| = max(|ImgS_0(x,y)|, |ImgS_1(x,y)|, \cdots, |ImgS_n(x,y)|)$$

This process is done by our proprietary software called MA Synthesize.

3.3 High-Resolution All-Focused Imaging

For generating an all-focused image, the following process is automatically done. For this process, depth image that is acquired in the previous process is used to specify the pixels used to construct the all-focused image.

$$ImgAF(x,y) = ImgC_{|ImgD(x,y)|}(x,y)$$

Our proprietary computer program synthesizes these images to put together only focused pixels to construct an allfocused image.

3.4 Transparency Capturing

In the natural world, there are semi-transparent materials such as a glass, feather of insects. To represent these semitransparent objects in computer graphics, it is indispensable to take into account transmission, refraction and diffusive reflection(Figure 9).

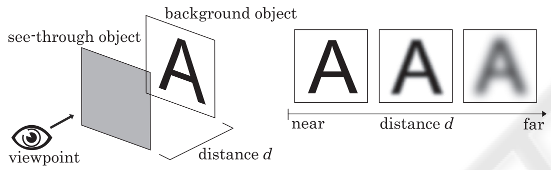


Figure 9: Diffusive Effect.

To deal with these optical characteristics of semi-transparency in photography, it is needed to check the materiality of the object corresponding to each pixel of an image. However, it is time-consuming, expensive and practically difficult. In existing research, there are several methodologies proposed that uses blue-screen to measure semi-transparency. In

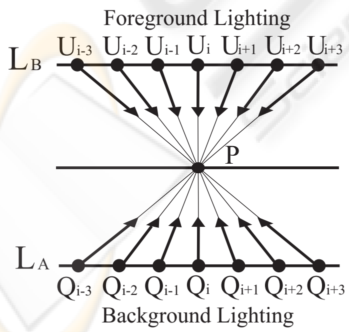


Figure 10: Lighting Model.

fact, even with these methods, semitransparency is assigned to a virtual object in computer graphics by empirical assessment of an engineer and an artist. Also, diffusion effect, where a background image gets blurred in accordance with the distance between the background object and a foreground semi-transparent object, is hardly considered. In case of need, an object is modeled so that it appears to have a diffusion effect. In this research, we propose a new methodology to capture two characteristics of transmission and diffusion effect of a thin semi-transparent object from a series of photographic images and represent them in computer graphics.

The target object is fixed between the vertical lighting system and the background illuminator. As shown in figure 10, assuming that the vertical lighting is composed of a number of points $\mathbf{U}_i$ and the background illuminator is composed of points $\mathbf{Q}_i$, the color $\Gamma(\mathbf{x}) = [x_R, x_G, x_B]^T$ which is observed at the point x on the camerafs projection plane can be described by Lambertfs cosine law and inverted square-root law as follows.

$$\begin{aligned}\gamma(\mathbf{x}) \quad = \quad & \kappa' \mathbf{L}_A \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\cos\left(\arctan\left(\frac{\sqrt{X_d'^2+Y_d'^2}}{Z_d'}\right)\right)}{X_d'^2+Y_d'^2+Z_d'^2} dX_d' dY_d' + \\ & \kappa \mathbf{L}_B \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\cos\left(\arctan\left(\frac{\sqrt{X_d^2+Y_d^2}}{Z_d}\right)\right)}{X_d^2+Y_d^2+Z_d^2} dX_d dY_d + \iota \mathbf{L}_B, \\ & = 2\pi\kappa' \mathbf{L}_A + 2\pi\kappa \mathbf{L}_B + \iota \mathbf{L}_B. \qquad (1)\end{aligned}$$

Here, $\mathbf{U}_i - \mathbf{P} = [X_d', Y_d', Z_d']^T, \mathbf{Q}_i - \mathbf{P} = [X_d, Y_d, Z_d]^T \kappa'$ are diffusive reflection coefficients when observed from the front side, κ is the diffusive reflection coefficient when the semitransparent object is observed from the backside and κ represents transmission coefficient of the semi-transparent object observed from the backside. It is assumed that the brightness $\mathbf{U}_i$ of the vertical lighting $\mathbf{U}_i$ is composed of uniform color elements $\mathbf{L}_A = [L_A, L_A, L_A]^T$ and the brightness $\mathbf{Q}_i$ of the background illuminator $\mathbf{Q}_i$ is also composed of uniform color elements $\mathbf{L}_B = [L_B, L_B, L_B]^T$.

Estimation of the color of semi-transparent object $\Gamma(\mathbf{P})$ and its diffusive reflection coefficient a The sum of κ and ι is defined to be diffusive reflection coefficient a.

Using α, the equation (1) can be rewritten as follows.

$$\Gamma(\mathbf{x}) = (1-\alpha)\Gamma(\mathbf{P}) + \alpha \mathbf{L}_B \quad , \quad \Gamma(\mathbf{P}) = \frac{2\pi\kappa'}{1-\alpha} \mathbf{L}_A \qquad (2)$$

Here, the point $\Gamma(\mathbf{P})$ can be presumed to be a point on the semi-transparent object $\mathbf{P}$.

From the equation (2), By measuring the color of the semi-transparent object $\Gamma(\mathbf{x_W})$ captured on a white background, the color of the white background $\mathbf{L}_W$, the color of the semi-transparent object $\Gamma(\mathbf{x_G})$ captured on a gray background and the color of the gray background $\mathbf{L}_G$, it is possible to calculate $\Gamma(\mathbf{P})$ and α shown in the table 2.

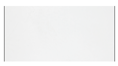
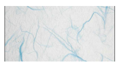
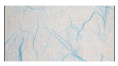
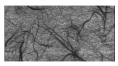
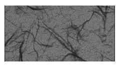
Estimation of diffusive reflection coefficient κ and transmission coefficient ι, acquired α split into diffusive reflection coefficient κ and transmission coefficient ι.

With an object that has a known diffusive reflection coefficient, it is possible to measure κ' of a semi-transparent object. In our method, a target object is assumed to be a very thin object. Therefore, it is assumed that κ can be approximated to κ' as long as it does not exceed α and κ, ι are approximated by the following equation.

$$\kappa' = \min(\alpha, \kappa), \qquad \iota = \alpha - \kappa_B. \tag{3}$$

Acquired κ, ι are shown in the table 2.

Table 2: Acquired transparency maps of a sheet of japanese hand-made paper.

 $Img(\mathbf{L}_W)$	 $Img(\Gamma(\mathbf{x_W}))$	 $Img(\mathbf{L}_G)$	 $Img(\Gamma(\mathbf{x_G}))$
 $Img(\Gamma(\mathbf{P}))$	 $Img(\alpha)$	 $Img(\kappa)$	 $Img(\iota)$

3.5 Rendering

To render with acquired coefficients, three images, the rendered image of the semi-transparent object $Img(\Gamma(\mathbf{P}))$, the image blurred in accordance with the distance between the background object and the semi-transparent object $Img(Blur(L_B))$ and the background image $Img(L_B)$, are prepared. As shown in the table 2, $Img(\alpha)$, $Img(\kappa)$, $Img(\iota)$ are applied to the blending map of each image.

We proposed a method for measuring diffusive reflection coefficient and transmission coefficient from photographic images and a rendering method for them. By this, it became possible to easily measure pixel-by-pixel transmission and diffusion effect from a photography. It also became possible to represent diffusion effect, which has been hardly considered in conventional computer graphics. Since we can not exactly know diffusive reflection coefficient and transmission coefficient, which this paper deals with yet, the validity of our method has not yet been fully proved. However, because elements needed for photo-realistic computer graphics are variables relative to neighboring pixels, our method is expected to be highly effective.

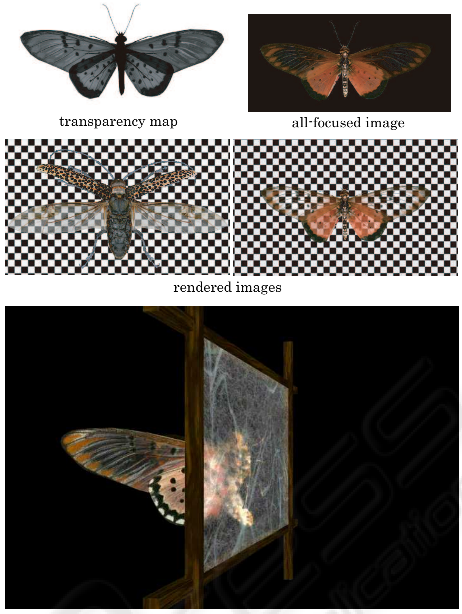


Figure 11: Examples of scanned transparency map and rendered images.

4 POST PROCESS

4.1 Integrating Coordinate System

Our system scans a target object from multiple directions. The multiple model surfaces are in different coordinate systems and needed to be in a common coordinate system to be aligned and merged. Our technique does this by calculating how big in a captured image an object in a known size is represented. This size is represented in a unit called PPM(pixels per millimeter). The XY coordinates of the scanned all-focused image and the Z coordinate of the depth data are converted into a common 3-dimensional coordinate by this parameter.

4.2 Mesh Alignment

Because our system can capture a target object from only one direction at one time. To create a model that can be observed from 360 degree, mesh data from multiple direction have to be combined seamlessly. Our system utilizes a commercial software called Geomagic Studio 6. This software is used to align surface models captured from different angles.

4.3 Mesh Merging

Once the surface models are aligned, they are merged together to form a continuous surface. This operation is done by our proprietary software called Micro Archiving Mesh Editor.

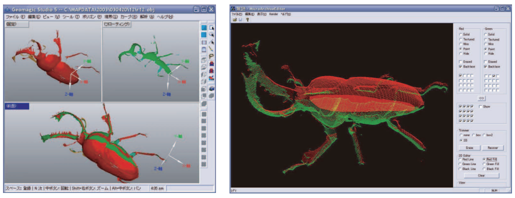


Figure 12: Mesh aligning.

5 RESULTS

The current maximum scannable texture size is 5000 x 3400 pixels and our technique allows maximum model data size of about 30,000,000 bytes (2.3 G bytes).

For a target object in the size of 2.0 cm long, it takes about 30 minutes to scan from one direction. Usually to create 360 degree model, a target object needs to be scanned from 8 directions. Therefore it takes 240 minutes to scan the whole target object.

6 APPLICATIONS

6.1 Web3d/webstereo

On the current broadband Internet, Web3D technology can potentially be used for various kinds of applications such as online museums and multimedia database systems for both general public and researchers specialized in a certain region. This fact will necessitate rapid development of content for such applications. Our Micro Archiving technology provides a technical solution. We created some Web3D contents public on an Internet website where anybody can observe and interact with high-resolution 3-dimensional models. Users can freely zoom into a detail to observe the minute structures.

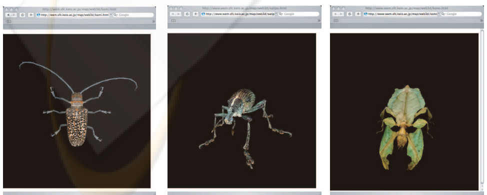


Figure 13: Web3D contents.

6.2 Animation

The 3-dimensional models captured by our method can be edited on many kinds of 3D computer software for various purposes. One possible application would be 3D computer animations. Such as digital films, games and other many different kinds of entertainment media that requires photorealistic 3-dimensional models.

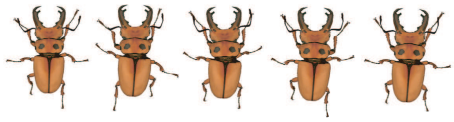


Figure 14: Animation sequence.

6.3 Academic Research

Entomology, which is a study on insects, often requires real specimens of insects to conduct a research. The models that can be captured by our methodology has enough resolution, accuracy and dense information including color, shape and transparency. We also succeeded in combining X-ray scanning structural data. With our proprietary interaction software, anybody can interact with and observe the 3D models. This would be strong application software for academic researchers who always need access to specimens.

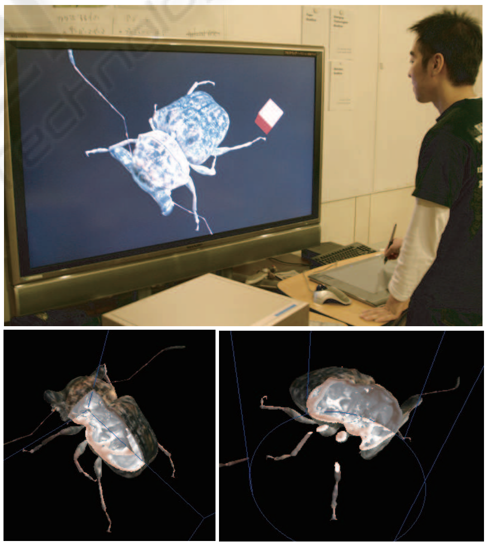


Figure 15: A proprietary interactive viewer.

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