Evaluation of Fast Estimation Algorithm for Calculation of Reflectance Map based on Wiener Estimation Technique

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ABSTRACT

We evaluated the performance of a fast estimation algorithm for calculation of reflectance map based on Wiener estimation technique. Duration time and accuracy for the estimation of the method was evaluated by only numerical simulation in the previous paper. In this paper, we performed the practical experiments to evaluate the duration time and accuracy for the estimation of the method. Accuracy for the estimation of the method was evaluated under two conditions: various numbers of measured data and various numbers of sample data for Wiener estimation technique. From the experiment, we found the method could estimate reflectance map rapidly and accurately from a few measured data in the practical situation.

1. INTRODUCTION

With the development of the digital imaging system, a digital archiving system has been used in museums to preserve the collections and exhibit them on the digital display. For this archiving, reflectance maps of objects must be recorded accurately to preserve the reflectance property of the objects. [1] The reflectance map of an object is a function of angle for incident light and it denotes a ratio between radiance of reflected lights from objects and radiance of incident lights to objects. The radiance to outgoing angle is measured against incident lights from many directions as shown in Figure 1. The reflectance maps of objects can be calculated by fitting the bidirectional reflectance distribution function (BRDF) models such as Blinn-Phong model[2] and Ward model[3] to the measured radiances. However, it takes much time to fit the model to the measured radiances at each point of the object surface, since this fitting operation needs non-linear iterations. For rapid estimation of reflectance map for the measured data, we have already proposed a fast estimation algorithm based on Wiener estimation technique (Wiener method) [4]. Duration time and accuracy for estimation of reflectance map by the method was evaluated by only numerical simulation in the previous paper.

In this paper, we perform experiments to evaluate duration time and accuracy of estimation of Wiener method. Four real objects: acrylic resin, plastic, tile and styrene plastic are measured in the experiment. In section 2, we will briefly review Wiener method. In section 3 and 4, we will describe experimental environments to evaluate Wiener method and results of the experiment, respectively. Conclusion and discussion will be described in section 5.

2. METHOD[4]

We define estimated reflectance map $\hat{\boldsymbol{\rho}}$ which is a column vector, where each element of vector indicates reflectance at each angle of the incident light. The estimated reflectance map $\hat{\boldsymbol{\rho}}$ is calculated by Wiener method from measured radiances $\boldsymbol{v}$ of reflected lights as $\hat{\boldsymbol{\rho}} = G\boldsymbol{v}$. $\boldsymbol{v}$ is a column vector, where each element of vector indicates measured radiance of reflected light at each angle of incident light. G is the estimation matrix which is determined based on Wiener estimation technique to minimize an ensemble average of square error between sample data of reflectance map and estimated reflectance maps. The estimation matrix is

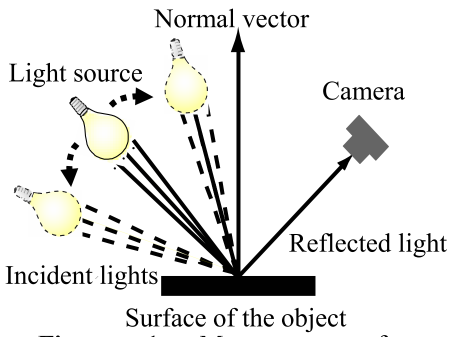


Figure 1: Measurement for reflectance property of the object.

previously calculated based on the sample data. In Wiener method, the reflectance map of objects is estimated rapidly by a linear operation between the measured radiances of reflected lights.

Table 1: Number of model parameters for evaluation of estimation accuracy.

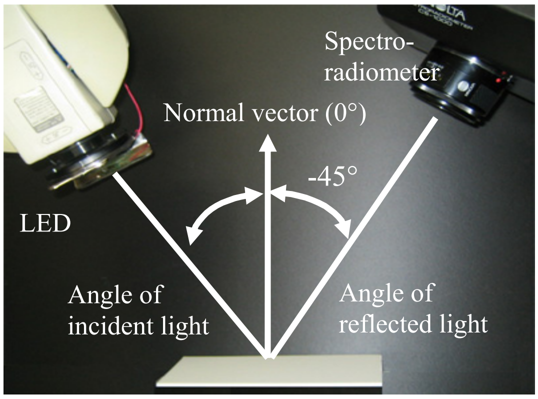
Condition	A	B	C	D	E
Number of sample data	125	50	50	50	8
Number of parameters for diffuse reflection	5	2	5	5	2
Number of parameters for specular reflection	5	5	2	5	2
Number of parameters for surface shininess	5	5	5	2	2

Table 2: Range of model parameters for sample data used to calculate estimation matrix in Wiener method.

	diffuse reflection	specular reflection	surface shininess
Range for all objects	0.159-0.318	0.5-100	10000-50000
Range for styrene plastic	0.159-0.318	0.5-1	100-1000

3. EXPERIMENTS

Reflectance maps of four real objects were measured to evaluate duration time and accuracy of Wiener method. Figure 2 shows the system for measurement of reflectance map. The objects are illuminated by LED from arbitrary direction and reflected radiance is measured by a spectro-radiometer (CS1000 KONICA MINOLTA) in the system for measurement. We assume that the LED is a point light source in this experiment, since size of the LED is small enough. The real objects were illuminated from angle of 10 degrees to 80 degrees at 1 degree intervals where surface normal was defined as angle of 0 degrees. Reflected radiance to angle of -45 degrees was measured by the spectro-radiometer.



Measured object

Figure 2: Measurement system of reflectance map.

Reflectance maps were estimated from a few measured data using the estimation matrix. Using Blinn-Phong model, the estimation matrix was calculated by changing the number of sample data, which was evaluated for accurate estimation in this experiment. Parameters of Blinn-Phong model are coefficients of diffuse, specular and surface shininess. We calculated the estimation matrix under the five conditions of the parameters as shown in Table 1. Table 2 shows ranges of the model parameters for sample data. We changed the number of measured data in the estimation to evaluate the accuracy of estimation by Wiener method. The number of measured data was 2, 5 and 9 as shown in Figure 4.

4. RESULTS

As the first step of the evaluation, we evaluated duration time for the estimation of the conventional and Wiener methods in this section. The duration time of each method with 9 measured radiances are shown in Figure 3. The duration time for each object in Wiener method is constant, since the method can estimate reflectance map from measured data by linear operation. We can see Wiener method can estimate reflectance map several thousand times faster than the conventional method.

As the second step, we evaluated accuracy of estimation by Wiener method. The number of measured data for estimation was changed in the experiment. The RMSEs of the conventional and Wiener methods at each number of measured data for estimation are shown in Figure 4. The RMSEs are normalized by RMSE of the conventional method with 9 measured radiances. The estimation accuracies of the reflectance maps for acrylic resin, plastic and tile were the same for both methods. However, the estimation accuracy of the reflectance map for styrene plastic by Wiener method was low compared with the conventional method, because the reflectance property of styrene plastic is different from that of the other objects. When a few measured data were used for estimation, the accuracy of the estimation was low by the conventional method. In contrast, we can see that the accuracy of the estimation by Wiener method was better, because the reflectance properties of the sample data were available. However, when the reflectance properties of the measured objects and the sample data do not match each other, the accuracy of the estimation by Wiener method will be lower as we see in the estimation of the reflectance map for styrene plastic. To evaluate the influence of the reflectance properties of the sample data for estimation, we changed the sample data used for calculation of the estimation matrix to reduce the estimation error in the case of styrene plastic. The new sample data are calculated in the range of model parameters as shown in Table 2. The RMSEs of the estimation are shown in Figure 4. We can see that the estimation was highly accurate at each number of measured data. From this evaluation, we can see that sample data which have similar reflectance properties to the measured objects must be selected for use in the proposed method.

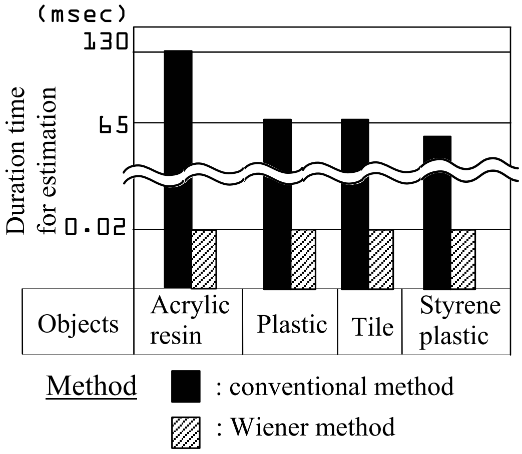


Figure 3: Duration time for estimation of the conventional and Wiener methods with 9 measured radiances.

Finally, we evaluated the number of sample data used to calculate the estimation matrix for accurate estimation by Wiener method. Figure 5 shows RMSEs of the estimation for reflectance map of objects under five conditions in Table 1. The RMSEs are normalized by RMSE of the estimation for each object under condition 1. The accuracy of the estimation is reduced as the number of sample data is reduced. This tendency is the same in the case of acrylic resin, plastic and tile. The estimation accuracy of Wiener method depends on the number of sample data. We can see that the parameter of surface shininess greatly influenced the accuracy of the estimation compared with other parameters.

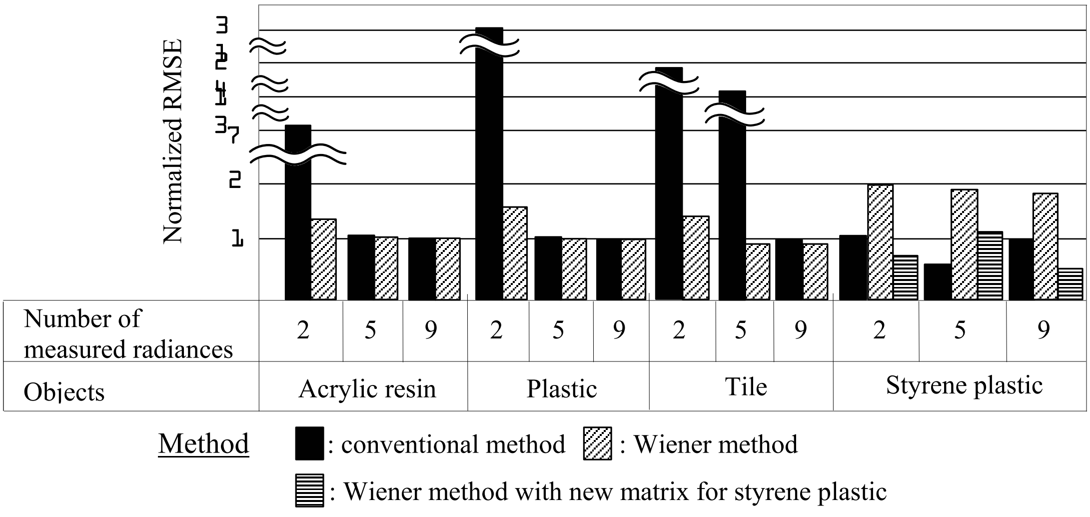


Figure 4: Normalized RMSEs of the conventional and Wiener methods.

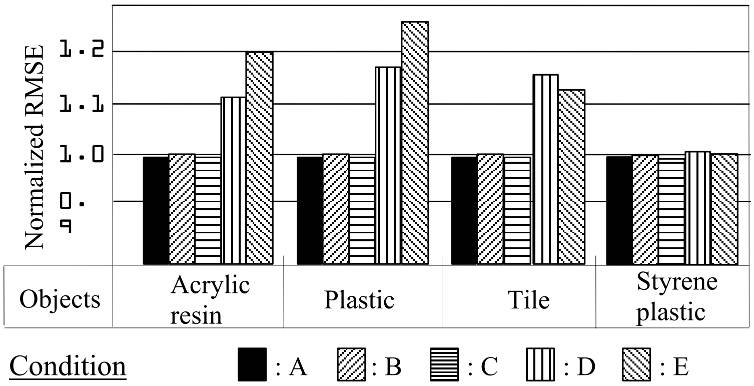


Figure 5: Normalized RMSEs of the estimation for reflectance map of objects under five conditions in Table 1.

It is difficult to estimate a reflectance map from sample data calculated from a few surface shininess, because the model parameter influences reflectance maps with highly non-linear property. However, the accuracy of the estimation does not depend on the number of sample data in the case of styrene plastic. The sample data for the estimation matrix have reflectance properties similar to styrene plastic, because the range of the model parameters calculated for new estimation matrix is small as shown in Table 2. Therefore the number of sample data did not influence the accuracy of the estimation.

5. CONCLUSIONS AND DISCUSSIONS

The duration time and accuracy for estimation of Wiener method were evaluated by the practical experiment. In this experiment, the duration time for estimation of Wiener method was 0.02 and did not depend on measured objects. The accuracy for the estimation of the method was evaluated under two conditions. From these evaluations, we found Wiener method could estimate reflectance map accurately from a few measured data. We also found surface shininess which is a parameter of sample data influenced estimation accuracy of Wiener method. Sample data which have reflectance properties similar to the measured objects must be selected in Wiener method.

In the case of reflectance map estimation of three dimensional objects, surface normals of the objects face into several directions. In Wiener method, the estimation matrix is necessary for each direction of surface normals. One solution to this problem is that sample data facing into any direction are stored in the database. All sample data can be stored in the resource, since the volume of computational memory resource is increasing. However, duration time required to search for the estimation matrix should be considered in a practical experiment. Another solution is to rotate specular directions to 0 degrees by rotating the reflectance maps as Wood et al[5]. In this case, we need only sample data whose direction of specular reflection is at an angle of 0 degrees. However, estimation error may increase at an angle of incident lights which is far from the specular angle. In our future work, we will reproduce three dimensional objects by Wiener method with the above solutions.

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