

## ESTIMATION OF HAZE DENSITY FOR VISIBILITY ASSESSMENT OF LANDSCAPE

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(a) Input haze image



(b) Dark channel image



(c) The transmission rate  $T$



(d) Inappropriate results in (c)

Figure 1. main images in this paper

### ABSTRACT

Beautiful landscapes which people are interested in need to be evaluated quantitatively in tourism industry. For that, we try to evaluate a part of a landscape, “visibility”, quantitatively at first. Visibility of a landscape gets worse by haze, and haze is occurred by scattered light. So the purpose of this research is to estimate scattered light in a landscape for quantitative assessment of visibility of a landscape. Scattered light is calculated by atmospheric light and a transmission rate. We use He’s method to estimate atmospheric light and we estimate a transmission rate using some assumptions or approximation. However the result has a problem that the transmission rate map is not proportional to the depth of a landscape. We are trying to improve the estimation using another approach.

### 1. INTRODUCTION

People have been interested in a landscape since the old days and a landscape has been influenced not only arts and architecture but also a policy and ethical perspective. People are interested in a beautiful landscape especially today. In sightseeing, a beautiful landscape is one of the important factors. Because of this, there are a lot of research which study what makes a landscape beautiful. They are almost based on human subjective opinion or a qualitative method like SD method (Semantic Differential method). However it is difficult to evaluate a landscape correctly using existing qualitative method because a landscape changes diversely in real time. So we try to quantitatively evaluate a landscape which changes diversely. There are several kinds of optical or meteorological phenomena. Among them, haze greatly affects landscape quality, in particular visibility. Haze is caused by particles in the air. When light passes through

particles in the air, it is scattered and it causes haze (Fig.1(a) and Fig.2). Haze density is the amount of aerosol and scattered light depends on haze density. So if we quantitatively estimate scattered light in a landscape, we can get a visibility assessment about the landscape. Finally the purpose of our research is to estimate scattered light from a landscape in order to quantify the visibility.

There are some researches about removing haze from a landscape image. They usually need to estimate scattered light to remove haze, so estimation of scattered light has also been studied. One of researches using single haze image is He's method [1]. This method is using Dark Channel Prior, which means a statistical fact that non-haze images have low intensity at least one channel in a local region. However white color object breaks this rule and causes false estimation of scattered light. One of researches using multi haze images is Joshi's method [2]. Joshi's method uses over 100 images which are captured by fixed camera and 90km away. This method is able to remove the haze clearly by weight average but it does not consider about haze of each image so it is not able to estimate scattered light of every image. One of researches using information other than the image is Schechner's method [3]. Schechner's method uses two kind of polarization filter and remove the haze by calculating the difference of polarized images. However this method needs two polarization filters so it can be applied restrictively.

So we propose a method which estimates scattered light from a landscape using time sequence haze images captured by a fixed camera. Our method needs just only images, and estimates scattered light from each image more effectively than the research using single image. In this point, our research has an advantage.

The landscape which we use in this paper has three properties. 1. Fixed angle. 2. Big change of the depth. 3. Time sequence data.



Figure 2 Non-haze and cloudy landscape

## 2. HAZE EQUATION

Haze usually causes in cloudy weather. So we use equation in cloudy to simplify problem. Haze equation is widely known as Eq. (1):

$$I(x, t) = I_{sky}(x, t)T(x, t) + A(t)(1 - T(x, t)) \quad \dots(1)$$

where  $I$  is a pixel value of captured image,  $I_{sky}$  is reflected light from objects in a landscape,  $T \in [0,1]$  is a transmission rate which means how much light is attenuated by haze,  $A$  is atmospheric light which means the light from most hazy area.  $A$  is also haze color.  $x$  and  $t$  are an index of a pixel and time.

Eq. (1) shows that a haze image can be obtained by sum of attenuated light from objects by haze and scattered light from haze. So scattered light which we should estimate is the term of  $A(t)(1 - T(x, t))$  and we try to calculate atmospheric light  $A$  and a transmission rate  $T$  in this research.

### 2.1. Reflected light from object

Reflected light from objects  $I_{sky}$  can be represented by Eq. (2):

$$I_{sky}(x, t) = r(x)L_{sky}(t) \quad \dots(2)$$

where  $r \in [0,1]$  is a reflection coefficient of each object,  $L_{sky}$  is skylight. Reflected light means reflected skylight on objects in a landscape.

## 3. DEFINE UNKOWN PARAMETERS

In this section, we explain how to calculate each parameters in Eq. (1).

### 3.1. Atmospheric light $A$

We use He's method to estimate atmospheric light  $A$  [1]. A process of He's method is next 3 steps.

- I. Create dark channel image
- II. Select top of 0.1% brightest pixels in dark channel image
- III. Regard the highest intensity pixel in the input image  $I$  among these selected pixels as atmospheric light  $A$

To create dark channel image, we follow two procedure. First, we update the input image to the minimum value of color channel about each pixel. Second, we also update the image to the minimum value in small area (usually  $15\text{pix} \times 15\text{pix}$ ). We show dark channel image (Fig. 1(b)). In Figure 1(b), yellow pixels are the area selected at above step 2.

### 3.2. Transmission rate $T$

We explain how to calculate a transmission rate  $T$ . Organizing Eq. (1) by a transmission rate  $T$ , we obtain Eq. (3):

$$T(x, t) = \frac{I(x, t) - A(t)}{I_{sky}(x, t) - A(t)} \quad \dots(3)$$

We also substitute Eq. (2) for Eq. (3) and we obtain Eq. (4):

$$T(x, t) = \frac{I(x, t) - A(t)}{r(x)L_{sky}(t) - A(t)} \quad \dots(4)$$

So we estimate a reflection coefficient  $r$  and sky light  $L_{sky}$  to calculate the transmission rate  $T$  at following sections.

### 3.3. Reflection coefficient of each object $r$

A transmission rate  $T$  in non-haze frame is one. We substitute  $T=1$  for Eq. (1) and organize it by a reflection coefficient  $r$ . So we obtain Eq. (5):

$$r(x) = \frac{I_{non}(x, t_2)}{L_{sky}(t_2)} \quad \dots(5)$$

where  $I_{non}$  is non-haze frame,  $t_2$  is the number of non-haze frame.

### 3.4. Sky light $L_{sky}$

Sky light is not reflection light from objects and not direct light from a light source. In hazy landscapes, light which reaches a camera from a most hazy area is not reflection light from objects and not direct light. So we regard sky light  $L_{sky}$  as atmospheric light  $A$  and we obtain Eq. (6):

$$L_{sky}(t) \approx A(t) \quad \dots(6)$$

### 3.5. Non-haze frame $I_{non}$

In non-haze landscape, we are able to view far away of it clearly. In this situation, it is assumed that the contour of objects in a landscape is clear. Because of this, we can estimate a degree of haze roughly by calculating an edge of an image. So we calculate the gradient of each pixel using Sobel operator. We regard the frame which has the maximum sum of intensity of edges in all pixels as the non-haze frame  $I_{non}$ . Figure 3 shows input images and the images applied Sobel operator. Actually, the frame which has maximum sum of intensity of edges can be seen clearly.

## 4. RESULT OF A TRANSMISSION RATE $T$

Applying Eq. (5) and Eq. (6) to Eq. (4), we finally obtain Eq. (7):

$$T(x, t) = \frac{A(t_2)}{A(t)} \frac{A(t) - I(x, t)}{A(t_2) - I_{non}(x, t_2)} \quad \dots(7)$$

We show a part of the result  $T$  in Figure 1(c). We ignore the sky region because Eq. (1) does not work in the sky region. In Figure 1(c), black means there is deep haze ( $T$  is close to 1), and white means there is little haze ( $T$  is close to 0). A global feature looks adequate. A distant area which is deep haze is close to black and a close area which is little haze is almost white. However, details of this result are inadequate in Figure 1(d). In same depth, the transmission rate  $T$  must have the same value but  $T$  of the same object is a little different. Therefore the contour of objects appears obscurely. We should consider this problem.

## 5. DISCUSSION

We consider inverse problem about a transmission rate  $T$ . If the depth of two pixels is the same, the transmission rate  $T$  should also have the same value. We set two pixels  $p$  and  $q$  in the same depth in Eq. (1) and we take the difference of pixel value  $I$  between  $p$  and  $q$ . So we obtain Eq. (8):

$$I(p, t) - I(q, t) = T(t)(I_{sky}(p, t) - I_{sky}(q, t)) \quad \dots(8)$$

We organize it by the transmission rate  $T$  as with Section 4. So we obtain Eq. (9):

$$T(t) = \frac{A(t_2)}{A(t)} \frac{I(p, t) - I(q, t)}{I_{non}(p, t_2) - I_{non}(q, t_2)} \quad \dots(9)$$

which suggests that we can estimate the transmission rate  $T$  by designating two pixels of the same depth. We try to calculate  $T$  setting two pixels (Figure 4). We use the dataset whose haze has been clearing off gradually. In first half of scenes, the further (: the more haze) the depth of  $p$  and  $q$  is, the lower value  $T$  has. Now we are trying to define  $p$  and  $q$  stably.

## 6. CONCLUSION

We try to estimate scattered light from landscape images and we have obtained atmospheric light  $A$  using He's method and a transmission rate  $T$  by approximating. However the result  $T$  is not in proportion to the depth in a landscape. We try to improve the result by approaching the inverse process. As the future study, we will evaluate the visibility of the landscape using scattered light. We will make evaluation equation of the visibility.

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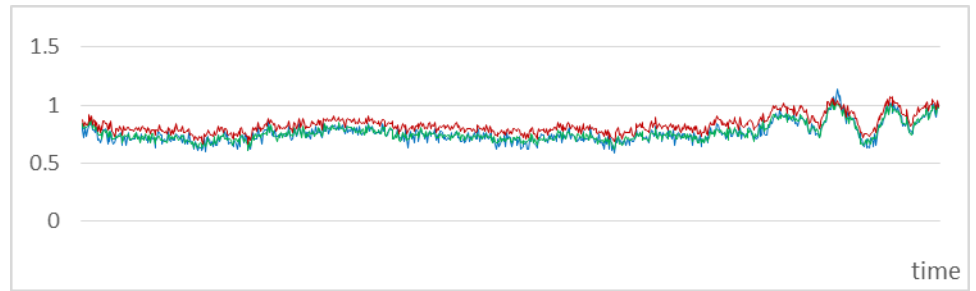


(a) The frame which has the minimum sum of intensity of an edge

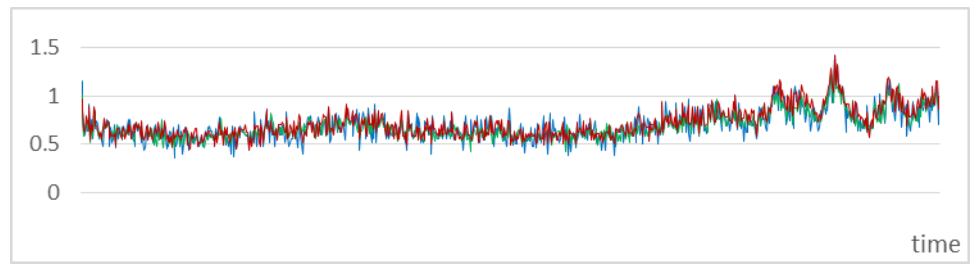


(b) The frame which has the maximum sum of intensity of an edge

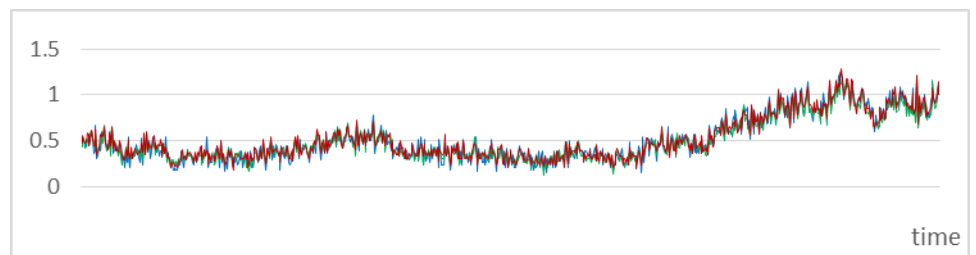
Figure 3 the input image (left) and the image applied Sobel operator (right)



(a) Setting  $p$  and  $q$  in a close white building



(b) Setting  $p$  and  $q$  in a dusky building which is a little further than (a)



(c) Setting  $p$  and  $q$  in an object which is further than (b)

Figure 4.  $p$  (red) and  $q$  (blue) of the same depth (left), time series variation of the transmission rate  $T$  using Eq.(9) (right)