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Atmospheric visibility and Angström exponent measurements through digital photography

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ABSTRACT

This paper presents a low-cost system for the measurement of atmospheric visibility. The measurement setup is composed by a consumer digital camera which is controlled by a computer. The camera acquires photos of the landscape that include natural dark objects. Then the computer calculates the atmospheric visibility based on the apparent contrast, against the background, of these dark objects through the Lambert–Beer law. Two different approaches are proposed so that the system is able to measure the atmospheric visibility both under normal and low visibility conditions. The use of the three color channels of the camera allows the measurement of the extinction coefficient at different wavelengths along with the Angström exponent which is an important parameter in the classification of atmosphere aerosols.

Measurements performed with the developed system are presented and include the atmospheric visibility, the extinction coefficient and the Angström exponent. The results presented correspond to the measurements performed along a week that included a desert dust event. This event dramatically reduced the atmospheric visibility due to the desert dust particles. Angström exponent measurements were performed with another instrument for comparison. Finally, an uncertainty analysis of the measured atmospheric visibility is presented.

1. Introduction

Atmospheric visibility is an important meteorological parameter and its measurement has many applications [1]. For example, visibility is a crucial parameter especially for road [2] and airport safety [3]. It is also important in pollution analysis [4] as high levels of pollution reduce the atmospheric visibility. Additionally, good visibility is essential for sight-seeing based tourism. In [5], Malm described the basics of atmospheric visibility and discussed its effects in American national parks.

It is known that atmospheric visibility is related to the particle extinction coefficient, which is a measure of the amount of scattering and absorption of light by particles suspended in the atmosphere [6]. This relation between visibility and extinction coefficient was first described by Koschmieder [7] and it is based on contrast differences of a dark object and the sky at the horizon. Later it was refined as meteorological range based on a different contrast value [8]. For example, during a desert dust storm the visibility is substantially reduced due to the presence of the dust particles in the atmosphere [9], therefore its forecast can be important [10]. On the other hand, visibility

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can be used for validation of dust forecast models [10] or air quality models [11]. Visibility is also often used as an input parameter for radiative transfer calculations, for instance in the creation of ultra-violet (UV) maps [12].

Atmospheric visibility can be determined by a variety of methods. The easiest and probably oldest method is based on the recognition of a dark object against the sky horizon by a human observer. Visibility can be obtained by measurements of a physical quantity which is then converted into an equivalent visibility. Such instruments are transmissiometers or visibility meters [13]. Even ceilometer measurements are used to obtain the so-called vertical visibility [14]. However, the high cost of these instruments makes them inaccessible to many institutions and low-cost alternatives are highly desirable [15]. In the past, a method to measure the atmospheric visibility using digital photography was presented [16] and a low cost alternative based on a consumer digital camera was proposed in [17]. Additionally, the first measurements of the Angström exponent with a consumer digital camera were presented in [18]. However, the measurement procedure failed when the visibility was low such as when there was fog, rain or desert dust.

In this manuscript, a low cost setup based on a consumer digital camera that is capable of measuring the atmospheric visibility and Angström exponent even when the atmospheric conditions impose a low atmospheric visibility is presented. The measurement procedure consists on acquiring digital images with the camera, which are used for deriving the extinction coefficient and further the atmospheric visibility. The dark pixel approach is used, where 2 dark objects – preferably identical – at different distances appear with a different brightness in the image. When the visibility becomes so low that one of the objects is not visible anymore, a different procedure based on a single object is adopted. Furthermore the 3 red–green–blue channels of the image allow an estimation of the Angström exponent which provides an indication of the prevailing aerosol particle type such as large desert dust particles or small particles originating from forest fires [19].

The system was tested in the field and the results of a weeklong measurement campaign are shown. This week included normal visibility days along with days with low visibility due to the arrival of dust from the Saharan desert. The Angström exponent measurements obtained with the camera system are, for the first time, compared with measurements obtained by a nephelometer available at Centro de Geofísica de Évora (CGE). Additionally, an uncertainty analysis of the measured visibility is presented.

This paper has 5 sections including the introduction and the conclusions. In Section 2, the system setup, measurement principle and methods are described in detail. Section 3 presents the measurement results of the extinction coefficient of the 3 color channels of the camera, the atmospheric visibility and an estimation of the Angström exponent for a full week of measurements that included normal days and days with desert dust. A comparison of the measured Angström exponent with measurements from a different instrument is also presented in this section. In Section 4 an uncertainty analysis of the measured atmospheric visibility is presented.

2. Measurement system

2.1. Theory of operation

Atmospheric visibility can be defined as the maximum distance where a given object is still discernible against the background [13], which occurs when its contrast relative to the background becomes too small to be detected. Reversely, by measuring the contrast, against the background, of a dark object located at a known distance from the camera, it is possible to infer the atmospheric visibility. In this paper, the procedure used to obtain the atmospheric visibility consists on measuring the contrast of an object, obtaining the extinction coefficient and then calculating the atmospheric visibility.

The contrast between an object and the background can be obtained, for each color channel, from the measured intensities through

$$C(x) = \frac{I_B - I(x)}{I_B} \quad (1)$$

where I_B is the background intensity and $I(x)$ is the intensity of the object located at a distance x from the camera. It is known that the contrast of an object against the background varies according to the Lambert–Beer law [13]

$$C(x) = C_0 \exp(-b_{ext} x) \quad (2)$$

where b_{ext} is the extinction coefficient which is a measure of the scattering and absorption of light through the atmosphere. Constant C_0 is the intrinsic contrast of the object relative to the background which, for a perfectly black object, equals unity. Since in nature there are no perfectly black objects, sets of trees, which are sufficiently dark and widely available in rural landscapes, can be used. However, for trees the intrinsic contrast C_0 is not unity and is affected by several factors such as the sun position along the day, the amount of covered sky and the season of the year. Since its value is in general not known, a method using two sets of trees is proposed to remove the intrinsic contrast C_0 from the procedure.

In fact, by considering a tree set at a distance x_1 with contrast C_1 and another tree set at distance x_2 with contrast C_2, as shown in Fig. 1 results, from (2), into

$$\frac{C_2}{C_1} = \exp[-b_{ext}(x_2 - x_1)] \quad (3)$$

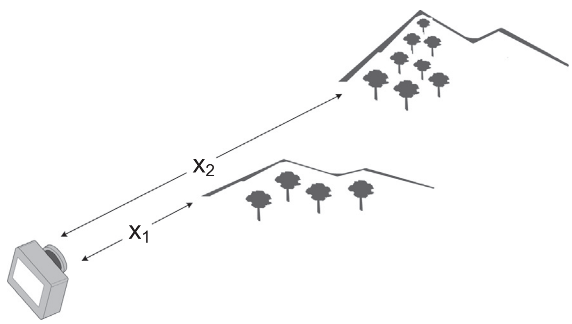

Fig. 1. Visibility measurement principle.