Measurement 43 (2010) 684–689

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Developments of low-cost procedure to estimate cloud base height based on a digital camera

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ARTICLE INFO

Article history:
Received 9 December 2009
Received in revised form 27 December 2009
Accepted 5 January 2010
Available online 11 January 2010

Keywords:
Cloud height
Digital photography
Environmental measurements
Image processing
Aviation safety

ABSTRACT

Cloud height, wind speed and direction at cloud height play an important role in air safety. This paper presents a low-cost system based on digital cameras to estimate cloud base height. It is shown that both wind speed and direction can also be obtained with this system. The method is based on triangulation and uses image registration to identify common cloud features in photographs taken from different positions. The wind speed and direction is obtained from two time-lapsed pictures taken from the same position. The measurement results are compared with LIDAR measurements performed on site.

1. Introduction

Cloud base height, wind speed and wind directions at cloud level are important information for weather forecast and air safety [1]. Especially low level clouds and/or high wind speeds at low altitudes influence the safety of aircrafts in the vicinity of airports and aerodromes. Furthermore clouds are one of the major components in the climate system and hence important for monitoring climate change [2].

In aerodromes, where aircraft movements are performed using Visual Flight Rules (VFR) mode, there are very strict rules with respect to the minimum cloud ceiling which ensures flight safety. However, small aerodromes usually cannot afford the expensive ceilometers that are available at major airports for cloud base height measurements.

In the past, cloud base height was determined using ceiling light, *i.e.*, a narrow light beam illuminating a cloud. Measuring the inclination angle at a certain distance from the vertical light beam gives the cloud base height via triangulation [3]. This method worked best during night time. Cloud base height can also be estimated from radio soundings [4], which are regularly performed by national weather service agencies. In modern times, ceilometers are used, which can operate continuously without human supervision [5]. In these systems, a laser pulse is emitted into the atmosphere and reflected at the cloud base. From the travel time of the laser pulse between the device and the cloud base, its height can be obtained with high accuracy. A Light Detection and Ranging (LIDAR) system can also be used to measure cloud height. These expensive devices are ideal for aerosol and cloud particles study and detection due to the small wavelength of the laser beam. The laser beam is highly reflected by particles and molecules with size similar to its wavelength in a process called backscattering [6].

The advent of low-cost high-resolution digital consumer cameras has led to the development of environmen-

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doi:10.1016/j.measurement.2010.01.007

tal instrumentation based on digital photography. Recently, a digital camera based system was proposed as an easily affordable atmospheric visibility measurement instrument [7]. Cloud base height estimation using whole sky imagers (WSI) was proposed by Allmen and Kegelmeyer [8] and improved by Seiz et al. [9].

In this paper, a method to estimate the cloud base height based on low-cost consumer digital cameras and image processing [10] is proposed. It will be demonstrated that the wind speed and direction at cloud height can also be estimated. The paper is divided into four sections including the introduction and the conclusions. Section 2 describes the experimental setup and the method used for cloud base height estimation. The digital camera is characterized in this section and the image processing steps explained. Section 3 contains the experimental measurements performed in laboratory conditions and also in the field. The results are compared to measurements performed with a LIDAR available on site. A list of factors that affect the uncertainty of the measurements is also presented.

2. Methods and setup

In this section, a method to estimate cloud base height is proposed and described. The procedure is based on triangulation from stereo photography. Angle estimation is needed for the triangulation and knowledge of the camera sensor size is required if the camera is operated at different zooms. Also, to perform the triangulation, the same point or feature must be identified in both pictures. This step is accomplished using image registration.

2.1. Theory

The triangulation procedure used to estimate the cloud base height is depicted in Fig. 1, where two pictures of the overhead sky are obtained from positions A and B on the ground. The distance between the two positions is d and the cloud base height to be estimated is h.

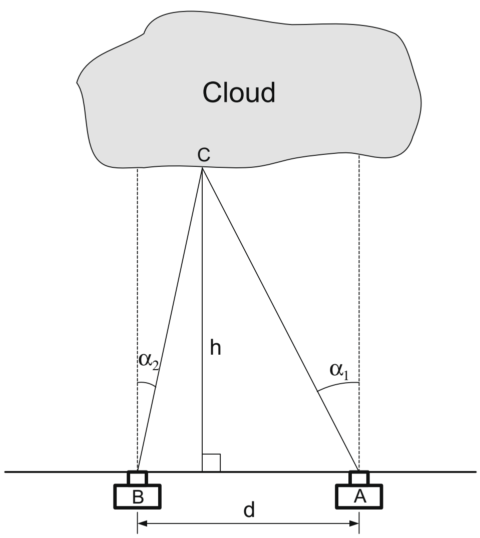

Fig. 1. Triangulation method used to measure distances.

The same cloud feature (point C in Fig. 1) is identified on the pictures obtained from the two sites and the angles α_1 and α_2 between the camera axis and the line connecting the sites to point C can be measured. If the cameras axes are perpendicular to the ground, the cloud base height is given by

$$h = \frac{\cos(\alpha_1)\cos(\alpha_2)}{\sin(\alpha_1 + \alpha_2)} d \quad (1)$$

Since only one camera is used, the pictures from the two sites are not simultaneously obtained. Therefore, the cloud movement due to the wind must be corrected in the second image. This can be done taking two time-lapsed pictures either at point A or point B. From these, the wind speed and direction (at cloud height) can be determined and used to correct the image taken at site B. Note that after this correction, the pictures from the two sites only exhibit a displacement along the direction of the line connecting the two sites.

The distance between sites A and B should be chosen according to the expected cloud height range. A large separation is desired to reduce the uncertainty of the measurement due to the finite number of pixels in each picture and the small misalignments of the two cameras. However, due to the limited field of view of the camera, if the distance between the two sites is large and the clouds are low, then the two cameras will capture non-overlapping regions of the clouds making impossible the task of estimating the cloud base height.

2.2. Camera characterization

The digital camera used is a 6 MPixel Olympus SP-500 UZ with 10× optical zoom (focal distance from 6.3 mm to 63 mm). The pictures were captured at resolution 2816 × 2112.

The triangulation procedure involves the determination of angles relative to the camera axis. This can be done by counting the number of pixels that point C is offset relative to the center of the picture. However, to convert pixels to an angle, the horizontal and vertical angles of view must be determined. Since these angles change with the camera focal distance F it is best to determine the effective sensor size. The zoom can then be automatically adjusted for different cloud heights, thus optimizing the system resolution. Fig. 2 illustrates this procedure for the vertical dimension. An object with known length L is located at a

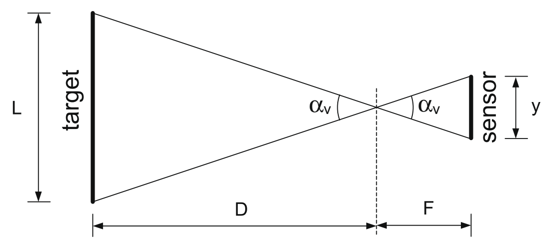

Fig. 2. Sensor size and angle of view definition.