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Advances in cloud base height and wind speed measurement through stereophotogrammetry with low cost consumer cameras

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ABSTRACT

Clouds play an important role in climate change, in the prediction of local weather and also on aviation safety when instrument assisted flying is not available. In the case of aviation safety, the most important parameters are the cloud base height and the amount of cloud cover. Cloud base height can be measured by a ceilometer which, due to its relatively high cost, is not available at many small aerodromes. Recently, a low cost solution, based in digital photography and stereovision has been proposed. This paper describes the developed prototype along with its measuring principle and the recent advances which include more robust but low cost hardware, an automated calibration procedure based on photos of stars that exhibit no parallax and an automated procedure to find the cameras orientation relative to geographic north. Measurements of the cloud base height by the proposed system are compared with measurements obtained by a LIDAR for validation. The wind speed and direction relative to geographic north are also measured and compared with results from a weather model. Finally, an uncertainty analysis of the measurement system is presented.

1. Introduction

Clouds play an important role in many aspects of our lives, by influencing the global climate and hydrological cycle [1], the amount of solar radiation that reaches the Earth's surface [2], the weather prediction and the safety of aircraft under visual flight rules [3]. Although national weather services acquire and report the amount of cloud cover, the approximate cloud base height and cloud type, the spatial coverage and temporal resolution of those measurements is usually very limited.

Climate change studies, quality increases in weather forecasts, or reliable prediction of the amount of energy produced in solar farms require that measurements with improved spatial resolution are performed. This usually means that an upgrade or extension of measurement networks is needed. Ground-based instruments that are available for the measurement of cloud base height include radars [4] ceilometers [5,6] and LIDARs [7] which are usually very expensive, in particular, if installed in a network. To avoid the usual high costs of such extensions, automated observation systems that are easily deployed, low cost and low maintenance are required.

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The height of a cloud is an important parameter because it is an indicator of the cloud type [8–10]. High clouds are formed from ice crystals whereas low clouds are formed from water drops. Such different clouds types have, in turn, a very different influence on the radiation field and consequently on the climate. The height of the clouds is also important for the three-dimensional radiative interaction of aerosols and clouds, since the radiative effects vary strongly depending whether the cloud is above, below or even embedded in an aerosol layer [11].

The low cost system for cloud base height measurement, described in this paper, is designed for aerodrome applications but can be used for weather or climate observations as explained above. Many small aerodromes do not have the facilities needed for instrument assisted flying and, thus, operate under Visual Flight Rules (VFRs), which impose very strict limits on atmospheric visibility, the amount of cloud cover and the cloud base height [3]. These rules ensure the safety of the pilots, aircraft and also the population near the aerodromes. For example, if the cloud base height is above 1200 m there are no restrictions in aerodrome operations. However, many small aerodromes do not have the financial resources to operate the expensive ceilometers available in larger airports for the measurement of the cloud base height, so a low cost alternative is needed.

In the past, a system using digital cameras with wide angle lenses and a sophisticated mounting system for accurate camera alignment was developed to measure cloud base height and map the cloud cover [12]. More recently, a system with two digital cameras coupled to fish-eye lenses was used to measure alto cumulus and cirrus clouds [13]. A review of the state of the art in the measurement of cloud base height has been presented in [2]. The first results of a system based on less expensive consumer cameras for cloud height measurements have been presented in [14,15].

In this paper, the recent improvements on a digital camera based prototype for the measurement of cloud base height through stereophotogrammetry are presented along with its principle of operation and image processing algorithms. The basic system, presented in [16], is capable of measuring the cloud base height and wind speed and direction at cloud height. It does not require an accurate alignment of the cameras because a manual in situ calibration procedure based on the visible stars was developed. In this paper, the manual calibration procedure is replaced by an automated one, thus allowing a statistical analysis of the calibration method. Furthermore, the absolute alignment of the cameras base line relative to geographical north is also automatically estimated using photographs of the overnight stars circular trails. Hardware changes aimed at reducing the cost of the system and improving its robustness to the environment are also detailed.

After calibration, measurements of the cloud base height and wind speed and direction were performed. For two different days, the cloud height measurements of cloud layers at different heights are compared to measurements obtained with a LIDAR available at Centro de Geofísica de Évora (CGE). The wind speed and direction at cloud level measurements were compared to results obtained from a weather model [17] due to the unavailability of measurements at those heights. An uncertainty analysis of the cloud height and of the wind speed and direction measurements is also performed following the guidelines of [18].

The paper is divided into five sections including the Introduction and the Conclusions. Section 2 is devoted to the principle of operation, hardware and algorithms description and calibration procedure. In Section 3, the measurement results are presented and compared with LIDAR measurements and weather model outputs for system validation. Finally, the uncertainty analysis is detailed in Section 4.

2. Measurement system

This section describes the triangulation principle and the hardware used in this paper to measure cloud base height as well as wind speed and direction at cloud base height. The stereovision digital camera system orientation and inherent misalignments require that the full setup is calibrated. The calibration procedure is performed through photos of the night sky which allows the automatic determination of the cameras misalignments and system orientation. At the end of this section, the image processing algorithms needed for the measurement of the cloud base height and wind speed and direction are described.

2.1. Working principle

The triangulation principle has historically been used to measure inaccessible distances and can also be used to measure the base height of clouds. Two digital consumer cameras pointing vertically and separated by a base distance d are placed as shown in Fig. 1. The two cameras are simultaneously triggered to acquire photos of the overhead clouds with features inside the angle of view of both

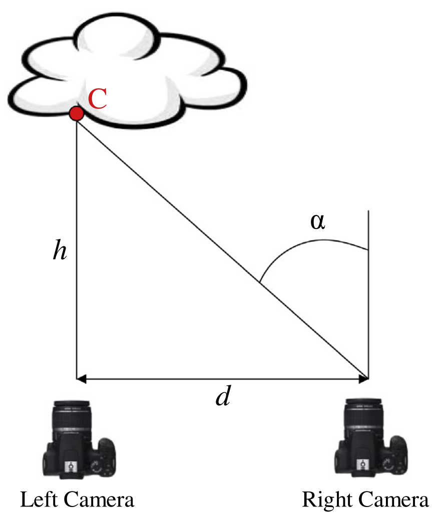

Fig. 1. System geometry for the measurement of cloud base height through triangulation.