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Short-term DNI forecasting using a sky imager

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1. Introduction

Interest for solar resource assessment and forecasting has been growing rapidly these past few years. Such enthusiasm comes from the necessity of improving quality of solar resource data to justify investments in solar technologies. Indeed, uncertainties on solar resource availability and variability are the largest sources of errors in power plant production estimates. Moreover, real-time solar resource assessment and forecasting would help plant operators to better manage their solar fields, and thus improve the plant efficiency, while improving the expected benefits. Among the different factors impacting solar energy production, transient clouds definitely influence the most Direct Normal Irradiance (DNI) and are responsible for large ramp events. Clouds' position and motion must be known in order to anticipate these events. At a power plant scale, sky imagers are the most suitable devices to deliver high resolution maps of the cloud distribution. In that context, PROMES-CNRS has decided to install an experimental unit on the laboratory roof in order to monitor the whole sky. The present paper focuses on the development of a short-term DNI solar forecasting tool, using a sky imager, in order to ultimately improve the management of CSP plants.

2. Experimental setup

The sky imager consists in a 4-megapixel color camera equipped with a fisheye lens and protected by a waterproof enclosure (Fig. 1). Color images are collected every 20 seconds at a resolution of 1580 x 1580 pixels, with 10 bits per channel. This is a second-generation prototype that is designed to outperform the first one installed at PROMES-CNRS since mid-2013. Among the different improvements, we find: a stronger neutral density filter (ND 2.0), a faster acquisition frame rate (≈ 30 fps), a higher bit depth, a camera temperature controller and, more generally, a full access to camera settings. The system is not equipped with a solar occulting device which is frequently used to reduce the light intensity reaching the sensor [1]. Indeed, although this device improves the sky visibility by reducing pixel saturation, it occults the circumsolar area, which provides vital information about the very short-term solar irradiance fluctuations. This issue is avoided by the sky imager because it is able to generate high dynamic range (HDR) images in order to fully capture the range of irradiance produced by sun and clouds.



Fig. 1: Overview of the PROMES-CNRS sky imager and two examples of HDR snapshots.

3. Model

The DNI (I) can be divided into two components: the clear-sky DNI (I_{cs}) and the clear-sky index (k). The former represents the DNI received at ground level, when no cloud is occulting the sun. The latter reflects the influence of clouds on the clear-sky DNI. We thus have:

$$I = I_{cs} \times k \quad (1)$$

The proposed concept to forecast the DNI is mainly based on forecasting these two terms. First, a new approach has been proposed to forecast the clear-sky DNI I_{cs} [2]. It combines an existing empirical model, with a new methodology for the computation of atmospheric turbidity. It takes advantage of the fact that changes in atmospheric turbidity are relatively small throughout the day in comparison to changes in DNI, even when the sky is free of clouds. Second, several methodologies have been developed in order to forecast the clear-sky index k . One of them uses information provided by our sky imager, i.e. the cloud detection [3] and the cloud motion estimation [4]. The cloud detection is based on an algorithm able to generate in real-time clear sky images using images acquired with the sky imager. This algorithm allows the background non-uniformity of the sky to be removed. For this reason, it outperforms standard thresholding techniques [1]. Regarding the cloud motion estimation, a block matching technique is used between two successive images in order to estimate the representative speed and direction of clouds. Finally, from this information, several areas of interest moving towards the sun are deduced (Fig. 2). They have been considered in our study to forecast the clear-sky index and then the DNI.

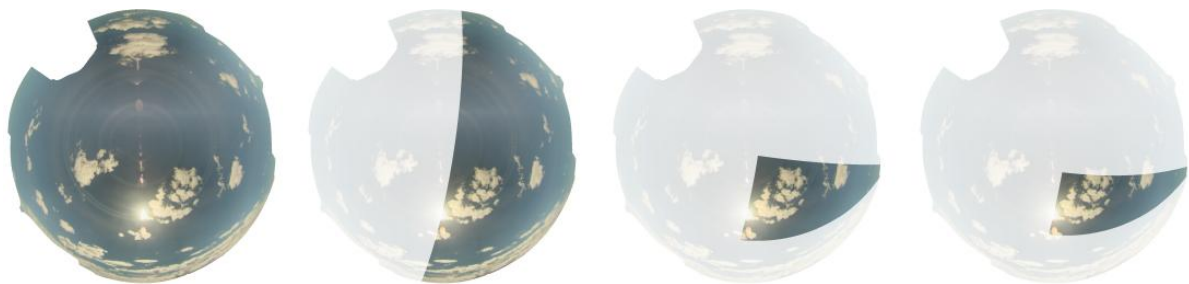


Fig. 2: Example of four areas of interest considered in the study.

4. Results

Three types of DNI forecasting models have been tested and compared using one-year of data. The first category corresponds to two models of reference, i.e. a persistence applied on DNI and a persistence on atmospheric turbidity. The second type of models considered in this comparative study uses information provided by the sky imager. According to the required forecasting time horizon and the state of the atmosphere, an appropriate area of interest in the image is considered to forecast the clear-sky index. The third category is a hybrid model derived from artificial intelligence techniques which combines properties of the two first types of models. In fact, the more the time horizon is high or the cloud cover important, the more the hybrid model uses information provided by the sky imager. Conversely, the more the time horizon is low or the sky free of clouds, the more the hybrid model uses the persistence on the clear-sky index. Because of its structure, the hybrid model outperforms the models of reference whatever the considered forecasting time horizon. In addition, these improvements are especially significant as the forecasting time horizon increases.

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