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A vision-based innovative system for terrestrial meteorological and solar measurements

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Abstract

An innovative and flexible system for performing terrestrial meteorological and solar measurements based on computer vision technology and edge artificial intelligence is presented here. The proposed reference architecture hardware was developed in the context of the DeepSky project and is able to deliver a fully working system for acquiring all sky images from different vision modalities and monitoring the meteorological and solar variabilities through the inspection of cloud instances in real-time. The corresponding software is able to provide cloud classification feedback, coverage percentage and depict weather statistics though a novel and efficient user interface.

Keywords: Digital all-sky images; Ground-based cloud recognition; Weather station networks; Machine learning; Edge Artificial Intelligence.

1. Introduction

During the last decade, devices for digital imaging of the sky have been introduced, operating both in the visible and thermal infrared spectrum as well as equipped with a maximum 180-degree lens (fish-eye) that can give a overall view of the firmament [1]. The initial trigger was a series of publications that highlighted the capabilities to analyze digital images of the sky to estimate the amount and type of cloud coverage [2] and also cloud speed and height [3]. Olivier Boucher won the Harry Otten Award for Innovation in Meteorology in 2015, using digital images of the sky to measure atmospheric wind and humidity at high altitude. Recently, the first efforts to observe clouds in the thermal infrared are accompanied by specific advantages: observation also at night, avoiding problems from overexposure near the Sun area or reduced contrast, better appreciation of high and thinner (and therefore more difficult to detect) high clouds, estimation of the optical depth of clouds and watering water. Additionally, it is possible to use digital imagery for rain detection [2] and visibility estimation as well as the presence of fog. In the field of solar energy, digital cameras have used to replace measurements from pyrometers [4], for short-term predictions of the solar potential [3] and for the estimation of the distribution of sky radiation at various polar angles.

2. DeepSky monitoring system and reference architecture

DeepSky is a novel weather station system based on the technology of commercial cameras. Unlike other systems, it makes use of simultaneous analysis of visible and infrared data, resulting in the estimation of numerous geophysical parameters in real-time through the integration of all the necessary computational tools in one camera without requiring several separate instruments. Its innovation lies in drastically reducing the cost of terrestrial measurements while maintaining quality and ease of use. In addition, it is the first system that combines visible and infrared images, estimates from propagation models of radiation, and computer vision and deep learning techniques to provide geophysical variables, both day and night.

2.1. DeepSky reference architecture

DeepSky system is designed and implemented in a way to incorporate the following basic principles: (i) Flexibility: allowing relatively simple or reasonable cost adaptation to new conditions or operational requirements, (ii) Reliability: this is a critical factor for the recording and evaluation of atmospheric and meteorological measurements of the system, (iii) Maintenance and updating: its operation, maintenance and updating / upgrading is performed by external entities and (iv)

User-friendliness: utilizing a simple user interface (UI) to ease operational use by amateur meteorologists.

Four subsystems are integrated in the overall architecture that implement both the UI and the infrastructure for managing the data and performing the analysis in real time for calculating the various atmospheric and meteorological quantities through the equipped sensors. First, the sensor subsystem is responsible for operating the system's sensors, recording and storing data/metadata. Thus, it includes a database management system and a file system for storing images (optical - thermal), temperature and humidity as well as metadata along with analysis results. The second is the algorithm subsystem that includes the data processing containers for the estimation of atmospheric and meteorological quantities. The third one is the coordination subsystem (CORE) that has the controlling role since it provides the interfaces to the users (via the UI subsystem) with the embedded devices and accepts and schedules the data processing requests for execution in the other subsystems. Finally, the UI subsystem is the way the user controls and adjusts the system as a whole, from the sensitivity of the sensors up to the calculation of geophysical quantities. A Web UI is served locally on a computing unit (or an edge device) for displaying a visual representation of the recording cameras for a certain period of time, as well as the results of processing the image data in the form of metadata which will be updated in real time with the captured data. Fig. 1 shows in detail the interconnection of the cameras in each processing step to which the rest of the meteorological measurement recording sensors will be driven. End users can connect to the system via Secure VPN, which accesses analytics (metadata) through an application programming interface (API).

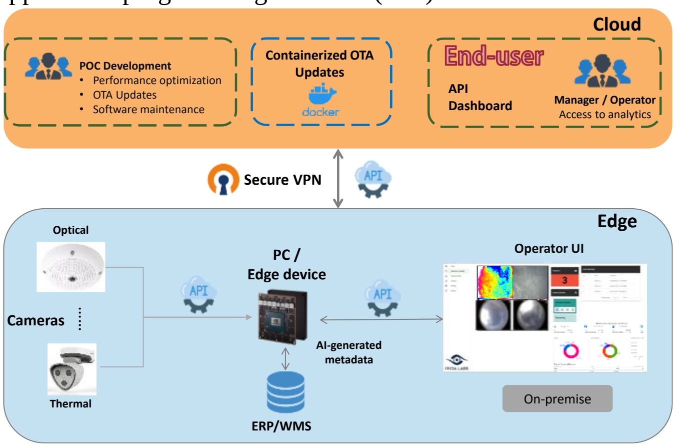

Fig. 1. DeepSky system reference architecture.

2.2. DeepSky sensors

Based on the architecture of the four subsystems mentioned above (i.e. sensors, algorithms, coordination and user interface) two DeepSky variants are implemented. A high-end system consisting of high-precision and high-resolution sensors combined with a high-end PC equipped with multiple graphics cards (GPUs) and state-of-the-art CPUs to enable both model training and the estimation of all necessary parameters, and a low-end variant that is more economical due to lower technical specifications, integrating the machine learning functionalities (through an edge device i.e. Nvidia Jetson Nano) to calculate the atmospheric and meteorological parameters in a more practical and portable use.

The DeepSky prototype (Fig. 2) includes: (a) A Mobotix Q26B optical camera that integrates an optical sensor for capturing all-sky images, (b) A dual camera Mobotix M73 (only at high-end system) having in one configuration a thermal and an optical sensor, providing registered images with a small scaling factor between them, being able to move to some predefined positions using a specialized mechanism, (c) A HikVision DS-2TD1217-3/V1 camera (at the low-end system), which is an IP camera that also includes a thermal and an optical sensor with lower resolutions and (d) the temperature and humidity sensors located in the same configuration.

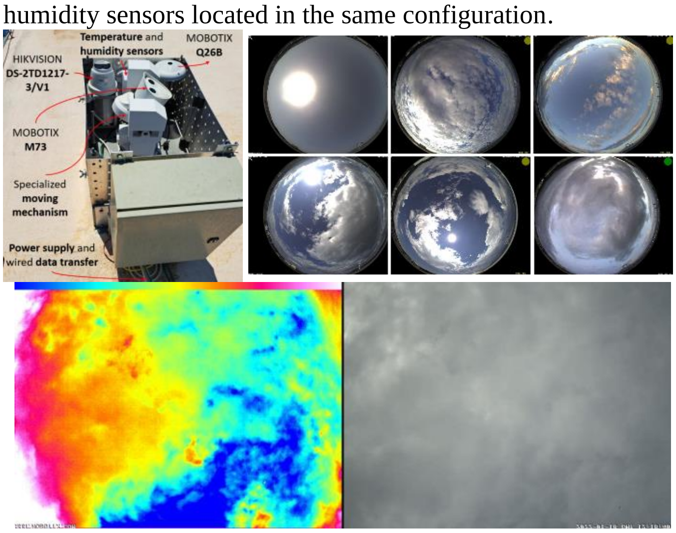

Fig. 2. Top left: The DeepSky system utilizing optical and thermal cameras sensors along with temperature and humidity sensors. Top right: Sample images from the Mobotix Q26B optical camera. Bottom: Sample image from the dual Mobotix M73 camera (IR on the left and optical on the right side).

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