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# Continuous sky digitalization using images from an all-sky camera

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**Abstract.** The designed networked system captures and stores high and medium resolution sky images every 2 seconds. The IP camera employed is low-cost, omnidirectional, and its images are accessible from any point with Internet connection, both in real time and to a database, thanks to the configuration of a VPN network. The images obtained by the camera can be utilised for a variety of purposes but are of particular interest for those applications where a large volume of separate images is required for the characteristics of the sky, as the system also provides an innovative method of measuring solar energy, which provides an unambiguous view of the cloud state on any given day.

**Key words.** All-sky images, Real-time network system, Solar energy measured, Meteorology, Astronomy, Renewable energy, Tourism.

## 1. INTRODUCTION

Nowadays, full-scan images of the sky in real time have become a popular method of monitoring the sky and its conditions. Quantitative analysis of these images can be archived and performed very efficiently, facilitating appropriate decision-making by professionals in various fields due to the optimal sky conditions offered by all-sky cameras, which can even provide images in bright sunny conditions, a fact that enormously contributes to the processing and analysis of these frames.

In this sense, all-sky cameras are a way of providing a sky view that complements satellites, where clouds can be identified more accurately and with a higher temporal resolution.

The applications of these systems are wide, as there are several sectors in which the study of cloud cover is of vital importance. For example, they can be used from educational tools to sources of valuable data in fields such as meteorology, astronomy, forecasting systems in renewable energy plants [1], cloud state detection for airports, tourism, research, etc.

This document presents a system that is considered low cost, as well as efficient and reliable, with high resolution image and that has, as an added value, a backup system that supplies daily curves of generated solar energy, which facilitates the detection of the sky state on a given day by observing this curve. Consequently, these features make this system an ideal data source, demonstrating a high degree of robustness and of incalculable value, especially for educational purposes and various research subjects.

In this regard, this study represents a cost-effective and of a general purpose variant in the literature, and also could be of particular support for future research requiring a network-accessible, accurate and robust sky imaging system. However, many studies have opted for professional cameras specialised in meteorology, which are not very affordable. For example: [2]-[4].

Despite the difference in cost, the images of the sky obtained with our IP camera are more than acceptable in terms of resolution and sharpness.

Nevertheless, there are many researchers that opt for a more economical alternative of the high-resolution digital type, but not accessible from Internet, which is not practical or suitable to support long periods of weathering; as in [5], [6] and [7].

It is also worth mentioning the high utility that the photovoltaic system incorporates for simple detection of the sky state. This tool greatly simplifies the selection and subsequent labelling of images in those investigations that attempt to classify the sky situation by means of Machine or Deep learning techniques. These processes require a large volume of images and saving time and effort can be very significant. Examples of studies applying machine learning techniques to sky images: [8]-[11].

This paper describes in detail how the data in this system is acquired, analysed and archived. These processes are structured as follows: Section 2 presents the optical instrumentation (image acquisition) and also the elements necessary for the correct handling and storage of these images. In addition, the PV backup system is also detailed, as well as the interpretation of the power curves obtained for an easy access to the different sky states captured and stored. Then, in Section 3, the image processes on the route of digitisation and archiving are explained, and the results are shown in Section 4. Finally, the conclusions of this proposal are grouped in Section 5.

## 2. DESIGN OF CAPTATION SYSTEM

The entire system is integrated in such a way that the sky images are acquired at different resolutions and in chronological order. Moreover, a system for reading diffuse solar irradiance received is included in order to have access in a simple way to images containing a specific state or sky conditions (clear, partly cloudy or totally cloudy).

For this purpose, the equipment selected for the implementation of the image capture and archiving system is: a Vivotek FE9381-EHV omnidirectional IP camera; a Dell server; a TP-Link wireless access point; a 10/100/1000 switch; a Raspberry Pi 3 computer board; an external storage hard disk, and finally, a PV system for obtaining data on the photovoltaic power generated. The complete system is shown in Figure 1.

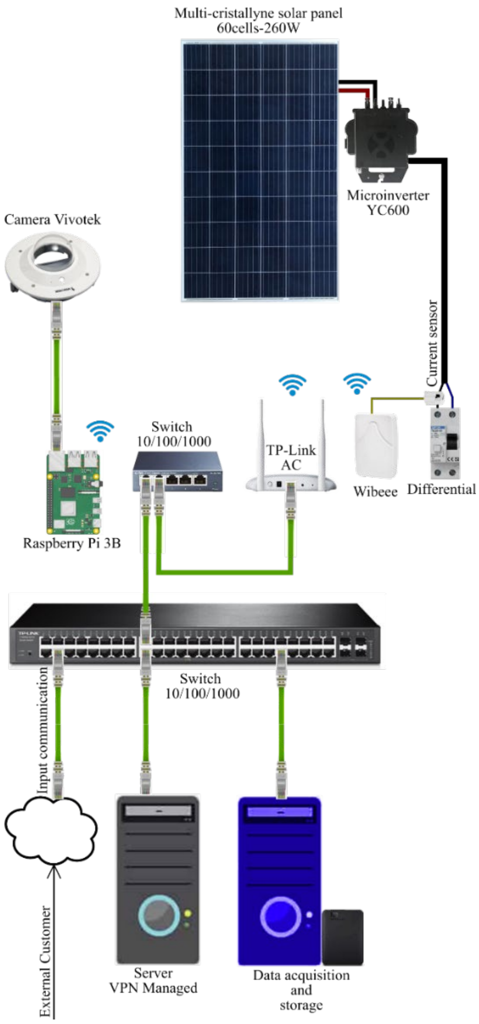


Fig. 1: System schematic.

As can be seen, the system is designed for locations that allow an adequate location of an omnidirectional camera next to a photovoltaic panel, in such a way that shadows and the appearance in the images of buildings and/or objects are voided.

In turn, those devices that are connected wirelessly must be logically placed within the coverage provided, while those that are connected via data cable may be situated at any other point enabled by the infrastructure as indicated by the symbol that separates the cable line that connects the two switches shown in the figure.

And finally, in the following subsections, a more detailed technical analysis of each element that forms the system is added, as well as those indications to consider that, in our experience, must be considered to obtain satisfactory results.

### *A. IP camera Vivotek*

VIVOTEK FE8391-EHV is an omnidirectional IP camera designed for outdoor video security applications. Its low cost in comparison to the specialized all-sky cameras for meteorological applications, as well as its weather resistance (IP66) and dome inclusion, make it perfectly suitable to focus on the sky. In addition, thanks to its high resolution (5 MP), fisheye lens (360° surround view), IR cut filter (day/night function) and built-in WDR technology for high contrast environments, high coverage and contrast images of the sky are obtained both day and night. . For more information, refer to the manual [12].

Based on our experience, a very short minimum shutter time of the camera is of vital importance in order to avoid saturation of the CMOS sensor at the moment of direct focus on the sun. This time on the VIVOTEK FE8391-EHV is sufficiently short (1/32,000 sec.) to acquire an image that is not saturated by the excessive brightness captured.

Another aspect to consider is that the Vivotek FE9381-EHV does not include its own power supply. That is because these are network cameras that can be powered by an external power adapter or, more commonly, by the network through Power over the Ethernet (PoE) technology. In order to avoid multiple power supply elements that would overload the space dedicated to the entire system management and storage (300x400x160 mm watertight box), we decided to develop our own power supply that would provide sufficient voltage for both the camera (12V) and Raspberry Pi (5V).

Logically, and whenever possible, important aspects in its installation are: on the one hand, a location that avoids shadows and the recording of elements that can block the totality of the sky, and on the other hand, the camera must be attached to a horizontally levelled surface, and if possible, also oriented to the north in such a way that the sun appears on one side of the image and disappears on the other for simplicity in the image processing.

This orientation process considerably facilitates, for example, the calculation of sun paths throughout the year, as carried out, for instance in [13], and is shown in Figure 2.

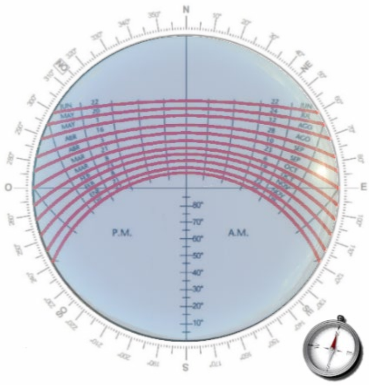

Fig. 2: Solar chart in the image of the whole sky.

No less important than the installation performed, and the appropriate manual adjustment of the camera's parameters is the periodic cleaning of the dome to obtain images suitable for digital image processing.

This aspect becomes crucial particularly in adverse weather conditions because the visualisation of drops or dust in the images complicates especially, for instance, the adequate distinction of clouds from the sky or the correct detection of the aerosol concentration in form of dust in suspension on the sky.

Therefore, it is recommended to maintain a compromise between accessibility to the camera location and the highest point at which the camera can be placed, since it has to be accessed in a safe way with a certain frequency.

### B. *Single Board Computer Raspberry Pi 3*

Since the VIVOTEK FE8391-EHV IP camera does not have WiFi support and does not allow managing communications by means of the VPN network, it is necessary to use a Raspberry Pi interface device to fill this lack. Hence, the Raspberry Pi 3 card provides accessibility to the camera for all users connected to the VPN wirelessly.

In addition, a 16GB SD card is included to support the Raspbian operating system.

For more technical information visit [14].

### C. *Wireless Access Point*

Since a data communication infrastructure is not normally available via cable to a location that enables an ideal panoramic view for the camera, the image transfer is carried out wirelessly thanks to the WIFI module included in the Raspberry Pi 3 platform.

In our study, having a WIFI access point in the room closest to the camera's location (TP-Link, 802.11 bgn), allows a data connection with the images captured by the Raspberry Pi without any need to use a data cable, with all that this implies, both in terms of infrastructure and visual impact.

### D. *Server*

It is responsible for managing communications within the VPN network. Therefore, it gives the user access to the different devices connected to it, which in our case, access is to the web interface of the camera or to the images saved on disk. The main specifications of the server used are detailed in Table 1.

Table 1. Server specifications.

| Item | Description |
|---|---|
| Processor | Intel(R) Xeon(R) |
| CPU(s) | 2 |
| Memory | 2 GB |
| Hard Disk | SSD 512 MB |
| Operating system | Linux (Debian) |
| Architecture | X86_64 |

### E. *Image acquisition and storage equipment*

This includes all the equipment necessary to create and store a medium-resolution version of the images and the high-resolution images in an orderly sequence. Its most relevant specifications are attached in Table 2.

Table 2. Acquisition and storage equipment specifications.

| Item | Description |
|---|---|
| Processor | AMD Phenom(tm) II X4 955 Processor |
| CPU(s) | 4 |
| Memory | 8 GB |
| Hard Disk | SSD 256 MB |
| External Hard Disk | SSD 4 TB |
| Operating system | Linux (Debian) |
| Architecture | X86_64 |

### F. *Storage Hard Drive*

As in the case of the Raspberry Pi, a wrong choice of storage disk can cause it to act as a bottleneck in terms of the computational speed of the system, so it is important that the file system to be utilised supports high speed (as in our example, EXT4). Furthermore, the storage capacity will depend on the number of images to be saved, which will vary depending on the application that the system is intended to be used for. In our demonstration, images are saved at maximum and medium resolution (400x400) every 2 seconds, so we decided to add a 4GB disk to the system.

### G. *Indirect solar irradiance measurement sensor*

As an added value, in the system for capturing and storing images of the entire sky, is included the possibility of knowing the location of captures that contain a desired sky condition without having to visualise the images of each day. This aspect is of high value, especially in those applications in which it is interesting to classify various conditions that may occur in the sky, due to the necessity of separating the database for each condition.

This operation can be particularly tedious when dealing with a large number of captured images. In the proposed system, this action is reduced to the visualisation of the power curve generated in a day from a photovoltaic panel installed next to the camera.

To acquire these curves, a clamp ammeter is required to get the current values generated in the photovoltaic panel (after conversion from 24V to 220V in the inverter). These values are managed and sent to the Wibeee cloud platform server, from which the daily consumption curves of the photovoltaic installation can be displayed, among other aspects. More information in [15].

The most important technical specifications of both the SunMax PV panel and the AP systems microinverter are shown in Table 3.

Table 3. PV panel and microinverter specifications.

| Item (PV Panel) | Description |
|---|---|
| Model | SM-SP-260W-DC-EU |
| Number of cells | 60 |
| Cell type | Multi-Crystalline |
| Nominal Power | 260 W |
| **Item (Microinversor)** | **Description** |
| Model | YC600 |
| PV Module Power | 200Wp-365Wp |
| Number of cells supported | 60-72 |
| Maximum output power | 300W |
| Standard Test Condition Irradiance (STC) | 1000 W/m$^2$ (25º) |
| Cell Temperature | 25º |

## 3. DIGITALIZATION: STORING ALL-SKY IMAGES

To carry out the capture and storage of images by means of the equipment detailed in subsection *E*, two scripts are utilised: on the one hand, to manage the capture of images obtained from the camera, and on the other, to classify and archive them in an organised and intuitive manner. All this is achieved using the languages and protocols specified in Table 4.

Table 4. Software setup.

| Item | Details |
|---|---|
| Base system | Linux |
| Development software | C, scripting Bash and Python |
| Graphical user interface | Console |
| Secure networking | Security Shell (SSH) |
| Timekeeping | Network Time Protocol (NTP) |
| ASC control | All-sky camera software |

Initially and as mentioned, the first script carries out the proper image acquisition. Utilising Bash language (Borune-again shell) and the FFmpeg library, it is possible to communicate through RTSP protocol supported by the sky camera. Once the communication is established, time, day, month, and year data are collected for future storage in chronological order.

As discussed above, the above task provides images every 2 seconds, and then the second script starts to play (using Python 3 language), whose function is to store them in the corresponding target by utilising the directory structure in year/month/day sequence, as shown in the example in Figure 3.

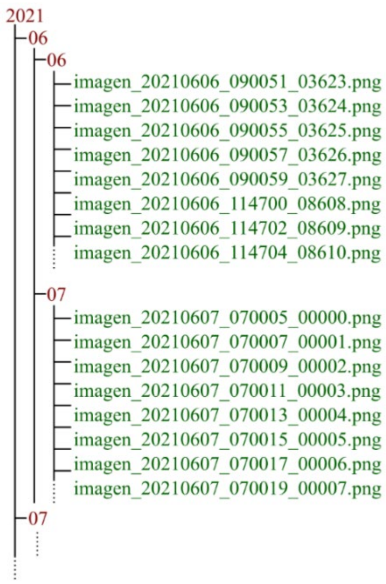


Fig. 3: File storage structure.

In turn, in each of the final directories for each day, a second directory is created to store images resized to 400x400 pixels. This is done for those applications where computational time is critical, and possibly a lower resolution of the images would provide more satisfactory results.

## 4. RESULTS

Once the system has been designed and the access to the captured images has been configured, the result of the chosen IP camera location is as shown in Figure 4.

Fig. 4: Vivotek FE8391-EHV mounting location

As can be seen and as previously recommended, the camera is horizontally levelled, with no buildings or obstacles to cause shadows or interfere with the sky captures. As shown in an example in Figure 5.

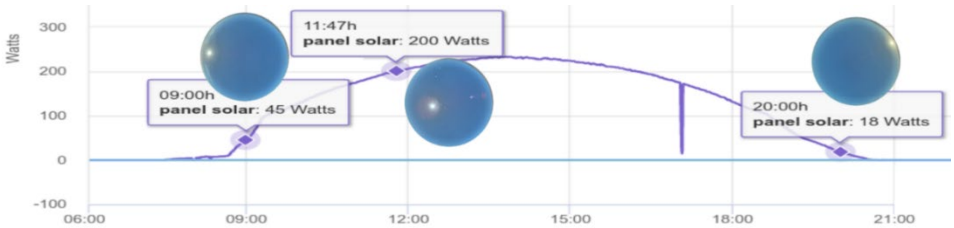


Fig. 7: Clear day curve.

Fig. 5: 400x400_20210606_210002.0100_25199.png.

In addition, access is easy to carry out the periodic cleaning of the protective dome and the photovoltaic panel, which was placed horizontally to monitor the complete line of the sun.

This figure demonstrates the visualisation of a file saved and stored on the external hard disk as detailed in the previous section. However, if you wish to access the camera in real time via VPN and through the web interface provided by Vivotek, it will be as simple as connecting to the network and entering the camera's IP into the web browser in which you wish to view it. The result of this sequence of steps is shown in Figure 6.

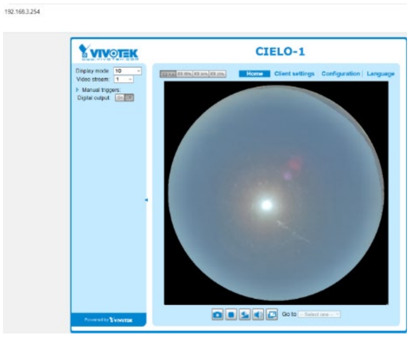


Fig. 6: Vivotek web interface.

Referring to Figure 3, the data volume amounts to over 4 months of recording at two different resolutions every 2 seconds, resulting in a total of over 5 million all-sky images. This fact can give an idea of how valuable a simple sky monitoring system could be.

In addition, the power curves acquired through the Wibeee web platform (see section *G*), provide a perfect visualisation to pre-determine in advance in which cloudy state the sky is, as shown in Figure 7, the shape of the curve contains no fluctuations in radiation, except for a drop to 0 at 17:30, which may be due to a failure of the inverter or the Wibee datalogger (see Figure 8). It can also be observed that its maximum value is close to 260 W, which, in turn, is the maximum that the photovoltaic panel can provide. With these characteristics we can know without visualising the stored images that we are a clear day and also without in sufficient aerosol concentration to influence the solar irradiance.

The generated curve would look different if it had been a cloudy day, since the occlusion of the clouds would leave a trace on the curve in the form of a voltage drop, but never to 0 as in the case before. This cloudy state is shown in Figure 9. As can be seen in the sky images associated with the instant displayed on the information panels, the curve is lower in the case of a sky with denser clouds (23 W), while at higher peaks (236 W) the sky is no longer completely cloudy, and the sun begins to appear between clearings.

Another possible state to detect is the case of aerosol concentration (usually dust due to haze) enough to cause a decrease in solar irradiance in the clear sky. This situation is shown in Figure 10. This curve is like Figure 7 (without fluctuations), but in this situation, its maximum barely reaches 200W. As can be seen in the figure acquired by the camera the sky presents a sandy haze.

Finally, after presenting the images and curves obtained by the system, Figure 8 shows the result of the installation detailed in Figure 1, omitting the devices below the first switch since it is understood that their visualisation is of less interest.

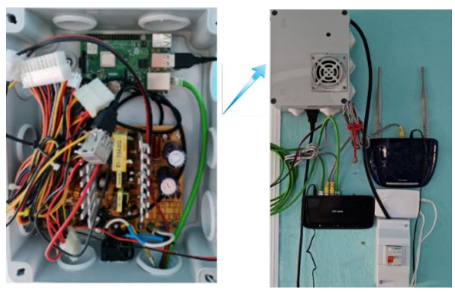

Fig. 8: Raspberry Pi, Power Supply, Access Point, Switch, Wibee and Differential.

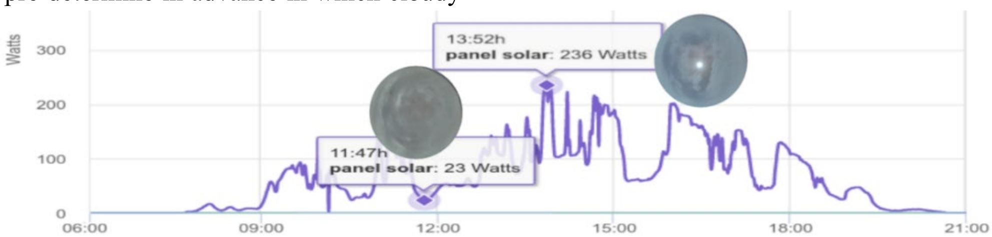


Fig 9: Cloudy day curve.

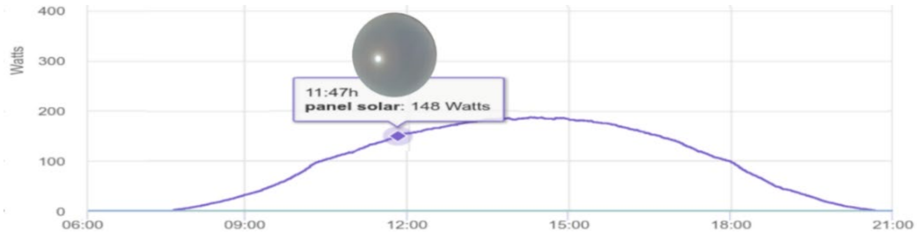


Fig. 10: Clear sky curve with aerosol concentration.

In summary, this prototype stores an image every 2 seconds, therefore, we can have 1800 images per hour; under two resolutions: 1900 x 1900 pixels and 400x400 pixels, respectively. Besides, the image can be classified according to the value of the solar radiation.

## 5. CONCLUSIONS AND FUTURE WORK

Despite the utilisation of a low-cost camera, the system provides the user with optimal all-sky images that are perfectly archived, accessible from any point and easily located depending on the cloudy state of the sky. Thus, the system has been operating routinely since March 2021 providing resources in an extraordinarily reliable and valuable manner.

Furthermore, the network, its access points and the capture system are designed and configured to be flexible, reliable and scalable enough to meet the needs and requirements of studies and applications that involve an optimal image capture and access system of all-sky images.

Future improvements are aimed at taking advantage of the fact that a photovoltaic system is added to the system, in such a way that the system can be supplied exclusively by solar energy and be able to provide solar irradiance measurements for each of the images captured by installing a clamp ammeter, as the Wibeee platform only provides values averaged every minute.

This advancement, in turn, allows complete and more accurate image and data management for solar irradiance prediction applications. It now enables simple labelling by duration windows, whose length will vary depending on the prediction to be covered by the application. For instance, the 1-minute prediction period determined by Feng et al. [16], in their estimation of the global horizontal irradiance (GHI), as well as Caldas and Alonso-Suárez [17], who also calculate the GHI but this time for forecasts between 1 and 10 minutes.

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