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(Article begins on next page)

All Sky Camera for the CTA Atmospheric Calibration work package

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Abstract. The All Sky Camera (ASC) is a passive non-invasive imaging system for rapid night sky atmosphere monitoring. By design, the operation of the ASC will not affect the measurement procedure of the CTA observatory, for which we discuss its application in this report. The data collected should enable improved productivity and increased measurement time for the CTA observatory. The goal of ASC is to identify cloud position, atmosphere attenuation and time evolution of the sky condition, working within the CTA Central Calibration Facilities (CCF) group. Clouds and atmosphere monitoring may allow near-future prediction of the night-sky quality, helping scheduling. Also, in the case of partly cloudy night sky the cameras will identify the uncovered regions of the sky during the operation time, and define potential observable sources that can be measured. By doing so, a higher productivity of the CTA observatory measurements may be possible.

1. Introduction

The CTA (Cherenkov Telescope Array) project is an initiative to build the next generation ground-based very high energy gamma-ray instrument currently under prototyping phase and soon to be built [1]. In a possible design scenario, the southern hemisphere array of CTA will consist of three types of telescopes with different mirror sizes (SST-4m, MST-12m, LST-23m) in order to cover the full energy range. The northern hemisphere array would consist of the two larger telescope types. The Cherenkov light yield depends on the atmospheric characteristics, therefore a careful and continuous monitoring and characterization of the atmosphere is required. The CTA concept of atmospheric monitoring is divided into several tasks as climatology, off-line data selection, off-line data correction, on-line smart scheduling and weather now-cast, fore-cast, alerts and protection. To fulfill these tasks, CTA will make use of several instruments and methods like Ceilometer [2], Lidar, FRAM [3], weather stations and sensors, Cherenkov Transparency Coefficient method etc. One of the instruments is the All Sky Camera. The data from this monitoring device will provide an input for smart scheduling and short time weather forecast.

2. All Sky Camera measurement and analysis

The All Sky Camera is a versatile, passive, fast instrument for atmospheric monitoring. We use a G2-4000 astronomical CCD camera by Moravian Instruments with a KAI 4022 cooled CCD chip (50 degrees Celsius below ambient temperature), five-position filter wheel, three standard astronomical BVR filters, clear BK7 glass and Sigma 4,5 mm F 2,8 Fish-eye Lens. The camera

generates low-noise 16 bit 2056 × 2062 pixel RAW images. The camera head uses internal mechanical blade shutter which guarantees longer lifetime than standard iris shutter (see Fig. 1). The angular resolution of the ASC is approx. 0.1 degree. The whole 180 × 180 deg. field of view (FOV) covers 1750 × 1750 pixel area of the CCD chip (see Fig. 1). The three types of CTA telescopes (LST, MST and SST respectively) are designed with FOV of 5, 8 and 10 angular degrees (diameter of circular FOV). Thus the CCD area of the ASC similar to the FOV of CTA telescopes corresponds to 2000, 4000, 6200 pixels respectively. The resolution of the ASC is sufficient to determine clouds and atmosphere extinction within the FOV of the CTA telescopes. The ASC is placed in a robust aluminum waterproofed body and covered with an anti-reflex glass dome. The glass dome is warmed by the waste heat of the Peltier CCD cooler and automated internal thermoelectric heater. This solution avoids the condensation of the exterior humidity on the glass dome of the ASC and protects the dome against the ice and snow during the winter period. The distortion of the image due to the water drops and ice is thus eliminated.

The testing phase is recently ongoing (September 2014) at Los Leones site of the Pierre Auger Observatory in Malargüe (Argentina) (see Fig. 2). The result of the testing campaign will be compared with Auger's optical FRAM telescope. The FRAM telescope (see Fig. 3) is wide-field automated photometric telescope which measures the sky quality above the fluorescence telescope at Los Leones and it provides very precise sky quality measurement. The data from FRAM could be taken as a reference for the ASC and the ASC could be calibrated using FRAM. The operation of the ASC will provide two main outputs with respect to atmosphere characterization. The most important task is the detection of cloud positions and clouds map production. The second task is the atmospheric extinction measurement. The data from the clouds detection together with data from other
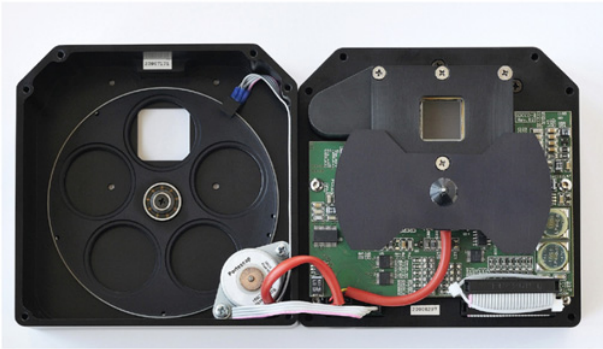
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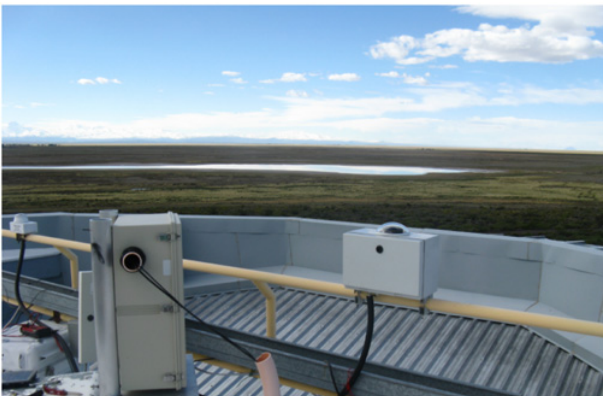**Figure 1.** 5-positions filter wheel and blade shutter inside the G2-4000 camera head.

Figure 2. All Sky Camera at Los Leones fluorescence telescope. The testing phase is ongoing.

instruments could be used for short time weather forecast like clouds movement prediction, storms prediction etc. Here we benefit from the huge data set of night-sky images from CTA candidate sites that were already collected by our previous versions of all-sky cameras. The data is now investigated and the new algorithm for clouds movement direction is tested. The goal of the analysis is to developed an algorithm to estimate the clouds movement direction and compare the result with the wind direction from the weather stations, satellites data etc. In case of a good correlation the algorithm could be used for the Central Scheduler to predict the behavior of the clouds of the night sky during the CTA measurement. The first analysis was done for Aar (Farm Aar – south Namibia) and Armazones (Cerro Armazones – north Chile) CTA candidate sites and it shows very good correlation between wind direction from Atmoscopes weather station and estimations of clouds movement direction using ASC data (70% agreement). The estimation of the direction was done first visually by comparing time sequence of data sets of cloudy images. The direction of the movement was estimated with the error ±20 deg which we found as a good approximation. The result from ASC was compared with the wind direction from 10 m wind tower. The analysis and preparation of an automatic algorithm is in process.

2.1 Clouds map measurement

The methodology of clouds detection and detailed analysis was used and evaluated within the CTA Site Selection

Figure 3. FRAM – F(/Ph)otometric Robotic Atmospheric Monitor is an optical telescope equipped with CCD cameras, and it automatically observes a selected fields of well-calibrated stars.

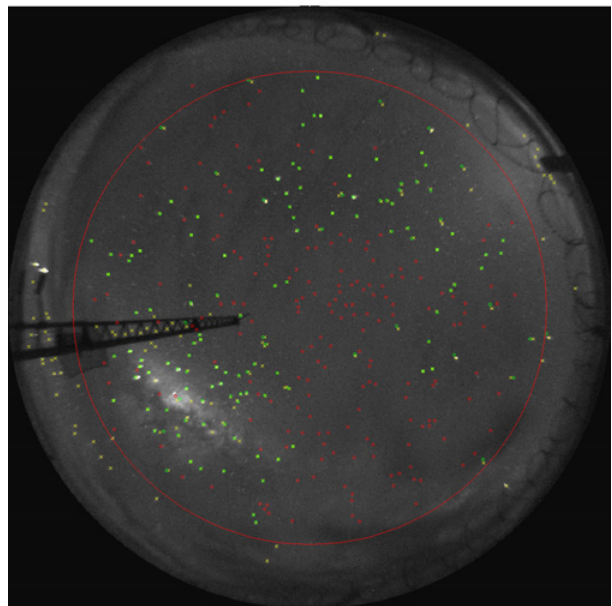CF(60°)=59 %; dew = 0; CatStar#(60°)=321; ImgStar#(60°)=169

Figure 4. Clouds analysis – yellow crosses are detected stars, green circles are detected stars corresponding to a catalog stars position and red circles are catalog stars without detected stars (covered stars).

campaign and described for example here [5,6]. The methods analyze cloud position by identification of visible stars using their catalog positions (see Fig. 4). The position of the clouds could be identified as sectors without detected stars and clouds map for central scheduler could be created and applied.

The ASC is calibrated in the lab in terms of optical distortion to correct the star catalog position to the image position. Then the nearby surrounding within 0,5 degree of the catalog position is investigated and the image star is located. We use TYCHO2 catalog [4] up to 8 star magnitude in U and 10 magnitude in V wavebands respectively. We compare typically 2500 stars with their catalog positions.

The result could be interpreted as image of full sky divided into a specific number of hexagons. The cloudcover of each hexagons is investigated separately. Figure 5 shows partly covered sky from San Antonio de Los Cobres candidate site (Mexico).
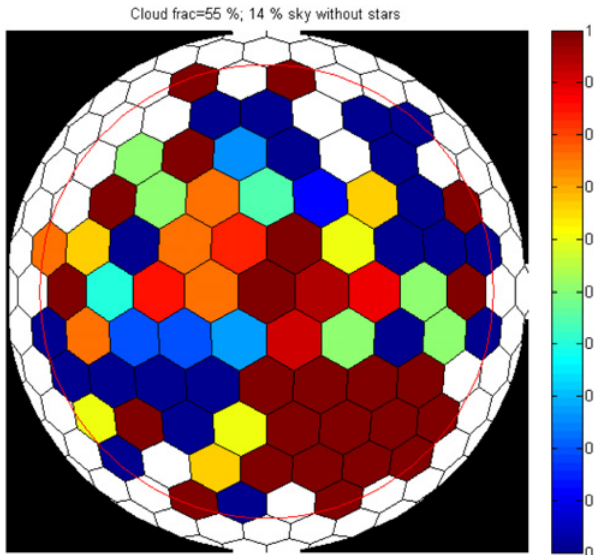
Figure 5. Clouds analysis of nightsky image from San Antonio de Los Cobres. The image is divided to hexagons, the color represent cloud fraction of each segment. Blue color represents clear sky of the segment, red fully covered. Part of the sky (several segments – white hexagons) is without stars (14%) it is caused by lower sensitivity of the ASC of Site Selection Campaign.
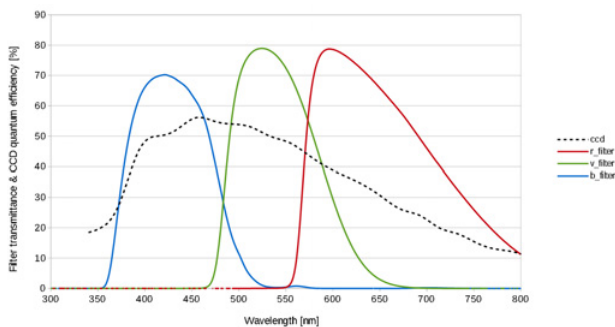

Figure 6. Spectral transmission of camera filters and quantum efficiency of the CCD of the camera.

2.2 Atmospheric extinction measurement

The knowledge of transparency of the night atmosphere is very important for the CTA measurement. The ASC could provide integral measurement of the atmospheric profile for the whole sky in different wavebands. The whole sky could be measured and analyzed in relatively short time. We use standard astronomical BVR filters (see Fig. 6) and TYCHO2 star catalogs. The flux from a star in selected waveband (transmitted by one of the BVR filter) is compared with its catalog value and corrected with the calibration constants. The atmospheric extinction of detected star could be obtained. The result from the measurement could be a sky map with raw atmospheric extinction. The most important sky regions

(scheduled in the observatory measurement plan) could be remeasured using more precise instrument like FRAM, Lidar or Ceilometrs to achieve better description of actual atmospheric condition.

2.3 Output for the Central Scheduler

The Central (Auto) Scheduler is an iterative system for observatory measurement correction. The system collects the data from different atmospheric condition instruments and could correct or change the measurement schedule according to the present atmospheric conditions. The ASC will provide clouds position maps and atmosphere extinction maps for this system.

2.4 Operation within CTA

The ASC system will be operated using Array (ALMA) Control Software (ACS). The interface between the ACS and the ASC will be provided by OPC UA server (Object Process Control Unified Architecture). The OPC UA server provides the DAQ process, data transfer and hardware communication. The analysis of the data from ASC is performed using the custom Matlab application developed for CTA. The system is running Scientific Linux SL6, OPC UA server and Linux Matlab application.

3. Conclusions

The design and system description of ASC for CTA CCF group was briefly presented. The ASC system will serve as an atmosphere condition measurement system providing clouds and extinction maps for the CTA observatory operators and the Central Scheduler. The development of the algorithm of estimation of clouds movement direction and velocity is in progress. The testing phase of the system hardware is already ongoing at the Pierre Auger Observatory.

References

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