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Mitigation of Atmospheric Effects on Satellite Imagery by Optimal Electro-Optic Structure

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Abstract

Nowadays, various systems and, tools have been used to study the components of the atmosphere. In atmospheric correction of satellite images, it is necessary to identify and use the specifications of the atmosphere during satellite crossing. For this purpose, in this research, designed and constructed an optimal sun-photometer system to determine the local atmospheric parameter. LabVIEW environment has been used to record Aerosol Optical Depth (AOD) data and guide motors in two axes for accurate sun tracking. In this research, by calculating the aerosols optical depth and studying its behavior on different days, two CCD (Charge-Coupled Device) and CMOS (Complementary Metal–Oxide–Semiconductor) sensors have been compared to record data. A comparison of the two sensors under the same conditions showed that the responsibility of the CCD sensor is more linear than the CMOS sensor. To evaluate the performance of the designed sun-photometer system, the MODIS sensor data of Aqua and Terra satellites were used. The results showed the high capability of the developed system in measuring AOD in comparison to MODIS AOD data. By comparing the CCD and CMOS sensor data with the Terra satellite data, 80% and 71% data matching, respectively, are observed.

***Keywords**:* Atmosphere, Sun-photometer, AOD, Satellite Images, CCD, CMOS.

1. Introduction

Images received from satellites are not very accurate due to the presence of the atmosphere and the effects of diffusion caused by the contents of the atmosphere. For this reason, to eliminate the influences of the atmosphere in satellite images, we need to know the absorption and scattering of the atmosphere. Aerosol (solid particles or suspended liquid) and gaseous molecules and clouds make up the Earth's atmosphere (Wang et al., 2019). When electromagnetic energy is emitted from a solar source, on its way

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to objects and phenomena on Earth, it passes through an environment called the atmosphere. The atmosphere, which is a spherical shell of various gases around the Earth, exhibits different behaviors in absorbing, transmitting, and reflecting electromagnetic waves at different wavelengths. One of the common phenomena observed in aerial images is the existence of artificial effects in the images caused by the absorption and scattering of the atmosphere on the path of propagation of light. Therefore, to correct these effects, it needs to know the amount of absorption and dispersion, which is done by ground-based remote-sensing devices (Awais et al., 2018). Aerosols to play a key role in the radiation rate of the Earth, reducing the visibility of the atmosphere, the quality of clouds, air quality, and human health (Zhao et al., 2018). Sun-photometer is a type of passive ground-based photometer that measures the intensity of direct light and scattered light of the sun from an atmospheric particle at specific wavelengths less than 10 nm wide and with a limited field of view (Chewa et al., 2011). As sunlight experiences absorption and scattering in the atmosphere before reaching the sun-photometer, the recorded intensity is significantly reduced. Thus, the sun-photometer can be used to study the atmosphere and its properties to determine the optical parameters of aerosols such as the aerosols optical depth and the dimensions of the aerosols and, the Angstrom exponent. By measuring the mentioned parameters, the artificial effects of the atmosphere on satellite images can be corrected. The most comprehensive and important parameter that forms the optical activity of aerosols in the atmospheric column is the aerosol optical depth (AOD). This is also a key parameter used in atmospheric column aerosol modeling and in satellite observations. The Angstrom exponent calculates the AOD spectral dependence (Cuevas et al., 2019). Also used for the calibration of the sun-photometer from the Langley theory (Guerrero-Rascado et al., 2013).

(Xie et al., 2015) has used CE318 (Cimel Electronique318) ground-based remote sensing technology to obtain the column concentration of the most important greenhouse gas in the atmosphere, carbon dioxide. In this research, CO2 column information is obtained according to the principle of differential absorption index.

(Wu et al., 2009) Observed aerosols in ground-based multi-wavelength elastic-Raman LIDAR, sun-photometer, and satellites in a remote sensing. Measurements with ground-based LIDAR, sun-photometer and satellites provide aerosol attenuation characteristics and optical depth of aerosols. In this research, systems have been compared with recorded data.

(Gong., 2018) evaluated the optical depth of marine aerosols and airborne water vapor with a Microtops II sun-photometer and compared it with CE318 data in the distance 100 km of the AERONET website. Microtops II marine AOD values are well-matched to CE318 values.

The updated models of sun-photometer are equipped with solar trackers, spectral filters, and data recording systems that allow a more detailed study of the atmosphere. The purpose of this study is to investigate the optical structure for the study of aerosols and molecule concentrations and to introduce an optimal electro-optical structure for this subject. In this research, the setup of a precise solar tracking platform, the optimal electro-optic knowledge, and the effect of different detectors such as CCD and CMOS for best measurement are discussed. Also, one of the most important goals of this research is to measure the concentration of aerosols and solving problems before calibration of aerial images. The most important advantage of this research is the use of various detectors such as CCD and CMOS.

2. Material and Methods

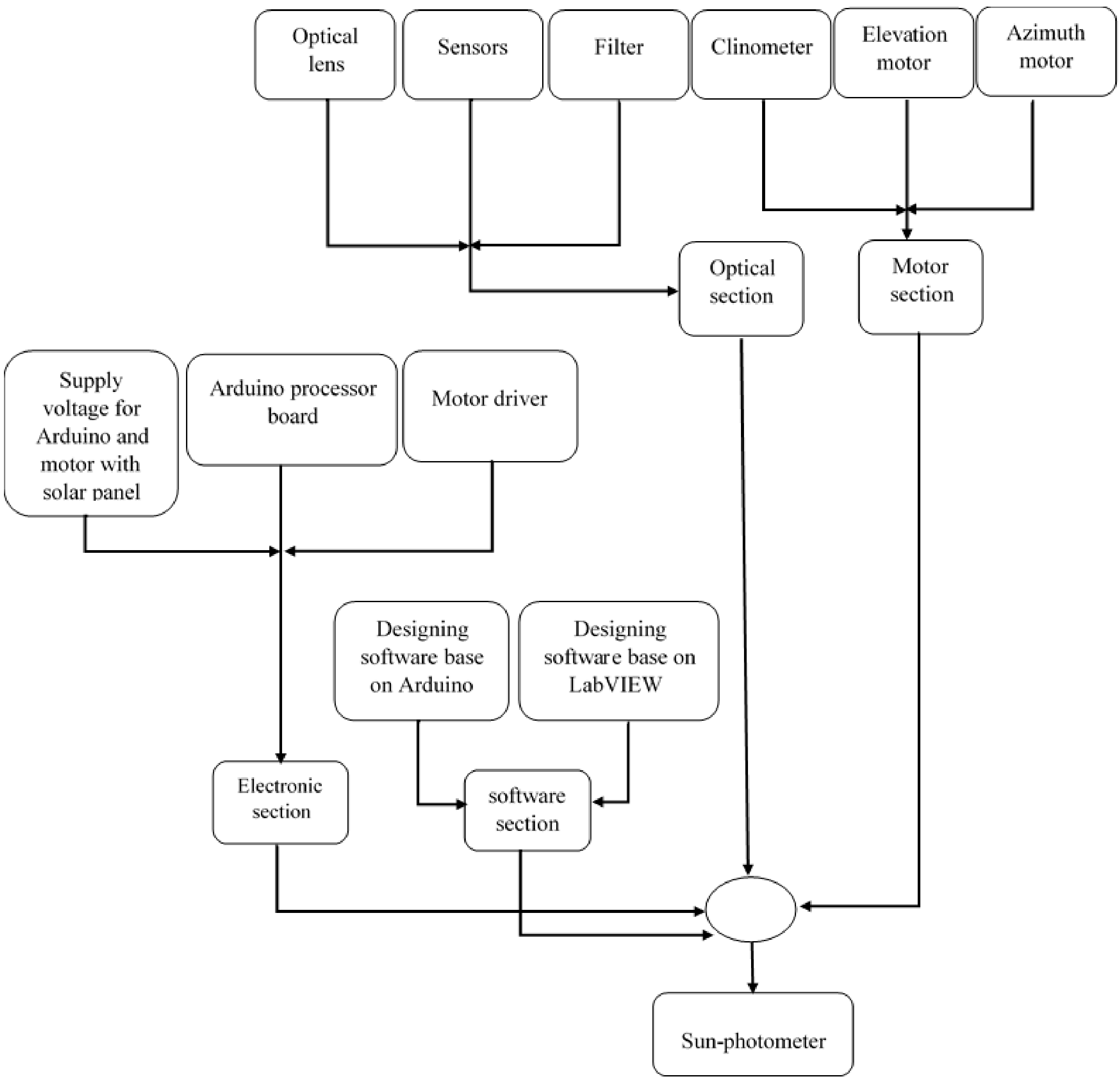


Figure 1. Sun-photometer System Diagram Block

2.1. Designing and Constructing of a Precision Solar Tracking Platform

Designing and constructing an optimal sun-photometer and record the moments of the measured intensities for calibration of satellite images, is necessary to set up an accuracy solar tracking platform with tenth-degree accuracy and automatic capability. The designed sun-photometer consists of three parts: motor system, electronic box, and optical part. To set up such a platform, CMOS and CCD imaging instruments, intensity and transient filters, imaging lens, GPS module, Clinometer, and DC motor have been used.

Motor Section

To track the sun's momentum to measure direct light and the scattered light of particles in the Earth's atmosphere, the camera must track the sun in both Azimuth and Elevation directions with high accuracy. For this reason, two DC motors equipped with an encoder were used to track the moment of the sun in two directions, Azimuth and Elevation. Also, due to the need for high torque or power, a 12-volt DC motor was used. Figure (2) shows an example of a sun-photometer system.

Figure 2. View of the deployment of sun-photometer system

Electronic Section

Each of the Azimuth and Elevation motors is equipped with an encoder that starts pulsing as soon as each motor starts moving. Then, with the code designed in Arduino software and selecting the Arduino Mega 2560 board, the pulse received from the encoder was counted. In the next step, for the control of motor with Arduino code from ASCII to decimal data conversion is used, which consists of printable characters. To store and transfer data and perform sunlight measurement automatically from Arduino hardware and code designed in LabVIEW were used. The power supply of the DC motor is 12 volts, and the hardware of the Arduino is 8 volts, which used a solar panel. The solar panel produced two voltages of 5 volts, which were converted into increasing voltages to 12 and 8 volts. To track the sun, LabVIEW software was used. Azimuth and Elevation angles are calculated with the GPS module, which converts these angles into pulses according to the calculations specified in the LabVIEW code. Finally, the motors move entirely and accurately by the calculated pulse. To calibrate satellite images, we need to record solar images with code designed with LabVIEW, cameras, and various filters. To calculate the best accuracy and minimum offset in tracking and imaging the sun, the device must be placed in the alignment model with the least error. Therefore, a high-precision Clinometer has been used to adjust the slope angle of the surfaces with high accuracy. Requires data on date, time, and geographic coordinates to record and analyze solar images. An accurate GPS module must also be used to calculate the position of the sun and the angles of Azimuth and Elevation. In the next step, according to the practical components in the discussion of atmospheric correction for the design and implementation of sun-photometer based on measuring the aerosols, optical depth requires optical and electronic elements.

Electro-Optical Structure

Optical instruments include intensity filters, bandpass filters, and imaging lenses. Electronic devices include CCD sensor, CMOS sensor, interface boards, and electric motors. The specifications of the camera, lens, and filter used in this research are shown in Table (1).

Table 1. Specifications of the camera, lens, and filter used in this research

Detector type	**CCD sensor**	**CMOS sensor**
Camera (model)	Thorlabs camera (DCU224M)	BASLER camera (acA1300-200µm)
Detector size	1.2 Inch	1.2 Inch
Number of pixels	1280 x 1040	1280 x 1024
Pixel dimensions	4.65 µm x 4.65 µm	4.8 µm x 4.8 µm
Focal length	75mm	75mm

Compare Image Sensors

Response to received intensity is nonlinear in CMOS sensor but linear in CCD sensor .Quantum efficiency in CMOS sensors is weaker than CCD sensors. CMOS sensors are cheaper to build than CCD sensors because they require less electronic equipment, also CMOS chips are faster (Hain et al., 2007). CCD sensor consumes more power than CMOS sensor but produces better images (Carlson., 2002).

To capture images of the sun, two cameras with equal pixel sizes were used, such as the Thorlabs camera equipped with a CCD sensor and the Basler camera equipped with a CMOS sensor. The reason for this is the comparison of CCD and CMOS sensors. For this reason, both sensors were in the equal condition in terms of exposure time (3 milliseconds). The settings were made when the sun was at the highest possible condition, the maximum intensity recorded in the sun-photometer system.

2.2. Algorithm for Calculating the Optical Depth of Aerosols

AOD is derived from the direct solar radiation measured by Sun photometer according to the Beer-Lambert-Bouguer Law as follows Equation (1): (Cerqueira Jr et al., 2014; Giles et al., 2019)

$$V(\lambda)= V_0(\lambda)+ \left(\frac{d_0}{d}\right)^2 \exp(-m\tau_t(\lambda)) \qquad (1)$$

Here $V(\lambda)$ is the signal measured by the instrument at wavelength λ, $V_0(\lambda)$ is the extraterrestrial signal at wavelength λ, d_0 is the average earth-sun distance in Astronomical units, d is the earth-sun distance at the time of observation. m is the optical air mass and is calculated by the solar zenith angle θ_0 according to Kasten and Young base on Equation (2): (Cerqueira Jr et al., 2014)

$$m=\frac{1}{\cos\theta_{sun}+0.50572(96.07995-\theta_{sun})^{-1.6364}} \qquad (2)$$

$\tau_t(\lambda)$ is the sum of the aerosol optical depth $\tau_a(\lambda)$, Rayleigh optical depth $\tau_r(\lambda)$ base on Equation (3) and Equation (4). And the Rayleigh optical depth $\tau_r(\lambda)$ can be expressed by a function of wavelength λ and atmospheric pressure P: (Gong., 2018; Cerqueira Jr et al., 2014; Giles et al., 2019)

$$\tau_r(\lambda)=(16.407-0.0852\,\lambda+0.00011522\,\lambda^2)\,\frac{P}{P_0} \qquad (3)$$

$$\tau(\lambda)_{Aerosol}=\frac{LnV_0(\lambda)-Ln(V_0(\lambda)((\frac{d_0}{d})^2))}{m}-\tau_r(\lambda) \qquad (4)$$

3. Results and Discussion

As the validity of ground-based data is higher than other available data, but due to the higher resolution accuracy of satellite data, sun-photometer data were calibrated based on satellite data. Therefore, the ground data of Shemiranat region was used to select a satellite whose data is closer to the visible data of Shemiranat region. These data were compared with the optical depth aerosol data of Terra and Aqua satellites due to the proximity of Shemiranat meteorological station to the position of the sun-photometer. Equation (5) is used to convert AOD data to visible data and vice versa (Zhang et al., 2020).

$$\tau = H\left(\frac{3.912}{V}\right) \tag{5}$$

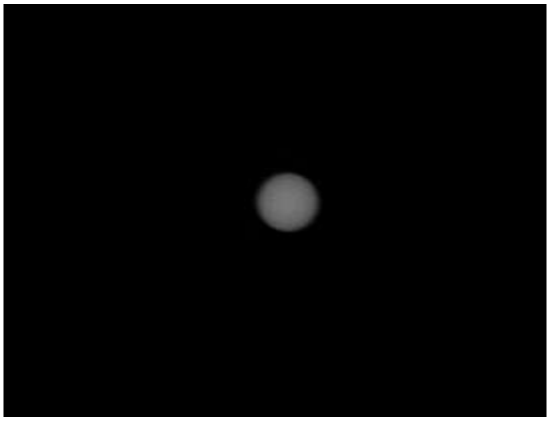
where V represents the horizontal visual range, τ is the total optical depth of atmospheric molecules and aerosol particles, and H is the atmospheric scale height.

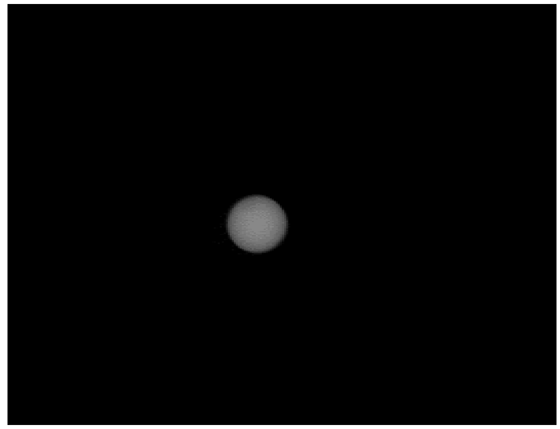
The passage of Aqua and Terra satellites over Iran and the AOD view recorded by these two satellites are shown in Figure 3.

(a) **(b)**

Figure 3. (a) AOD recorded by Aqua and Terra satellites on Sept. 27 (b) The passage of Aqua and Terra satellites on Sept. 27

Data recording and measurement of aerosols optical depth were performed by sun photometer in autumn for the city of Tehran with longitude 51° 34' 41.960" and latitude 35° 45' 20.208" for five days from 8:00 AM to 6:00 PM. In this experiment, two sensors, CCD and CMOS, were used to record AOD data with a 532 nm filter. To match the output images, the exposure time in the two sensors was set to a certain value and equal. Figure 4, to reduce the intensity of sunlight input that leads to saturation of the signal level in the sensors, it has been used (ND = 5).



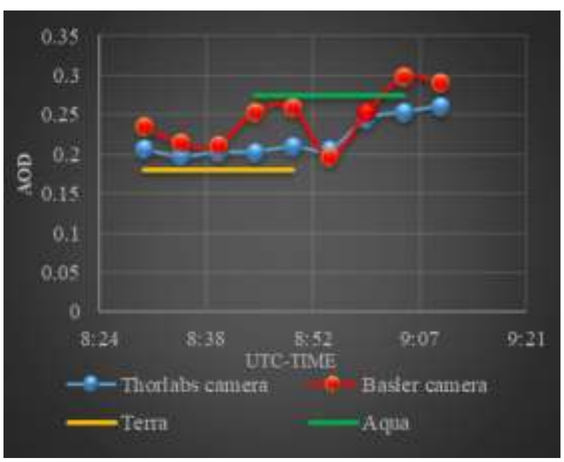


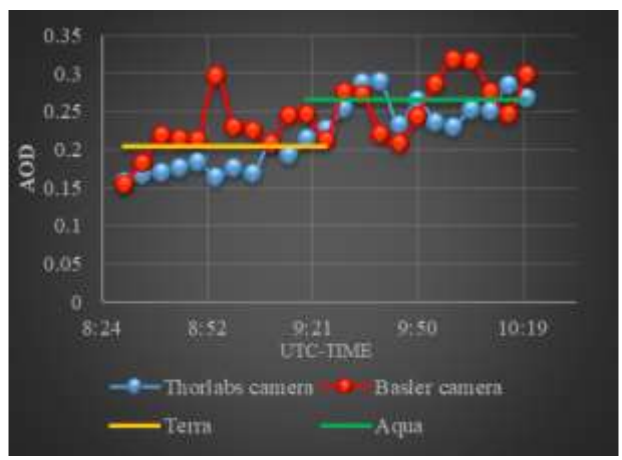
(a) **(b)**

Figure 4. (a) The captured image with a CCD sensor (b) The captured image with a CMOS sensor

3.1. Comparison of CCD and CMOS Sensors

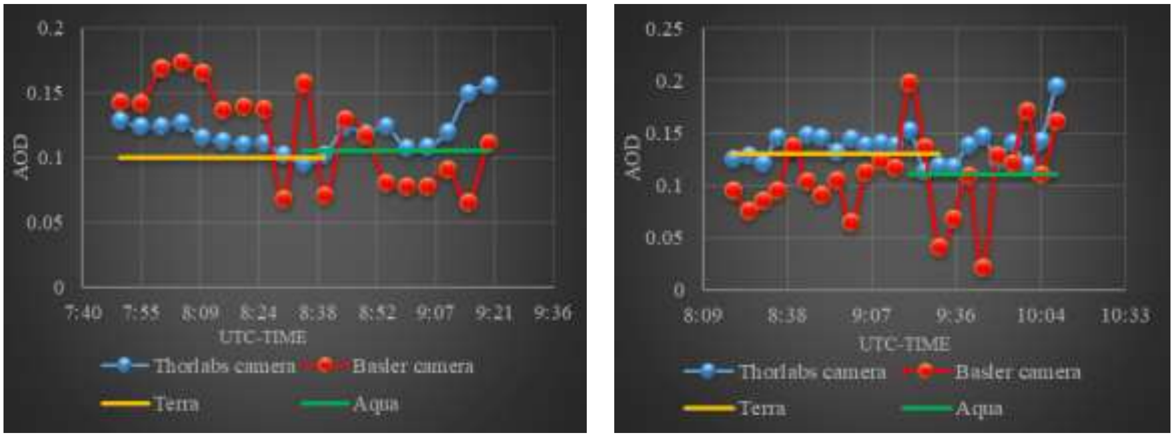
Data recording was performed to compare the two sensors in five days, with the same exposure time. In order to validate and compare the data measured by the solar radiation meter, the MODIS sensor data installed on Aqua and Terra satellites have been used. A comparison of the two CCD and CMOS sensors is shown in Figures 5, 6 and 7 in five different days. In these daily data, CCD sensors data showed more linear behavior than CMOS sensors.





(a) **(b)**

Figure 5. (a) AOD in 23 September 2020 (b) AOD in 24 September 2020



(c) **(d)**

Figure 6. (c) AOD in 26 September 2020 (d) AOD in 27 September 2020

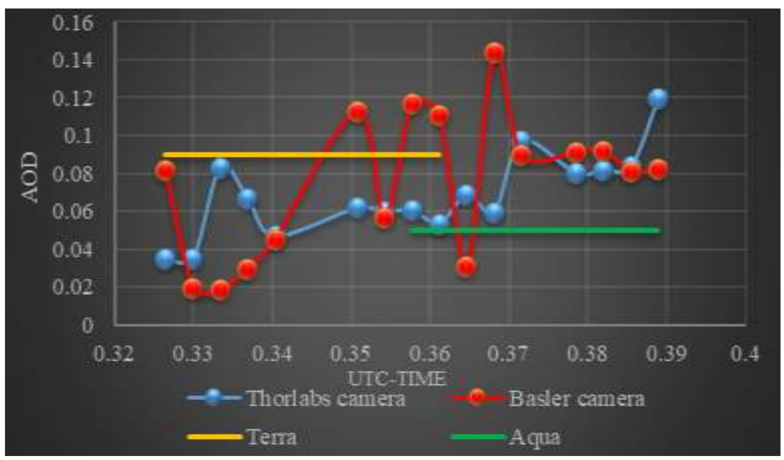


Figure 7. AOD in 30 September 2020

3.2. Evaluation of AOD

After examining the effect of sensors linearity in the daily data, the difference between CCD and CMOS sensors was compared over a period of several days. Terra satellite data was used to calibrate the sun-photometer data for four consecutive days. As shown in Figure (8), CCD sensor data is more compatible with satellite data than CMOS sensor data. After reviewing the results obtained from a sun-photometer equipped with a CCD sensor and a Terra satellite and comparing them, 80% data matching was observed. Also, the results obtained from the sun-photometer equipped with CMOS sensor and Terra satellite, and their comparison showed a 71% data matching.

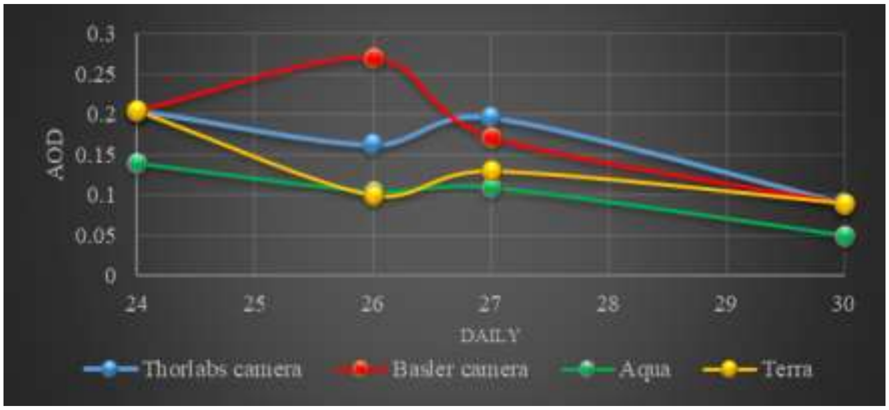


Figure 8. Aerosol Optical Depth chart at the wavelength of 550 nm

In an article (Choupanian et al., 20202), has used Aqua satellite and Mehrabad airport data to validate AOD data. It was also recorded in a few days with a CMOS sensor. In the present paper, two CCD and CMOS sensors are used to record AOD data and were compared with the data of Aqua and Terra satellites. Also (Xie et al., 2015: Wu et al., 2009: Gong., 2018) articles, only one sensor has been used to evaluate the sun-photometer system, while in this research, two CCD and CMOS sensors have been used.

4. Conclusion

In this article, first, the necessity of studying the atmosphere and performing atmospheric correction was discussed. A report was presented on how to design and construct a sun-photometer according to the available facilities. This system has been used to measure the aerosols optical depth during five days with a wavelength of 532 nm in Tehran. This measurement was performed to compare the performance of two CCD and CMOS sensors. To validate and compare the data recorded by the solar radiometer, the Terra and Aqua satellite data and ground horizontal visibility data of Shemiranat meteorological station were used. According to the results presented in this study, the response performance of the received intensity in the CCD sensor is more linear than the CMOS sensor. This result, in addition to being shown in the daily data over a period of several hours, was also fully realized in the long-term data of a few days. This shows the better validity of the CCD sensor than the CMOS sensor. Comparison of daily data showed an 80% correlation of CCD sensor data with Terra satellite data. These results indicate the high capability of the system designed to measure AOD.

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