Solar spectrometer based on the Ocean Optics USB650 spectrometer

Introduction

Aerosol content in the atmosphere is critical factor that influences the amount of the light pollution in the night. Hence, the accurate knowledge of the aerosol parameters is crucial for the interpretation of the light pollution levels. A simple method of determining the aerosol content is based on the gathering a set of solar spectra during the day. As the Sun approaches the horizon, the sunlight passes through thicker layer of the atmosphere, the aerosol influences the solar spectrum increasingly and the role of the aerosol on the absorption of the sunlight can be separated. The wavelength dependence of the absorption caused by the aerosol contains the information about the size distribution and/or the material composition of the aerosol particles. So a construction of a simple solar spectrometer is of a great interest.

Ocean Optics USB 650 is a relatively cheap spectrometer based on optical grating and CCD detector. Its range is 350-1000nm (step 1 nm) and is controlled by PC via USB port. However, its minimal exposure time 1/3000s is too long for direct gathering the sunlight. So, a neutral filter with the transparency of ca 0.2% has to be placed in front of the input. We developed a simple neutral filter that can be directly mounted to the input of the spectrometer. The filter has two variations: the first one is based on the reflection from standard microscope slide and the second one is based on home-made MoC absorption filters.

First variation – filter based on the refection from glass

The design of the filter is shown on the Fig. 1. The sunlight is reflected from a standard microscopic glass, where ca 4% of the light is reflected from the front surface and the rest is absorbed in black coloured back of the glass. The second reflection at the angle of incidence ca 45 degrees results in the reflection coefficient of ca 5%. So, the final transmission coefficient of the filter is ca 0.2%.

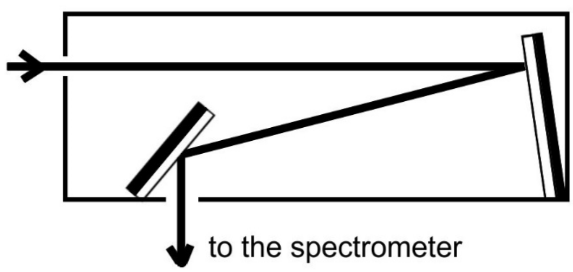

Fig. 1. Design of the solar filter based on the reflection from a glass

Fig. 2 shows the plastic parts of the spectrometer that can be easily 3D-printed. The main part is the box, where both mirrors are fixed. The attachement has to be screwed to the USB650 input and the top part (circular meander) matches the box (light-tight connection). The third part (upper cover) is used as an aiming device.

a)

b)

Fig. 2. a) Parts of the filter: box with mirrors (right up), attachment to the USB650 (down) and the cover with aiming device (left up). b) a complete setup of the spectrometer

Second variation – filter based on the MoC absorbing filters

The design of the filter is shown in the Fig. 3. The sunlight passes through a set of three filters made from a thin layer of MoC deposed on a sapphire substrate. Then the light is reflected by a mirror (Al layer deposed on the Si substrate) to the USB650 input opening. The transmission coefficient of the filters are 0.115, 0.115 and 0.13 respectively, the reflection coefficient of the Al mirror is ca 0.92, so the resulting transmission coefficient of the filter is ca 0.16%. The plastic mechanical parts are similar to the parts shown in Fig. 2 and can be 3D-printed.

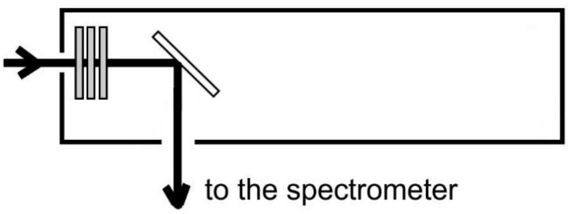

Fig. 3. Design of the solar filter based on the MoC absorption layer

Software

The USB650 spectrometer is controlled via OmniDriver distributed by Ocean Optics. OmniDriver is written in Java, so, we decide to write our software in Java, too. This solution is simple and platform-independent. The software allows to measure the solar spectrum in three steps:

1. Starting the program. In this step the program checks the presence of the USB650 spectrometer on a USB port. Then the program reads the list of "hot" pixels (can be empty) and the list of calibration coefficients of individual CCD pixels (wavelengths).
2. The user is asked to cover the input opening of the filter and to press any key. After the key is pressed, the "dark" spectrum is taken. Note, that the zero-level of the spectrum is artificially shifted in the USB650 spectrometer, so the noise can be properly digitized also for very low intensity levels.
3. The user is asked to uncover the opening of the filter and to aim the spectrometer to the Sun. The aiming is simple thanks to the presence of the aiming device – a combination of a hole in the front of the spectrometer and a screen with a cross at the end of the spectrometer. The solar spectrum is continuously measured three times in a second. Each spectrum is corrected for "hot" pixels (an average of two signals from neighbouring pixels is used) and calibrated using calibration coefficients of individual pixels. Every time the software detects higher intensity of the light, new spectrum is recorded and an acoustic signal is produced. After very few seconds of aiming to the Sun the sound signals stop (no higher intensity is detected), so the last recorded spectrum is the solar spectrum.

Building the filter

To build the first variation of the filter (mirrors made from a microscope slide) follow next steps:

1. Download 3D models of plastic parts from http://davinci.fmph.uniba.sk/~kundracik1/solar_spectrometer/solar_spectrometer1.zip . Print them from black PETG filament (polyethylene terephthalate glycol). The cover you have to print with supports (only from build plate).
2. Cut two pieces from a microscope slide with length of 40 mm and 25 mm. Paint one side of them by black matt colour. Put mirrors into holders in the main box and fix them by a small droplet of a glue.
3. Fix the cover to the main box, e.g. by adhesive tape. Stick white paper to the back of the cover for easier aiming.
4. Screw the attachment to the USB650. Put the main box on the top of USB650 and fix it using adhesive tape.
5. During the first measurement draw a cross on the paper in the aiming system to the position of the light spot in the moment when maximum signal is detected by the software.

Results and discussion

An example of gathered solar spectrum (first variation of the filter, 1/3000 s exposure time) is shown in fig. 4. Note the strong absorption line near 760 nm that is caused by the water vapour present in the atmosphere. Fig. 5 shows the solar spectrum gathered by the second variation of the filter.

The spectral dependence of the transmission coefficient is different for two above mentioned variants of the filter. The refraction coefficient of a typical soda lime glass changes from 1.518 (750 nm) to 1.544 (350nm). So, within the visible spectrum the reflection coefficient changes from 0.0423 to 0.0457. The reflection from two surfaces results in ca 16% difference in the transmission coefficients of the filter for the wavelengths 350 nm and 750 nm, respectively. The transmission coefficients of the MoC-based filters change less than 3% within the visible spectrum, the reflectivity of the Al mirror change from 0.87 to 0.92 within the visible spectrum (ca 6% difference). So, the combination of three filters and the Al mirror results in ca 11% difference in the total transmission coefficient. For the measurements of the aerosol content in the atmosphere we need only the relative change of the intensity. For other purposes the whole system has to be calibrated. An example of the suppression of the blue part of the spectrum in the evening is demonstrated in Fig. 6. Note the big difference at 760 nm caused by the increase of water content in the atmosphere in the evening. The values over 900 nm are very noisy due to exposure time chosen. Measurements in NIR need longer exposure time.

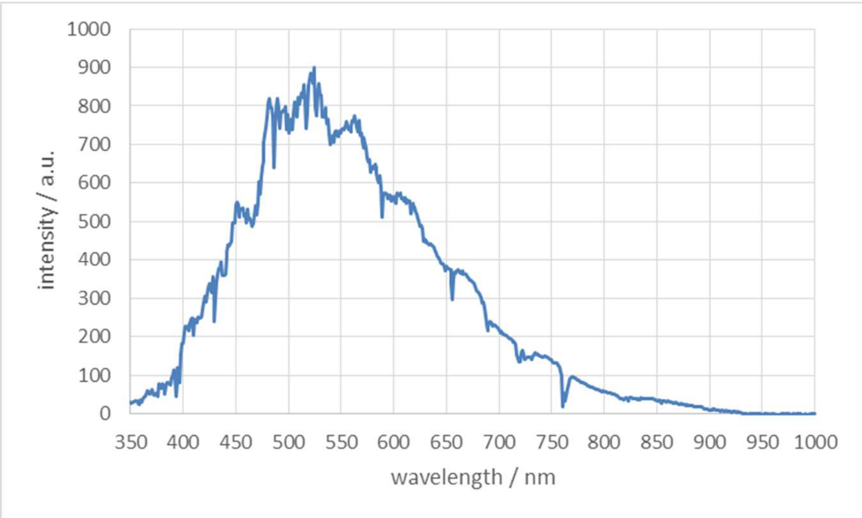

Fig. 4. Solar spectrum obtained using the first variation (microscopic glass) of the neutral filter and 1/3000 s exposure time

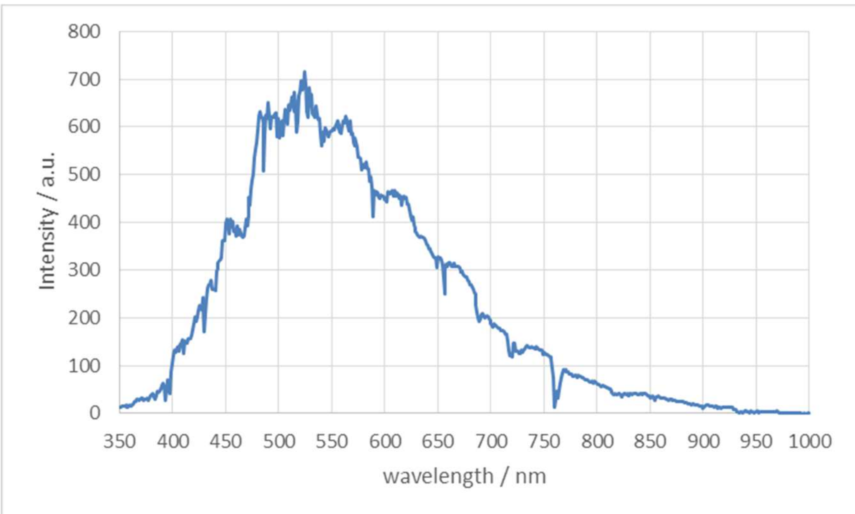

Fig. 5. Solar spectrum obtained using the second variation (MoC absorbers) of the neutral filter and 1/3000 s exposure time

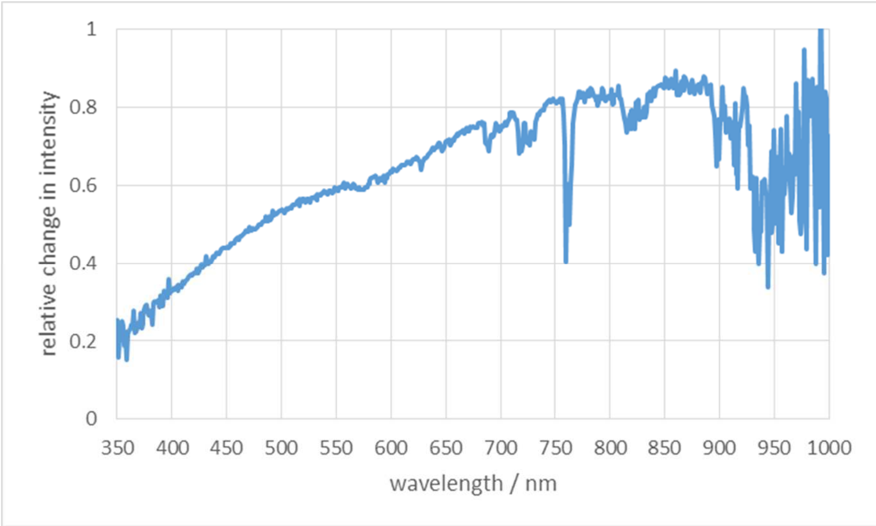

Fig. 6. Relative change of the solar spectrum during a sunny winter day on 19.2.2019 in Bratislava, Slovakia. Two spectra were taken at 13:45 and 15:45.