Development of Cost-efficient Wireless Network for Solar UV Irradiation Monitoring in Bulgaria

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Abstract. Human over-exposure to solar UV radiation has been identified as a serious health problem which needs intensive screening and monitoring. The goal of this study is to present recent success in solar UV irradiation monitoring in Bulgaria in the frame of INTERGA_UV project (No. KII 06 /24H - 2018 of National Research Fund of Bulgaria). The research efforts has been focused on development of an independent on-ground UV sensors network, which uses MQTT sensor protocol, local databases and remote access to monitoring center. The developed UV monitoring system is intended to withstand severe climatic conditions at a reasonable price of equipment and components. It differs from conventional scientific instruments with an open architecture and smooth upgradability due to implementation of modern digital sensors, Arduino-based controllers and Wi-Fi communication modules. The software bridging modules are based on open-source Python applications, open-source InfluxDB database and Grafana visualization tool.

1. Introduction

Researches in the last decades have identified exposure to solar UV radiation as one of the most important problems for human health. Possible consequences of UV over-exposure are skin tanning, sun burning or even skin cancer in humans. The absorption of UVA radiation by the water content of cells may cause ionization and may produce free radicals. The UVB radiation has higher energy per photon and may provoke direct collision with DNA molecules. The proteins are found also to absorb strongly in the UV–C region with a maximum around 280 nm.

Fortunately, ozone in the atmosphere prevents the most harmful UV-C radiation from reaching the biosphere. Aerosols, water drops and cloud cover are other factors that play a dominant role in the variability of UV irradiation. These optical and absorption effects have to be monitored carefully in order to prevent people from extraordinary risk. The widespread use, easy maintenance of UV sensor equipment and dense population of UV monitoring points will improve further the accuracy of UV forecasting and will convince the citizens in the responsibility of researchers and their work.

Regular UV monitoring activities have been initiated after the ozone hole was discovered in 1984. A systematical measurements of UV irradiances by ground-based spectroradiometers, can be obtained...
from the World Ozone and UV Data Center archive (WOUDC; 2002) but it covers monitoring stations in Canada, Japan, Taiwan, Russia, Slovakia, USA, Argentina and Palmer station-Antarctica (http://www.woudc.org). Obviously there are no reliable databases for Eastern European region. This gap has to be filled with new monitoring stations.

The INTEGRA_UV project is oriented to implementation of cost-efficient sensor network for environmental monitoring and especially for solar ultraviolet (UV) irradiation monitoring in Bulgaria. Seven locations with different local climate have been selected for sensor equipment deployment - BEO - Moussala, AO - Rozhen, AO - Belogradchik, Sofia city, Varna-rest house, HMS-Ahtopol, Hotovo village. The highest peak of Rila mountain (Moussala, 2925 m) gives opportunities for highest UV doses measurements including in UVC range. The astronomical observatories in Rozhen and Belogradchik offer combination of high altitude with clear transparent sky during the most days of the year. City of Varna, Ahtopol and Hotovo village offer opposite climate conditions from salty, windy sea shore to the dry climate of Struma river region. City of Sofia as an urban area with concentrated research centers could also be an example of human-generated air pollution location. At figure 1 a map of BG territory with the selected locations is depicted. The results are summarized in this report.

2. Developed hardware platforms
The Data logging of solar UV irradiation informs the user of variations in UV fluxes over certain location which can be dangerous for humans or which can influence over plants, animals, machine equipment, human behavior, etc. Measured parameters are UVA, UVB, UVC irradiation and calculated UV-index.
These designs, illustrated at figure 2, are based on GaN, AlGaN digital detectors sensitive only in UV narrow bands. The sensing IC chips contain optical interdigital filters; own 16-bit ADC, I²C data-reading controller and temperature compensation algorithms.

Figure 2. Sensor heads for simultaneous measurements in UVA, UVB and UVC ranges.

3. Software methodology and programs
Open-source hardware and software is the main approach behind the project implementation. On figure 3 the general software concept of the equipment is presented. The sensors are separated in plastic boxes from the base computers, accessed by WiFi connection, in order to prevent damages from occasional atmospheric discharges -strikes and lightning’s in the mountain locations.

Figure 3. Software pipeline.

The typical architecture of modern IoT distributed sensor monitoring system consists of numerous remote sensors connected wireless or wired to internet. In our project in order to ensure the reliable data logging the data is stored locally on small machines and transferred later to a central server. Local storage is important feature for reliable communication with fast sensors in short logging interval. Depending on the available communication infrastructure the data is transferred asynchronously to the server in longer time-intervals.

MQTT is a lightweight open-source message M2M protocol using a broker (server) developed for telemetry or unreliable high-latency networks. It is based on messages separated in topics among subscribers and publishers. A broker is a server program that keeps track of all the MQTT traffic.

Mosquitto is a fully compliant MQTT broker. InfluxDB is an open-source platform designed for time-based data to be collected in a compact time-series database. The bridge between the MQTT broker and the InfluxDB is a Python3 script and python-influxdb library.

Regarding to timing of data-logging process, in InfluxDB, time stamps are used to coordinate and assign data, using the local time of a host in UTC. The host clock is synchronized with true UTC using NTP servers.

Grafana is a web-based, open-source, general purpose data visualizing tool that can be connected to InfluxDB. It has a web-browser GUI interface that can setup custom dashboards and metric analytics, SCADA alerts and notifications and can zoom in- and out of the data sets.

The final solution intended for remote UV monitoring combines variety of software technologies: sensor readings, data manipulation and local data storage, data transfer and remote monitoring. These tasks have been fulfilled using cost-effective, open-source components (Arduino, RaspberryPi, Odroid),
illustrated in figure 4, which can be delivered easily and can be replaced at low-cost due to the open architecture and free software libraries.

![Diagram of UV sensor station](image)

**Figure 4.** General scheme of UV sensor station.

### 4. Testing of UV sensor stations

The sensor boxes include Li-Ion batteries, 5-10Wp PV module, GSM and Wi-Fi communication blocks. All stations after system assembling have been tested for a week at a solar test field of Central Laboratory of Solar Energy (CL SENES) in Sofia (figure 5).

![Image of UV monitoring stations](image)

**Figure 5.** Stand-alone UV monitoring stations under testing in real conditions.

### 5. Results and discussions

In Northern hemisphere the highest UV doses are to be expected in June and July. Due to the eccentricity of the orbit of the Earth the closest distance to the Sun is on 4 July (aphelion). At medium latitudes of 40-43°N the peak UV index can often exceed 10 (i.e., “extreme” UV) during the summer months, so at some times of the year, there is a risk of skin damage in as short a time as 15 - 20 minutes. For some biological processes, peak UV intensity may be more important than the mean value. The maximum
summer-time UV index measured during our measuring campaigns in 2019 and 2020 is 12.0 with an average value for July 2020 of about 9.6.

**Figure 6.** Atmospheric and solar UV irradiation anomalies at low SZA.

**Figure 7.** IR channels (a) and daily profile of UVA, UVB (b) during a cloudy day and comparison to visible, (sharp UVA, UVB peaks could exceed by 300% the normal value in a period of 2-5 min).
Figure 6 the result of a single day UV irradiation over Moussala peak as a function of daytime is shown. UVB irradiation (dark purple) is abnormally high it even exceeds UVA (light purple) during morning hours of low solar zenith angle (SZA).

There is a striking difference between recent measurements on high mountain peak (Moussala) and the other locations. It can be attributed to vertical columnar air structure above the mountain peak and changes in total ozone - natural annual cycle of ozone concentrations caused by the Brewer-Dobson circulation [4].

In Figure 7 the result of one-day UV irradiation in summer-time over Sofia city is presented. Cloud attenuation is largest during afternoons. UV sharp peaks are considerably above the clear-sky values, indicating that enhancement of UV radiation by “scattered-clouds” sky — which is a well-known effect at mid-latitude sites [5]. An extreme example is shown in figure 7. Photons passing through a hole in the broken cumulus cloud are reflected multiple times from the cloud edges which result in increase of the UV diffuse component and the total UV irradiation measured by the sensors. Thin cirrus clouds are passing high above 7 km in the atmosphere. They are optically thin but are composed of ice crystals which could affect significantly the UV light reflections.

As indicated in figure 8, a small asymmetry in the daily profile of UVA irradiance in Sofia during a day with clear sunny sky could be observed. It could be compared to solar visible and IR light. A shift in UVA max compared to visible light and increased UVA/UVB absorption are observed, maybe due to air pollution with solid particles and human-originated gasses.

![Figure 8. Daily profile of UVA, UVB during a sunny day and UVA/UVB absorption anomaly.](image)

Obviously in urban areas, the tropospheric ozone and local air pollution by NOx modulate the sky transparency, which decrease the effect of UV light. The red line shows the visible and near infrared radiation on the same day.

On the Black sea coast of Ahtopol the daily solar irradiation profiles (VIS, IR, UVA, and UVB) are symmetrical during a clear sunny day of August 2020 (figure 9). This is a normal behavior of solar light propagation through the atmosphere.
These measurements have significance also in solar PV plant sector. It is of great importance in identifying the reasons for fluctuations of output power injected to the electricity grid. From measuring and data-logging processes, future trends can be identified and predicted in short time.

![Figure 9. Daily profile of UVA, UVB during a sunny day at sea level.](image)

6. Conclusion and recommendations

To summarize our results, an UV monitoring network has been developed based on open-source hardware platforms and open-source software. The results of our UV measurements agree with other research groups [6, 7]. The largest anomalies occur for UV measurements in high-mountain location. The collected data graphs from high-mountain locations reveal underestimated dangerous UV peaks during summer days with dispersed clouds. In mountainous regions, snow cover may also persist at lower latitudes, and for longer seasons. In each case, the UV monitoring data presented here confirms the underestimation the actual ambient UV dose. The “daily UV dose” is an appropriate quantity for investigating cumulative UV exposures over long time-periods but it does not estimate the impact of transient high UVA and UVB peaks that may occur during moments with combination of clear sky/dispersed clouds and ozone depletion.

In urban locations a shift in the maximum of UV-A and UV-B irradiation compared to visible sunlight is observed. Satellite-derived annual averages tend to overestimate measurements by averages of 30% for polluted mid-latitude urban regions [8] because satellite UV dose estimation methods do not account for UV-absorbing aerosols. Regional-scale absorbing aerosols, probably associated with plumes of biomass burning smog-generated ozone, SO$_2$, NO$_2$, etc., have been detected although quantification remains a challenging area of research. Direct ground-based UV radiation measurements are preferable for such locations.
The collected database during one and half-year field measurements could be involved in deep-learning algorithms for short-term UV forecasting.

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