Advances in UV Dosimeters, 2018

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Abstract. Scienterra dosimeter firmware has been updated to provide new features, including improved calibration stability, a four-fold increase in measurement range, better indication of battery health, error logging, and faster wireless communication. These improvements are available for existing instruments via a user-applied firmware update. The shape of the radome diffuser has been changed to improve the style and feel of the device.

A new instrument has been developed to measure three independent broadband sensors, providing concurrent data for UVA, UVB, and visible radiation. By measuring three wavebands simultaneously, we get additional information that would otherwise be impossible to know. In particular, indoor activity can be characterised, and non-compliance can be easily flagged. Other applications are explored.

Introduction

Scienterra electronic UV dosimeters are wearable devices that measure broadband personal UV exposure. They are accurate, lightweight, configurable, and reusable (Sherman, 2014). At the 2014 NIWA UV workshop in Auckland, a dosimetry breakout session generated ideas about additional features. These features expand the instrument's ability to enable productive research. While implementing these enhancements, we improved other features as well.

The most sought-after improvement was a means of detecting compliance, i.e. knowing whether a research participant is actually wearing the device. This feature required additional circuitry, so a new instrument was required. This new instrument measures visible light as a means to detect compliance. Additionally, UVA and UVB photodiodes are both measured.

Improvements to existing UV dosimeter

Improved calibration stability

In 2014, a set of older dosimeters had developed significant offsets in their calibration curves as shown in Figure 1a. These offsets had not been present during their previous calibration. Tests revealed that varying degrees of offset were associated with each photodiode sensor, and the problem appeared to be caused by a change in the non-ideal behaviours of the semiconductor material. The exact nature of this change is still to be determined.

Offsets had emerged in specific sensor components, while other units had maintained perfect responses. We sought to develop a firmware solution to automatically compensate for the offset in afflicted units, whilst leaving the unaffected units functionally unchanged. A new measurement technique was devised. Since coding the new technique, the calibration offsets have disappeared, as shown in Figure 1b.

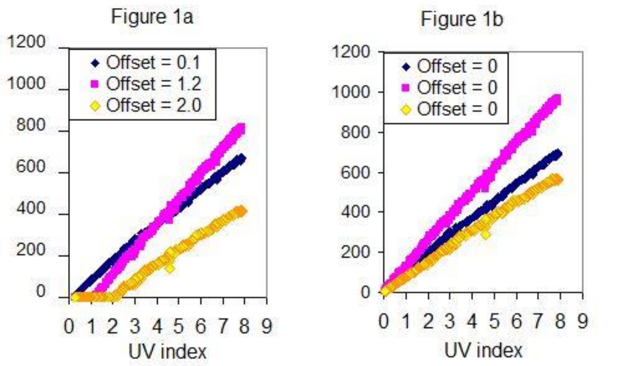

Figure 1a. Uncalibrated data prior to the update. In these figures, slope is arbitrary; non-zero intercept is the flaw that requires attention. Note the offsets where data cross the x-axis. **Figure 1b.** The same instruments after applying the update. Note all data converges at the origin.

Expanded measurement range

The dosimeter's sensitivity is adjustable, to allow for changing seasonal conditions. When a dosimeter's integration time is accidentally set too high (i.e., too sensitive), the measurement is clipped as seen in Figure 2a. This resulted in lost information in the clipped region. The revised instrument recovers this lost information by using two simultaneous measurement methods for each data point, and then selecting the appropriate result. This enhancement effectively quadruples the measurement range of the instrument, as shown in Figure 2b.

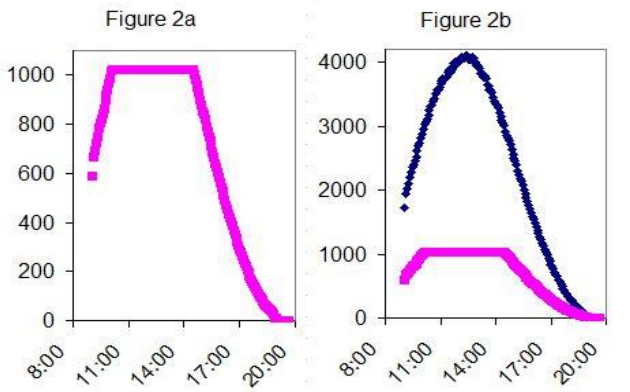

Figure 2a. Raw dosimeter data is displayed as a function of time. The dosimeter's sensitivity has been set too high, causing high-UV data to be clipped. **Figure 2b.** Data from the same instrument after the update. Note the sensitivity has been increased even further, to demonstrate the entire measurement range.

Improved indication of battery health

The voltage of a lithium battery does not linearly decrease as the battery discharges. Rather, the voltage declines gradually until the very end of its life, when the voltage suddenly plummets. This presents a challenge when trying to determine a battery's remaining charge.

The new firmware has an innovative solution. When current is drawn, a weak battery will sag more than a fresh battery. The dosimeter now measures the battery voltage before and during a power-hungry operation; the difference between these two measurements provides an indication of the battery's health, better than either measurement alone.

Error logging

Personal dosimetry is fraught with unanticipated events that can corrupt data. Simply getting out of a car can cause a 7000-volt static discharge that could reset the instrument. To make data analysis easier, the dosimeter now records a timestamp and a coded error description in a safe section of memory. An entry is logged at each of these events: an interruption in battery power; a failure to record data (usually due to a weak battery); and an unanticipated reset (usually caused by static electricity).

Reliable and fast wireless communication

All aspects of the wireless communication have been refined, with faster timing and better error correction. Reliable communication has been optimised for all operating conditions.

Upgrade available for all existing instruments

The above enhancements can be achieved by applying a simple firmware update. Even our oldest dosimeters can be easily rejuvenated to the latest version.

Rounded radome diffuser

As shown in Figure 3, the diffuser has been reshaped to a smoother and more graceful form. The new diffuser can be provided as a replacement part for older instruments, as it was designed to accommodate older circuit boards.

Figure 3. The new radome diffuser is smaller and more rounded, which appeals to many users. Diameter is 36mm and height is 12mm.

Development of a new instrument that senses multiple spectra

There has been a growing interest in simultaneous measurements of UVA and UVB. While UVB is linked to vitamin D synthesis, erythema, and skin cancer, UVA is linked to aging. More research is being done on the harmful effects of UVA. Measuring both wavebands is therefore ideal.

Detecting non-compliance

UV radiation is greatly reduced indoors, especially UVB. When UVB dosimetry data includes a string of zeroes during daylight hours, it usually means that the dosimeter was indoors. However, this does not necessarily mean that the study participant was indoors; perhaps so, or perhaps the dosimeter was lying forgotten on a nightstand while the participant was outside. When interpreting data from a single-spectrum dosimeter, this situation is ambiguous because the string of zeroes looks the same.

The ability to detect and flag such non-compliance adds value to dosimetry data. The easiest way to achieve this is through motion detection. Many popular fitness wearables use accelerometers to quantify physical activity. Alternatively, motion can be detected by measuring variations in visible light. Unlike UV, visible light is ubiquitous during active hours; variations correspond to changes in the dosimeter's position or orientation.

Both methods of motion detection were considered. As the new dosimeter already has the required circuitry to measure two photodiodes, we decided to add a third photodiode to measure visible light.

Testing of prototypes

We exposed two sets of dosimeters to sunlight under mixed sun-and-cloud conditions, for the purpose of comparing the new triple-spectra dosimeters to a set of single-spectrum dosimeters that had been calibrated with Robertson-Berger (RB) type radiometers.

As shown in Figure 4, UV measurements from the new triple-spectra dosimeters compared favourably to data from standard single-spectrum dosimeters carrying the RB calibration.

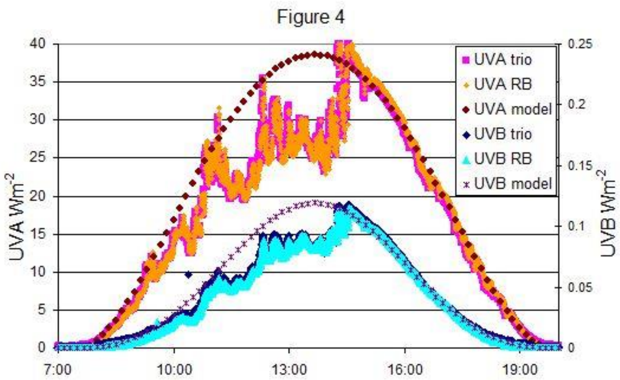

Figure 4. UVA and UVB data from two single-spectrum dosimeters are plotted together with data from a triple-spectra dosimeter, Oamaru, New Zealand, 30 March 2018. UVA scale is on the left and UVB scale is on the right. Note that the data fall on top of each other.

As we do not yet have a reference instrument for visible light, the visible measurements were compared to a radiative transfer model. The results were slightly non-linear, but they were repeatable, monotonic, and consistent between instruments. Some work remains, but if the non-linearity cannot be corrected in firmware, it can be corrected in calibration, as shown in Figure 5. For the purpose of flagging non-compliance and characterising indoor activity, this is sufficient.

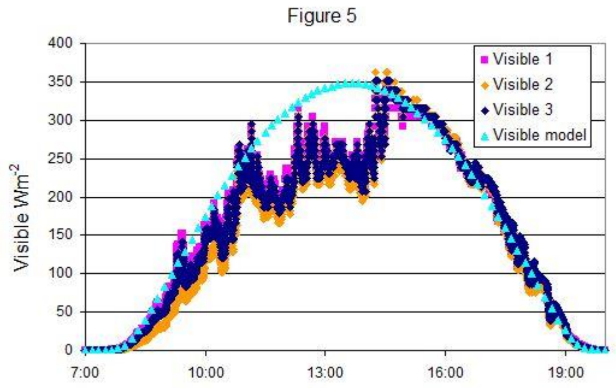

Figure 5. Visible light measurements from three different instruments, after adding a small correction for non-linearity, Oamaru, New Zealand, 30 March 2018. The correction is 0.03 times the square of the measurement. Note the consistency between instruments.

Applications of multiple-spectra dosimetry

A dosimeter that measures multiple wavebands can answer questions that would otherwise remain mysteries. For example, when using a single-spectrum UVB dosimeter, if UVB suddenly goes to zero, there are two possibilities: the participant has either gone indoors, or he has accidentally covered the sensor with his sleeve. When using a multiple-spectra dosimeter, data from the other sensors can reveal which of these scenarios is correct.

Looking deeper, the extra data can reveal even more information. In Figure 6, dosimetry data is used to characterise a participant's time as outdoor-active, indoor-active, or indoor-sedentary. When UVB is non-zero, the dosimeter is outdoors. When UVB is zero, and visible light data is bouncing around, then the participant is probably moving his body, characterising active time. Long periods when the visible light data is quiet indicate that his wrist is not moving, inferring sedentary behaviour.

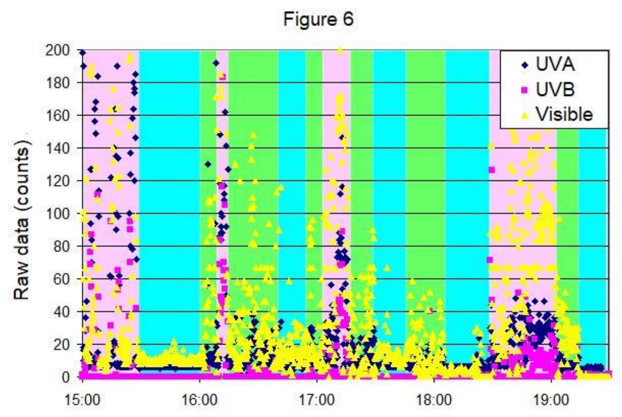

Figure 6. Dosimetry depicting indoor-outdoor transitions, and different modes of indoor behaviour. UVB becomes zero when participant moves indoors. Non-zero wavebands (UVA and visible) can reveal active or sedentary behaviour. In this figure, outdoor time is highlighted in pink, indoor-active time is highlighted in green, and indoor-sedentary time is highlighted in blue. The leftmost blue episode (starting at 15:30) may be a 'sleeve' event, as the transition is quite sudden.

Multi-channel dosimetry can also reveal information about the participant's reflective outdoor environment. When UVA, UVB, and visible rays strike various natural and architectural surfaces, they reflect differently (Turner and Parisi, 2012 and 2013). Ratios between the three wavebands can potentially reveal differences between these surfaces, as seen in Figure 7. This may or may not have real-world implications for dosimetry; the concept demonstrates just one way that the interpretation of dosimetry data could be expanded.

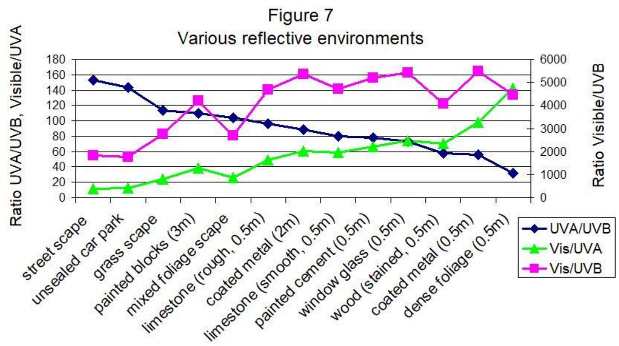

Figure 7. Ratios can reveal different reflective qualities of various environmental surfaces. All data was obtained by pointing the dosimeter south (away from the sun) at midday with a clear sky. Categories with distances (e.g., 0.5m) measure reflections from vertical surfaces normal to the dosimeter. Remaining categories measure reflections from mostly horizontal surfaces. (Preliminary)

Summary

New firmware has improved the performance and feature set of the Scienterra UV dosimeter. Researchers who purchased instruments prior to 2015 can enjoy these enhancements by applying a firmware update.

A new instrument has been developed that measures UVB, UVA, and visible wavebands. Simultaneous measurements of these wavebands are useful for many aspects of data analysis. Multiple-spectra dosimetry has the potential to enable new types of research.

References

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