**4. Feasibility analysis of sun photometers**

The objectives of this feasibility analysis are to identify the advantages and disadvantages of the sun photometers used in past experiments, analysing the feasibility of sun photometer in this research, and identify the research opportunities through integrating with radio communications. Sun photometers described in Section 4.1, Section 4.2, Section 4.3, Section 4.4, Section 4.5 and Section 4.6 have various features, which made them feasible for past experiments.

**4.2. GLOBE Sunphotometer**

GLOBE Sunphotometer is a two-channel mobile sun photometer made by David Brooks in Institute of Science Research and Education. It contains a green LED, which detects voltage response at 500nm and a red LED, which detects voltage response at 625nm. The hardware implementation of this sunphotometer contains two transimpedance amplifiers with a toggle switch to select the voltage reading. A 9V battery supplies power to the sunphotometer with a toggle switch to activate it. [43]. It costs $140 to order this sunphotometer. The advantage of using this sunphotometer is it is easy to build, and it only contains several components with a digital voltmeter interface. However, it does not provide the full range of detecting aerosols optical depth since it only has two channels to detect the aerosol thickness. [43]. The main difference between GLOBE sunphotometer and the sunphotometer designed for this research is the number of active channels for aerosol optical depth measurements. There are various aerosol sizes in the atmosphere, and it is better to detect different wavelengths from the sun with more active channels. A display will be mounted into the sunphotometer for display multiple measurements at the same time. (Active channels – more wavelength detection and can detect more size of aerosol content) GLOBE sunphotometer only enables detecting one voltage data with selectable toggle switch, whereas the sunphotometer designed for this research is capable to detect wavelengths at 440nm, 525nm, 635nm, 870nm, and 940nm. It has 5 detection channels and able to detect the voltage simultaneously. It is also capable for miniaturization, as it is important for integration with radio transceiver modules.

**4.3. SkyClarity Device**

SkyClarity Device is a mobile sun photometer made by Dr. Andrew Kufel. It contains 5 optical channels, a pressure sensor, and a humidity sensor. The device has a data interface with an application in iPhone platform through an audio jack cable. The application shows the recorded data on each channel. The sensor is tuned through temperature characterisation. There is a magic tape on the case to secure an iPhone on the sunphotometer. The advantage of using SkyClarity Device is it eliminates extra LEDs for signal conditioning by using switchable gains through a multiplexer. However, it requires an audio jack cable to interface between the phone and device, which means that an energy harvesting circuit is required to store the input power from the phone in order to supply the device. [44] [45] [46]

The main differences between SkyClarity Device and the sunphotometer for this research are the method of power supply and data communications.  SkyClarity device enables both power supply and data communications with a mobile phone through an audio jack cable, whereas solar panels will supply power to the sunphotometer in this research. The solar panels will then go through a voltage regulating circuit to supply regulated voltages to the sunphotometer. It also has 16-bit ADC with programmable gains, which can give a flexibility on adjusting the amplification of the circuit to 5V. The resolution of the instrument is also capable for accurate measurements. The sunphotometer designed for this research will also be able to communicate to mobile devices through GSM mobile communications, and the device will be autonomous on datalogging the voltages, and able to produce Langley calibration plots.

**4.4. Sun and Sky Monitoring Station by Radioshack**

Sun and Sky Monitoring Station, also called as Radioshack, is a monitoring station made by Forest Mims. It contains 4 channels, which enables voltage detections at 525nm, 625nm, 816nm, and 940nm.  It also has an adjustable shadowband, a collimator, a compass, a sun angle and air mass scale. The advantages of using this device are it is convenient to set up the amplification of the channels with the digital readings LCD screen. It also has an adjustable shadow filter to detect the effects of shadowing the sunphotometer. However, the disadvantage of using this station is it does not record data simultaneously. This means the user needs to do data logging into the notebook in order to analyse the data. [47] The digital readout can only present an output of one sensor channel through a selectable switch.

The differences between Sun and Sky Monitoring Station by Radioshack and the sunphotometer designed for this research are the sun-tracking device, the number of active sensor channels, and the datalogging method.  The sunphotometer for this research is capable on recording 5 sensors channels, and record them simultaneously. It is capable to be a datalogger, where the data can be automatically stored on the SD card and the computer. The detection wavelengths at the sunphotometer for this research will be at 440nm, 525nm, 635nm, 870nm, and 940nm.  A tracking device will be mounted with a sunphotometer for tracking the path of the sun. This will give the sun angle, and air mass of the device. A computational program will be installed into the tracking device, where it can transfer the air mass data with the sunphotometer for logging data into the processing unit. This will enable autonomous data calibration using Langley Extrapolation and Perez Dumoriter Model.

**4.5. Sun and Sky Monitoring Station by University of Southampton**

Miss Zainab Orooq and Mine Ericas make Sun and Sky Monitoring Station from University of Southampton. This device enables user interface through Bluetooth. It has 5 sensor channels, which has detection wavelength at 480nm, 565nm, 768nm, 816nm, and 935nm. The channels have signal conditioning with both trans-impedance and instrumentation amplifiers, where they take the difference between the light current and the dark current to obtain the voltage response from the channels. The advantage of using this sensor is the sensor is simply controlled by the trans-impedance amplifier gain setting. The device is also portable and easy to interface with mobile applications. The disadvantage is there are variations on spectral response between two same photodiodes. Besides, it requires spectral calibration on the photodiodes in order to detect desired spectral wavelengths.[48]

The main difference between Sun and Sky Monitoring Station by University of Southampton and the sunphotometer used for this research is the architecture of instrumentation amplifier. Sun and Sky Monitoring Station used AD620 dual-rail instrumentation amplifier, which requires both positive 5V supply and negative 5V supply. This means that it requires a dual regulated voltage circuit to supply both voltages towards AD620 instrumentation amplifier.

The sunphotometer designed for this research uses ADS1115 Analog-Digital-Converter (ADC) as the instrumentation amplifier. It is a 16-bit ADC instrumentation amplifier with programmable gain controls, 4 analogue input channels and enables I2C interface to the processing unit. The main advantage of using this instrumentation amplifier is the resolution of voltage detection, as each step is 1.875mV. The Arduino can also support 4 instrumentation amplifiers with 4 different I2C addresses. A 5 channel sun photometer can fit with 2 ADS1115 instrumentation amplifiers to detect incoming voltage data.

**4.6. Microtops**

Microtops is a handheld sunphotometer, which provides AOT measurements for wavelengths at 340, 380, 440, 500, 675, 870, 936, and 1020nm. World Meteorological Organisation recommends five of those wavelengths. The advantages of using Microtops are it provides various detection wavelengths, portable, and has read-only memory. The disadvantages are it is expensive, and consumes a lot of processing space.[49]

The main difference between Microtops and the sunphotometer designed in this research is the channels used for aerosols optical depth measurements. The sunphotometer designed for this research has 5 channels, whereas Microtops has 8 channels. The advantage of having fewer channels is it saves the processing memory consumption in software programming.

Table 1 – Summary of the feasibility of previous sunphotometers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sun photometer device | Detection wavelengths | Advantages | Disadvantages | Used experiments |
| Proposed instrument | * 440nm * 535nm * 635nm * 870nm * 940nm | * 16 bit ADC resolution * Simultaneous voltage response on LCD screen * Able to present pollution level * Capable for Data logging * Calibration is in the direction of the sun | * Expensive * LED requires further calibration | Educational use  PhD Research |
| GLOBE sun photometer[45] | * 500nm * 625nm | * Switchable Channels * Easy to build | * No full range of wavelength detection | Educational use |
| SkyClarity Device[48] | * 480nm * 525nm * 565nm * 768nm * 814nm | * Switchable gains with a multiplexer * Elimination of a dark LED for signal conditioning * Portable | * Needs an audio-jack wire for power and data interface * Consume phone battery | LED Temperature Characterisation  Edinburgh |
| Sun and sky monitoring station Radioshack [49] | * 620nm * 640nm * 816nm * 940nm | * Adjustable Resistor Gains | * No longer produced * Needs manual datalogging | Educational Use |
| Sun and Sky Monitoring Station (Zainab Orooq)[50] | * 480nm * 565nm * 768nm * 870nm * 935nm | * Single trans-impedance gain control * Portable | Need solar cell battery  May have different detection wavelength for the dark LED | University of Southampton MSc Project |
| Microtops | * 340nm * 380nm * 440nm * 500nm * 675nm * 870nm * 936nm * 1020nm | * Ease of use * Portable * Datalogger to ROM (read-only memory) * Various detection wavelengths than other sun photometers | * £8000 cost * Expensive * Requires large memory space on the processor | 1999 Sky Type Discrimination in South Dakota[9]  2006 AOT measurements in Mohal-Kullu [53] |

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