# Wearable UV Spectroradiometer for Dosimetry

## Introduction

Background

Cannabis farms frequently use ultraviolet radiation (UV) emitting lamps to provide supplemental light for crops1, and research team has observed that farm workers routinely work underneath these lit fixtures. However, measurement of worker exposure to UV proves a challenge because all currently wearable devices produce a single integrated measurement weighted by the spectral response of the measurement device. Thus, these devices do not allow accurate measurement of worker exposure to UV radiation in cannabis farms that contain more than one spectrum in a single growing environment. If farms only contained grow environments with radiation of a single spectrum, the currently available wearable technology would suffice. However, the research team observed that farms frequently use multiple spectra in a growing environment, and farms with grow environments having a single spectrum are the exception.

Purpose

Commercially available lab bench spectroradiometers can measure the spectral distribution of an environment, and thus do not suffer from the spectral mismatch issue that plagues current wearable devices. The currently available Ocean Optics Flame-S Spectroradiometer can measure wavelengths outside the solar wavelength range, but its design restricts use to lab bench settings. Thus, this project’s purpose is to develop a microcontroller system that allows researchers to mount and use the Ocean Optics Flame-S Spectroradiometer as a wearable UV measurement device.

## Hardware

Spectroradiometer

The Ocean Optics Flame-S Spectrometer can measure UV radiation from 200 to 860 nm, almost fully encompassing the range considered by the American Conference for Governmental Industrial Hygienists (ACGIH)2.



**Figure 1:** Our Ocean Optics Flame-S Spectrometer.

This spectroradiometer can use a variety of communication standards allowing communication with an external device, usually a traditional computer. The external device can execute a spectral scan by sending a command along one of these communication interfaces, and the command can contain many parameters. The most important parameters are integration time, number of scans to average, and communication rate. This device uses the Recommended Standard 232 (RS232) communicate with the microcontroller, with bits represented as high and low voltages of +2.5V to +6V and -2.5V to -6V.3 A subsequent section will cover this communication.

Microcontroller

This project uses the Arduino Due microcontroller board. Arduino Due is a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3 CPU. The board has 54 digital input/output pins, 12 analog inputs, a USB connection, a power jack, an In Circuit Serial Programming (ICSP) header and a reset button. The board communicates using the transmitter – transmitter logic (TTL) standard with bits represented as high and low voltages from 3.3V and ground.

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**Figure 2:** A top view of the Arduino Due microcontroller

MicroSD Interface

The platform uses a microSD transflash breakout to interface the Arduino Due and the microSD card. This peripheral allows the platform to store spectrum data. Figure 3 shows this peripheral.

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**Figure 3:** The microSD Transflash breakout

Spectroradiometer Interface

The Ocean Optics breakout box is a passive module that wires the signals from the spectroradiometer's JAE DD4 40-pin connector port to an array of standard connectors and headers. This platform uses the breakout box’s DB9 connector port to connect to the Arduino. Figure 4 presents this interface.

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**Figure 4:** The spectroradiometer JAE DD4 40 pin port connecting to the Spectroradiometer (circled), the Ocean Optics Breakout Box (indicated by arrow), and the DB9 port connection to the Arduino TTL to RS232 converter (dashed circles).

Real Time Clock

The DS3231 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted.4

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A picture containing text, electronics

Description automatically generated**Figure 5:** The DS 3231 RTC.

TFT Screen and User Interface

The platform has a thin-film-transistor (TFT) (128x160) liquid-crystal display and four buttons (not pictured) that together allow a user interaction with the device. In addition to an LCD screen, the TFT has a built in microSD card reader separate from the peripheral discussed previously. The platform does not use this microSD card reader, but is fully hooked up for use should a need case arise.

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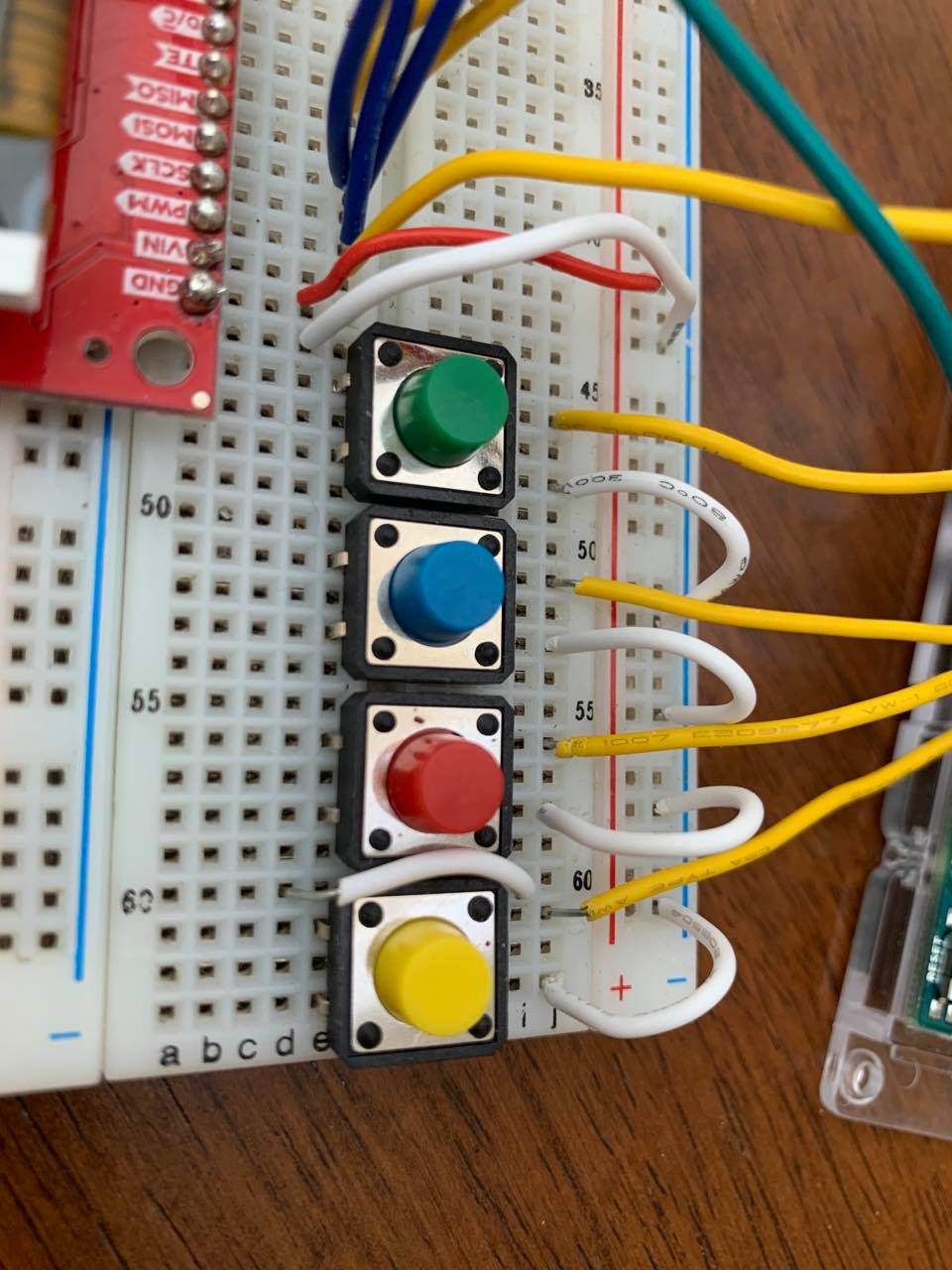
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**Figure 6:** The SparkFun 1.8” TFT LCD Breakout

This interface allows the user to initiate a single measurement, start a sampling session, and look at measurement data present on the device.

Buttons

Figure 7 contains an image of the four buttons that allow user interaction with the device.



**Figure 7:** Four colored buttons connected to the Arduino Due. The buttons allow interaction with the platform menus during operation.

## Platform Electrical Circuitry

Figure 8 displays the electrical connections between the Arduino Due, peripheral devices, and the spectroradiometer, RTC, and microSD interface. Table 1 details all labelled pins in this diagram.

Diagram

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**Figure 8:** The wiring schematic for the platform. The yellow rhombus represents a connection to the 3.3V wire and the brown rhombus represents a connection to the electrical ground.

**Table 1:** Descriptions for each pin label.

|  |  |  |
| --- | --- | --- |
| **Label** | **Name** | **Description** |
| VIN | Voltage High (3.3V) | Connects the peripheral to the 3.3V wire. |
| GND | Voltage Low (0V) | Connects the peripheral to the platform electrical ground. |
| MOSI | Master Out Slave In | connection for the master device to send data to the slave device |
| MISO | Master In Slave Out | connection for the slave device to send data back to the master device |
| SCK | Serial Clock | the line that carries the clock pulse generated by the master device |
| SDCS  OR  LCDCS | Chip Select  (for SD card or LCD screen) | the connection used by the master device to inform the slave device that it will send or request data. The SS/CS pin should be set to LOW to inform the slave that the master will send or request data. Otherwise, it is always HIGH |
| D/C | Data/Command pin | Switch on the TFT to send data to the SD card or the LCD screen |
| TE | Tearing Effect | an optional output from the display to synchronize data writes, avoiding the ‘Tearing Effect' that is seen when data is changed halfway through a screen refresh |
| PWM | Pulse width modulation | Allows the input of a PWM signal to dim the backlight of the LCD screen |
| RX | RS232 Data Receiving Pin | The Recommended Standard 232 pin that sends data from the device. |
| TX | RS232 Data Transmitting Pin | The Recommended Standard 232 pin that receives data from the device. |
| Pins  3-12 | Arduino Due Pins | Multi-purpose pins that allow transmitting or receiving bits to and from the Arduino Due. |
| SDA | Serial Data Line | Data gets sent through this pin and gets synchronized with the clock signal on the SCL |
| SCL | Serial Clock Line | The pin that receives the clock signal. |
| DE-9 | RS232 Port | Former industry standard for serial data transmission |
| JAE-40 | JAE Electronics DD4 Series Docking Connector | A general-purpose router interface connector compatible with high-speed signal transmissions such as USB 3.0 |

Figure 9 displays a physical implementation of the Figure 7 schematic.

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**Figure 9:** The physical implementation of the platform allowing the Ocean Optics Flame Spectroradiometer to operate as a wearable device.

## Communication Between Components

RS-232 Standard

This platform uses the Recommended Standard 232 for communication between the Arduino Due and the spectroradiometer. The standard formally defines signals connecting between a data terminal equipment (DTE), in this case the Arduino Due, and a data communication equipment (DCE). Researchers and engineers commonly opt to use the RS232 serial communication standard to control scientific equipment because of its simple implementation and adaptability. The standard facilitates synchronous and asynchronous one-way data transmission between equipment designated as the data terminal equipment (DTE) and the data connection equipment (DCE). The standard represents bits as positive and negative voltages within a range of +3V to +15V and -3V to -15V.5

Serial Peripheral Interface

The platform uses the Serial Peripheral Interface (SPI) for communication between the Arduino Due and the SD card reader/ TFT screen. SPI is a synchronous serial communication protocol that provides two-way master-slave type communication between a microcontroller and its peripherals. SPI facilities this communication using synchronization bits and preset data transfer speeds. An SPI interface communicates using at least four lines, with an additional line required for each additional peripheral device.

Inter-Integrated Circuit Communication

The platform uses Inter-Integrated Circuit Communication (I2C) to communicate between the Arduino Due and the RTC. I2C consists of an SCL and SDA. The data to be transferred is sent through the SDA wire and is synchronized with the clock signal from SCL. The standard formally defines signals connecting between a master device, in this case the Arduino Due, and a slave device, in this case the RTC.

## Platform Functions

This platform facilitates the following functions of the Ocean Optics Flame-S spectroradiometer.

This project developed a platform that allows researchers to use the Ocean Optics Flame-S Spectroradiometer as a wearable device to measure UV and visible radiation. The Arduino Due commands the DCEs through a series of steps that together facilitate measurement of radiation and storage of the measurement data on a micro-SD card. This series of steps is coded in the Arduino programming language and automatically begins executing as soon as the platform connects to power.

**Table 1:** The six steps that the platform performs to measure UV and store measurement data on a micro SD.

|  |  |  |
| --- | --- | --- |
| **#** | **Step** | **Details** |
| 1 | Ocean Optics Flame spectroradiometer connects to a 5V power source | The spectroradiometer must connect to power prior to the Arduino Uno |
| 2 | Arduino Uno connects to a 9V power source | This step executes automatically once the platform connects to power. The Arduino initializes itself and goes to step 2. |
| 3 | Establish DTE/DCE connections | In this step, the Arduino Uno and establishes serial connection between itself and the SD shield and the RTC. |
| 4 | Setup Micro SD | In this step, the Arduino Uno tells the SD shield to create a time stamped file on the Micro SD that will store data from spectrum measurements. |
| 5 | Setup spectroradiometer | In this step, the Arduino Uno establishes a connection with spectroradiometer and sets the parameters of integration time and number of spectral scans to average. |
| 6 | Take a spectral measurement | In this step, the Arduino tells the spectroradiometer to take spectrum. This step executes continuously |
| 7 | Save the measurement data | In this step, the Arduino takes the data generated by the spectroradiometer and sends it to the SD shield |
| 8 | Stop | Steps 5 and 6 repeat until the platform powers down. |

## Software

The software is coded in the Arduino programming language, which is a set of C/C++ function calls that run through a C/C++ compiler upon execution . The program facilitates the execution of the operational steps listed in Table 1 via the execution of many sub-functions within a single operation step. Table 2 details the operational steps the software sub-functions underlying them.

**Table 2:** Software functions executed to perform each of the operational steps.

|  |  |  |
| --- | --- | --- |
| **#** | **Step** | **Software Sub-Functions** |
| 1 | Ocean Optics Flame spectroradiometer connects to a 5V power source | None |
| 2 | Arduino Uno connects to a 9V power source | Library imports  initialization of global variables  command declarations |
| 3 | Establish DTE/DCE connections | Establishment of spectroradiometer communication baudrate  designate pins by which the Arduino Uno communicates with the SD Shield and the real time clock |
| 4 | Setup Micro SD | Create new file where the Arduino will send spectrum data. |
| 5 | Setup spectroradiometer | Set the Arduino Uno and spectroradiometer communication baudrate  Set spectroradiometer the integration time and averaging time parameters to fixed values. |
| 6 | Take a spectral measurement | Tell the spectroradiometer to take a measurement |
| 7 | Save the measurement data | Pass the data from the spectroradiometer, through the Arduino Uno, and to the SD shield.  Tell the SD shield to save the data in the created file |
| 8 | Stop | The process stops once the platform disconnects from power. |

The first step is to connect the spectroradiometer to connect to power and allow at least a second before supplying power to the Arduino Uno. This time gap allows the spectroradiometer to prepare to receive commands from an external device. Once the Arduino powers on, it immediately loads firmware for the board itself. In this step, the Arduino Uno loads the SD, RTC, Time, and Wire libraries. The SD library allows for reading from and writing to SD cards. The RTC library provides commands to access functions and data from the RTC. The Time library allows the Arduino Uno to read the time on the RTC, convert the time format to other formats, and pass the time data to other devices. The Wire library allows the Arduino Uno to communicate with Inter-Integrated Circuit devices like the RTC.

After the Arduino Uno has loaded its own firmware, it proceeds to establish a connection with the SD shield, RTC, and then establishes a connection with the spectroradiometer at a baudrate of 9600. Once complete, the Arduino Uno has completed establishing connections, it calls for and receives the current date and time from the RTC. Then, the Arduino Uno includes the date and time in a communication that tells the the SD shield to create a file on the micro SD. The created file has a name starting with the word “Flame” then the date (Y’YY’\_M’MM’\_D’DD’) and time (Tue\_H’HH’\_M’MM’\_S’SSS’) followed by the filetype post-fix “.csv”. An example of a filename is: “Flame\_Y16\_M04\_D21\_Tue\_H21\_M23\_S300.csv”.

The Arduino Uno then sends a series of commands to the spectroradiometer. The commands are a series of datawords that the spectroradiometer manufacturer pre-programmed on the device, which make the device change its settings upon receipt. In this instance, the commands tell the spectroradiometer to change the integration time to 10 milliseconds and not to perform any averaging of scans. Then, the Arduino Uno sends the command that instructs the spectroradiometer to return a spectral scan.

The spectral scan data contains metadata about the scan, the spectral scan data itself, and a specific dataword that signals the end of spectrum data. The metadata contains a dataword indicating whether the data is compressed (a feature this project does not use), the number of scans averaged, the integration time setting, specification of the most and least significant bits contained in the spectrum data, and a dataword specifying whether all or only some of the spectroradiometer radiation measurement pixels are active (a feature this project does not use). The spectrum data comprises of unsigned integer values between 0 to 65535. The specific dataword that signals the end of spectrum data is ‘0xFFFD’.

## Test Runs

The platform successfully captured multiple time stamped spectra and stored the data on a micro SD card. The test occurred with the spectroradiometer powered via a USB jack and the Arduino Uno powered with Arduino Universal Power Supply that converted USA standard 100-240V AC to 9V 2A.

## Next Steps

The next step is to select a power source and design a power supply system to provide the spectroradiometer with 250 mA at +5 VDC and the Arduino Uno with 500 mA at +9 VDC. Additionally, the platform needs the capability to adjust the integration time of measurement so that the platform can dynamically adjust to high and low light conditions.

## Appendix A: Platform User Interface

Power On

When the platform connects to power, the graphic presented in Figure 9 appears on screen.

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**Figure 9:** the graphic that appears on the TFT at startup.

After a half a second delay, the main menu replaces the UW graphic.

Main Menu

Figure 10 contains a presentation of the main menu.

Graphical user interface

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**Figure 10:** The main menu that appears at power up of the device.

The main menu consists of the heading “Main Menu” in the upper right corner of the screen. The upper left corner of the screen contains the live date and time. The four colored rectangles correspond to the color of a button on the device. indicate the four accessible sub-menus from this screen. The “Take Dark Spectrum”

Dark Spectrum Interface

In

Text

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**Figure 11:**

## Appendix A – Arduino Code

/\*

Author: Max Chmielinski

Title: Wearable Flame Spectrometer Firmware

\*/

#include "SD.h" //for using the SD card

#include "DS1307RTC.h" //for using Real time clock, specifically the DS1307

#include "Time.h" //for using functions that process clock outputs

#include "Wire.h" //for acquiring clock outputs

define rtc 0x68 //mapping the expected location of the clock

File SDcard; // creation of an SD card object

int number\_of\_spectrum = 0; //Keep track of the number of spectrum

int response; //variable that collects non-specta responses from the Spectrometer

byte spectrum\_dataword; //variable that collects each byte of data from the spectrometer

String hours, minutes, seconds, temp; //Strings to separate out the time values for convinience

String current\_time; //String to store the current time

String current\_file\_name;//the name of the current file on the SD card

boolean flame\_ok = false; //For future validation and checkup code

boolean SD\_ok = false; //For future validation and checkup code

byte bcdToDec(byte val) // Convert binary coded decimal to normal decimal numbers

{

return ( (val / 16 \* 10) + (val % 16) );

}

/////////////////////////////////////////////////////////////////////////////////

String getTimeRTC() //a function to get the time. Here is an example of the expected output: Y16\_M04\_D21\_Tue\_H21\_M23\_S30

{

// Reset the register pointer

Wire.beginTransmission(rtc);

Wire.write(0);

Wire.endTransmission();

Wire.requestFrom(rtc, 7);

byte second, minute, hour, dayOfWeek, dayOfMonth, month, year;

second = bcdToDec(Wire.read() & 0x7f);

minute = bcdToDec(Wire.read());

hour = bcdToDec(Wire.read() & 0x3f);

dayOfWeek = bcdToDec(Wire.read());

dayOfMonth = bcdToDec(Wire.read());

month = bcdToDec(Wire.read());

year = bcdToDec(Wire.read());

String t = "";

t += ("Y");

t += String(year, DEC);

t += ("\_");

t += ("M");

t += String(month, DEC);

t += ("\_");

t += ("D");

t += String(dayOfMonth, DEC);

t += ("\_");

if(dayOfWeek == 01){

t += ("Mon");

}

if(dayOfWeek == 02){

t += ("Tue");

}

if(dayOfWeek == 03){

t += ("Wed");

}

if(dayOfMonth == 04){

t += ("Thr");

}

if(dayOfWeek == 05){

t += ("Fri");

}

if(dayOfWeek == 06){

t += ("Sat");

}

if(dayOfWeek == 07){

t += ("Sun");

}

t += ("\_");

t += "H";

t += String(hour, DEC);

t += ("\_");

t += "M";

t += String(minute, DEC);

t += ("\_");

t += "S";

t += String(second, DEC);

return(t);

}

void setup() {

Serial.begin(9600); //begin communication with the Arduino at a baud rate of 9600

Serial.println('aA'); // change Flame to ACSII mode

response = Serial.read();

if (response = 21){

Serial.end();

Serial.println("Error - NAK");

}

Serial.println('K4');// increase the baudrate to 38400

response = Serial.read();

if (response = 21){

Serial.end();

Serial.println("Error - NAK");

}

delay(100);

Serial.begin(38400);

Serial.println('K4');

response = Serial.read();

Serial.println(response);

if (response = 21){

Serial.end();

Serial.println("Error - NAK");

}

Serial.println('A1'); // acquire and sum a scan, the number indicates the number of scans to be summed

response = Serial.read();

if (response = 21){

Serial.end();

Serial.println("Error - NAK");

}

Serial.write('i10'); // set integration time, in microseconds of

response = Serial.read();

if (response = 21){

Serial.end();

Serial.println("Error - NAK");

}

current\_time = getTimeRTC();//get the time string

temp = current\_time.remove(0,14);//creation of the two digit hour string for convinience

hours = temp.remove(2);

temp = current\_time.remove(0,17);//creation of the two digit minutes string for convinience

minutes = temp.remove(2);

temp = current\_time.remove(0,20);//creation of the two digit seconds string for convinience

minutes = temp.remove(2);

current\_file\_name = "FlameData" + current\_time + ".csv";

SDcard = SD.open(current\_file\_name, FILE\_WRITE);

SDcard.println("Count,Time,179.38nm,179.75nm,180.13nm,180.5nm,180.88nm,181.25nm,181.63nm,182nm,182.38nm,182.75nm,183.13nm,183.5nm,183.88nm,184.25nm,184.63nm,185nm,185.38nm,185.75nm,186.13nm,186.5nm,186.87nm,187.25nm,187.62nm,188nm,188.37nm,188.75nm,189.12nm,189.5nm,189.87nm,190.24nm,190.62nm,190.99nm,191.37nm,191.74nm,192.11nm,192.49nm,192.86nm,193.24nm,193.61nm,193.98nm,194.36nm,194.73nm,195.1nm,195.48nm,195.85nm,196.22nm,196.6nm,196.97nm,197.35nm,197.72nm,198.09nm,198.47nm,198.84nm,199.21nm,199.59nm,199.96nm,200.33nm,200.71nm,201.08nm,201.45nm,201.82nm,202.2nm,202.57nm,202.94nm,203.32nm,203.69nm,204.06nm,204.44nm,204.81nm,205.18nm,205.55nm,205.93nm,206.3nm,206.67nm,207.04nm,207.42nm,207.79nm,208.16nm,208.53nm,208.91nm,209.28nm,209.65nm,210.02nm,210.4nm,210.77nm,211.14nm,211.51nm,211.88nm,212.26nm,212.63nm,213nm,213.37nm,213.74nm,214.12nm,214.49nm,214.86nm,215.23nm,215.6nm,215.98nm,216.35nm,216.72nm,217.09nm,217.46nm,217.83nm,218.21nm,218.58nm,218.95nm,219.32nm,219.69nm,220.06nm,220.43nm,220.81nm,221.18nm,221.55nm,221.92nm,222.29nm,222.66nm,223.03nm,223.4nm,223.77nm,224.15nm,224.52nm,224.89nm,225.26nm,225.63nm,226nm,226.37nm,226.74nm,227.11nm,227.48nm,227.85nm,228.22nm,228.59nm,228.97nm,229.34nm,229.71nm,230.08nm,230.45nm,230.82nm,231.19nm,231.56nm,231.93nm,232.3nm,232.67nm,233.04nm,233.41nm,233.78nm,234.15nm,234.52nm,234.89nm,235.26nm,235.63nm,236nm,236.37nm,236.74nm,237.11nm,237.48nm,237.85nm,238.22nm,238.59nm,238.96nm,239.33nm,239.7nm,240.07nm,240.43nm,240.8nm,241.17nm,241.54nm,241.91nm,242.28nm,242.65nm,243.02nm,243.39nm,243.76nm,244.13nm,244.5nm,244.87nm,245.23nm,245.6nm,245.97nm,246.34nm,246.71nm,247.08nm,247.45nm,247.82nm,248.18nm,248.55nm,248.92nm,249.29nm,249.66nm,250.03nm,250.4nm,250.76nm,251.13nm,251.5nm,251.87nm,252.24nm,252.61nm,252.97nm,253.34nm,253.71nm,254.08nm,254.45nm,254.82nm,255.18nm,255.55nm,255.92nm,256.29nm,256.66nm,257.02nm,257.39nm,257.76nm,258.13nm,258.49nm,258.86nm,259.23nm,259.6nm,259.96nm,260.33nm,260.7nm,261.07nm,261.43nm,261.8nm,262.17nm,262.54nm,262.9nm,263.27nm,263.64nm,264.01nm,264.37nm,264.74nm,265.11nm,265.47nm,265.84nm,266.21nm,266.58nm,266.94nm,267.31nm,267.68nm,268.04nm,268.41nm,268.78nm,269.14nm,269.51nm,269.88nm,270.24nm,270.61nm,270.98nm,271.34nm,271.71nm,272.07nm,272.44nm,272.81nm,273.17nm,273.54nm,273.91nm,274.27nm,274.64nm,275nm,275.37nm,275.74nm,276.1nm,276.47nm,276.83nm,277.2nm,277.57nm,277.93nm,278.3nm,278.66nm,279.03nm,279.4nm,279.76nm,280.13nm,280.49nm,280.86nm,281.22nm,281.59nm,281.95nm,282.32nm,282.68nm,283.05nm,283.42nm,283.78nm,284.15nm,284.51nm,284.88nm,285.24nm,285.61nm,285.97nm,286.34nm,286.7nm,287.07nm,287.43nm,287.8nm,288.16nm,288.53nm,288.89nm,289.25nm,289.62nm,289.98nm,290.35nm,290.71nm,291.08nm,291.44nm,291.81nm,292.17nm,292.54nm,292.9nm,293.26nm,293.63nm,293.99nm,294.36nm,294.72nm,295.09nm,295.45nm,295.81nm,296.18nm,296.54nm,296.91nm,297.27nm,297.63nm,298nm,298.36nm,298.72nm,299.09nm,299.45nm,299.82nm,300.18nm,300.54nm,300.91nm,301.27nm,301.63nm,302nm,302.36nm,302.72nm,303.09nm,303.45nm,303.81nm,304.18nm,304.54nm,304.9nm,305.27nm,305.63nm,305.99nm,306.35nm,306.72nm,307.08nm,307.44nm,307.81nm,308.17nm,308.53nm,308.89nm,309.26nm,309.62nm,309.98nm,310.35nm,310.71nm,311.07nm,311.43nm,311.8nm,312.16nm,312.52nm,312.88nm,313.24nm,313.61nm,313.97nm,314.33nm,314.69nm,315.06nm,315.42nm,315.78nm,316.14nm,316.5nm,316.87nm,317.23nm,317.59nm,317.95nm,318.31nm,318.68nm,319.04nm,319.4nm,319.76nm,320.12nm,320.48nm,320.84nm,321.21nm,321.57nm,321.93nm,322.29nm,322.65nm,323.01nm,323.37nm,323.74nm,324.1nm,324.46nm,324.82nm,325.18nm,325.54nm,325.9nm,326.26nm,326.62nm,326.99nm,327.35nm,327.71nm,328.07nm,328.43nm,328.79nm,329.15nm,329.51nm,329.87nm,330.23nm,330.59nm,330.95nm,331.31nm,331.67nm,332.03nm,332.39nm,332.75nm,333.12nm,333.48nm,333.84nm,334.2nm,334.56nm,334.92nm,335.28nm,335.64nm,336nm,336.36nm,336.72nm,337.08nm,337.44nm,337.8nm,338.16nm,338.51nm,338.87nm,339.23nm,339.59nm,339.95nm,340.31nm,340.67nm,341.03nm,341.39nm,341.75nm,342.11nm,342.47nm,342.83nm,343.19nm,343.55nm,343.91nm,344.27nm,344.62nm,344.98nm,345.34nm,345.7nm,346.06nm,346.42nm,346.78nm,347.14nm,347.5nm,347.85nm,348.21nm,348.57nm,348.93nm,349.29nm,349.65nm,350.01nm,350.37nm,350.72nm,351.08nm,351.44nm,351.8nm,352.16nm,352.52nm,352.87nm,353.23nm,353.59nm,353.95nm,354.31nm,354.66nm,355.02nm,355.38nm,355.74nm,356.1nm,356.45nm,356.81nm,357.17nm,357.53nm,357.88nm,358.24nm,358.6nm,358.96nm,359.32nm,359.67nm,360.03nm,360.39nm,360.75nm,361.1nm,361.46nm,361.82nm,362.17nm,362.53nm,362.89nm,363.25nm,363.6nm,363.96nm,364.32nm,364.67nm,365.03nm,365.39nm,365.75nm,366.1nm,366.46nm,366.82nm,367.17nm,367.53nm,367.89nm,368.24nm,368.6nm,368.96nm,369.31nm,369.67nm,370.02nm,370.38nm,370.74nm,371.09nm,371.45nm,371.81nm,372.16nm,372.52nm,372.88nm,373.23nm,373.59nm,373.94nm,374.3nm,374.66nm,375.01nm,375.37nm,375.72nm,376.08nm,376.43nm,376.79nm,377.15nm,377.5nm,377.86nm,378.21nm,378.57nm,378.92nm,379.28nm,379.63nm,379.99nm,380.35nm,380.7nm,381.06nm,381.41nm,381.77nm,382.12nm,382.48nm,382.83nm,383.19nm,383.54nm,383.9nm,384.25nm,384.61nm,384.96nm,385.32nm,385.67nm,386.03nm,386.38nm,386.73nm,387.09nm,387.44nm,387.8nm,388.15nm,388.51nm,388.86nm,389.22nm,389.57nm,389.93nm,390.28nm,390.63nm,390.99nm,391.34nm,391.7nm,392.05nm,392.4nm,392.76nm,393.11nm,393.47nm,393.82nm,394.17nm,394.53nm,394.88nm,395.24nm,395.59nm,395.94nm,396.3nm,396.65nm,397nm,397.36nm,397.71nm,398.06nm,398.42nm,398.77nm,399.12nm,399.48nm,399.83nm,400.18nm,400.54nm,400.89nm,401.24nm,401.6nm,401.95nm,402.3nm,402.66nm,403.01nm,403.36nm,403.71nm,404.07nm,404.42nm,404.77nm,405.12nm,405.48nm,405.83nm,406.18nm,406.53nm,406.89nm,407.24nm,407.59nm,407.94nm,408.3nm,408.65nm,409nm,409.35nm,409.71nm,410.06nm,410.41nm,410.76nm,411.11nm,411.47nm,411.82nm,412.17nm,412.52nm,412.87nm,413.23nm,413.58nm,413.93nm,414.28nm,414.63nm,414.98nm,415.34nm,415.69nm,416.04nm,416.39nm,416.74nm,417.09nm,417.44nm,417.8nm,418.15nm,418.5nm,418.85nm,419.2nm,419.55nm,419.9nm,420.25nm,420.6nm,420.96nm,421.31nm,421.66nm,422.01nm,422.36nm,422.71nm,423.06nm,423.41nm,423.76nm,424.11nm,424.46nm,424.81nm,425.16nm,425.51nm,425.86nm,426.21nm,426.56nm,426.92nm,427.27nm,427.62nm,427.97nm,428.32nm,428.67nm,429.02nm,429.37nm,429.72nm,430.07nm,430.42nm,430.77nm,431.12nm,431.47nm,431.81nm,432.16nm,432.51nm,432.86nm,433.21nm,433.56nm,433.91nm,434.26nm,434.61nm,434.96nm,435.31nm,435.66nm,436.01nm,436.36nm,436.71nm,437.06nm,437.41nm,437.75nm,438.1nm,438.45nm,438.8nm,439.15nm,439.5nm,439.85nm,440.2nm,440.55nm,440.89nm,441.24nm,441.59nm,441.94nm,442.29nm,442.64nm,442.99nm,443.33nm,443.68nm,444.03nm,444.38nm,444.73nm,445.08nm,445.42nm,445.77nm,446.12nm,446.47nm,446.82nm,447.16nm,447.51nm,447.86nm,448.21nm,448.56nm,448.9nm,449.25nm,449.6nm,449.95nm,450.3nm,450.64nm,450.99nm,451.34nm,451.69nm,452.03nm,452.38nm,452.73nm,453.08nm,453.42nm,453.77nm,454.12nm,454.46nm,454.81nm,455.16nm,455.51nm,455.85nm,456.2nm,456.55nm,456.89nm,457.24nm,457.59nm,457.93nm,458.28nm,458.63nm,458.97nm,459.32nm,459.67nm,460.01nm,460.36nm,460.71nm,461.05nm,461.4nm,461.75nm,462.09nm,462.44nm,462.79nm,463.13nm,463.48nm,463.82nm,464.17nm,464.52nm,464.86nm,465.21nm,465.55nm,465.9nm,466.25nm,466.59nm,466.94nm,467.28nm,467.63nm,467.97nm,468.32nm,468.67nm,469.01nm,469.36nm,469.7nm,470.05nm,470.39nm,470.74nm,471.08nm,471.43nm,471.77nm,472.12nm,472.46nm,472.81nm,473.15nm,473.5nm,473.84nm,474.19nm,474.53nm,474.88nm,475.22nm,475.57nm,475.91nm,476.26nm,476.6nm,476.95nm,477.29nm,477.64nm,477.98nm,478.33nm,478.67nm,479.01nm,479.36nm,479.7nm,480.05nm,480.39nm,480.74nm,481.08nm,481.42nm,481.77nm,482.11nm,482.46nm,482.8nm,483.14nm,483.49nm,483.83nm,484.18nm,484.52nm,484.86nm,485.21nm,485.55nm,485.89nm,486.24nm,486.58nm,486.92nm,487.27nm,487.61nm,487.95nm,488.3nm,488.64nm,488.98nm,489.33nm,489.67nm,490.01nm,490.36nm,490.7nm,491.04nm,491.39nm,491.73nm,492.07nm,492.41nm,492.76nm,493.1nm,493.44nm,493.78nm,494.13nm,494.47nm,494.81nm,495.16nm,495.5nm,495.84nm,496.18nm,496.52nm,496.87nm,497.21nm,497.55nm,497.89nm,498.24nm,498.58nm,498.92nm,499.26nm,499.6nm,499.95nm,500.29nm,500.63nm,500.97nm,501.31nm,501.66nm,502nm,502.34nm,502.68nm,503.02nm,503.36nm,503.7nm,504.05nm,504.39nm,504.73nm,505.07nm,505.41nm,505.75nm,506.09nm,506.44nm,506.78nm,507.12nm,507.46nm,507.8nm,508.14nm,508.48nm,508.82nm,509.16nm,509.5nm,509.84nm,510.19nm,510.53nm,510.87nm,511.21nm,511.55nm,511.89nm,512.23nm,512.57nm,512.91nm,513.25nm,513.59nm,513.93nm,514.27nm,514.61nm,514.95nm,515.29nm,515.63nm,515.97nm,516.31nm,516.65nm,516.99nm,517.33nm,517.67nm,518.01nm,518.35nm,518.69nm,519.03nm,519.37nm,519.71nm,520.05nm,520.39nm,520.73nm,521.07nm,521.41nm,521.75nm,522.09nm,522.43nm,522.76nm,523.1nm,523.44nm,523.78nm,524.12nm,524.46nm,524.8nm,525.14nm,525.48nm,525.82nm,526.15nm,526.49nm,526.83nm,527.17nm,527.51nm,527.85nm,528.19nm,528.52nm,528.86nm,529.2nm,529.54nm,529.88nm,530.22nm,530.56nm,530.89nm,531.23nm,531.57nm,531.91nm,532.25nm,532.58nm,532.92nm,533.26nm,533.6nm,533.94nm,534.27nm,534.61nm,534.95nm,535.29nm,535.62nm,535.96nm,536.3nm,536.64nm,536.98nm,537.31nm,537.65nm,537.99nm,538.32nm,538.66nm,539nm,539.34nm,539.67nm,540.01nm,540.35nm,540.69nm,541.02nm,541.36nm,541.7nm,542.03nm,542.37nm,542.71nm,543.04nm,543.38nm,543.72nm,544.05nm,544.39nm,544.73nm,545.06nm,545.4nm,545.74nm,546.07nm,546.41nm,546.75nm,547.08nm,547.42nm,547.75nm,548.09nm,548.43nm,548.76nm,549.1nm,549.43nm,549.77nm,550.11nm,550.44nm,550.78nm,551.11nm,551.45nm,551.79nm,552.12nm,552.46nm,552.79nm,553.13nm,553.46nm,553.8nm,554.13nm,554.47nm,554.8nm,555.14nm,555.48nm,555.81nm,556.15nm,556.48nm,556.82nm,557.15nm,557.49nm,557.82nm,558.16nm,558.49nm,558.83nm,559.16nm,559.49nm,559.83nm,560.16nm,560.5nm,560.83nm,561.17nm,561.5nm,561.84nm,562.17nm,562.51nm,562.84nm,563.17nm,563.51nm,563.84nm,564.18nm,564.51nm,564.85nm,565.18nm,565.51nm,565.85nm,566.18nm,566.52nm,566.85nm,567.18nm,567.52nm,567.85nm,568.18nm,568.52nm,568.85nm,569.18nm,569.52nm,569.85nm,570.19nm,570.52nm,570.85nm,571.19nm,571.52nm,571.85nm,572.18nm,572.52nm,572.85nm,573.18nm,573.52nm,573.85nm,574.18nm,574.52nm,574.85nm,575.18nm,575.51nm,575.85nm,576.18nm,576.51nm,576.84nm,577.18nm,577.51nm,577.84nm,578.17nm,578.51nm,578.84nm,579.17nm,579.5nm,579.84nm,580.17nm,580.5nm,580.83nm,581.16nm,581.5nm,581.83nm,582.16nm,582.49nm,582.82nm,583.16nm,583.49nm,583.82nm,584.15nm,584.48nm,584.81nm,585.15nm,585.48nm,585.81nm,586.14nm,586.47nm,586.8nm,587.13nm,587.47nm,587.8nm,588.13nm,588.46nm,588.79nm,589.12nm,589.45nm,589.78nm,590.11nm,590.44nm,590.78nm,591.11nm,591.44nm,591.77nm,592.1nm,592.43nm,592.76nm,593.09nm,593.42nm,593.75nm,594.08nm,594.41nm,594.74nm,595.07nm,595.4nm,595.73nm,596.06nm,596.39nm,596.72nm,597.05nm,597.38nm,597.71nm,598.04nm,598.37nm,598.7nm,599.03nm,599.36nm,599.69nm,600.02nm,600.35nm,600.68nm,601.01nm,601.34nm,601.67nm,602nm,602.33nm,602.66nm,602.99nm,603.32nm,603.64nm,603.97nm,604.3nm,604.63nm,604.96nm,605.29nm,605.62nm,605.95nm,606.28nm,606.61nm,606.93nm,607.26nm,607.59nm,607.92nm,608.25nm,608.58nm,608.91nm,609.23nm,609.56nm,609.89nm,610.22nm,610.55nm,610.88nm,611.2nm,611.53nm,611.86nm,612.19nm,612.52nm,612.84nm,613.17nm,613.5nm,613.83nm,614.16nm,614.48nm,614.81nm,615.14nm,615.47nm,615.79nm,616.12nm,616.45nm,616.78nm,617.1nm,617.43nm,617.76nm,618.09nm,618.41nm,618.74nm,619.07nm,619.4nm,619.72nm,620.05nm,620.38nm,620.7nm,621.03nm,621.36nm,621.68nm,622.01nm,622.34nm,622.66nm,622.99nm,623.32nm,623.64nm,623.97nm,624.3nm,624.62nm,624.95nm,625.28nm,625.6nm,625.93nm,626.26nm,626.58nm,626.91nm,627.23nm,627.56nm,627.89nm,628.21nm,628.54nm,628.86nm,629.19nm,629.52nm,629.84nm,630.17nm,630.49nm,630.82nm,631.14nm,631.47nm,631.79nm,632.12nm,632.45nm,632.77nm,633.1nm,633.42nm,633.75nm,634.07nm,634.4nm,634.72nm,635.05nm,635.37nm,635.7nm,636.02nm,636.35nm,636.67nm,637nm,637.32nm,637.65nm,637.97nm,638.3nm,638.62nm,638.95nm,639.27nm,639.59nm,639.92nm,640.24nm,640.57nm,640.89nm,641.22nm,641.54nm,641.86nm,642.19nm,642.51nm,642.84nm,643.16nm,643.48nm,643.81nm,644.13nm,644.46nm,644.78nm,645.1nm,645.43nm,645.75nm,646.07nm,646.4nm,646.72nm,647.05nm,647.37nm,647.69nm,648.02nm,648.34nm,648.66nm,648.99nm,649.31nm,649.63nm,649.95nm,650.28nm,650.6nm,650.92nm,651.25nm,651.57nm,651.89nm,652.22nm,652.54nm,652.86nm,653.18nm,653.51nm,653.83nm,654.15nm,654.47nm,654.8nm,655.12nm,655.44nm,655.76nm,656.09nm,656.41nm,656.73nm,657.05nm,657.37nm,657.7nm,658.02nm,658.34nm,658.66nm,658.98nm,659.31nm,659.63nm,659.95nm,660.27nm,660.59nm,660.91nm,661.24nm,661.56nm,661.88nm,662.2nm,662.52nm,662.84nm,663.16nm,663.49nm,663.81nm,664.13nm,664.45nm,664.77nm,665.09nm,665.41nm,665.73nm,666.05nm,666.37nm,666.7nm,667.02nm,667.34nm,667.66nm,667.98nm,668.3nm,668.62nm,668.94nm,669.26nm,669.58nm,669.9nm,670.22nm,670.54nm,670.86nm,671.18nm,671.5nm,671.82nm,672.14nm,672.46nm,672.78nm,673.1nm,673.42nm,673.74nm,674.06nm,674.38nm,674.7nm,675.02nm,675.34nm,675.66nm,675.98nm,676.3nm,676.62nm,676.94nm,677.26nm,677.58nm,677.9nm,678.22nm,678.54nm,678.85nm,679.17nm,679.49nm,679.81nm,680.13nm,680.45nm,680.77nm,681.09nm,681.41nm,681.72nm,682.04nm,682.36nm,682.68nm,683nm,683.32nm,683.64nm,683.95nm,684.27nm,684.59nm,684.91nm,685.23nm,685.55nm,685.86nm,686.18nm,686.5nm,686.82nm,687.14nm,687.45nm,687.77nm,688.09nm,688.41nm,688.73nm,689.04nm,689.36nm,689.68nm,690nm,690.31nm,690.63nm,690.95nm,691.27nm,691.58nm,691.9nm,692.22nm,692.54nm,692.85nm,693.17nm,693.49nm,693.81nm,694.12nm,694.44nm,694.76nm,695.07nm,695.39nm,695.71nm,696.02nm,696.34nm,696.66nm,696.97nm,697.29nm,697.61nm,697.92nm,698.24nm,698.56nm,698.87nm,699.19nm,699.51nm,699.82nm,700.14nm,700.45nm,700.77nm,701.09nm,701.4nm,701.72nm,702.03nm,702.35nm,702.67nm,702.98nm,703.3nm,703.61nm,703.93nm,704.24nm,704.56nm,704.88nm,705.19nm,705.51nm,705.82nm,706.14nm,706.45nm,706.77nm,707.08nm,707.4nm,707.71nm,708.03nm,708.34nm,708.66nm,708.97nm,709.29nm,709.6nm,709.92nm,710.23nm,710.55nm,710.86nm,711.18nm,711.49nm,711.81nm,712.12nm,712.43nm,712.75nm,713.06nm,713.38nm,713.69nm,714.01nm,714.32nm,714.63nm,714.95nm,715.26nm,715.58nm,715.89nm,716.2nm,716.52nm,716.83nm,717.15nm,717.46nm,717.77nm,718.09nm,718.4nm,718.71nm,719.03nm,719.34nm,719.65nm,719.97nm,720.28nm,720.59nm,720.91nm,721.22nm,721.53nm,721.85nm,722.16nm,722.47nm,722.79nm,723.1nm,723.41nm,723.73nm,724.04nm,724.35nm,724.66nm,724.98nm,725.29nm,725.6nm,725.91nm,726.23nm,726.54nm,726.85nm,727.16nm,727.48nm,727.79nm,728.1nm,728.41nm,728.72nm,729.04nm,729.35nm,729.66nm,729.97nm,730.28nm,730.6nm,730.91nm,731.22nm,731.53nm,731.84nm,732.15nm,732.47nm,732.78nm,733.09nm,733.4nm,733.71nm,734.02nm,734.34nm,734.65nm,734.96nm,735.27nm,735.58nm,735.89nm,736.2nm,736.51nm,736.82nm,737.13nm,737.45nm,737.76nm,738.07nm,738.38nm,738.69nm,739nm,739.31nm,739.62nm,739.93nm,740.24nm,740.55nm,740.86nm,741.17nm,741.48nm,741.79nm,742.1nm,742.41nm,742.72nm,743.03nm,743.34nm,743.65nm,743.96nm,744.27nm,744.58nm,744.89nm,745.2nm,745.51nm,745.82nm,746.13nm,746.44nm,746.75nm,747.06nm,747.37nm,747.68nm,747.99nm,748.3nm,748.61nm,748.92nm,749.22nm,749.53nm,749.84nm,750.15nm,750.46nm,750.77nm,751.08nm,751.39nm,751.7nm,752nm,752.31nm,752.62nm,752.93nm,753.24nm,753.55nm,753.86nm,754.16nm,754.47nm,754.78nm,755.09nm,755.4nm,755.71nm,756.01nm,756.32nm,756.63nm,756.94nm,757.25nm,757.55nm,757.86nm,758.17nm,758.48nm,758.79nm,759.09nm,759.4nm,759.71nm,760.02nm,760.32nm,760.63nm,760.94nm,761.25nm,761.55nm,761.86nm,762.17nm,762.47nm,762.78nm,763.09nm,763.4nm,763.7nm,764.01nm,764.32nm,764.62nm,764.93nm,765.24nm,765.54nm,765.85nm,766.16nm,766.46nm,766.77nm,767.08nm,767.38nm,767.69nm,768nm,768.3nm,768.61nm,768.91nm,769.22nm,769.53nm,769.83nm,770.14nm,770.44nm,770.75nm,771.06nm,771.36nm,771.67nm,771.97nm,772.28nm,772.59nm,772.89nm,773.2nm,773.5nm,773.81nm,774.11nm,774.42nm,774.72nm,775.03nm,775.33nm,775.64nm,775.94nm,776.25nm,776.55nm,776.86nm,777.16nm,777.47nm,777.77nm,778.08nm,778.38nm,778.69nm,778.99nm,779.3nm,779.6nm,779.91nm,780.21nm,780.52nm,780.82nm,781.12nm,781.43nm,781.73nm,782.04nm,782.34nm,782.65nm,782.95nm,783.25nm,783.56nm,783.86nm,784.17nm,784.47nm,784.77nm,785.08nm,785.38nm,785.68nm,785.99nm,786.29nm,786.6nm,786.9nm,787.2nm,787.51nm,787.81nm,788.11nm,788.42nm,788.72nm,789.02nm,789.33nm,789.63nm,789.93nm,790.23nm,790.54nm,790.84nm,791.14nm,791.45nm,791.75nm,792.05nm,792.35nm,792.66nm,792.96nm,793.26nm,793.56nm,793.87nm,794.17nm,794.47nm,794.77nm,795.08nm,795.38nm,795.68nm,795.98nm,796.28nm,796.59nm,796.89nm,797.19nm,797.49nm,797.79nm,798.1nm,798.4nm,798.7nm,799nm,799.3nm,799.6nm,799.9nm,800.21nm,800.51nm,800.81nm,801.11nm,801.41nm,801.71nm,802.01nm,802.32nm,802.62nm,802.92nm,803.22nm,803.52nm,803.82nm,804.12nm,804.42nm,804.72nm,805.02nm,805.32nm,805.62nm,805.92nm,806.23nm,806.53nm,806.83nm,807.13nm,807.43nm,807.73nm,808.03nm,808.33nm,808.63nm,808.93nm,809.23nm,809.53nm,809.83nm,810.13nm,810.43nm,810.73nm,811.03nm,811.33nm,811.63nm,811.93nm,812.23nm,812.52nm,812.82nm,813.12nm,813.42nm,813.72nm,814.02nm,814.32nm,814.62nm,814.92nm,815.22nm,815.52nm,815.82nm,816.12nm,816.41nm,816.71nm,817.01nm,817.31nm,817.61nm,817.91nm,818.21nm,818.51nm,818.8nm,819.1nm,819.4nm,819.7nm,820nm,820.3nm,820.59nm,820.89nm,821.19nm,821.49nm,821.79nm,822.08nm,822.38nm,822.68nm,822.98nm,823.28nm,823.57nm,823.87nm,824.17nm,824.47nm,824.76nm,825.06nm,825.36nm,825.66nm,825.95nm,826.25nm,826.55nm,826.85nm,827.14nm,827.44nm,827.74nm,828.03nm,828.33nm,828.63nm,828.93nm,829.22nm,829.52nm,829.82nm,830.11nm,830.41nm,830.71nm,831nm,831.3nm,831.6nm,831.89nm,832.19nm,832.49nm,832.78nm,833.08nm,833.37nm,833.67nm,833.97nm,834.26nm,834.56nm,834.85nm,835.15nm,835.45nm,835.74nm,836.04nm,836.33nm,836.63nm,836.92nm,837.22nm,837.52nm,837.81nm,838.11nm,838.4nm,838.7nm,838.99nm,839.29nm,839.58nm,839.88nm,840.17nm,840.47nm,840.76nm,841.06nm,841.35nm,841.65nm,841.94nm,842.24nm,842.53nm,842.83nm,843.12nm,843.42nm,843.71nm,844.01nm,844.3nm,844.59nm,844.89nm,845.18nm,845.48nm,845.77nm,846.07nm,846.36nm,846.65nm,846.95nm,847.24nm,847.54nm,847.83nm,848.12nm,848.42nm,848.71nm,849.01nm,849.3nm,849.59nm,849.89nm,850.18nm,850.47nm,850.77nm,851.06nm,851.35nm,851.65nm,851.94nm,852.23nm,852.53nm,852.82nm,853.11nm,853.4nm,853.7nm,853.99nm,854.28nm,854.58nm,854.87nm,855.16nm,855.45nm,855.75nm,856.04nm,856.33nm,856.62nm,856.92nm,857.21nm,857.5nm,857.79nm,858.09nm,858.38nm,858.67nm,858.96nm,859.25nm,859.55nm,859.84nm,860.13nm,860.42nm,860.71nm,861.01nm,861.3nm,861.59nm,861.88nm,862.17nm,862.46nm,862.75nm,863.05nm,863.34nm,863.63nm,863.92nm,864.21nm,864.5nm,864.79nm,865.08nm,865.38nm,865.67nm,865.96nm");

}

/////////////////////////////////////////////////////////////////////////////////

void loop() { //everything inside the loop is repeated forever

number\_of\_spectrum = number\_of\_spectrum + 1;

current\_time = getTimeRTC();

SDcard.println(number\_of\_spectrum); //the header of the spectrum

SDcard.println(",");

SDcard.println(current\_time);

SDcard.println(",");

Serial.println('S'); // acquire a spectrum based on the settings specified in the setup

spectrum\_dataword = Serial.read(); //Eight bytes of unneeded data descriptors

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

spectrum\_dataword = Serial.read();

while (spectrum\_dataword != 65533){ // Take each byte of spectrum data and store it to the SD card

spectrum\_dataword = Serial.read();

SDcard.println(spectrum\_dataword);// take each byte of data sent from the spectrometer and save it to the SDcard

SDcard.println(",");

}

SDcard.println('/n');

}//loop end