FINAL PRODUCT OF PERSONAL PROJECT:
NIR TECHNOLOGY AND IDENTIFICATION OF MATERIALS VIA SPECTROSCOPY

Laboratory report presented to
Mr. Daniel Deschênes
teacher of 505

written by Luca Scavone

Collège Jean-de-Brébeuf
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Table of contents

Summary

This laboratory report presents the results of an experiment involving near infrared technology. With the planet facing significant recycling challenges, it is essential to explore alternatives to the manual sorting of recyclable materials at recycling centers. A potential solution would therefore be near infrared technology (NIR technology). This type of spectroscopy, using a spectroscopic sensor, analyzes the degree of reflection of 18 electromagnetic frequencies located between 410 and 940 nm to identify various types of materials thanks to a database and a program that I wrote. To judge the viability and potential of this technology, I added about twenty different materials to a database at first, then I scanned about ten materials already in the database to determine the reliability of the sensor. I then scanned a few objects not found in the database, but made of the same materials to assess the ability of the sensor to identify unknown materials. After the experiments, I was able to establish the following conclusion: the identification of materials using a spectroscopic sensor remains a technology that has great potential in the field of recycling, but homogeneous materials with smooth and monochrome surfaces are ideal as they provide consistent data.

Introduction

Our 21st century society faces several global challenges. A growing population and rising consumption in developed and emerging countries has led to a global waste crisis as millions of tons of plastics are dumped into the world's oceans. This supposedly life-saving material due to its great utility, malleability and high heat capacity is, however, very difficult to recycle, according to an article by *National Geographic*, since there are several types of plastics that are not compatible when recycled. Since their recycling requires intensive sorting, several developed countries export their plastic waste to developing countries, explains Juliette Campion in her article for France Info. Unfortunately, exported waste is not sorted at all, which makes recycling much more difficult and less profitable. This explains why nearly 300 million tons of plastic waste are generated every year and the vast majority of plastics are simply buried in landfills as reported by the UN.

An updated plastics recycling system is therefore at the heart of this global problem that must be resolved to ensure the survival of our planet's ecosystems. The experiment I have designed will attempt to explore a potential solution to recycling plastics using near infrared technology, a technology that encompasses the electromagnetic spectrum between 800 and 2500 nm to measure light reflection on any material. According to *spectralengines.com*, this technology would make it possible to identify, using a spectroscopic sensor, various materials via their levels of reflection of ambient and infrared light which vary from one material to another. In everyday life, this technology would improve the waste sorting system in recycling centers and could also be included in portable tools or public recycling bins, thus allowing better recycling of materials at home or in public places.

In this experiment, my goal will therefore be, firstly, to code a program in Python which will make use of a spectroscopic sensor to scan and compare materials to a database then, secondly, to judge the viability and potential of this technology in the global problem in which it is part.

To do this, I will use the spectroscopic sensor to take five measurements per frequency of any material (the sensor takes measurements at 18 different frequencies included in the near infrared electromagnetic spectrum) and then average them to obtain 18 averages that I will compare to a database of frequencies of various recyclable or non-recyclable materials. To compare the data, I will calculate the Euclidean distance between the data of the bank and that of the material to be identified to determine the material to which the material to be identified comes closest. In order to check the regularity of the data, I will add several materials to the database then I will scan these same materials several times to judge the reliability of the measuring instrument since the latter could be a major cause of error.

Materials and methods

- Arduino UNO
- USB-Arduino cable
- Black construction paper
- tape
- Soldering
- Various plastic or paper materials used for the
- Pycharm[2]
- SparkFun IDE AS7265x Arduino Library[4]
- 4 electrical wires (red, black, blue, green)
- Cardboard
- White lead pencil
- scissors
- equipment
- SparkFunTriad Spectroscopy Sensor - AS7265x[1]
- Arduino IDE[3]

1. **Manufacture of the case[5]**:
    i. On thin cardboard, draw the decomposed shape of a prism with a rectangular base whose base measures a little more than 3.5 cm x 4.0 cm and the height, 3.8 cm. Omit second base.
    ii. Cut out the shape, fold and glue the sides with adhesive tape to obtain a box where the spectroscopic sensor should fit perfectly. If necessary, secure the sides with additional cardboard. Use the exacto or scissors.
    iii. Repeat steps 1 and 2 with black construction paper without gluing the sides. This second box should fit easily into the cardboard box. Use the exacto or scissors.
    iv. Place the sensor in the box and mark the location of the 4 holes next to which are written GND, 3V3, SDA and SCL.

[1] Consult this link to visit the site of the sensor: [https://www.sparkfun.com/products/15050].
[2] Check this link to download the program: [https://www.jetbrains.com/pycharm/download/#section=mac].
[3] Check this link to download the program: [https://www.arduino.cc/en/software].
[4] Check this link to download the file: [https://github.com/sparkfun/SparkFun_AS7265x_Arduino_Library].
[5] See Appendix III, Figure 1 for an overview.

v. Remove the sensor and cut a thin hole of approximately 0.2 cm x 1 cm at the location of the 4 holes.

vi. Repeat step 5 by drilling the hole in the black construction paper casing. By placing this second case in the cardboard one, the two holes should line up.

2. **Circuit assembly**[6]:

   i. Solder the black wire to the hole marked GND passing through the bottom of the sensor. Thus, the wire should be able to exit the housing through the hole drilled in the base of the latter.

   ii. Repeat step 1 with the other three threads. For the sake of convention, the red wire will be attached to the 3V3 and the other two wires can be interchanged, but will be attached to the SDA and SCL.

   iii. Insert the sensor and wires into the housing making sure the wires all exit through the hole in the base of the housing.

   iv. On the Arduino, insert the black wire into one of the two pins marked GND.

   v. On the Arduino, insert the red wire into the pin marked 3.3V.

   vi. On the Arduino, insert the wire connected to the SDA into the pin marked 4.

   vii. On the Arduino, insert the wire connected to the SCL into the pin marked 5.

   viii. Connect the Arduino to the computer via the USB-Arduino cable.

3. **Programming the Arduino section**

   i. Download the Arduino IDE application and open it.

   ii. Download Computer Library[7] SparkFun's

   iii. Open a new project and copy the code from appendix I.

   iv. Click on the arrow at the top left. This will upload the program to the Arduino.

   v. To test the program, click on the magnifying glass at the top right and type "g". If everything works correctly, a series of 18 digits should appear.

4. **Programming section Python**

   i. Download the Pycharm IDE application and open it. If necessary, consult a video[8] to install it correctly.

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[6] See Appendix III, Figure 2 for an overview.

[7] See this link to download the file: [https://github.com/sparkfun/SparkFun_AS7265x_Arduino_Library].

[8] HAMEDANI, Mosh. Software engineer. 2019. "Python Tutorial - Python for Beginners." *Programming with Mosh*. On line. [https://www.youtube.com/watch?v=_uQrJ0TkZlc&ab_channel=ProgrammingwithMosh]. Page accessed October 4, 2020.

ii. Open the app and click on *Terminal* at the bottom of the screen. This will open a small window at the bottom of the application.
iii. For the program to work, you will need to install a few additional programs. In the window opened in the previous step, type the following command: *pip install numpy* + [enter].
iv. After downloading Numpy, type the following command: *pip install pyserial* + [enter].
v. Open a new project and copy the code from appendix II.
vi. In the 13th line of the program, you will have to modify what is between the quotation marks. Return to the Arduino application and determine the port to which the Arduino (microprocessor) is connected. On a Mac, click to *Tools* + *Port* find the port name. Replace " /dev/cu.usbmodem1D11141 " with the name found. Be sure to copy the name literally. Otherwise, the program will not know where to collect the data.
vii. Download the following file: data_bank_example.csv[9].
viii. On Pycharm, right click on the project name at the top left in the directory.
ix. Click on “Reveal in finder” and drag the file into the project directory.
x. On lines 68, 70, 85 and 105, replace " Data_Bank.csv " with the name of the file downloaded in step 7: " Data_Bank_Example.csv ". This file contains a dozen materials already analyzed, but the file is easily editable in Pycharm and could be completely erased.

5. **Experimentation and adding data**

i. On the Pycharm application, click on the small green triangle at the top right to run the program. A small menu will appear showing the possible commands.
ii. To add the data of a material to the database, type the number 1 then the letter y, making sure to completely cover the box containing the sensor with the desired material. In order to obtain accurate results, it is preferable to cover transparent or semi-transparent materials with a sheet of white paper and to keep a constant illumination on the sensor. This will limit the impact of ambient light on the data.

[9] Check this link to download the file: [https://drive.google.com/file/d/1UbrQQE_CB15NvumLK9oWos2e5qbjGppV/view?usp=sharing].

iii. To compare the data of a material with those of the database, type the number 2 then the letter y, always making sure to completely cover the box and the sensor. Follow the same suggestions as in step 2.

iv. Type 3 to get a complete list of materials included in the database.

v. Type 4 for a short description of the program.

vi. Type 0 to end the program.

Results

Table 1: Values measured at 18 different frequencies for 22 materials from a database

Matériau:	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm
Cardboard - Brown (1mm)	642.82	248.32	418.36	160.79	276.2	349.5	208.02	239.6	149.56	65.9	239.08	110.99	559.92	222.97	87.13	71.58	232.38	591.04
Cardboard - Brown (2mm)	561.43	211.16	348.48	139.41	234.2	299.73	184.15	225.95	146.37	64.21	242.07	112.91	540.83	219.29	86.28	70.73	229.17	592.95
Cardboard - White (1mm)	3035.47	1045.34	1702.47	700.04	1044.29	1174.36	718.65	788.87	527.66	201.49	428.97	199.6	1706.96	672.99	237.48	181.51	491.48	1101.06
Construction Paper - Black	585.39	175.66	256.82	103.16	159.55	169.77	86.44	99.06	61.56	106.95	337.21	146.4	183.2	219.29	199.72	140.27	327.71	858
Construction Paper - Purple	1150.98	488.73	831.09	268.6	342.43	334.36	193.07	213.57	321.64	253.44	335.65	154.05	579.67	784.27	300.18	193.44	356.77	853.93
Construction Paper - Blue	1110.38	468.13	816.02	314.51	379.6	333.14	148.79	159.92	180.11	242.97	332.41	153.1	347.75	667.68	310.26	196.85	349.46	865.17
Construction Paper - Green	747.38	237.1	378.43	272.32	525.31	527.18	260.22	246.38	115.36	211.63	333.7	151.18	358.51	439.2	301.72	192.59	357.48	868.99
Construction Paper - Yellow	726.39	248.32	350.29	315.81	776.22	946.22	666	909.63	749.63	254.88	357.97	172.23	2205.66	871.25	286.51	200.09	450.32	928.27
Construction Paper - Orange	848.18	293.39	433.24	266.74	395.11	410.45	273.49	615.52	856.41	277.02	344.48	166.49	2508.22	957.01	310.26	210.31	439.98	905.32
Construction Paper - Pink	1166.82	545.57	929.83	361.35	472.62	515.31	366.07	726.65	838.81	274.99	344.48	167.45	2481.24	945.78	307.53	211.17	445.15	890.02
Paper - White	2267.3	1466.56	2006.66	860.63	1027.13	1069.63	633.09	673.3	429.62	182.48	413.66	192.33	1445.21	606.83	220.4	167.02	457.09	1055.17
Food Wrapping - Semi-Clear	3143.4	1258.16	1911.55	642.78	998.53	1204.63	614.58	647.16	359.49	164.49	362.26	159.6	1197.07	512.5	186.91	145.04	394.9	859.67
Single-Use Bag - Semi-Clear	3762.26	1312.6	2123.54	761.19	1267.05	1562.58	459.54	587.58	425.61	167.1	388.09	177.59	1435.34	594.58	216.81	161.91	450.14	960.29
Styrofoam - White	2590.69	1099.23	1644.75	664.34	916.5	997.36	597.4	628.22	385.85	169.81	361.48	166.49	1357.23	537.62	199.89	149.98	407.91	892.65
Thicker Plastic Bag - Semi-Clear	3902.27	1770.8	3007.63	1116.41	2149.24	2437.21	598.29	869.41	481.6	205.29	416.38	185.63	3617.97	876.76	409.36	269.97	621.04	937.35
Plastic Sticker Material - White	3575.32	1252.46	2012.29	681.26	1134.6	1321.63	648.26	697.11	380.83	152.49	404.31	183.14	1627.1	534.96	194.6	155.09	469.57	1029.84
Plastic Food Container - White (PP-5)	2687.33	1451.12	1990.32	732.75	1039.02	1167.68	595.06	631.71	361.13	140.24	305.67	146.4	1397.38	482.49	171.87	132.94	365.14	770.28
Plastic Food Container - Blue (PETE-1)	1772.41	612.34	1059.78	251.87	513.87	500.59	88.78	74.61	45.6	69.27	171.46	83.44	285.22	132.52	114.47	79.25	184.62	423.02
Plastic Shrimp Bag - White/Grey	2008.07	680.03	1355.99	376.04	724.29	831.54	305.84	346.92	176.19	83.55	312.55	131.85	661.5	199.69	80.98	79.93	277.11	657.72
Plastic Milk Bag - White	4370.82	1326.96	1972.9	694.83	1276.24	1413.67	765.6	973.97	513.25	192.53	296.84	150.22	2976.43	732.4	287.54	201.28	520.35	740.17
Plastic Cider Container - Semi-Clear (HDPE-2)	1536.55	471.81	751.23	253.92	409.11	471.27	220.29	248.81	175.73	71.39	99.94	57.22	572.86	222.76	88.84	60.67	120.47	214.14
Ziploc Bag - Clear	3983.07	1278.57	1772.16	783.68	1251.55	1331.17	348.11	573.19	376.46	151.56	360.18	168.22	1722.32	389.78	191.35	128.68	365.68	563.08

Figure 1: Graph of values[10] measured at 18 different frequencies for 22 materials from a database

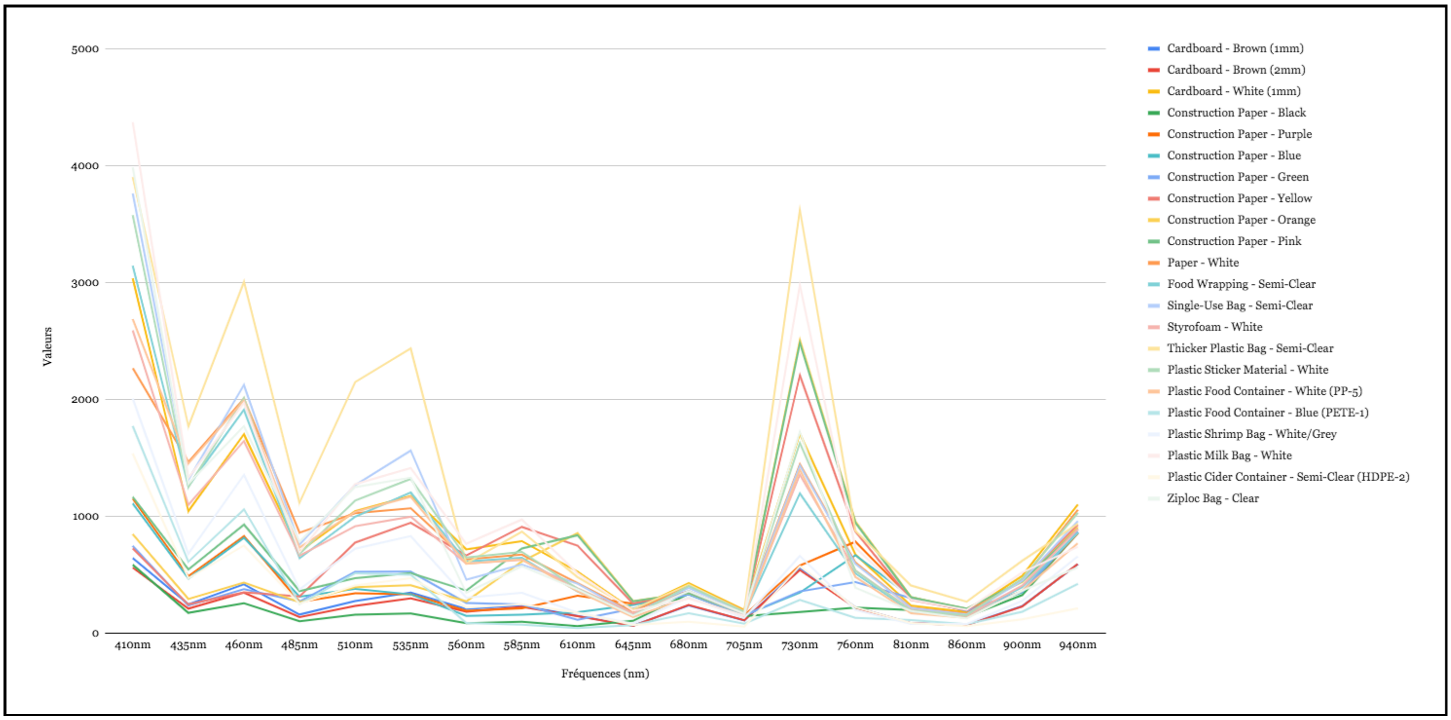

Table 2: Values measured at 18 different frequencies for brown cardboard (1mm) at five different positions

Carton brun - 1mm:	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	☑	648.96	247.4	406.01	161.53	269.43	342.27	192.4	231.77	151.84	65.05	238.82	111.95	548.07	229.91	87.99	71.58	222.22	590.56	1.12
Essai 2:	☑	648.96	247.4	406.38	161.72	269.58	342.41	192.51	231.77	151.84	65.05	238.82	111.95	548.51	230.93	87.99	71.58	222.04	589.85	1.12
Essai 3:	☑	652.72	249.24	418.18	161.53	275.45	349.09	206.35	237.38	148.01	65.9	238.95	111.95	558.38	223.58	87.13	71.58	222.22	582.91	0.28
Essai 4:	☑	640.24	247.4	411.1	167.29	276.35	346.5	199.65	239.82	153.57	65.05	238.82	111.95	564.74	224.4	87.99	71.58	221.68	585.54	0.42
Essai 5:	☑	658.47	250.71	414.91	158	271.68	346.36	197.31	229.87	147.74	65.64	238.3	111.95	543.02	226.65	87.13	71.58	222.22	587.46	0.94

[10] The values measured by the sensor are measured in terms of $\mu W/cm^2$, but this unit is inconvenient and difficult to visualize. We will therefore speak of data measured in values (*counts*).

Table 3: Values measured at 18 different frequencies for white cardboard (1mm) at five different positions

Carton blanc - 1mm:	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	3024.39	1042.77	1709	686.65	1024.27	1165.63	682.28	759.35	499.84	188.73	425.73	198.07	1632.58	620.92	221.25	170.43	462.26	1079.07	2.34
Essai 2:	✓	3024.39	1050.85	1739.31	679.77	1022.01	1172.58	682.73	756.59	494.56	187.3	426.25	198.07	1615.25	618.88	220.57	170.43	459.94	1076.92	2.32
Essai 3:	✓	3041.02	1056.56	1759.09	662.67	1014.34	1168.77	701.47	750.67	476.32	188.39	420.54	194.43	1626	604.79	219.54	169.58	457.62	1056.36	2.51
Essai 4:	✓	2972.5	1032.28	1700.83	670.85	1012.23	1153.36	704.93	770.67	492	187.13	418.33	194.24	1629.95	605.6	219.54	168.56	451.04	1041.07	3.46
Essai 5:	✓	2970.92	1034.85	1719.71	639.25	987.69	1151.04	662.2	712.89	456.25	183.32	409.76	190.41	1563.69	614.39	215.96	167.71	451.39	1060.19	5.05

Table 4: Values measured at 18 different frequencies for black paper at five different positions

Papier noir:	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	583.01	175.29	258.46	101.31	158.95	170.45	85.89	96.95	60.19	100.11	334.09	144.67	181.01	216.84	177.68	126.12	307.76	842.46	2.3
Essai 2:	✓	577.47	174.74	258.64	103.16	160.45	173.18	85.89	97.89	60.92	100.11	334.87	145.44	185.4	218.89	179.22	126.46	308.65	846.77	1.89
Essai 3:	✓	566.97	174	258.64	98.33	153.23	169.09	78.08	92.07	59.73	98	329.03	142.57	170.69	218.07	176.83	125.27	304.73	833.38	4.14
Essai 4:	✓	585.39	175.11	256.82	101.31	158.04	169.77	84.77	97.37	61.56	100.11	333.7	145.44	175.52	214.8	177.68	125.27	305.26	831.71	2.84
Essai 5:	✓	565.39	173.45	257.73	98.52	152.02	166.36	76.96	91.02	58.82	97.15	325.92	141.61	174.43	216.44	176.83	125.27	305.44	844.38	4.16

Table 5: Values measured at 18 different frequencies for white paper at five different positions

Papier blanc:	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	2266.51	1467.48	2004.66	869.74	1035.11	1075.49	634.77	674.57	422.51	179.1	426.51	197.49	1450.92	585.6	215.1	164.47	452.28	1081.22	0.19
Essai 2:	✓	2277.99	1460.12	1957.65	879.78	1029.84	1049.58	637.23	679.55	427.62	178.68	421.83	196.15	1443.46	576.21	212.71	161.06	441.95	1040.12	0.68
Essai 3:	✓	2310.47	1493.05	2020.82	883.31	1041.43	1076.72	630.31	672.98	427.07	180.37	428.97	199.02	1444.33	585.8	216.47	164.47	450.32	1070.7	0.8
Essai 4:	✓	2347.9	1516.23	2058.75	892.79	1055.43	1091.45	632.43	672.98	425.52	181.29	433.78	201.32	1456.18	594.79	218.69	167.02	455.31	1084.56	2.02
Essai 5:	✓	2316.21	1501.51	2038.79	878.48	1038.57	1078.49	625.4	668.86	423.51	178.26	426.9	198.07	1443.02	587.64	216.13	165.32	450.5	1075.96	0.9

Table 6: Values measured at 18 different frequencies for blue PETE plastic at five different positions

PETE (#1) - bleu	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	1792.21	610.86	1096.81	257.26	483.76	453.82	88.67	75.14	48.61	63.78	169.77	83.25	286.32	125.77	114.47	78.4	173.04	409.64	0.8
Essai 2:	✓	1783.1	613.07	1098.07	257.45	484.06	454.23	88.67	75.14	48.61	63.78	169.77	83.25	286.76	127.2	114.47	78.4	173.22	410.12	0.84
Essai 3:	✓	1799.74	651.52	1176.12	250.57	503.78	492.68	88.67	75.14	44.23	61.67	170.03	81.33	298.39	149.05	116.18	81.81	181.06	435.21	2.92
Essai 4:	✓	1683.29	695.48	1068.49	252.43	502.73	469.77	88.67	75.14	45.6	64.04	172.63	82.29	301.68	132.31	113.62	77.55	176.6	422.55	0.6
Essai 5:	✓	1777.56	718.47	1156.15	259.49	508.6	497.72	88.67	75.67	45.6	65.05	170.03	83.63	331.3	137.62	115.32	80.1	187.29	418.48	3.78

Table 7: Values measured at 18 different frequencies for dark blue PETE at five different positions

PETE (#1) - bleu v2	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	1380.7	500.87	897.7	209.31	382.61	386.18	75.63	75.14	39.67	26.61	218.7	95.68	253.41	98.01	44.42	47.72	214.2	559.73	17.38
Essai 2:	✓	1473.58	518.34	951.61	204.1	403.24	435.14	75.85	74.61	39.21	28.3	218.7	95.68	217.21	90.25	41.86	46.02	206.54	547.54	14.03
Essai 3:	✓	1451.59	541.89	949.61	229.38	420.24	429.27	75.85	84.14	44.69	32.95	221.3	99.51	272.72	84.54	42.71	45.85	209.39	542.05	11.86
Essai 4:	✓	1472.79	564.7	1087	226.59	439.51	451.63	74.73	74.61	40.58	27.03	210.92	94.73	201.19	85.76	41.86	47.72	215.27	554.71	9.33
Essai 5:	✓	1372.18	517.42	948.16	215.62	447.19	468.68	72.5	77.47	42.41	34.21	214.81	96.64	248.58	120.88	45.28	49.43	216.88	570.25	12.03

Table 8: Values measured at 18 different frequencies for HDPE plastic at five different positions

HDPE (#2) - semi-tr	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	1409.22	446.06	737.8	235.88	397.37	473.18	223.75	242.04	166.43	69.7	98.13	55.12	558.82	208.27	80.3	56.24	116.72	218.92	4.37
Essai 2:	✓	1373.17	431.89	699.86	224.73	367.71	437.86	217.16	232.83	160.96	67.59	92.15	53.58	548.51	204.38	79.45	55.56	116.01	214.14	8.42
Essai 3:	✓	1493.97	458.38	700.59	264.88	417.84	473.32	224.41	254.53	190.6	70.54	99.29	56.83	599.19	224.6	84.57	57.09	117.79	221.07	0.62
Essai 4:	✓	1501.89	460.59	730.72	258.19	410.91	478.22	228.1	259.82	181.93	71.22	100.59	56.45	594.58	225.83	83.72	57.95	119.58	218.2	0.14
Essai 5:	✓	1467.24	454.51	738.34	230.49	387.88	471.41	215.27	229.66	162.6	69.27	97.35	54.54	549.61	218.48	80.3	57.09	117.79	224.66	3.78

Table 9: Value s measured at 18 different frequencies for PP plastic at five different positions

PP (#5) - blanc	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	2628.51	1439.34	2002.67	712.49	1031.49	1172.04	596.4	626.64	348.37	139.82	304.37	143.91	1416.47	467.17	170	131.75	354.99	761.2	0.84
Essai 2:	✓	2629.31	1437.87	2001.58	712.12	1031.19	1171.22	596.62	626.74	348.37	139.82	304.37	143.72	1415.59	467.37	169.66	131.23	355.16	762.16	0.86
Essai 3:	✓	2656.63	1432.72	1960.56	740.55	1048.35	1173.4	596.18	634.67	359.68	140.66	308.52	146.4	1434.46	480.65	170.85	132.09	359.61	779.61	0.09
Essai 4:	✓	2647.32	1431.8	1961.28	719.92	1037.36	1162.9	595.73	624.83	351.01	141.08	305.8	144.48	1437.09	480.03	170.85	132.09	359.08	773.87	0.64
Essai 5:	✓	2683.96	1448.17	2001.76	754.31	1059.79	1188.95	616.36	666.74	382.56	144.46	309.17	147.73	1463.64	482.49	175.12	134.64	357.83	766.46	1.46

Table 10: Values measured at 18 different frequencies for plastic wrap at five different positions

Film alimentaire	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	Single-use bag	3935.54	1372.38	2210.48	703.75	1201.43	1614.68	599.52	655.74	401.17	183.41	391.85	175.48	1629.95	623.98	211	162.25	458.16	983.23	4
Essai 2:	PP (#5)	2776.84	1184.21	1765.63	729.22	1121.35	1275.95	576.99	632.56	386.94	183.75	377.19	172.23	1553.81	546.6	197.85	147.42	416.64	904.36	2.55
Essai 3:	Ziploc bag	4631.44	1583.18	2281.45	870.3	1361.58	1539.94	701.36	823.9	446.4	193.04	396.01	180.27	1861.42	629.5	224.67	168.73	457.62	920.86	6.88
Essai 4:	Single-use bag	3371.74	1544.92	2425.2	852.83	1362.48	1492.76	519.66	614.57	380.28	169.64	373.81	175.68	1652.11	586.62	213.73	161.57	420.92	881.66	2.25
Essai 5:	Plastic sticker ma	3289.95	1331.92	2183.08	671.22	1173.43	1460.17	622.05	623.35	353.75	170.15	389.52	173.19	1537.8	598.46	213.56	168.22	466	977.5	0.31

Table 11: Values measured at 18 different frequencies for a milk bag at five different positions

Sac de lait - transpare	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	PP (#5)	2947.75	1125.72	1948.4	620.85	1314.47	1544.72	386.26	452.32	270.48	135.59	372.12	143.53	1608.67	441.24	179.39	129.53	374.41	703.13	0.88
Essai 2:	Ziploc bag	4251.6	1236.27	1857.47	429.02	1028.03	1315.49	393.73	433.38	262.28	145.06	322.15	132.04	1370.84	479.63	188.79	138.9	385.63	757.62	4.04
Essai 3:	✓	3798.3	1206.84	1942.77	594.45	1225.21	1488.67	367.41	462.49	283.53	155.11	296.58	133	2675.63	535.78	275.92	175.21	384.39	675.17	16.37
Essai 4:	Styrofoam	2798.82	1008.92	1682.32	483.29	954.73	1183.49	414.7	498.68	310.61	123.43	322.54	140.66	1326.95	485.55	223.47	159.01	393.3	751.88	3.81
Essai 5:	Single-use bag	3286.58	1300.46	2207.94	547.79	1120.75	1316.58	394.63	491.38	305.5	134.83	328.9	144.67	1516.3	466.76	223.98	146.57	391.52	760.72	2.14

Table 12: Values measured at 18 different frequencies for thin styrofoam at five different positions

Styromousse mince	Identification	410nm	435nm	460nm	485nm	510nm	535nm	560nm	585nm	610nm	645nm	680nm	705nm	730nm	760nm	810nm	860nm	900nm	940nm	% d'écart
Essai 1:	✓	2640.39	1112.84	1642.21	667.69	913.64	996.13	606.21	641.23	382.2	164.74	366.67	168.98	1363.59	507.6	189.98	144.87	396.86	890.74	0.21
Essai 2:	✓	2647.32	1120.57	1637.49	679.77	918.01	984.4	606.88	646.21	389.13	163.89	366.28	169.55	1343.41	495.35	188.79	142.31	389.38	865.41	0.1
Essai 3:	✓	2581.58	1087.46	1580.13	660.62	892.27	979.08	566.06	620.07	393.96	161.78	360.05	167.45	1328.93	516.38	189.64	143.16	391.69	900.06	1.83
Essai 4:	✓	2640.59	1097.58	1586.67	654.12	894.07	972.95	587.81	618.17	379.46	165.08	365.5	169.17	1310.06	517.81	187.93	143.16	393.65	891.94	1.41
Essai 5:	✓	2586.13	1108.8	1607.54	687.2	906.41	975.68	593.5	652.56	404	161.7	364.59	168.6	1362.06	511.68	190.5	143.5	392.76	889.79	0.44

The experiment mainly took place in two stages. Table 1 and graph 1 illustrate the spectra of about twenty different materials that are part of the program's database. The values collected are an average of five measurements taken by the sensor for each of the 18 frequencies it measures between 410nm and 940nm. This frequency length includes part of the visible electromagnetic spectrum as well as part of the near infrared. While the sensor measures the amount of reflected light, the greatest differences between materials can be observed at frequencies of 410, 460 and 760nm and the smallest differences at frequencies of 645, 680, 705, 810, 860, 900 and 940nm which suggests that similar results would be obtained without considering these values in the identification of materials.

Tables 2 to 12 contain the spectra of 11 different materials which I then scanned at five different locations to observe the variation of the spectra due to the position and the scanned part of each material. I also noted the percentage of difference between the data of the bank and those of each test to be able to quantify the said variation of the spectra. Finally, I noted whether the material identification was a success or a failure. If the identification was unsuccessful, I noted the name of the misidentified material.

Tables 2 through 5 show the spectra of pieces of brown and white cardboard as well as black and white paper that I scanned five times at different locations on the pieces. We therefore see a slight variation in the values with each test, but the results remain extremely precise all the same, since the average percentage difference between the values in the database and the values measured rarely exceeds 4%. In addition, the materials were identified each time. However, I note that the brown cardboard and the white paper had significantly lower deviation percentages than the white cardboard and the black paper.

Tables 6 and 7 are special since they are the spectra of two almost identical objects. Table 6 contains the spectrum of a small blue plastic container belonging to Category 1 (polyethylene terephthalate). It is also the spectrum of this container that is found in the database. Note that the average deviation percentage for the five trials is minimal. Table 7 contains the spectrum of a very similar container, but whose color and thickness differ slightly from the container in Table 6. However, despite their similarities, the average percentage difference is much greater, i.e. about 15%. Despite a high average deviation percentage, the two containers were identified correctly without problems.

Tables 8 and 9 group the spectra of hard plastic objects, ie categorie 2 (high-density polyethylene) and 5 (polypropylene) of the CIR. The deviation percentages are relatively small and the two materials were identified without fault. This is the same case for table 12 whose spectrum corresponds to that of styrofoam, a soft and malleable plastic.

Finally, tables 10 and 11 contain the spectra of soft plastics: plastic wrap and a bag of milk. These two plastics are more or less transparent and had uneven surfaces that made them difficult to identify. In five attempts, the plastic wrap was never identified correctly and the bag of milk only once. The deviation percentages are also extremely varied. Note also a trend that is maintained through the majority of the spectra collected: the frequencies previously identified as having small differences between the various materials have in fact less great variations in the experimental results.

Discussion

In my experiment, several factors were at play. Let's start with the sensor. The latter illuminates objects with three diodes of different electromagnetic frequencies: ultraviolet, visible (white) and infrared. These three lights ensure uniform illumination for each object. According to the manipulations presented in this report, in order to control the distance at which the spectroscopic measurements are taken, I have fixed the height of the case at approximately 3.8 cm (1.5 inches). In addition, the housing serves to control the ambient light since it can have a considerable impact on the results obtained. However, several of the objects that were part of the experiment were more or less transparent. Thus, the amount of ambient light that reached the sensor varied depending on the transparency and thickness of the material. To control this variable, I illuminated the whole sensor with an LED powerful enough for the ambient light to be negligible during the experiment.

In order to meet my goal of evaluating the viability and potential of this technology in the recycling industry and the identification of materials, I chose a set of materials for the database that were part of everyone's daily life. : paper, cardboard, plastic containers, juice containers, etc. I then used my program to add their spectra to the database. At the same time, I inserted this data into a graph, as shown in figure 1. As mentioned, during the description of the results, it is noticed that certain frequencies have very small variations, regardless of the material. It would therefore be possible to redo this same experiment by omitting certain frequencies to reduce the amount of calculations that the program must do. We would still obtain similar results despite a slight loss of precision in the data.

Following this step, I continued the experiment by analyzing these same materials again, as illustrated by tables 2 to 12. What I wanted to check was the sensor's ability to faithfully identify the same material that I had used for the database. If it couldn't identify the same piece of cardboard repeatedly, I knew the experiment was automatically a failure. Fortunately, this was not the case: the vast majority of materials were identified correctly several times. However, some materials such as plastic wrap (Table 9) and milk bag (Table 10) were never correctly identified by the sensor.

I can explain this by a very simple, but very problematic reason. Since the sensor measures the amount of light reflected by each object, it is very sensitive to the surface of the materials. A material with a smooth, flat surface reflects light more evenly, providing reliable data with every measurement. Thus, cardboard, paper and hard plastics are exceptional candidates for this technology since they present surfaces that are easy to scan.

However, plastic wrap in particular is a soft plastic that reflects a lot of light and has an extremely "rugged" surface. When rolled into a ball or flattened, this material reflects light in all directions, which is very difficult to identify since the angles of reflection are always different, regardless of the direction and orientation of the object on the case. This situation also concerns the milk bag which, due to its softness, is difficult to position flat on the housing. This explains why I could not identify these materials during the experiment.

I then became interested in the ability of the sensor to identify similar materials of the same type, but whose spectra had not been added to the database. I managed to find a blue plastic container (PETE) very similar to the one I had added to the database (tables 6 and 7), but whose color was a little darker. Besides that, the two containers were identical. While the original container had been identified with a deviation percentage of approximately 1.5%, this percentage increased to 15% when the second container was identified. Despite this, the container was successfully identified on each of the 5 occasions.

During the experiment, I also noticed that some materials were not correctly identified, but their deviation percentage was still smaller than that of the second blue plastic container (Table 7). I explain this by the fact that the distribution of spectra of different materials is not uniform. Indeed, all the spectra of my program are found in an interval of about 400 to 4000 values, but the spectra of several materials are more or less similar to each other. Thus, less difference between the experimental values and those in the database is necessary for the program to incorrectly identify the given material. Following this observation, I asked myself another question which constitutes a major challenge for the use of this technology in recycling centers: what would happen if the database contained hundreds, even thousands of different materials?

If this were the case, chances are that the program would be unable to identify the materials correctly since the data variation would be too small between each material. Thus, a given material could be identified as several different materials. A significant improvement would therefore be to integrate an artificial intelligence program into the code, which would allow the program itself to shape its own database by grouping similar spectra under the same "category". Indeed, artificial intelligence would also make it possible to better process the data and could identify similar materials, but of different colors. Indeed, preliminary experiments have shown me that the color of an object has a considerable impact on the data collected by the sensor. Obviously, knowing that increasingly white surfaces reflect more and more light, lighter colors have higher spectra and the reverse is also true for increasingly dark colors.

I believe it is also extremely important to note that the uncertainty associated with the sensor is extremely high: either plus or minus 12%. This could explain, among other things, certain very high deviation percentages. Thus, in terms of possible improvements for the experiment, there are several relevant suggestions: better control of ambient light, use of flatter materials whose slightest movement does not completely change the results, use of a spectroscopic sensor whose uncertainty is smaller, use even more everyday objects and integrate artificial intelligence code into the program.

Conclusion

In order to issue my conclusion, let's recap a bit. Using my program written in Python, my spectroscopic sensor was able to identify faithfully and on several occasions, several cardboard, paper and plastic elements that we generally use on a daily basis. The goal being to determine the viability and potential of this technology in the field of plastic recycling, the sensor correctly identified the spectra of 9 different materials out of a total of 11, which proves the precision and reliability of the sensor. As for the other two cases (plastic wrap and bag of milk), the materials involved presented wavy and semi-transparent surfaces which influenced the ambient light around the sensor and varied the angles of reflection to provide constant illumination on the materials. Thus, it was very difficult to obtain representative spectra for these materials and the sensor results varied greatly. While considering the uncertainty of the sensor, the experimental results, the conditions of the experiment and the few materials contained in the database, I can therefore establish the following conclusion: there is no doubt as to the necessary improvements. for this technology to be applicable to real-life situations, but the potential remains there. This experience showed me that near infrared technology has a phenomenal ability to identify materials. The experiment was a success since, on the whole, the program worked perfectly and the vast majority of the problems and possible improvements lie in the data processing and not in the sensor itself. However, the identification of hard plastics and smooth and homogeneous surfaces remains to be preferred since heterogeneous, semi-transparent and wavy surfaces do not provide coherent data to the sensor used in this experiment. Finally, given the quantity of objects processed by the recycling centers, an artificial intelligence integrated into the program would be necessary to identify thousands of different materials colored in a thousand and one colours.

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APPENDIX I
Program Arduino

```
char userInput;
#include "SparkFun_AS7265X.h"
AS7265X sensor;

#include <Wire.h>

void setup() {
  Serial.begin(9600);

  if(sensor.begin() == false)
  {
    Serial.println("Sensor does not appear to be connected. Please check
wiring. Freezing...");
    while(1);
  }

  sensor.disableIndicator(); //Turn off the blue status LED

}

void loop() {
```

```
  if(Serial.available() > 0){

    userInput = Serial.read();

      if(userInput == 'g'){
        sensor.takeMeasurementsWithBulb(); //This is a hard wait while all 18 
channels are measured

        Serial.print(sensor.getCalibratedA());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedB());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedC());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedD());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedE());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedF());
        Serial. print(" ");

        Serial.print(sensor.getCalibratedG());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedH());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedI());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedJ());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedK());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedL());
        Serial. print(" ");

        Serial.print(sensor.getCalibratedR());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedS());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedT());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedU());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedV());
        Serial. print(" ");
        Serial.print(sensor.getCalibratedW());
        Serial. print(" ");

        Serial.println();
      }
   }
   delay(50);
}
```

APPENDIX II

Python program

```
from ast import literal_eval
import csv
import serial
import numpy as np
import math
import time

data_bank = [[], [], [], [], [], [], [], [], [] , [], [], [], [], [], [], [],
[], []]
data_bank_average = [[], [], [], [], [], [], [ ], [], [], [], [], [], [], [],
[], [], [], []]
average_list = []
ser = serial.Serial("/dev/cu .usbmodem1D11141", baudrate=9600, timeout=1)


def updating_list():
   counts = 0
   while counts != 5:
       ser.write(b'g')
       data = ser.readline().decode('ascii')
       split_data = data.split()
       material = split_data
       updated_material = []
       for m in material:
           updated_value = float(m)
           updated_material.append(updated_value)
       print(updated_material)

       for d in range(0, len(data_bank_average)):
           data_bank_average[d ].append(updated_material[d])
       counts += 1
       time.sleep(0.2)
   print(data_bank_average)
   return


def finding_average():
   for d in range(0, len(data_bank_average)):
       average = 0
       for i in range( 0, len(data_bank_average[d])):
           average += data_bank_average[d][i]
       average = average / len(data_bank_average[0])
       average = round(average, 2)
       average_list.append(average)
```

```
   return average_list


print('''
Welcome to the Material Identifier. What would you like to do?
> Add a material (1)
> Scan a material (2)
> See a list of the available materials (3)
> About the program (4)
> Terminate (0)
   ''')
while True:
   command = str(input( "Enter command: "))
   if command == '1':
       add_data = input('Add data? (press "y") ').lower()
       if add_data == 'y':
           average_list = []
           data_bank_average = [ [], [], [], [], [], [], [], [], [], [], [],
[], [], [], [], [], [] , []]
           updating_list()
           print(f'The data collected is: {finding_average()}')
           with open('Data_Bank.csv', 'r') as read_file:
               reader = csv.reader(read_file)
               with open( 'Data_Bank.csv', 'a') as write_file:
                   writer = csv.writer(write_file)
                   material_name = input('What material do you wish to add? ')
                   writer.writerow([material_name, average_list])
               for row in reader :
                   print(row)
   elif command == '2':
      add_data = input('Get data? (press "y") ').lower()
      if add_data == 'y':
            average_list = []
            data_bank_average = [[], [], [], [], [], [], [], [], [], [], [],
[], [], [], [], [] , [], []]
            updating_list()
            finding_average()
            np.asarray(average_list)
            print(f'The data collected is: {average_list}')
            with open('Data_Bank.csv', 'r') as read_file:
                  reader = csv.reader(read_file)
                  next(reader)
                  min_final_array = 1000000
                  for row in reader:
                        final_array = 0
                        data_row = np.array(literal_eval(row[1]))
                        inter_array = (data_row - average_list)**2
                        for val in inter_array:
```

```
                                final_array += val
                          final_array = math.sqrt(final_array)
                          if final_array <= min_final_array:
                                min_final_array = final_array
                                material_name = row[0]
                                exp_values = 0
                                theo_values = 0
                                for dd in data_row:
                                      exp_values += dd
                                for ddd in average_list:
                                      theo_values += ddd
                                percentage_difference = (abs((theo_values -
exp_values))/theo_values)*100
                                percentage_difference =
round(percentage_difference, 2)
                   print(f'The material was identified as {material_name} with
a {percentage_difference} % deviation.')
   elif command == '3':
       print('Fetching data...')
       with open('Data_Bank.csv', ' r') as read_file:
           reader = csv.reader(read_file)
           for row in reader:
               print(row[0])
   elif command == '4':
       print('''
Luca Scavone created this Python program as part of his
Secondary 5 Personal Project. The program scans materials
using a NIR (near infrared) scanner and compares the
results to a data bank in order to identify various types
of materials (plastic, wood, paper, etc.)
           ''')
   elif command == '0':
       break
   elif command == '':
       continue
   else:
       print('Wrong Command. Try Again.')
       continue
```

APPENDIX III

Spectroscopic sensor assembly

Figure 1: Spectroscopic sensor housing

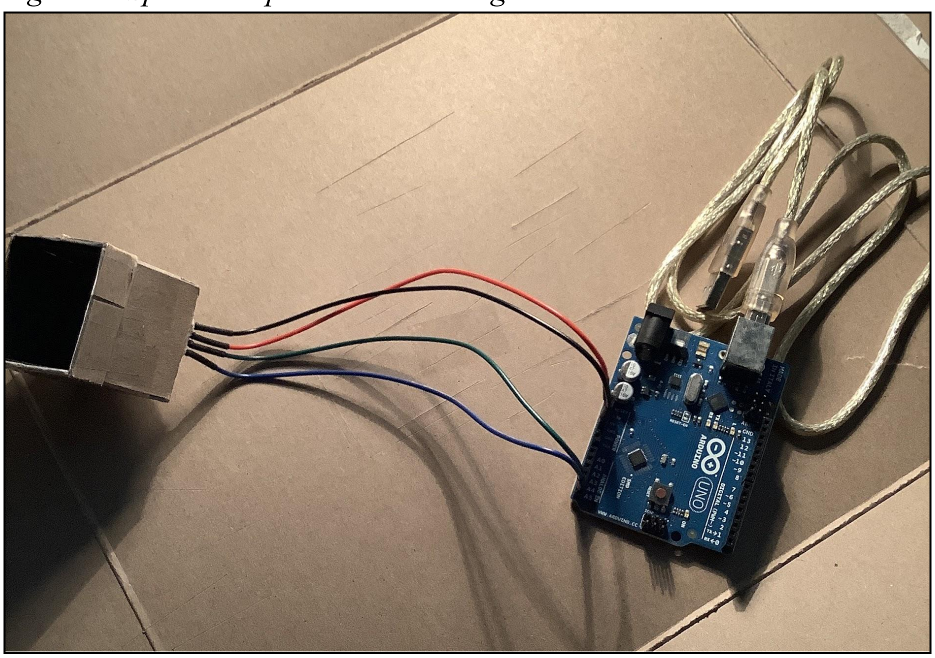

Figure 2: Spectroscopic sensor fully completed