QUARTERLY PROGRESS REPORT
December 1, 2018 – February 28, 2019

PROJECT TITLE: Detection and Separation of Recyclable Plastics from Municipal Solid Waste (Year 1)

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AFFILIATION: University of Central Florida

COMPLETION DATE: August 31, 2019 **PHONE NUMBER:** 407-823-4575

PROJECT WEB SITE: https://www.nanoscience.ucf.edu/research/hinkley-project.php

Work accomplished during this reporting period:

The first Technical Awareness Group meeting was held on November 1, 2018 attended by 6, representing academia, consulting, and industry. The webinar has been archived at our project web site.

Task 1: Hand-Held Device Design and Integration

- The hand-held probe with IR light guiding optical fiber (1 m long) and rear-end spectrometer coupler was tested with null result. Though the fiber optic was selected in such a way that it complies with the IR band of interest, signal losses were too great to achieve successful operation.
- Design will be reviewed and alternative fiber optic cables that may be developed will be watched for and evaluated.
- An alternative design has been proposed, which does not require the use of a laboratory grade spectrometer. This design utilizes a ZnSe prism to disperse reflected MIR light off the plastic samples. Components for this design are readily available from COTS suppliers.
- Simulations of this design using spectral data already obtained are being performed and early results are promising.

Remote handheld scanner development: In our current work we are developing a portable modular probe coupled to the spectrometer, and in principle any spectrometer as conceptually displayed in Fig. 1. However, this has proven a formidable task due to the restricted light availability, but a viable portable alternative is under development. The remote detection system is devised to carry IR light from the source to the point of detection and to collect it back to the detector. It is comprised of an IR-compliant flexible optical fiber joint at the front end with the high collection angle objective and at the rear end to an optical coupler to guide light in-and-out the spectrometer. This system, along with the multispectral fingerprint detection mechanism currently under development, would work as the core for further integration into more specialized solutions for recycling and recovery applications. The prototype portable system is shown in Fig. 4(b). It comprises of an optical coupler from/to the spectrometer, a MIR-compliant optical fiber and the sample probe. This prototype will exploit the concept portrayed in Fig. 4(a) for a single remote hand-held, which will give the flexibility of a remote plastic identification system.

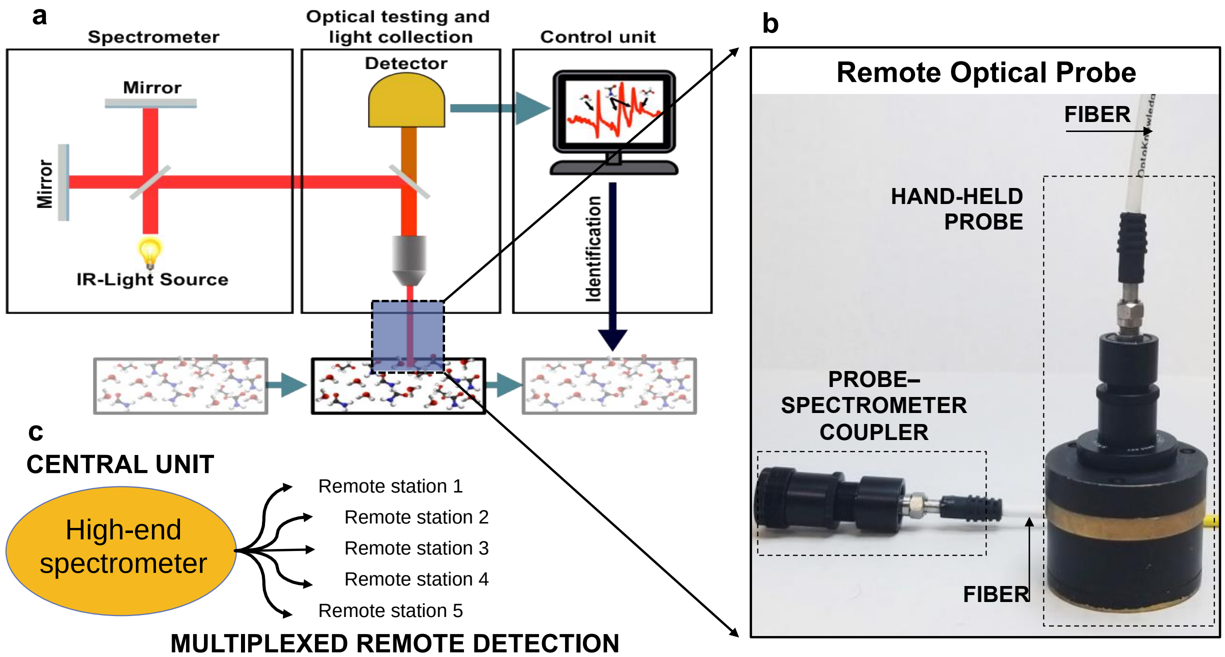

Figure 1. (a) MIR detection system based on spectrometer, remote probe and control and identification unit. (b). Hand-held probe designed to perform remote MIR spectroscopy. (c) Centralized detection conceptualization. The high-end MIR spectrometer has a set of multiplexed optical probes for multiuser mode of operation. *Concept developed based on Year-1 research progress.*

Task 2: Sample Collection and Characterization

- The team has partnered with UCF Recycles program in order to collect a statistically relevant plastic sample population.
- The number of samples in the spectral library has been expanded from 77 to 127, with approximately 10 new samples being added weekly. Many of these new samples are contaminated in various ways and are being scanned both with contaminants intact and after cleaning.

Task 3: Optimization of the Identification Algorithm

- Neural networks have been trained on the spectral data with encouraging results. Spectral features used are focused on compatibility with both the lab spectrometer and the proposed fieldable device.
- Enhancement of the spectral database is important to further development of automated identification algorithms, so effort on Task 2 is a prerequisite to progress on this task.

Artificial intelligence based spectral fingerprint search: Initial stages of this investigation simply matched the spectral features found in the reflectance spectra with those stored in the multi-resonance library. To automate the identification with a large library of diverse spectra, however, as the library expands, especially when considering polymer resin blends or fillers, necessitates the use of computer pattern recognition techniques. Classification tools based on neural networks, the multilayer perceptron for example, have proven to be useful for numerous similar problems.

The first step in the approach for automating classification with machine learning was to reduce the dimensionality of the input. The spectral signature produced by the spectrometer consists of 3271 data points of reflectance vs. wavenumber. As a first simple attempt at data reduction, we averaged the reflectance over 100 equally-spaced consecutive wavelength intervals. Figure 5 displays the raw spectral signature of PVC, while Figure 6 shows the result of this wavelength averaging process on the PVC spectral signature. This process reduced the spectral resolution from 3271 data points to 100 points.

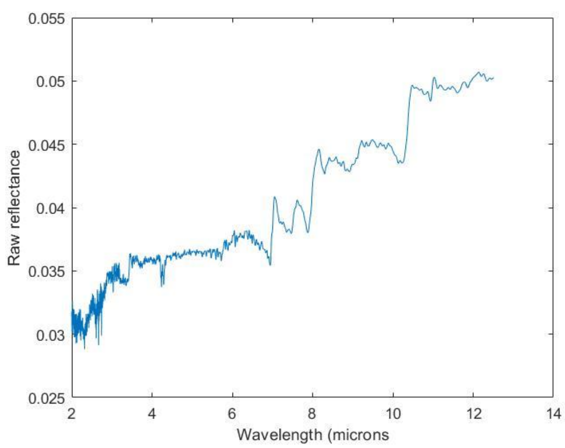

Figure 3. Raw spectrometer data (3271 points)

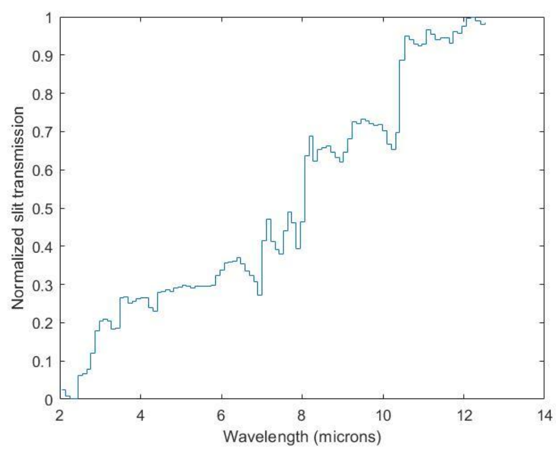

Figure 4. Wavelength average data (100 points)

These 100-point signatures were used as inputs for a multi-layer perceptron neural network with a single hidden layer. This neural network was trained on 2 scans of 5-6 samples of 7 different plastics to produce the results shown in confusion matrix form in Figure 7. In the network training confusion matrix, the labels along the top row indicate the actual ground truth category of plastic for that column, while the labels in the left column show the classification assigned by the neural network. Therefore, the diagonal elements show the number of samples correctly identified by the neural network, while off-diagonal elements show classification errors. For example, the box containing the number 2 shows the neural network incorrectly classified 2 samples of HDPE as LDPE, an understandable error as both are forms of polyethylene.

It is important to note that the confusion matrix shown is an accumulation of training, cross-validation, and test results, as the number of available signatures is small. This is therefore an optimistic prediction as data used in training the neural network was also used in testing it. This situation will be remedied as the project progresses and the spectral signature library grows. Neural network performance generally improves with a larger number of training samples, so these early results are encouraging.

	Acetyl	HDPE	LDPE	PET	PP	PS	PVC
Acetyl	12	0	0	0	0	0	0
HDPE	0	9	1	0	0	0	0
LDPE	0	2	10	0	1	0	0
PET	0	1	0	12	0	0	0
PP	0	0	1	0	11	0	0
PS	0	0	0	0	0	12	0
PVC	0	0	0	0	0	0	10

Figure 5. Neural network training confusion matrix for various randomly selected plastics.

Work to be completed next quarter

- Assemble and test the proposed prism spectrometer (Task 1).
- Continue to expand the plastic spectral library (Task 2).
- Analyze data and implement neural network and other classification algorithms (Task 2 & 3).

Metrics:

1. List graduate or postdoctoral researchers who were funded by this Hinkley Center project.

Name	Rank	Department	Professor	Institution
Pablo Manuel Cencillo Abad	Postdoctoral Researcher	NanoScience Technology Center	Debashis Chanda	University of Central Florida

2. List undergraduate students who worked on this Hinkley Center project.

Name	Rank	Department	Professor	Institution
Ed DeRouin	Undergraduate Student	Physics	Debashis Chanda	University of Central Florida
Juan Perilla	Undergraduate Student	Mechanical Engineering	Debashis Chanda	University of Central Florida

3. List research publications resulting from this Hinkley Center project.
   N/A

4. List research presentations resulting from this Hinkley Center project.
   The research has been presented at an invited talk at University of Antioquia, Colombia on March 14, 2019.

5. List who has referenced or cited your publications from this project?
   N/A

6. How have the research results from this Hinkley Center project been leveraged to secure additional research funding?
   Our pre-proposal to EREF has been accepted. We are submitting the full proposal based on the preliminary work funded by Hinkley Center.

7. What new collaborations were initiated based on this Hinkley Center project?
   N/A

8. How have the results from this Hinkley Center funded project been used (not will be used) by the FDEP or other stakeholders?

   - None to date