Document Title:	**Development of a Novel Human Materials Hyperspectral Remote Sensing Tool for Forensic Investigations and Operations for U.S. Law Enforcement**
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Final Summary Overview for National Institute of Justice (NIJ) FY 15 Research and Development in Forensic Science for Criminal Justice Purposes award 2015-DN-BX-K011, "Development of a novel human materials hyperspectral remote sensing tool for forensic investigations and operations for U.S. law enforcement."

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The purpose of the project

The purpose of the project was to produce a hyperspectral software tool for the interpretation of hyperspectral remote sensing images and train students in this effort. Extensive data was collected by Miami University staff, numerous students, and the software was developed by Harris Geospatial. Academic goals include training of undergraduates in geomaterials research and novel forensic methods, the development of several manuscripts, and promoting the project.

Project subjects

110 human subjects were involved in data collection of reflective spectra of skin and hair. Subjects also filled out questionnaires regarding physical traits and personal care product use. All work conformed to human subject protocols approved by Miami University.

Project design and methods

The reflective spectra and metadata of numerous materials as well as human skin, hair and blood were collected as feasible at Miami University. These data were then sent to Harris

Geospatial to assemble in a software plug-in for their ENVI remote sensing package. Extensive effort was made in collecting reflective spectra and metadata and these efforts are summarized below.

The USGS hyperspectral library was integrated into the tool directly and this saved a great deal of time and effort and allowed additional content to be added. Over 60 new geomaterial samples are included to represent areas of interest such as data on street sediment from Gary, Indiana, and samples from the New Mexico – Texas / Mexico border. The USGS and these samples have metadata and can be used as analogs for a wide variety of environments globally. Data was collected from over 300 clothing samples in both wet and dry conditions. Compositional information for each item is provided as metadata. Reflective spectra of skin and hair for 110 human subject volunteers of various ages and ethnicities were collected from numerous points on the body. Additional information was provided voluntarily by each subject in the form of a questionnaire. Reflective spectra were acquired on human blood and aging experiments were also performed. Extensive data was collected on fuel spills for gasoline, diesel and jet fuel.

Data analysis

The nature of this project was primarily to develop a software tool and data analysis was done in numerous contexts but primarily in abstracts presented at meetings and in peer-review literature. The analysis of data thus far has resulted in 4 peer-reviewed publications (Barnes et al., 2020; Burke et al., 2019; Dietrich et al. 2019; Dietrich et al. 2018) and a fifth on fuels is in review. These involved 5 undergraduates, one graduate student and two technicians. Analysis of data has resulted in 12 abstracts at national meetings involving 28 examples of undergraduate authorship. Additionally, at least 6 manuscripts are in development at a level of 50 to 75% complete on topics of human skin and hair, human blood, animal materials and geologic materials. There is still an extensive amount of data that is still to be analyzed and published in the peer-review literature and this will be done over the next 2-3 years.

Project findings

The software tool is completed and is the primary deliverable for the project. This tool was produced by Harris Geospatial. Barrett Sather was the project lead for this at Harris and David Starbuck was the lead when Sather left the company. The software tool (Spectral Search and Discovery Tool) is completed, however Harris Geospatial is still in the process of determining how to be host the software. The latest available link is https://transfer.harris.com/download/8b06a512-675a-4dc3-b85f-05a23a6b1f95 and access can also be obtained through David Starbuck (dstarbuc@harris.com) as well or Bryan Justice (JJUSTI01@harris.com). Note that Harris Geospatial is currently exploring the export compliance issues best pathways and a permanent access pathway will be provided to the agency and the public once resolved. This tool functions with ENVI and is available at no cost to any user (pending export compliance). Below the tool is described and examples of the software are shown below.

The Spectral Search and Discovery Tool is a customized ENVI extension written using the IDL programming language designed to help users find custom targets within hyperspectral imagery. Currently, the tool is only available for Windows. The tool provides a Graphical User Interface (GUI) that runs in conjunction with ENVI, and it can be launched either through

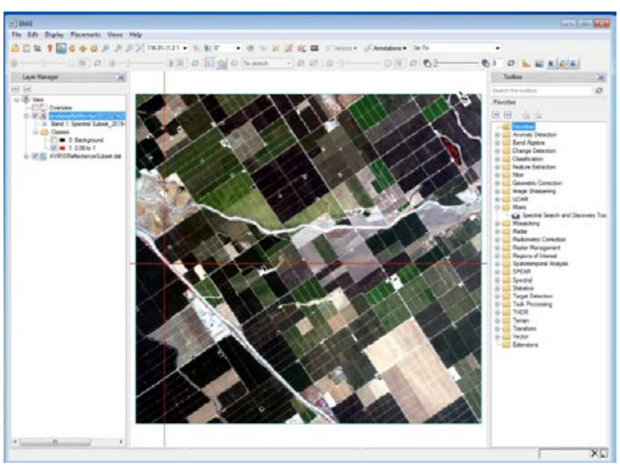
ENVI's toolbox or through a shortcut in the Windows Start menu (this will automatically launch ENVI as well). Once launched, a user can use the tool to browse spectral data from a variety of sources including human tissue samples, clothing, and earth materials both natural and synthetic in origin. The tool indexes this data and allows users to search, filter and combine these spectra. The tool can then be used to create libraries to search for and determine possible locations of these spectra within a hyperspectral image, thus identifying a location.

The first time the Spectral Search and Discovery tool is launched, the locations on the file system and the structure of the data is saved to a binary data file on the system. The Spectral Search and Discovery tool references this binary data file to quickly search and filter through the spectral data included within the tool. The organization and names of these custom spectra will appear in a data tree within the tool's GUI. When a user selects spectral data in the tree the spectral signatures and metadata images from the spectral data samples are read on demand. The Spectra provided within the tool can be combined into custom spectra (multiple spectra combined together to form a new spectra) or added to spectral library (multiple spectra that will be individually analyzed while searching through imagery). When creating a new custom spectrum, the user specifies which spectra will included and the percent weights that will be applied to each spectrum when combining them. New custom spectrums can include other custom spectrums that have been previously generated.

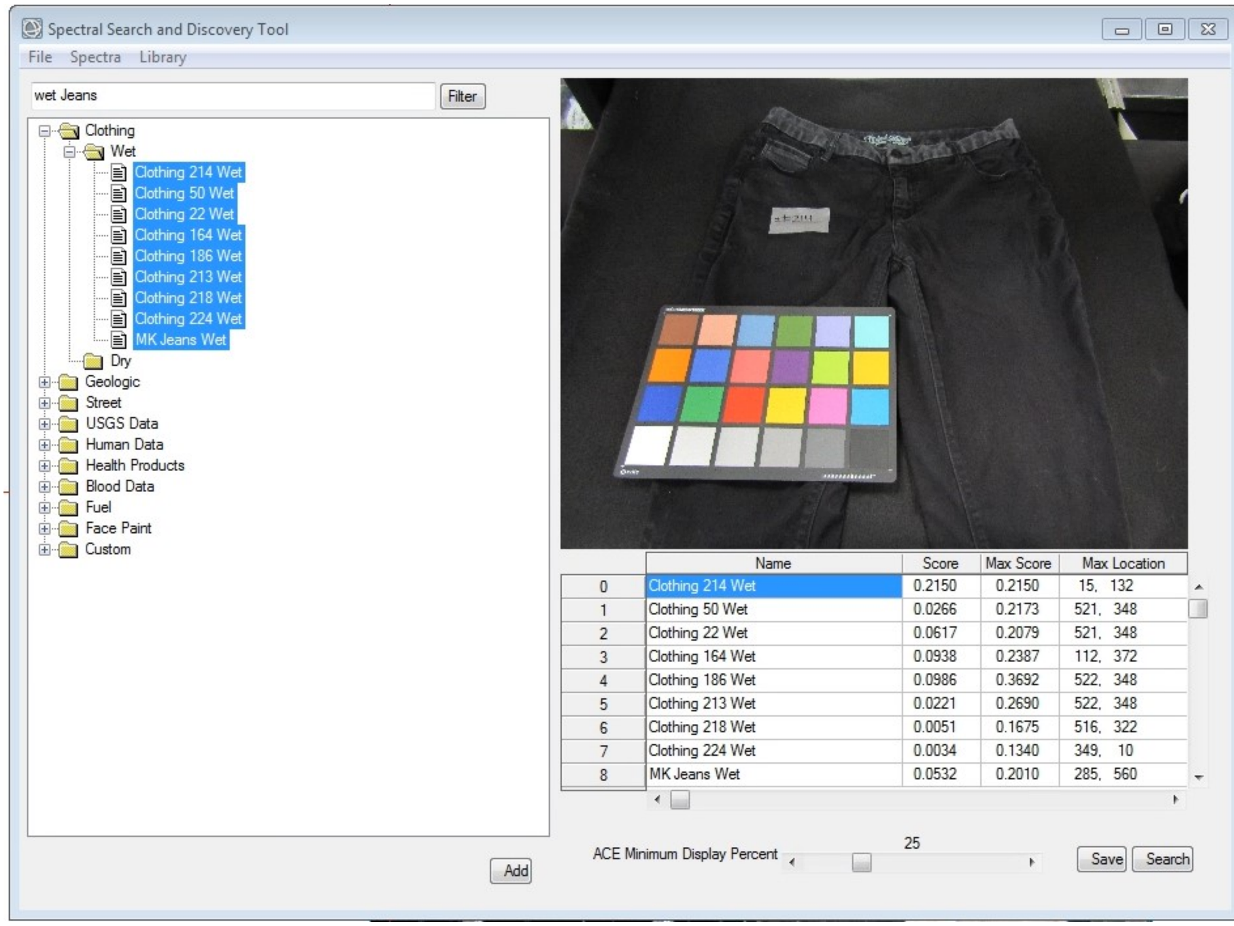
The spectra data provided with Spectral Search and Discovery Tool, as well as custom spectra created by the user can be used to create spectral libraries. Once a spectral library has been selected, the user can execute a search on a hyperspectral image for the spectra included in that library. The searchable spectra are first resampled to match the wavelengths of the hyperspectral image, and then the Adaptive Coherence Estimator (ACE) algorithm searches the image for the spectra within the spectral library and assigns a probability of how likely it is that each material is located each pixel of the hyperspectral image.

ACE is a common algorithm used for target identification and works especially well for rare materials in a scene. The algorithm is derived from the Generalized Likelihood Ratio approach and does not need to know the endmembers for a scene before executing the algorithm. Its output is an image that is the same spatial size as the search image and has as many bands as spectra that were searched. Each band has values ranging from 0.0 to 1.0, indicating the probability that a material is located in a certain pixel of the image. A 0.0 value means no probability and 1.0 means a 100% match. A slider in the Spectral Search and Discovery tool's GUI allows the user to specify a probability threshold for display. If the probability of a material is above this threshold, then the tool will highlight the pixel in red.

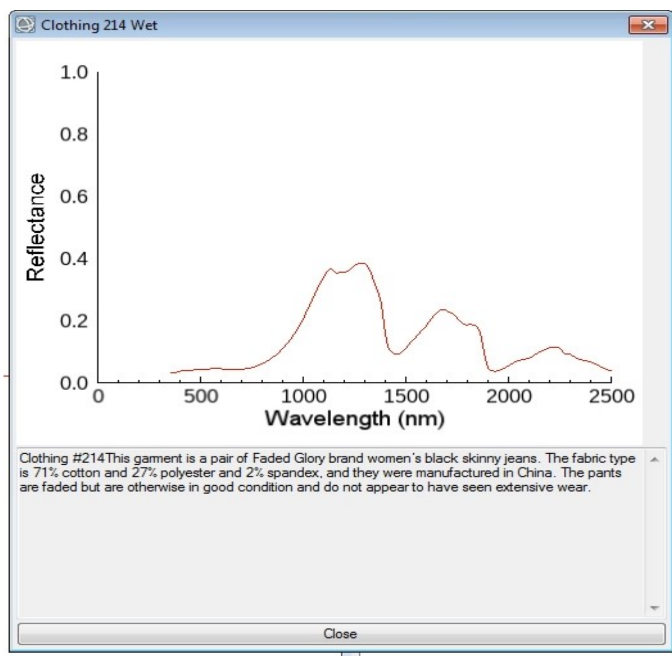
Final improvements and modifications made in April and May of 2019 on the tool include documentation / instructions, the creation of separate classes for each spectra and the addition of a heat map feature and allowing the tool to use an image already open in ENVI. Selected screen shots of the software tool are shown below for reference.



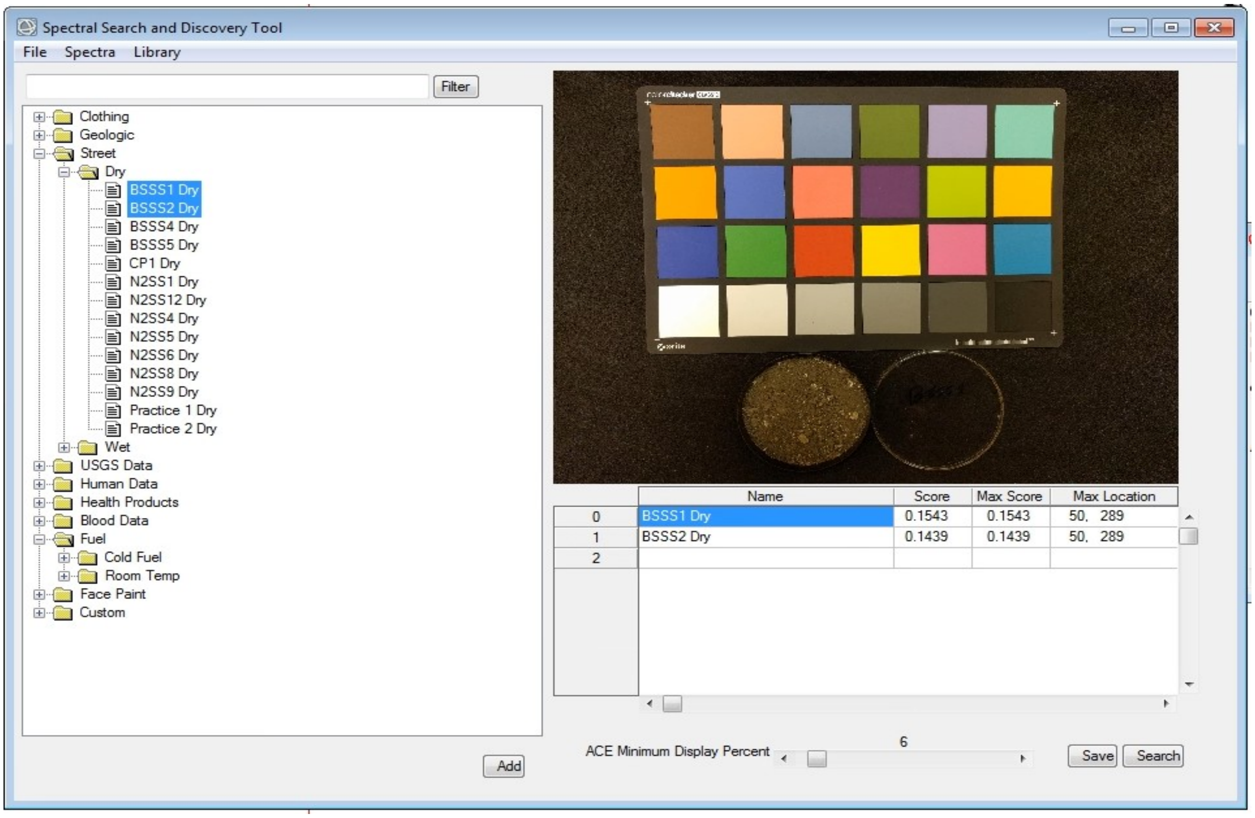
At left is a screen capture example image of a hypthetical area to be searched using the software tool showing strucutre of the program. Hypotheitcally an area such as this could be searched in approxiamtely 1 minute, enabling the "on the ground foot search area" to be dramatically reduced from a square mile to potentially one or a few targeted sites. This would result in a much shorter dicovery time for a missing person or body in critical situations.



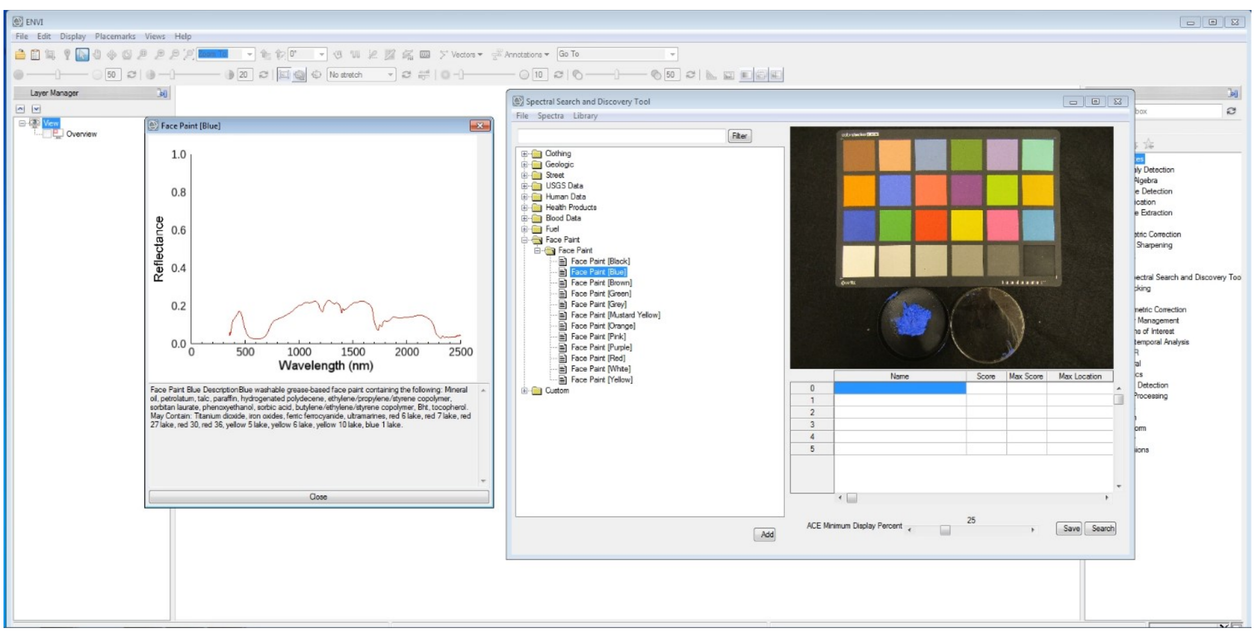
Example image of metadata and associated structure for one clothing sample. Over 300 clothing samples exist in the system. Wet and dry examples are provided for searching after rain events.



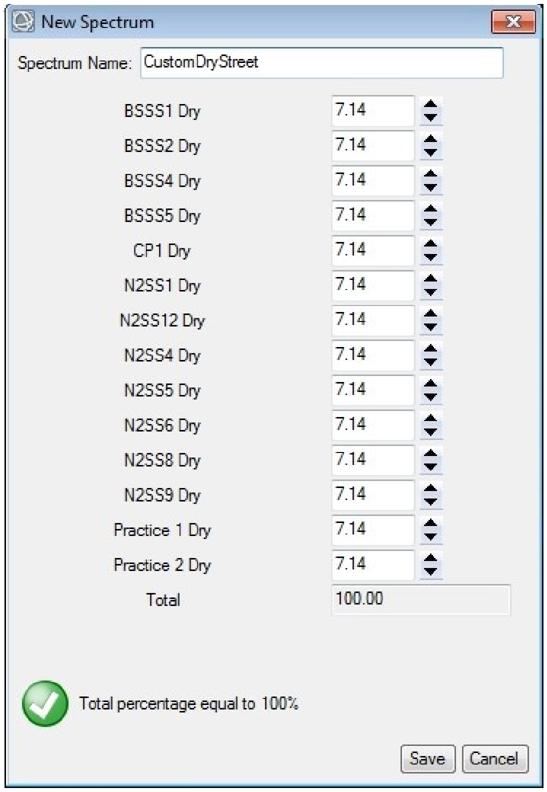
At left is a spectrum and descriptive detailed metadata for the pair of jeans above. Individual spectra that are accessible such this are useful as they can be compared to data from other sources directly. Each clothing item and has at least one spectra and such related meta data. This is useful for missing person searches if the clothing type or description of the person is known such as a blue cotton tee shirt or yellow polyester running pants. The metadata also offers comparison to similar clothing items and materials by verbal description.



An example of a geomaterials – urban street sediment that could be mixed with clothing articles. This image also shows the data tree for other items that could be theoretically mixed. Please see the mixing panel below for an example of percentage input to create mixed spectra.

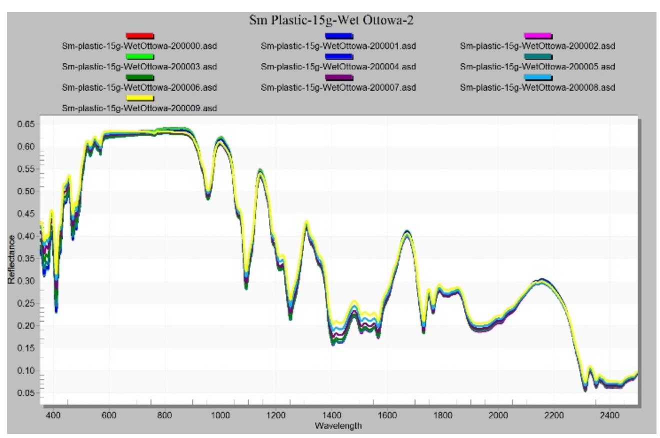


An example of spectra of face paint and related metadata. Such items would be useful in the case of abducted or missing children. Metadata also provides a reference for close analog materials.



The ability to create custom spectra makes the tool much more powerful than originally conceptualized. This allows fine tuning of artificially made spectra from any spectra in the library that can be saved. A screen capture of the mixing tool. Here items are set to 7.14% of different components of street sediment to produce an average for the City of Hamilton. Theoretical mixed spectra can be made from any component in the software library such as make up, clothing, human skin, hair and geologic materials. This feature makes the software extremely powerful and useful for non-ideal scenarios such as finding a person in the woods that is lost; using imagery from changing conditions such as after rain storms when clothing may be partially dry, or wind events in the desert where people or bodies may be covered in silt.

A signaling technology was developed as a side project based on the idea for rapid identification. Here we experimented with samarium oxide in a plastic carrier. Rare earths have distinct reflective spectra owing to their f-orbitals in their atomic structure.



Signalling panel under water and ottawa sand obscuration (Left) to simulate non-ideal conditions with spectra of thi experiment (Right). Features occuring between 350 to 1300 nm originate from the samarium oxide. No such spectra occurs in nature and thus even under non-ideal conditions a person could deploy the panel and it would likely function.

This technology could be used with other rare earth compounds and a set of such materials could be distributed for use by law enforcement as well as persons at risk for injury or getting lost outdoors. This includes park rangers, highway patrol, workers in remote situations, hikers and search and rescue teams themselves. This technology was not integrated into the software tool because it requires additional levels of validation. The optimal size, loading density and mechanical aspects of a signalling panel need to be worked out. Degradation in ultra violet light, wind abrasion and other mechanical stresses need to be determined. Several plastics manufacturers were approached over a period of 1.5 years but the risk of introducing the samarium oxide into their systems was too high to do without signifncant compensation. The technology does however have great promise and future proposals for this technology will be developed in the near future. The technology has potential in several ways for search and rescue on land and at sea. Specific versions were presented to the FBI in May of 2017 who had interest, but there was no funding avialable for development. We continue development as able.

Implications for criminal justice policy and practice in the United States

As hyperspectral remote sensing technology becomes more available to law enforcement the software technology developed for this project could routinely be used for identify clothing, human skin and blood in outdoor and urban environments in the near future. Collectively this tool could be used for investigating murders, sexual assault, bank robbery events, kidnapping and other major crimes domestically. The technology also could be used more broadly to investigate war crimes, terrorist activity and other relevant issues to law enforcement where direct access is not possible. Note that in the context of crime, evidence such as a missing piece of clothing or a blood trail or concentration would be obtainable that otherwise would not.

There is high potential to impact operational capability in search and rescue and investigation infrastructure. The potential reduction time in decision making and the more accurate direction of physical resources in search and rescue operations and numerous investigations will create more efficient operations. Potentially higher recovery rates and prosecution rates are expected to result. The software application should enable much faster identification of persons in the environment at large scale, saving large amounts of time. Search areas of a square mile can be processed in approximately a few minutes once proper imagery is acquired. Note that the imagery needs to be of sufficient resolution for target objects to fill the pixels in imaging and thus hyperspectral imaging from air plane or drone is suggested as the optimal method of hyperspectral remote sensing data acquisition.

One implication of this tool is that for it to be effectively used, there would need to be infrastructure made available to law enforcement to utilize it. One component of this is for law enforcement organizations of appropriate size to be equipped with hyperspectral drones or have access to airplanes that can fly over areas when needed. The second component of this is that data from drones or aircraft must be downloaded in reasonable time. New 5G network capabilities may solve this issue. The third component is that some field and forensic personnel would need to be trained to utilize the ENVI system efficiently and such training could be reliably and readily done by Harris Geospatial.

The partially developed technology holds promise and may be a method of signaling or marking rescue or retrieval by law enforcement in after validation. If adopted it would be of use to several law enforcement agencies. Currently no patents have been filed.

Publications/presentations (*denotes Miami undergraduate student, **denotes Miami graduate student co-authors)

Peer-review articles published (n=4):

*Barnes, M., McLeod, C., *Faraci, O., Chappell, C., Krekeler, M.P.S. (2020) Characterizing the geogenic background of the Midwest: A detailed mineralogical and geochemical investigation of a glacial till in southwestern Ohio. Environmental Earth Sciences 79:159.

Burke, M., *Dawson, C., Allen, C.S., *Brum, J., *Roberts, J., Krekeler, P.S., (2019) Reflective spectroscopy investigations of clothing items to support law enforcement, search and rescue, and war crime investigations. Forensic Science International 304: 109945. Contribution 35%

**Dietrich, M., Wolfe, A., Burke, M., Krekeler M.P.S. (2019) The first pollution investigation of road sediment in Gary, Indiana: Anthropogenic metals and possible health implications for a socioeconomically disadvantaged area. Environment International 128:175-192 (IF 7.943 / 8.763) Contribution 35%

**Dietrich, M., *Huling, J., Krekeler, M.P.S. (2018) Metal Pollution Investigation of Goldman Park, Middletown Ohio: Evidence for Steel and Coal Pollution in a High Child Use Setting. Science of the Total Environment. 618: 1350-1362 (IF:5.589/5.727) Contribution 35%.

Manuscripts in review (n=1)

*Brum, J., *Schlegel, C., Burke, M., *Dawson, C., Allen, C.S., Krekeler, M.P.S. (in preparation) Reflective spectroscopy investigation of gasoline, diesel and jet fuel on common substrates in laboratory and cold outdoor conditions: Implications for remote sensing of fuel spills. [submitted to Environmental Earth Sciences, ENGE-S-19-02475, August 26th, 2019] Currently in revision process.

Manuscripts in preparation (n=6)

*Ryan, L., *Sparks, J., Burke, M., *Dawson, C., Sullivan, S., Allen, C.S., Sather, B. Krekeler, M.P.S. (in preparation) Reflective spectroscopy investigation of Preserved animal specimens. Implications for remote sensing and conservation. (80% complete)

*Vest. J., *Dawson, C., Patrick, J., Dopeke, L., Chappel, Krekeler, M.P.S. (in preparation) Reflective spectroscopy of makeup and personal care products for forensic investigations. (50% complete)

Burke, M., *Dawson, C., *Roberts, J., Allen, C.S., Krekeler, M.P.S. (in preparation) Reflective spectroscopy and geomaterials investigation of sediment samples along the U.S. – New Mexico and U.S –Texas border: Remote sensing and forensic applications. (50% complete)

*Abbott, G., Burke, M., *Dawson, C., Allen, C.S., Sather, B., Krekeler, M.P.S. (in preparation) Reflective spectroscopy and geomaterials investigation of sediment of the Great Miami River: Remote sensing and forensic applications. (60% complete)

Burke, M., *Dawson, C., Allen, C.S., Sather, B. Krekeler, M.P.S. (in preparation) Reflective spectroscopy investigation of human skin and hair under ambient conditions. (50% complete)

Burke, M., Chappel C., Allen, C.S., Krekeler, M.P.S. (in preparation) Reflective spectroscopy investigations of blood on geologic substrate over time reveals age relationships. (30% complete)

Scientific Presentations (n=19):

*Vest, J., *Patrick, J., *Dawson, C., *Seibert, Z., McLeod, C., Krekeler, M.P.S. (2020) Using industrial mineralogical approaches to combat violence against women, abductions and human trafficking: Preliminary reflective spectroscopy investigations of makeup. Geological Society of America Abstracts with Programs Vol. 52, No. 5. Paper 11-5. doi: 10.1130/abs/2020NC-347849

Krekeler, M.P.S., Burke, M., Chappell, J.C., *Dawson, C., *Brum, J., Allen, C.S., McLeod, C., Sturmer, D. M., Fackey, D., Tselepis Loertscher, C. (2019) Final phase of development for a hyperspectral search and discovery tool optimized for rescue, disaster management, and crime scene investigations. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 187-8.

*Arrington, A., **Cymes, B.A., Dietrich, M., Krekeler, M.P.S., Sturmer, D. (2019) Transmission electron microscopy investigation of particulate matter in street sediment of Gary, Indiana: Cause for environmental health concerns. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 19-1

*Lockwood, A., Chappell, J.C., Fackey, D., Krekeler M.P.S. (2019) Reflective spectroscopy and aging experiments of some high-volume organic chemicals, food oils, and motor oils: Data to support hyperspectral remote sensing of chemical spills. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 22-3.

*Lambert, T., Chappell, J.C., Krekeler, M.P.S. (2019) Reflective spectroscopy investigation of Archean Basement Rocks from Torrey Canyon, Wyoming: Implications for future high-resolution hyperspectral mapping. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 41-10.

*Balash A., *Holmes I., Burke M., Krekeler M.P.S. (2018) Dirt, Blood, and Clothing: Reflective Spectroscopy investigations of human blood on geologic and other substrates to support forensic investigations. Abstracts and Program of the 2018 Annual Meeting of the Geological Society of America. Paper 24-4.

*Brum J., *Schlegel C., Burke M., Krekeler M.P.S. (2018) A reflective spectroscopy investigation of gasoline, diesel, and Jet Fuel-A in laboratory and cold weather environments: Implications for age models, detection and quantification. Abstracts and Program of the 2018 Annual Meeting of the Geological Society of America. Paper 22-1.

*Dawson C., Burke M., Krekeler M.P.S. (2018) Preliminary reflective spectroscopy results for rapid identification of mineral based makeup products and associated personal care products in the context of forensic and health investigations. Abstracts and Program of the 2018 Annual Meeting of the Geological Society of America. Paper 24-5.

Krekeler M.P.S., Loertscher C., *Dawson C., Burke M. (2018) Reflective spectroscopy of human materials, geologic materials and a review of geologic settings: A new investigative approach for violent terrorist activities. Abstracts and Program of the 2018 Annual Meeting of the Geological Society of America. Paper 24-2.

*Ryan L., Krekeler M.P.S., Burke M., *Sparks J. (2018) Reflective spectroscopy investigations of museum animal specimens supports development of a hyperspectral remote sensing tool for recovery of lost persons. Abstracts and Program of the 2018 Annual Meeting of the Geological Society of America. Paper 24-

Krekeler M.P.S., Burke, M., *Dawson, C., Allen C.S., Sather, B. (2018) Development of a Hyperspectral Remote Sensing Software Tool to Aid Law Enforcement in Investigations. Research Showcase Poster 30. Academy of Criminal Justice Sciences Annual Meeting.

Krekeler, M.P.S., Burke, M., Allen, C.S., Sather, B., *Dawson, C., *Roberts, J. (2017) Progress in developing a hyperspectral remote sensing library and software tool for finding persons in the environment. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 327-15

Krekeler M.P.S., **Dietrich, M., Vangala, S., Tully, J., LeGalley, E., Argyilan, E.P., Burke, M., Wolfe, A. (2017) Environmental properties and impacts of nanoparticles in urban landscapes of the Midwest: Microscopy studies of street sediment demonstrate cause for concern. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 69-36.

*Brum, J., *Schlegel, C., *Hernandez-Muniz, W., *Dawson, C., Burke, M., Krekeler, M.P.S. (2017) Laboratory reflective spectroscopy investigations of heavy fuels, plastics and geomaterials for hyperspectral remote sending based environmental monitoring. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 372-9.

*Hernandez-Muniz, W., Burke, M., Krekeler, M.P.S. (2017) Reflective spectroscopy of gasolines for the development of a hyperspectral library and development of age estimation techniques for spill investigation. Abstracts and Program of the Annual Meeting of the Geological Society of America. Paper 372-8.

*Linnekohl, S., *Dandenault, P., *Abbot, G., *Hoover, A., *Grzeskowiak, E., *Myers, J., *Martin, A., Burke, M., Krekeler, M.P.S. (2017) Grain characteristics and the mineralogy of modern Great Miami River sediment show complexity at Heritage Park, Colerain Township, Ohio. Abstracts and Program of the Joint Northeastern and North Central Sections of the Geological Society of America. Paper 25-17.

*Marshall, S., *Hoskins, N., *Schlegel, C., *Herlitz, T., *Free, J., *Breda, C., Burke, M., Krekeler, M.P.S. (2017) Laboratory hyperspectral investigations of geomaterials from the Great Miami River at Heritage Park, Colerain Township, Ohio: Progress in developing an environmental library for complex geologic settings. Abstracts and Program of the Joint Northeastern and North Central Sections of the Geological Society of America. Paper 68-3.

**Dietrich, M., Wolfe, A., Burke, M., Vangala, S., Argyilan, E.P., LeGalley, E., Krekeler, M.P.S. (2017) A preliminary urban geochemical exploration of street sediments of Gary, Indiana indicates major concerns are warranted. Abstracts and Program of the Joint Northeastern and North Central Sections of the Geological Society of America. Paper 65-6

Burke, M., *Roberts, J., Krekeler, M.P.S. (2017) Spectral reflectance investigation of geologic materials for creation of reference library tool. Abstracts and Program of the Joint Northeastern and North Central Sections of the Geological Society of America. Paper 55-3.

References list

There are no citations for the text of this report.