Blood Stain Detection on Camouflage Clothing Using Machine Learning Analysis of Noisy Hyperspectral Imagery

Nicholas V. Scott, Riverside Research, Open Innovation Center, Beavercreek, OH 45431

Sarah Jensen, Savor Safe Food, 6797 North High Street, Columbus, OH 43085

1. Introduction/Motivation:

- Military, law enforcement, and intelligence agencies are often tasked with forensic analysis-based operations in which there is a need to quickly assess the probabilistic presence of the wounded in remote positions.
- Hyperspectral imagery (HSI), a proven technology for the detection of anomalous substances in heterogeneous background environments, has seen use in the detection of the wounded through its use as a photonic-based detection tool. This is mainly but not exclusively in the area of imagery of blood stained clothing.
- Blood on clothing often appears in different configurations which changes due to stresses that smear the fluid along the material. The ability to detect this modulation is important in assessing the versatility of hyperspectral imaging technology in detecting surface signs on a wounded body.
- Blood detection under conditions of smearing on camouflage cloth is explored using HSI and machine learning algorithms. In particular, image segmentation under a variety of blood smear conditions is performed using non-negative matrix factorization, competitive leaky learning, and Laplacian eigenmap-based anomaly detection.
- HSI characterization of blood stains on clothing is the first step toward the creation of inexpensive multispectral imagery (MSI) technology capable of performing remote sensing-based blood stain image segmentation.

2. Hyperspectral Imagery Data Acquisition:

- A 10-inch square digital camouflage piece of cloth was placed inside a light diffuser box illuminated with a pseudo sunlight spectrum light source ensuring semi-Lambertian conditions. The experiment's date was February 14, 2020.
- Spectral imagery measurements of the cloth with and without **deer blood** smears were made using a Resonon Pika-L HSI camera possessing a spectral bandwidth spanning 300-1050 nm. The camera head was 42 inches from the light diffuser box and was tilted downward from the horizontal at approximately 60°.

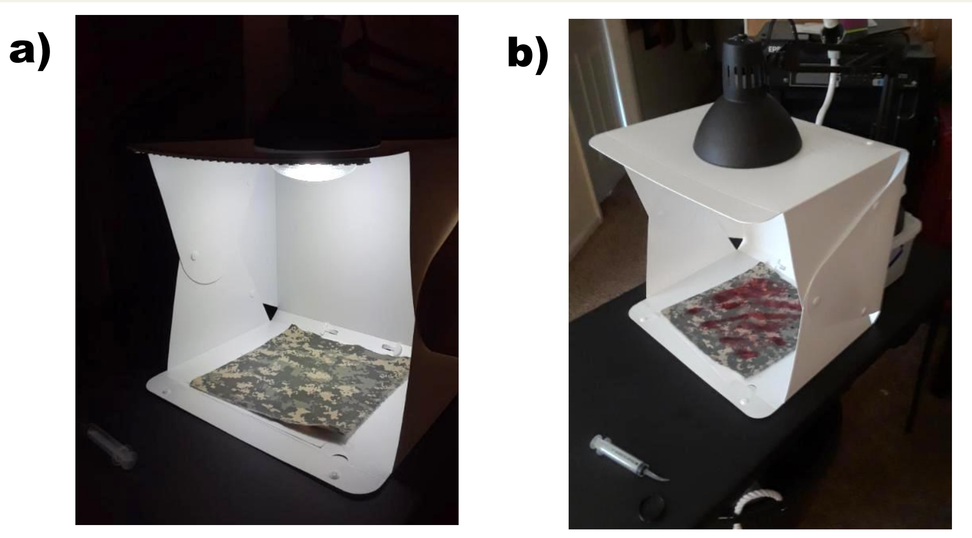

Figure 1: **Experimental set up of light source, diffuser box, and camouflage cloth. a) without blood smear and b) with blood smear. Syringe used for blood injection is shown.**

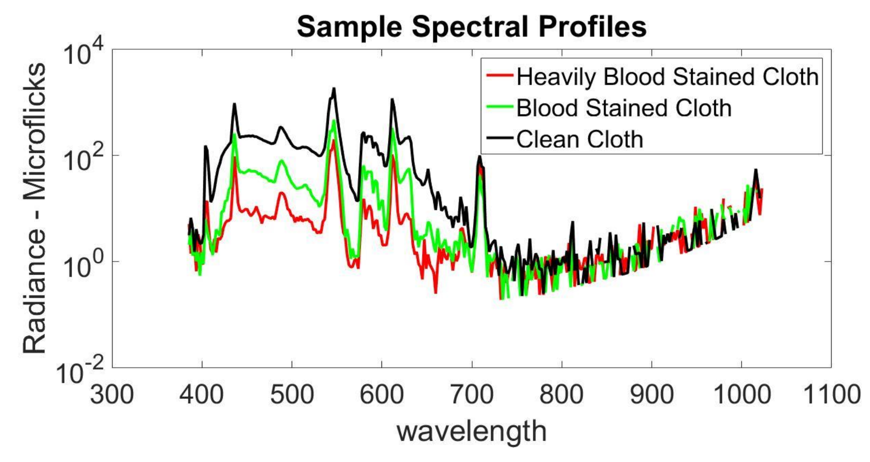

Figure 2: **HSI 300 band sample spectra of blood stained and clean cloth. Legend delineates different spectral curves for clean cloth and blood smeared cloth.**

2. Hyperspectral Imagery Data Structure:

- Averaged sample HSI spectra for clean cloth and blood smeared cloth are shown in Figure 2. Spectral amplitudes for blood stained cloth are lower than for clean cloth. Spectral signatures for both blood smeared cloth and clean cloth have distinctive peaks at 436 nm (blue), 547 nm (green), 612 nm (red), and 709 nm (red) related to both the true physical reflectance and the type of white light spectrum. Blood stained cloth has small spectral minima and maxima between 420-550 nm and between 620-700 nm. This is due to the blood stained cloth photonic structure.
- Three HSI cubes were taken of blood smeared cloth targets where each possessed increasing amounts of blood smear. RGB images of the targets are shown in Figures 3a from left to right. Each HSI cube possessed 800 scan lines where a single line had 900 pixels. The HSI camera frame rate was 89.8 Hz and the integration time was 0.18 seconds. The gain, the hardware spectral bin average interval, and scanning rotation speed was set to 0, 2 spectral bins, and 1.0 °/sec respectively.
- 201 X 201 and 61 X 61 pixel image chips were extracted (as shown by the white boxes in the RGB images displayed in Figures 3a and the white boxes in Figures 3d respectively) and underwent three different image segmentation transforms. These are shown below in Figures 3b-e.

3. Data Analysis Results for Nonnegative Matrix Factorization, Laplacian Eigenmap Analysis, and Competitive Leaky Learning:

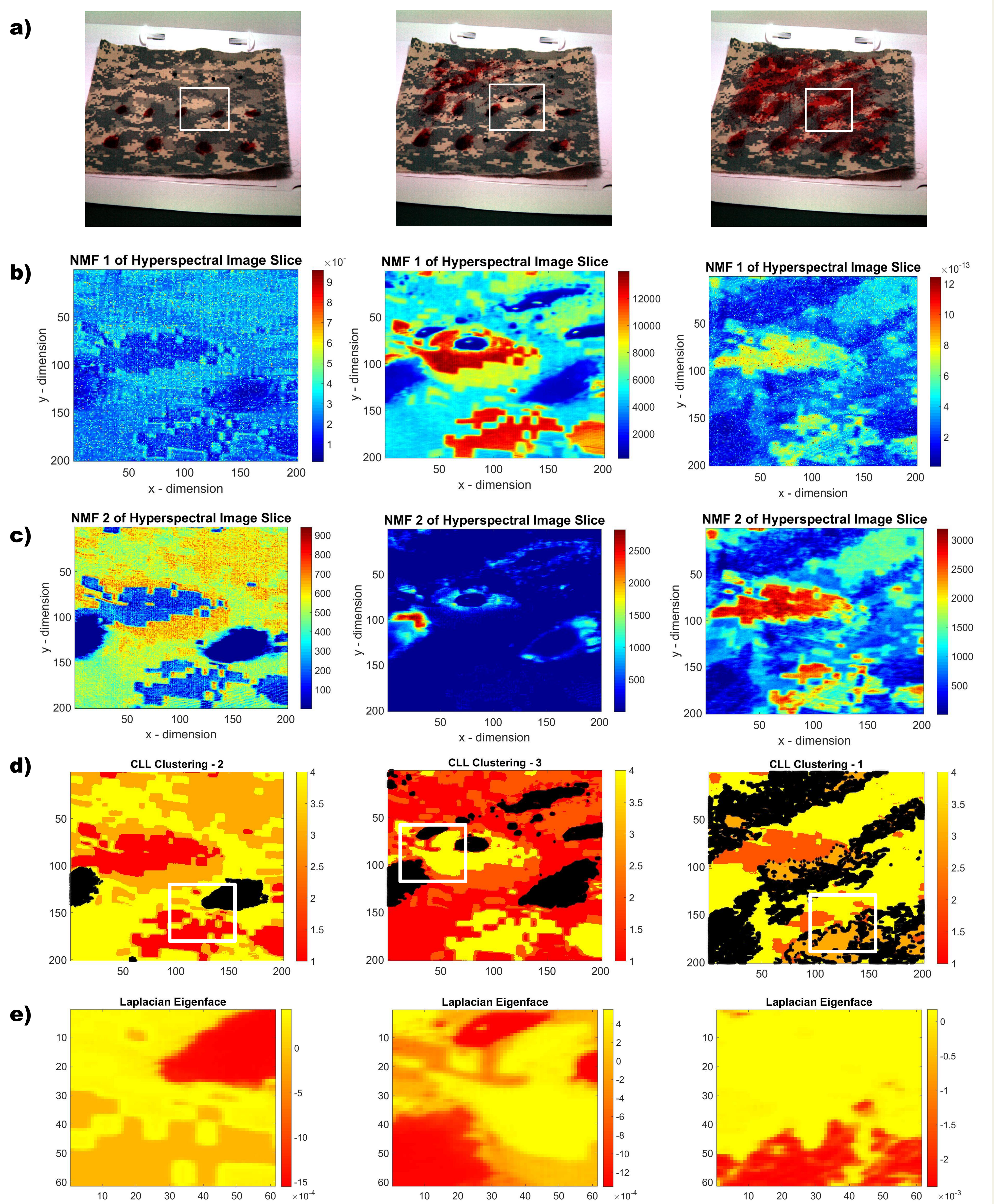

Figure 3: **a) RGB images for three different blood stained cloth targets. b) First NMF component and c) Second NMF component for three different blood stained cloth targets. d) Competitive leaky learning four component clustering maps of three different blood stained cloth targets. 201 X 201 pixel image chips used. Physical dimensional scale is approximately 1 square foot. e) First Laplacian eigenface for all three blood stained cloth targets. 61 X 61 pixel image chips shown.**

4. Data Analysis Results for Nonnegative Matrix Factorization, Laplacian Eigenmap Analysis, Competitive Leaky Learning, and Distance Metrics:

- Nonnegative matrix factorization (NMF) factors the HSI data into two different matrices – NMF eigenvector and abundance or weight matrices. The internal dimensional scale of the factorization is a priori set, representing a reduction in the scale of the system.
- The Laplacian Eigenmap (LE) method is a data driven, local preservation mapping that exhumes weak covariance structures in the HSI data. A local window is used in conjunction with an eigenmodal method applied to a similarity graph to accentuate anomalous spatial structures.
- Competitive leaky learning (CLL) clustering is a neural network-based algorithm where the similarity between the input spectral data vectors and weight vectors are calculated through numerical competition. With each iteration, spectral data vectors become more affiliated with certain weight vectors allowing for clustering of spectral signatures.
- NMF and CLL analysis were able to segment blood stained cloth and clean cloth for the first two target conditions shown in Figures 3b-d. This was performed using two NMF components and four CLL clusters respectively. There was a decrease in segmentation power in the third target.
- LE analysis was able to do the same robustly using four Laplacian eigenfaces for the sub-image chips delineated in Figures 3d. Figures 3e shows how one Laplacian eigenface segregates blood stained and clean cloth.
- As the blood stain spreads in surface area while conserving total mass, image segmentation power for all algorithms decreases with confusion occurring between the camouflage cloth pattern and blood stains.
- The Kullback-Leibler divergence (KLD), and the Bhattacharyya distance (BD), distance metrics sensitive to covariance, were calculated as a measure of the distance between clean cloth and blood stained cloth. Large values for these quantities indicate strong separation of clean cloth and blood stained cloth areas.

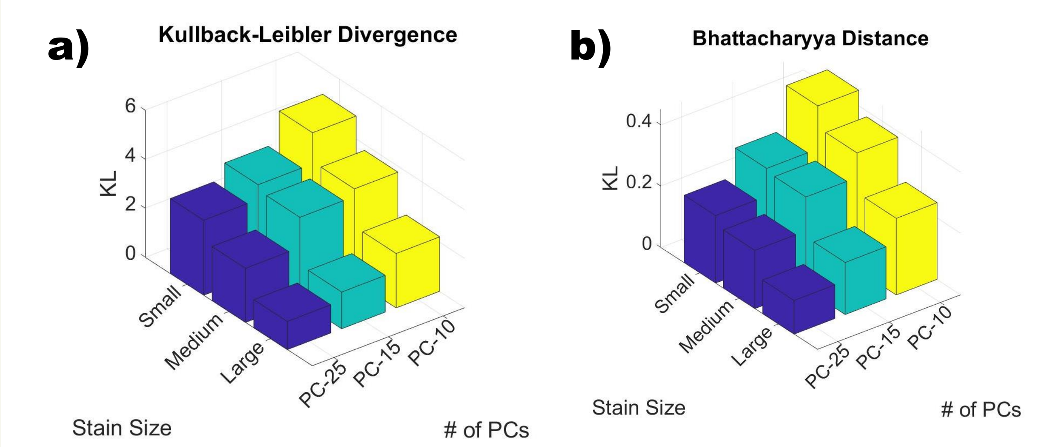

Figure 4: **a) KLD and b) BD of principal component (PC) analyzed image data for 10, 15, and 25 PC spectral wavelengths for different blood smeared cloth-clean cloth targets.**

- BD and KLD were small for highly smeared (large) blood stained cloth areas and small clean cloth areas and for the distance metrics calculated using a large number of principal components.

5. Conclusions:

- **HSI blood stain detection using machine learning analysis is possible, but its efficacy decreases as blood stain smear increases in surface area.**
- **Small PC numbers associated with high value distance metrics suggest that MSI technology for blood smear detection is possible.**