CAAP Quarterly Report

Date of Report: *June 30, 2020*

Contract Number: 693JK31950005CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *An Unmanned Aerial System of Visible Light, Infrared and Hyperspectral Cameras with Novel Signal Processing and Data Analytics*

Prepared by: *Missouri University of Science and Technology (Missouri S&T)*

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For quarterly period ending: *June 30, 2020*

Business and Activity Section

(a) General Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Dr. Bo Shang, a post doc at Missouri S&T, joined the research team in February of 2020. Dr. Shang is responsible for the hardware and software integration of visible light, infrared and hyperspectral cameras and associated validation tests under Dr. Chen's supervision. Mr. Pengfei Ma, a Ph.D. student in civil engineering at Missouri S&T, was on board since November 15, 2019. Mr. Ma is responsible for the laboratory and field tests of an integrated system of visible light, infrared and hyperspectral cameras and for image analysis under Drs. Chen and Shang's supervision. Mr. Jiao Pu, another Ph.D. student in civil engineering at Missouri S&T, was on board since October 1, 2019. As needed, Mr. Pu is responsible for the finite element model of an unmanned aerial system with cameras.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

This project aims to:
1. Develop and integrate a robust and stable, semi- or fully-automated UAS with multiple sensors for multi-purpose pipeline safety data collection,
2. Explore and develop novel signal and image processing techniques for data analytics, damage assessment, and condition classification, and
3. Evaluate and validate field performance of the integrated UAS for pipeline safety inspection.

These objectives will be achieved through analytical, numerical, and experimental investigations in three tasks:

1 To design and prototype the UAS for the collection of cohesive types of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers;

2 To develop and validate one-dimensional (1D) spectral analysis at each pixel of a hyperspectral image, two-dimensional (2D) image classification of changes, spatial analysis of a hyperspectral image and its fusion with other images for increased probability of detection, and three-dimensional (3D) object establishment for volume estimates; and

3 To develop a physically-interpretable, deep learning neural network for the selection of images (frames) with regions of interest from long hours of video footage, recorded as the unmanned vehicle flies along a pipeline, and demonstrate in field conditions the UAS performance in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground

objects, accident responses, and mapping system accuracy.

Task 1. To design and prototype the UAS for the collection of cohesive types of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers

1a Building of an indoor drone cage

In order to perform the necessary drone test in the laboratory before doing a field test, we designed and built a drone cage in our laboratory, as shown in Fig. 1. PVC pipes (2” in diameter) were used to build a 14’ × 10’ × 7’ frame. Bungee balls were used to hang the drone net to the frame. Colorful foam blocks were used to add more visual features and protect the drone from damage when landing.

Fig. 1 Indoor drone cage

1b Design of the integrated UAS and non-GPS navigation system

Duo Pro R640 camera (FLIR) and a VNIR hyperspectral camera (Headwall) are under procurement. Due to the COVID-19, major acquisitions are slow at Missouri S&T. The current unmanned aerial system (UAS) prototype in S&T laboratory is based on an open-source quadrotor platform. This test quad is based on the airframe designed by Missouri S&T.

Fig. 2 shows the test quadcopter. A Jetson TX2 onboard computer in the black case is mounted on top of the drone. The Jetson TX2 is a powerful embedded computer with GPU inside. It has several interfaces that can connect with different types of sensors. A ZED 2 depth camera is mounted on the front of the drone to work as a visual odometry and data collector. The visual odometry is working as a supplement when the drone goes to some places where GPS signals are weak, such as near buildings or in tunnels. The ZED 2 camera can detect objects such as humans and cars, and keep a safe distance from other objects. The two antennas on the Jetson case are for Wi-Fi and BlueTooth communications. The Wi-Fi is used to connect the Jetson TX2 to a ground control station. The black 3D printed frame around each motor is going to be used to mount safety carbon fibers to protect the propellers from hitting other objects.

Fig. 2 Test quadcopter with an onboard computer

Fig. 3 presents a signal flow diagram of the UAS. The ZED 2 camera is connected to Jetson TX2 via a USB 3.0 cable. This high speed connection can transfer real time image data up to 720 p at 60 Hz. This high updating rate helps compensate position drifts caused by disturbances such as wind. The ZED SDK does intensive computations with an algorithm, making use of both GPU and CPU to track the drone's position. This positional tracking information is imported to the ROS (Robotics Operating System) as a topic. ROS takes care of format and coordinate conversion based on the position where the ZED 2 camera is mounted. Eventually, a UART communication cable is used to transmit the local position estimation information and confidence level to the autopilot, which is called ArduCopter. EKF data fusion algorithm is used to fuse the local positional information from vision with data from IMU (Inertial Measurement Unit) on ArduCopter. This whole process solves the non-GPS navigation problem.

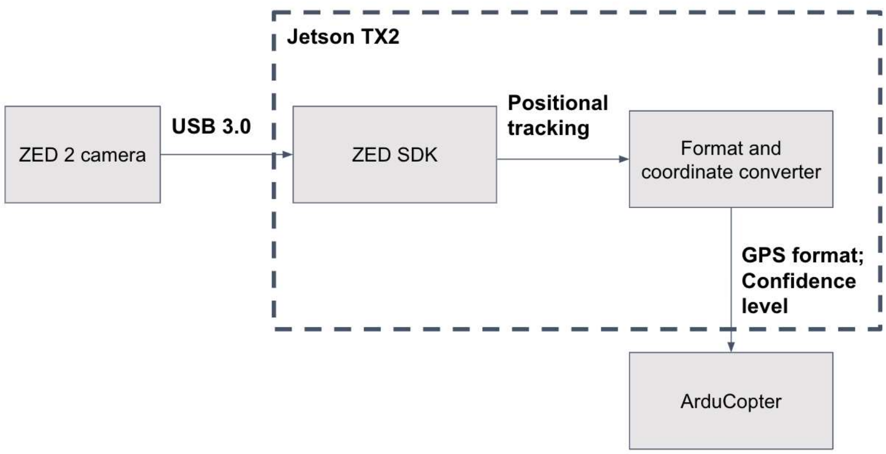


Fig. 3 Signal flow diagram of the UAS system

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

Task 2 can be divided into four sections: 1D spectral analysis of pixels from hyperspectral images, 2D image classification, spatial analysis of hyperspectral images for fusion, and 3D object establishment for estimation of the leakage volume.

Open literatures have been reviewed to understand the latest development in pipeline condition inspection and assessment with remote sensing. Progress has been made in terms of one-dimensional (1D) spectral analysis at each pixel of a hyperspectral. For the sake of detecting leakage, it is practical to first detect the changes occurred on surfaces and then progressively identify what results in the changes, namely, to qualify the materials corresponding to hyperspectral data.

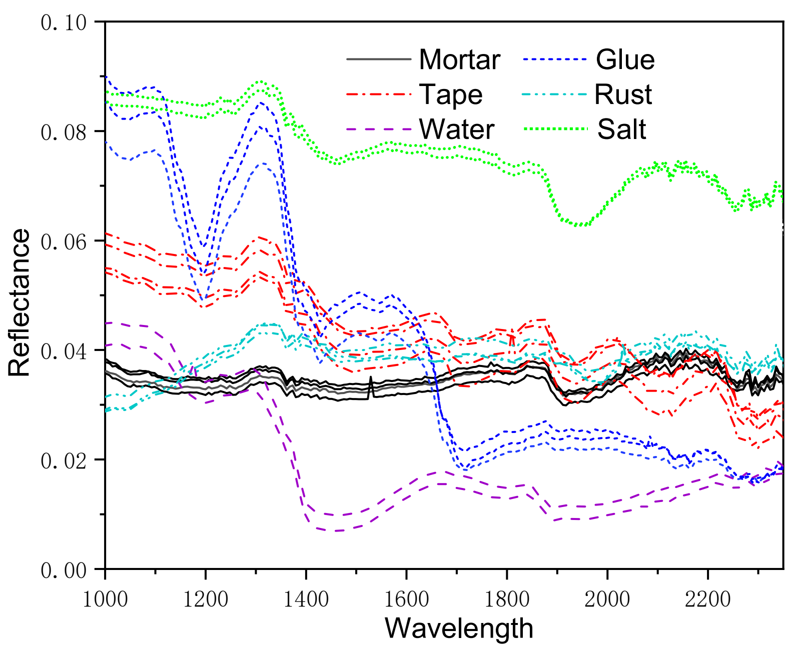
2a Change detection

The detection of changes on ground surfaces or from objects is based on the correlation between two adjacent pixels in a hyperspectral image. The correlation is derived from the two pixel hyper spectra that are obtained from a VNIR hyperspectral camera (Headwall). Since each hyper spectrum retains the intrinsic properties of materials in a molecular level, it would not be altered unless the material properties were changed in that micro level. Therefore, the correlation based on the hyper spectra at two pixels can be a robust indicator of the occurrence of changes.

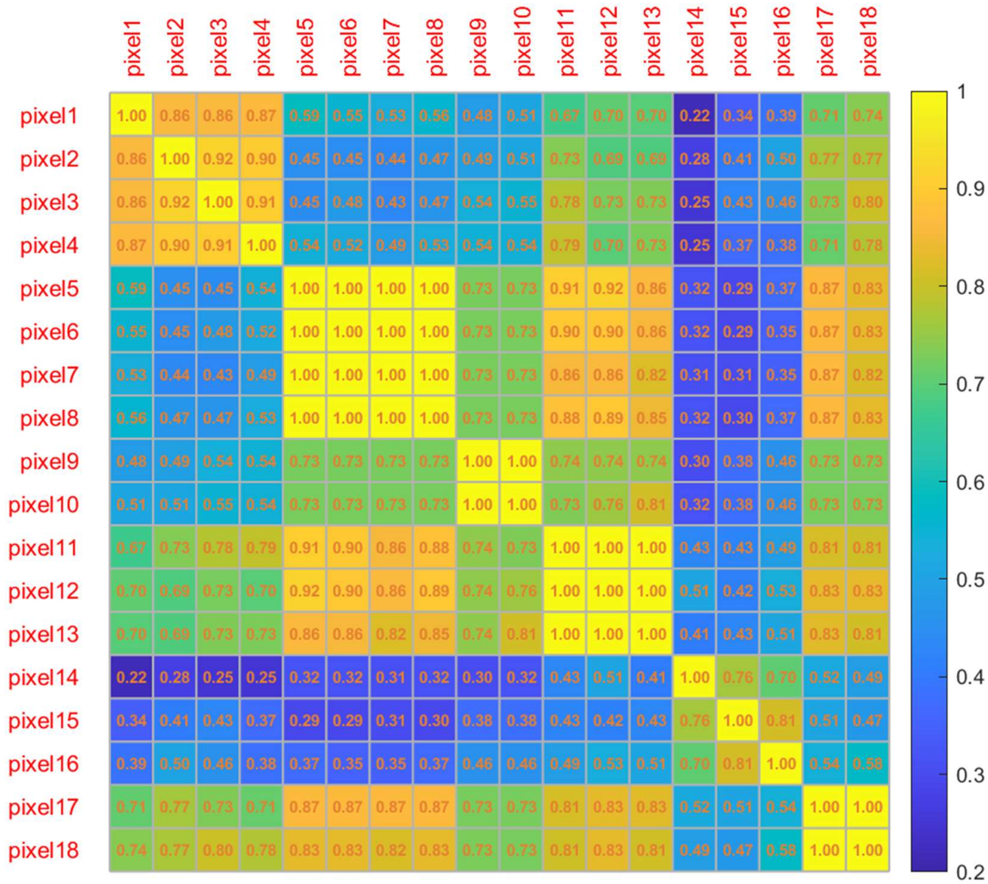
To test the above change detection concept, several objects (mortar, blue tape, water, glue, iron rust, and salt) were placed on the floor of SPAR Lab and scanned with a VNIR hyperspectral camera (Headwall) to provide spectral data concerning the surfaces of various objects. A total of 18 pixels were selected from the various objects as detailed in Table 1. The hyper spectra at the 18 pixels are shown in Fig. 4a. It is clearly seen from Fig. 4a that different spectra are quite different in shape unless they are taken from the same object, and therefore, include intrinsic features related to the materials. The maximal mutual information coefficient (MIC) between any two pixels is presented in Fig. 4b with color coded for various levels of correlation.

Table 1 Pixels corresponding to different objects

Pixel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Surfaces	Mortar				Blue tape				Water		Glue			Iron rust			Sodium	



(a) Spectra of different surfaces at 18 pixels



(b) Maximal mutual information coefficients-MIC

Fig. 4 Correlation between pixels

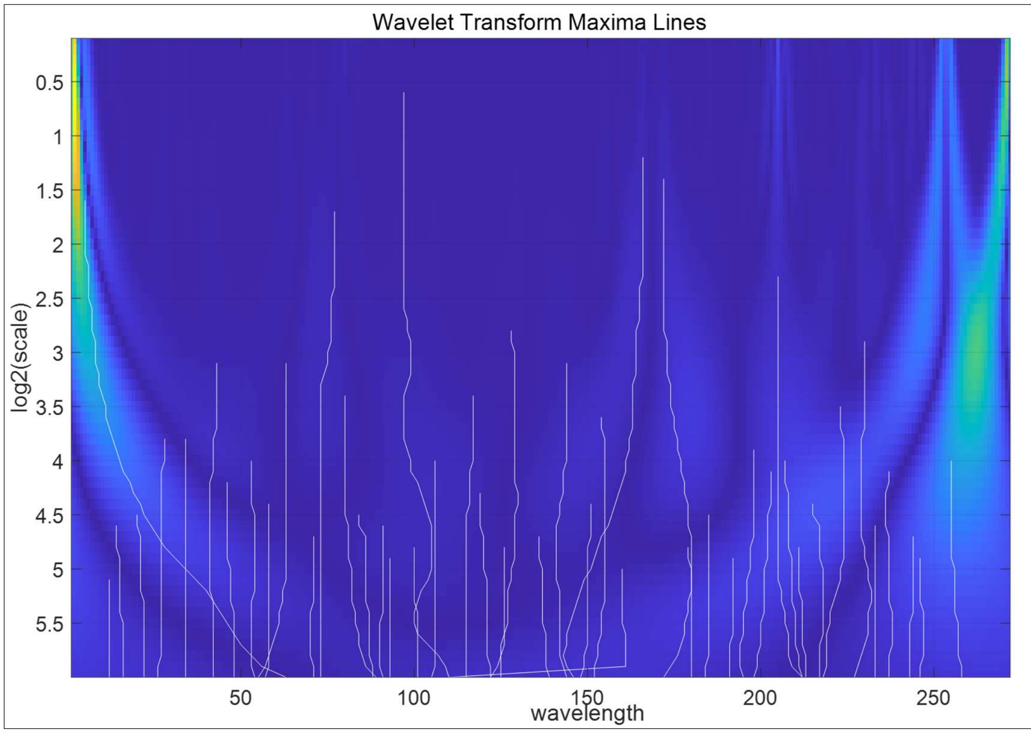
Changes can be located by the colormap of correlation coefficients in Fig. 4b. For two pixels from the same object, their correlation coefficient should be equal to approximately 1.0. Otherwise, the correlation coefficient values are smaller. Correspondingly, if changes happen, there will be a dramatic color transition between two adjacent pixels.

2b Object identification

Identification of different objects requires the understanding and knowledge of themselves. The innate properties should be a preferable basis to be used in material identification. The hyper spectrums are validated to provide the information of diverse components in a molecular level. Thus, the analysis of spectra can be a feasible tool to distinguish materials because of the uniqueness and robustness.

Features of spectra are commonly introduced to represent a particular attribute of objects. A feature in this context is the cluster of singularities in a hyper spectrum. Singularities are extracted with wavelet transform and characterized by the holder exponent at each potential point where the singularities may occur. The singularity feature is generalized as a set by summarizing the common singularities of spectra from pixels of a reference surface with the absolute value of corresponding holder exponent below 0.3.

The basic concept behind object identification is to compare the number and locations of singular points between the object and the reference. Fig. 5 shows the maxima lines of wavelet transform of the hyper spectrum at pixel 1. The 18 pixels has been selected and tested, 17 of which can be successfully recognized by the holder exponent method. Though a small data base, the result demonstrated the possibility of material identification using this method. Further expansion of the database and optimization of the proposed method will continue throughout the next reporting period.



	Sample	Holder Exponent
1	5	-0.9826
2	12	-1.4001
3	14	0.1478
4	20	0.2137
5	28	0.6235
6	34	0.5044
7	43	0.7797
8	46	-0.0298
9	53	-0.0051
10	58	-0.1811
11	63	0.2537
12	71	1.1306
13	77	0.4495
14	80	-0.3986
15	84	-2.5960
16	91	-2.3137
17	93	-1.6710
18	97	0.6749
19	100	-0.2392
20	106	0.0760
21	117	0.1224
22	119	0.4132
23	126	-1.7337
24	128	0.3490
25	136	0.9299
26	144	0.8706
27	151	0.0677
28	154	0.2599
29	160	0.9066
30	166	0.3088
31	172	0.8157
32	179	0.5998
33	185	0.0229
34	192	-2.5564
35	198	-0.6413
36	203	-1.3526
37	205	-0.2113
38	207	-1.3775
39	211	-0.3934
40	215	0.7641
41	223	0.3911
42	230	0.1462
43	233	-1.0294
44	237	-3.7729e-04
45	244	-0.7160
46	246	-1.0963
47	255	-0.0029

Fig. 5 Modulus maxima lines and holder exponent of Pixel 1

Task 3. Develop a physically-interpretable neural network for the selection of images (frames) from video footage and demonstrate in field conditions the UAS in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground objects, accident responses, and mapping system accuracy.

This task will not start till the 4th quarter in 2020.

(c) Planned Activities for the Next Quarter - The following activities will be executed during the next reporting quarter.

Task 1. Design and prototype the UAS for the collection of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers.

Continue to procure the hyperspectral and infrared cameras and integrate them into a UAS. Determine the final factors to include in the laboratory test and develop a thorough test plan. Have all necessary equipment, materials, space, and staff in place to fully prepare for laboratory tests and collect data for Task 2.

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

The 1D adaptive wavelet transform will be applied to extract the ground and material conditions along a pipeline through the abnormalities in space, which are represented by the changes in wavenumber. The effectiveness of the extended transform will be investigated using the data obtained in Task 1 from laboratory tests, once available.

(d) Problems Encountered during this Quarter and Potential Impact on Next Quarter – This project has been impacted by the COVID-19. At Missouri S&T, laboratories were closed on March 16, 2020, and re-opened on June 1, 2020 with social distancing and hand sanitizing practices in mind. To keep six feet apart between any two students in the laboratory, limited laboratory access is available to students. As such, students may have to work in different shifts.