CAAP Quarterly Report

Date of Report: *September 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*

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For quarterly period ending: *September 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 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.

Progress has been made in terms of one-dimensional (1D) spectral analysis at each pixel of a hyperspectral. For the purpose of detecting leakage, it is practical to first detect the changes occur on surfaces and then progressively identify what results in the changes, namely, to qualify the materials corresponding to hyperspectral data. A new method, maximal mutual coefficient, to characterize the changes on a surface has been investigated and the wavelet-based method is used to classify the culprit that causes the change. To demonstrate the practicality of the methods above, a lab test is arranged to capture data.

With the background of a leakage detection, gas leakage is firstly researched. In this context, plants are used as sensors to detect the gas leakage because the gas impacted plants will be stressed and the stress yields a change in the spectrum of leave pixels. Thus, the lab test concentrates on what specific features there are in the spectrum of plant leave pixels to characterize the gas leakage occurrence.

Plants work as sensors to obtain information of the gas leakage in the wild. Plants may behave differently when stressed by the gas and the exhibition of stress may also vary in view of the spectrum. Besides, there are diverse factors that may bring about stress on plants. Considering the factors, another three significant and common natural impacts, water deficit, saline soil and heavy metal contaminated soil are included in the test.

Plants

There are three types of plants included in the lab test in terms of their tolerances to the impacts illustrated above. They are selected to reflect the real cases in the wild. They include ornamental grass, and two types of shrubs, Gem boxwood with hard foliages and Ligustrum sinense with relatively soft foliage. There are three pots of plants for each treatment and another three without any treatment as a reference.

Table.1 Plants details

Plant	**Shrub**				**Grass**	
Type	Gem boxwood		Ligustrum sinense		Ornamental grass	
Factors	treated	reference	treated	reference	treated	reference
Amount	15 (4×3+3)		15 (4×3+3)		15 (4×3+3)	

(a) Gem boxwood (b) Ligustrum sinense (c) Ornamental grass

Fig.1 Plants for test

Treatments

The reason why plants get stressed due to impacts is that such impact will change the properties of soil and then indirectly affects the plants. The soil in which plants grow will be treated with different chemicals to simulate the real cases concerning the salinity and heavy metal contamination.

1. Gas (methane)

The gas leakage yields plant stress because methane will diffuse into the soil and replace the oxygen. Short of oxygen have a negative effect on the plants because the root system may stop transferring essential moisture and nutrients, which will slow down the photosynthesis and metabolism process. In the lab test, plants will be treated with CH_4 gas at a rate of 1.25lL/h to simulate the real case. The process lasts 12 hours per day repeatedly.

2. Saline soil

Saline soil is rich of Na^+, K^+, Ca^+, Mg^+ and Cl^-. The high concentration of these cations and anions creates an unfavorable environment for the root system of plants. The absorption of the additional ions will affect the growth of plants and alters the composition of leaves subtlety. The change can be identified with the hyperspectral camera because of the unique reflectance.

Generally, soil can be deemed as saline when the electrical conductivity (EC_e) exceeds 4dS/m. Plants' tolerance to salinity varies and the adopted EC_e in this test refers to Table. 2.

Table.2 Electrical conductivity (EC_e) of soil for plants

Plant	**Shrub**		**Grass**
Type	Gem boxwood	Ligustrum sinense	Ornamental grass
EC_e	10 dS/m	8 dS/m	8 dS/m

3. Heavy metal contaminated soil

Heavy metal ions accumulate in soils because of the fertilizers, natural irrigation, and the leakage of crude oil etc. Basically, heavy metal has a detrimental effect on plants and stress them in a harmful way. Likewise, the heavy metal soil is simulated with heavy metal salt. The amount to add refers to the limits regulated by the US Environment Protection Agency. In this context, copper, zinc, lead, chromium, nickel and arsenic are considered because of their abundance and availability.

Table. 3 Regulatory limits on heavy metals on applied soil

Heavy metal	Arsenic	Chromium	Copper	Lead	Zinc	Nickle
Limits /ppm	75	3000	4300	420	7500	75
Applied in test /ppm	62	1000	1500	420	2500	75

4. Water deficit

Water plays a vital role in the process of plant photosynthesis and metabolism as well. Lack of water slows down the growth of plants and these responses include changes in accumulation of solutes, changes in carbon and nitrogen metabolism, and alterations in gene expression. And the dehydration also impairs plants' resistance to strong sunlight and causes light burn. In response of the water stress, the biological and physical changes can be discerned through hyperspectral camera.

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.

The team will 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 continues to be impacted by COVID-19. 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.