MPC-460

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Project Title:
Technology and Workforce Development for Remote Sensing of the Transportation Infrastructure

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North Dakota State University

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Research Needs:

Maintaining the transportation system in a state of good repair is critical to sustaining our nation's economic well-being, and serving both the mobility and lifestyle of its citizens. However, monitoring performance and detecting risks across a vast transportation network is costly, time-consuming, complex, and requires a wide variety of expertise. The transportation infrastructure is a complex, expansive, expensive, and extremely open system that integrates multiple modes that move people and goods of all types across roads and bridges, railways, waterways, and the airways. Additionally, a complex network of aboveground and underground pipes moves critical resources such as oil, gas, and water.

The ability to accurately assess resource needs and make effective decisions requires enhanced visibility of the growing levels of transportation and logistics activities. Sensor technologies continue to evolve at a rapid pace to provide greater visibility, but we currently know very little about how to integrate and apply most of them to enhance the safety, security, and efficiency of transportation systems. Agencies have deployed wired and wireless sensor technologies, but only in sparse quantities because their high cost, size, and energy demands limit their ability to cover the entire expansive, multimodal, and intermodal transportation infrastructure (HPMS 2012). Remote sensing technologies that use satellite and manned aircrafts with multispectral sensor payloads can provide greater coverage but are limited in the type of information obtainable from their data sets. For example, the typical multispectral sensors cannot detect hydrocarbon spills and other hazardous materials underground (Otten, et al. 1998). Hyperspectral imaging offers a greater potential for improved remote sensing capabilities but their present size and cost limit are limiting factors for widespread deployment (Hart, Slough and Rafert 1998).

Research Objectives:

The primary goal of this study is to assess and develop means(including airframe and sensor integration, and demonstration flights) of optimizing hyperspectral remote sensing for use with lightweight (less than 50 pounds) unmanned aircraft systems (UAS) and to provide the relevant training necessary for future practitioners to construct and deploy full solutions. A secondary objective will be to investigate the use of ground or vehicle based hyperspectral systems. A variety of knowledge domain experts in signal processing, image analysis, data mining, data management, geospatial analysis, optics, rules-based engines, cloud computing and mobile computing are needed to implement complete solutions. Effective implementations will generally merge cross-disciplinary expertise to analyze the fusion of data from a variety of sources to quantify performance and assess risks, threats, and vulnerabilities in the transportation system (Bridgelall

2014). The transformation of remote sensing data into actionable information requires forms of signal processing and data analysis that are still evolving and/or not yet fully understood. The associated decision-support platforms and asset management systems rely on tailoring multidisciplinary aspects of the full solution to remote sensing applications for maximum effectiveness in realizing their potential benefits while reducing the complexity of human interfaces. Educators have placed little, if any, attention on inventorying the skill sets and workforce availability for personnel who can process and derive actionable information from these data sources.

To achieve this goal, the team will execute the following objectives:

1) Conduct a utility study to catalog current practices and high-priority emerging opportunities for hyperspectral sensing.
2) Identify emerging and related sensor technologies for inclusion in future transportation infrastructure needs assessments, including preliminary demonstration flights with hyperspectral sensors.
3) Formulate means that MPC members can utilize to build upon their existing curricula and ensure a properly trained workforce with relevant skills and understanding within those domains.

Research Methods:

To achieve the above objectives, this research will conduct a comprehensive *utility study* that will define and describe the complete set of existing, emerging, and potentially new remote sensing applications relevant to transportation infrastructure performance, management, and condition monitoring that include hyperspectral or multispectral techniques. The utility study will follow the general format of (Rafert and Rusk 1991). The utility study will be comprehensive, and cover all current types of land, air and space-based hyperspectral remote sensing devices that involve the use of visible, short-wave infrared (SWIR), and long-wave infrared (LWIR) hyperspectral methods (Meigs, et al. 1997), and applications spanning roadways, bridges, railways, pipelines, airways, and waterways.

The proliferation of ubiquitous high definition video sensors and the emergence of cloud computing and Big Data methodologies to process large datasets have created a new paradigm that could enable cost-effective hyperspectral sensing. To identify emerging and related sensor technologies, the team will conduct a literature search to assess key attributes of these small, low cost sensors and their and applicability for providing hyperspectral data.

The study will focus on research areas of interest to Mountain Plains Consortium (MPC) members, and on sculpting ways to leverage existing MPC curricular content for workforce development and training. The team will generate an inventory of the (i) research expertise, (ii) coursework, (iii) certificate and (iv) degree programs of all MPC members with relevant coursework or curricular content in remote sensing of the transportation infrastructure to include, but not be limited to the following areas:

- multimodal and intermodal transportation performance measures
- multimodal and intermodal infrastructure and equipment condition assessment
- intelligent transportation systems and technologies
- information theory considerations for advanced hyperspectral imagers
- correlation formalisms involved with the fusion of spatial and spectral datasets
- hyperspectral sensor signal processing and interfacing considerations for hyperspectral imagers
- feature extraction methods for hyperspectral remote sensing applications

- data mining techniques for hyperspectral remote sensing applications
- geographic information systems (GIS) and data visualization for hyperspectral remote sensing applications
- decision-support platforms based on remote sensing data
- asset management systems based on remote sensing data
- mobile computing applications tailored for remote sensing applications

The study will assess the availability, relevancy, and deficiencies of existing training programs and curriculum to process and understand data from remote sensors of the type proposed for this study, with a special focus on curriculum or program growth derived from the current areas of strength of the members of the MPC. As part of the gap assessment, the team will address the potential for developing online courses in remote sensing to streamline and tailor some of the above topics for commercial applications using both aerial- and ground-based unmanned vehicles.

The focus will be on classroom, online, hybrid, and immersive delivery mechanisms at the graduate level. Plans will consist of course offerings tailored to a variety of audiences that could include the broader academic community, as well as specific organizations such as state highway troopers, border patrols, and other personnel engaged in traffic safety enforcement. The team will also study emerging employer needs in each of the MPC states to identify areas in which critical capabilities, skills, and knowledge of the workforce in the area of remote sensing will be required in the future.

Production-oriented solutions for these applications will require integration with existing intelligent transportation systems platforms and standards such as those developed at the Upper Great Plains Transportation Institute (UGPTI) software development center in Lakewood, Colorado. Therefore, locating the PI/PD in Lakewood will maximize the potential for successful deployment of this initiative.

Expected Outcomes:

This study will result in the first-ever comprehensive survey of existing and future remote sensing applications for transportation infrastructure. As a searchable, easily updated, web-based reference, the utility study will identify opportunities for prioritized development. While hyperspectral sensing has not yet seen widespread operational use for monitoring and managing transportation infrastructure, recent advances in high-definition image sensor size and cost reduction, small and light UAS, Big Data analytics, and high-performance cloud computing will bring together all of the necessary pieces for implementing complete and cost-effective solutions.

The study will yield focused recommendations to the MPC concerning ways it, as a consortium, can optimally package, market, deliver, and continuously improve current and new courses, certificates, and degree programs of critical needs to the MPC states, and other national interests. Based on those recommendations, MPC members will develop new high-quality online certificate and degree programs at the graduate level in the area of remote sensing of transportation infrastructure that have the possibility to (i) meet future workforce training and development needs, and (ii) create new revenue streams for MPC members. The program will help to develop the next generation of professionals with the expertise needed to enhance the efficiency, safety, and security of our nation's evolving and converging multimodal transportation infrastructure.

The effort will also integrate a NDSU UAS with an advanced hyperspectral sensor that uses the new mosaic technology, to undertake demonstration flights that will observe a variety of transportation infrastructure targets of relevance to this project. We will also begin the process of categorizing and obtaining spectral signature libraries, which are a necessary component of future, detailed analyses.

Task 2.2 (part of the project workflow described below) of the MPC460 requires an assessment of key attributes of imaging components that enable new hyperspectral sensors. This sensor device is the first in the world that will preclude the need for "line scanning" operations with UAS that are inherently more unstable than spaceborne platforms. The device represents the current state-of-the-art in size and cost reduction. The PIs will install the hyperspectral camera aboard a small UAS (sUAS) that they have acquired separately. The complete solution will provide the team with an unprecedented opportunity to characterize the quality and utility of "snapshot" hyperspectral imaging from a sUAS. The PIs will be first in the world to do so. This opportunity will enhance the quality of the Task 2.2 deliverable and likely result in the first ever article to publish on the approach, fueling further research. The PIs also plan to demonstrate the system to MPC university partners with the objective of advancing Task 3 on "curricula and workforce development." In particular, such a system will spark ideas and discussions relating to laboratory and field experiences that could augment student research projects in remote sensing of the transportation infrastructure.

Relevance to Strategic Goals:

This study relates to the following strategic goals:

State-of-good-repair – the research products will enable significant advancements in hyperspectral remote sensing technologies to assess the operational performance of a multimodal and intermodal transportation infrastructure. Hyperspectral sensing has the potential to assess the load bearing capacity of roads, and to scan pipelines, railways, runways, bridges to identify defect formation and other potential risk factors or capacity constraints. The decision support platforms and asset management solutions enabled will provide practitioners with actionable information to optimize asset lifecycle.

Safety – remote sensing based on hyperspectral sensing technology potentially has the ability to detect a variety of distress symptom formation and mobility obstructions before they contribute to property damage, injuries, or fatalities.

Economic competitiveness – the ability to optimize asset lifecycle with more accurate and insightful data using trained experts will not only relieve the present financial burden of high maintenance costs but will also enhance capacity and level of service throughout the multimodal transportation system. The ability to monitor continuously network throughput and mobility risks, and taking remedial action in a timely manner will sustain economic growth.

Environmental sustainability – remote sensing based on hyperspectral sensing technology has the ability to detect a large number of hazardous substances, including hydrocarbon spills aboveground or underground. The timely detection and remediation of disastrous spills or leaks will protect the environment.

Educational Benefits:

Several students will be directly involved with the project, including one full-time Graduate Research Assistant (GRA) supported by this effort as well as various undergraduates. The PI will recruit the GRA from within the Physics, ECE, CS or other topically relevant technical fields. The primary educational benefit is large. This effort represents the first step of a major initiative to explore various ways that MPC members can leverage their considerable curricular and programmatic strength and take those efforts to the next level of excellence at national and global scales.

Work Plan:

The main tasks are as follows:

TASK 1: UTILITY STUDY OF PRACTICES (Months 1 – 12)

1) Catalog current practices of remote sensing of the multimodal transportation infrastructure
2) Identify new remote sensing applications relevant to transportation infrastructure performance
3) Identify emerging opportunities and their potential level of impact in infrastructure sensing
4) Identify hyperspectral specific opportunities and assess their relevant value and impact
5) Prepare and publish a report of the utility study
6) Publish the utility study in an online format

TASK 2: EMERGING AND RELATED SENSOR TECHNOLOGIES (Months 13 – 24)

1) Conduct a literature search of emerging and related remote sensing (RS) technologies
2) Assess key attributes of imaging components to enable new hyperspectral sensors, including demonstration flights of an integrated UAS and hyperspectral imaging system
3) Assess applicability of available/emerging data mining methods to process hyperspectral data
4) Prepare and publish a report of the assessment

TASK 3: CURRICULA AND WORKFORCE DEVELOPMENT (Months 1 – 24)

1) Inventory relevant research expertise, coursework, certificate/degree programs of MPC
2) Assess availability, relevance, and deficiencies of existing training programs in RS
3) Address the potential for developing online courses in relevant RS subject matters
4) Survey employers in each of the MPC states to identify gaps in RS skills/capabilities needed
5) Produce a report of recommendations based on the above findings

Project Cost:
Total Project Costs: $350K
Requested MPC Funds: $150K
Matching Funds: $200K (NDSU Salary for PI at 0.5 FTE in Year 1 and 0.5 FTE in Year 2)

TRB Keywords: Intermodal, Intelligent Transportation Systems, Multimodal, Remote Sensing, Spectrographic analysis

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