

## TRANSPORTATION POOLED FUND PROGRAM QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Missouri Department of Transportation

**INSTRUCTIONS:**

*Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.*

<b>Transportation Pooled Fund Program Project #</b> TPF-5(395)		<b>Transportation Pooled Fund Program - Report Period:</b> <input type="checkbox"/> Quarter 1 (January 1 – March 31) <input type="checkbox"/> Quarter 2 (April 1 – June 30) <input type="checkbox"/> Quarter 3 (July 1 – September 30) <input checked="" type="checkbox"/> Quarter 4 (October 1 – December 31)	
<b>Project Title: Traffic Disruption-free Bridge Inspection Initiative with Robotic Systems</b>			
<b>Name of Project Manager(s):</b> Genda Chen	<b>Phone Number:</b> (573) 341-4462	<b>E-Mail:</b> gchen@mst.edu	
<b>Lead Agency Project ID:</b> S064101S	<b>Other Project ID (i.e., contract #):</b> TR202004	<b>Project Start Date:</b> August 1, 2019	
<b>Original Project End Date:</b> July 31, 2024	<b>Current Project End Date:</b> July 31, 2024	<b>Number of Extensions:</b> 0	

Project schedule status:

- On schedule     
  On revised schedule     
  Ahead of schedule     
  Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
\$725,000	\$475,427	75%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
\$475,427 and (5.9%)	\$28,220.06	88.3%

*Note that the University of Missouri has recently implemented a new PI grant reporting system. The latest monthly report I received in December of 2021 includes expenditure up to November 30, 2021. For convenience, I will report expenditure up to one month prior to the progress report date. For example, the December 31, 2021, report includes expenditures till November 30, 2021.*

*Also note that this month's expenditure includes correction from the previous two years for research engineer's salary.*

## Project Description:

Bridge inspection often requires the use of heavy lifting and access equipment, thus increasing operation time and direct costs. When access to the inspected area must be made from bridge decks, the indirect costs associated with road closure multiply. In such a case, travelers are frustrated with traffic congestion and, both the travelers and inspectors are subject to a safety concern on high volume highways. Moreover, visual inspection is quite subjective and often inconsistent. It is thus of economic, psychological and social importance to develop an alternative platform for faster, safer, cheaper, and consistent bridge inspection with minimum impact on traffic flow.

The INSPIRE University Transportation Center (<https://inspire-utc.mst.edu>) at Missouri University of Science and Technology has been focused on the development of advanced technologies to aid in bridge inspection and maintenance. Specifically, structural crawlers, unmanned aerial vehicles (UAVs), and multimodal unmanned vehicles will provide a mobile platform for in-depth inspection of elevated bridges. In particular, a special multimodal unmanned vehicle, named Bridge Inspection Robot Deployment Systems (BIRDS), will be developed to combine both the driving capabilities of crawlers and the flying capabilities of UAVs into one system for bridge inspection.

At the INSPIRE Center, microwave and hyperspectral images will be developed to assess concrete delamination and steel corrosion of reinforced concrete (RC) bridges. Together with other existing technologies such as impact echo, impact sounding, and infrared images, they will provide a suite of measurement tools and methods for the nondestructive evaluation (NDE) of structural damage and deterioration conditions in RC and steel bridges. Innovative sensors such as UAV-based smart rocks for scour monitoring, integrated point and distributed optical fiber systems for strain and corrosion monitoring, and coupled antenna systems for strain and crack monitoring will provide mission-critical data, such as the maximum scour depth, corrosion-induced steel mass loss, and live load induced strains in order to normalize the NDE data taken over time at spatially distributed points.

The goals of this pooled-fund initiative are to engage closely with several state Departments of Transportation (DOTs) in the early stage of technology development at the INSPIRE University Transportation Center, and leverage the center resources to develop case studies, protocols, and guidelines that can be adopted by state DOTs for bridge inspection without adversely impacting traffic. The initiative involves the integration, field demonstration and documentation of a robotic system of structural crawlers, UAVs, BIRDS, NDE devices, sensors, and data analytics. Depending on the interest of participating DOTs, the objectives of this initiative include, but are not limited to:

- Development of inspection/operation protocols for various types of bridges with the robotic system integrated into current practice.
- Comparison and correlation of bridge deck inspections from the top and bottom sides of decks to understand the reliability of traffic disruption-free bridge inspection from the underside of decks.
- Design and technical guidelines of measurement devices on a robotic platform for the detection of surface and internal damage/deterioration in structural elements, and for the change in lateral support of foundations.
- Data fusion and analytics of measurements taken from various imaging and sensing systems for consistency and reliability.
- Development of best practices on bridge inspection using the robotic system.

To achieve the above objectives, the following tasks are proposed:

1. Bridge selection for manual and automated inspections. Develop a selection protocol of bridges that are appropriate for both manual visual inspection and automated NDE. Thus, the performance of robot-based NDE can be compared with the current practice of visual inspection. The main parameters considered in this selection include span length, bridge type, accessibility, and importance. For example, river-crossing bridges may be inspected in great depth with advanced technologies, while simple highway bridges with easy access may not require any robotic platform during inspection.
2. Operation of multimodal unmanned systems. Develop a field test facility (e.g., recreational vehicle for a three-person crew) of the robotic system, including the BIRDS equipped with two infrared cameras (e.g., dual-sensor FLIR Duo™ Pro) and one impact sounding/echo device for RC elements, and a structural crawler for other bridge elements. The inspection crew will consist of a research engineer in bridge inspection and maintenance, a research assistant professor in system integration and robotics, and a rotating graduate student intern.
3. Correlation of top and bottom deck inspections. Due to gravity, deterioration on the bottom surface (a safety issue) is more critical than that on the top surface (a serviceability concern). On the bottom side of a bridge deck, deterioration such as concrete cracking, concrete delamination, and reinforcement steel corrosion are easier to detect from underside of the deck. The detection results derived from inspections above and below the deck will be compared to understand their correlation or complementary nature.

4. NDE and sensing integration into visual inspection. Develop preliminary guidelines to test NDE devices, such as hyperspectral and microwave cameras, for surface mechanical and electrochemical features as well as internal corrosion condition of steel reinforcing bars in RC elements, and test in-line fiber optic sensors for simultaneous measurement of strain, temperature, and mass loss in cross section of the reinforcing bars. Normalize/calibrate the NDE test results with those of a few pre-installed fiber optic sensors in structural behavior assessment. All the detected deterioration with measurement data are compared with visual inspection results to understand and quantify the improvement in probability of detection compared to the current practice of inspection.
5. Case studies with a representative bridge inventory. Develop an inventory of geographically-distributed test bridges and conduct case studies to implement and demonstrate NDE devices and sensors for the detection of surface and internal damage and deterioration in structural elements, and implement and demonstrate UAV-based smart rocks with embedded magnets for the scour monitoring of bridges. Up to nine (9) highway bridges/year in three (3) age groups or one long-span bridge/year from each participating state will be tested starting in the 2nd year. Store and maintain curated data within six months of their collection at the Scholars' Mine of Missouri University of Science and Technology. Share the data with the INSPIRE University Transportation Center investigators and, upon approval of state DOTs, the public as appropriate.
6. Protocol and guideline modification. Evaluate and refine as needed the protocols and guidelines of field tests for disruption-free bridge inspections after three (3) years of field operation. Imaging and sensing data are fused together to improve the detectability of problem areas with reduced capacity. The test results and corresponding visual inspection results are evaluated and summarized in a mid-term report, based on the probability of detection for structural damage/ deterioration and the improvement of visual inspection practice of bridges.
7. Limited release of protocols, guidelines, and criteria. Conduct a beta version rollout of the protocols, guidelines, and performance criteria at the INSPIRE University Transportation Center and the Missouri Local Technical Assistance Program (LTAP) in 4th and 5th years. As part of this rollout, workshops on the workforce development with the developed protocols, guidelines, and field demonstration technologies are conducted. Upon request, in-house workshops are held at participating states once a year.
8. Final reporting and curation of main findings. Prepare and publish a final report on the protocols, guidelines, and performance criteria of field tests with the robotic system at the end of 5th year. Store and maintain curated data and the final report at the Scholars' Mine of Missouri University of Science and Technology. Share the data and the report with the INSPIRE University Transportation Center investigators and, upon approval of state DOTs, the public as appropriate.

The performance period of this project will be August 1, 2019, to July 31, 2024 for five years. Table 1 details the specific schedule of this project by year. The kickoff (K) meeting, mid-term (M) report, draft (D) report/deliverables, and final (F) report/deliverables are marked on the project schedule. The final report will be due by the contract termination date.

Table 1 Project Schedule by Year

Task	Year				
	1	2	3	4	5
1. Bridge selection for manual and automated inspections	K				
2. Operation of multimodal unmanned systems					
3. Correlation of top and bottom deck inspections					
4. NDE and sensing integration into visual inspection					
5. Case studies with a representative bridge inventory					
6. Protocol and guideline modification					M
7. Limited release of protocols, guidelines, and criteria					
8. Final reporting and curation of main findings					D F

- Notes:
- K Kickoff meeting at the beginning of this contract
  - M Mid-term report due at the end of 3 years
  - D Draft report/deliverables due 60 days prior to the contract termination date
  - F Final report/deliverables due by the contract termination date

**Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):**

Between October 1 and December 31, 2023, the following activities took place:

- Task 2. Horizontal hyperspectral imaging and LiDAR scanning data were analyzed. A new drone Elios3 was acquired for inspection in crowd areas such as between girders and through cross frames of girder bridges as well as box girders and culverts. The new drone was tested on more than 10 bridges in Missouri. Missouri S&T's invention – a hybrid flying and traversing drone was successfully tested on two highway bridges for the first time.
- Task 5. Stitching and visualization of thermal and RGB images from FLIR cameras continued for inspected bridges. RGB provides an overview of the inspected bridges. Thermal images provide a way to understand the potential defect in substrates.
- Task 6. A draft mid-term report was expanded and further reviewed. Recipe-like approach is developed to allow users to select various functions for labeling and machine learning during abnormality detection. Virtual collaboration between two inspectors wearing HoloLens is tested for the first time in augmented reality.
- Task 7. A journal paper related to streamlining remote sensing and digitization process for bridge inspection began to shape.

**Anticipated work next quarter:**

During the next quarterly, the following activities are expected to take place:

- Task 1. Continue to communicate with New York DOTs for bridge drawings for inspection planning.
- Task 2. Build the final hybrid drone prototype with a comprehensive design of maneuverability, propeller protection, and multiple functions for highway and long-span bridges.
- Task 5. Continue to summarize and update the field test protocol using drones for bridge inspection following the guidelines in the AASHTO Manual for Bridge Element Inspection.
- Task 6. Further develop virtual collaboration between two or more inspectors to complete a comprehensive inspection of bridges using a robotic platform and machine learning. Continue to improve and finalize the mid-term report and share it with the participating state DOTs.

**Significant Results:**

During this report period, the third generation of Missouri S&T's invention on a hybrid flying and traversing drone was tested at two bridge sites. The hybrid drone was successfully attached to the bottom flange of a steel girder and traversed along the girder for high-fidelity imaging on the underside of bridge decks and steel girders. The high-quality images and videos taken from the hybrid drone have significantly less noises than those taken from commercial drones due to illumination change, drone controllability, and wind-induced vibration.

**Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).**

The project currently moves forward at full speed. But due to the previous impacts of COVID-19, communication challenge with two state DOTs, delayed or interrupted appointment of the research engineer, the overall project was delayed for about one year.

**Potential Implementation:**

Once the field mobile testing facility is fully developed, some of the advanced technologies developed at the INSPIRE University Transportation Center will be tested and demonstrated at bridge sites in participating states. Pilot/inspector training for automated tele-inspection will be provided to participating state DOTs free of charge.