PROGRAM PROGRESS
PERFORMANCE REPORT #2

GRANT NO: 69A3551747126
GRANT PERIOD: 11/30/16 – 09/30/22
REPORTING PERIOD: 06/1/17-3/31/18

Inspecting and Preserving Infrastructure through Robotic Exploration (INSPIRE)

Tier 1 University Transportation Center Sponsored by the Office of the Assistant Secretary for Research and Technology (OST-R)

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Recipient Identifying Number:	00055082
Report Term or Frequency:	Semi-annual
Submission Date:	April 30, 2018

Signature of Submitting Official:

MISSOURI S&T • The City College of New York • Georgia Tech • CU • UNLV • N

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1. ACCOMPLISHMENTS

1.A - What Are the Major Goals and Objectives of the Program?

Center's Mission and Goal

The mission of the INSPIRE center is to make an impactful contribution to the overall University Transportation Center Program authorized under the Fixing America's Surface Transportation (FAST) Act by providing leadership in research, education, workforce development, and technology transfer aimed at infrastructure inspection and preservation solutions with advanced sensing and robotic technologies for a sustainable and resilient transportation system. This mission becomes increasingly important in addressing greater needs for condition assessment and maintenance of bridges as natural disaster risks increase and approximately 50% of bridges in the National Bridge Inventory approach their design life.

The overarching goals of the center in five years are to transform in at least two demonstration cases from manual to automated inspection and preservation of bridges with sensors, nondestructive evaluation (NDE) devices, multi-modal unmanned vehicles, and data logistics, thus providing cost-effective, consistent, and reliable solutions in bridge condition assessment and maintenance, and to develop diverse transportation workforces mastering the advanced technologies.

Research Objectives

To meet the above goals, three research objectives of the center are set:
1. To explore, develop, validate, and demonstrate standardized-integrated measurement technologies, decision-making tools, data logistics, and autonomous systems to facilitate the field inspection and maintenance of bridges;
2. To develop, validate, and demonstrate methods of robot-enabled resilience analysis and intervention technologies (retrofit and repair) of bridges; and
3. To develop innovative tools and methods for the next-generation transportation workforce training and the general public education.

Education Objectives

To achieve the center's goals, three education objectives are set and achieved through degree-granting programs with transportation components, transportation non-degree programs, and seminars/workshops/short courses:
1. To develop new education materials related to advanced sensing and robotic technologies, such as real-world examples and cases that can reinforce the learning objectives of current curriculums, and interdisciplinary topics for senior design/capstone projects that can promote cooperative learning among students from various disciplines;
2. To create new opportunities for knowledge expansion and skill training on non-traditional civil engineering subjects, such as sensing, NDE, and bridge inspection and maintenance with robotics, which can enrich existing civil engineering programs or non-degree certificate programs; and
3. To connect students with transportation industries and professionals through center meetings, annual transportation research board (TRB) meetings, an international conference, and the external advisory committee.

Workforce Development Objectives

To achieve the center's goals, two workforce development objectives are set and achieved through various outreach activities and close collaborations with professional organizations such as the Missouri Local Technical Assistance Program (LTAP) and the Center for Worker Education (CWE), New York:

1. To raise the public awareness of changes from adopting advanced technologies and attract new entrants from varying pipelines into transportation-related majors; and
2. To apply the robot simulator and video games developed as part of the research portfolio for a rapid and innovative workforce training of both current and prospective transportation workforces.

Technology Transfer Objectives

To achieve the center's goals, three technology transfer objectives are set:

1. To work in partnership with end users to facilitate technology transfer, including state and local governments, non-profit entities, and private enterprises, and assist them in mastering and implementing the developed technologies such as sensors, robots, and image analysis tools;
2. To protect intellectual properties with patent applications through the technology transfer and economic development offices and actively seek their licensing with small businesses such as InnovBot LLC; and
3. To disseminate research results through high quality peer-reviewed journals, conference proceedings, and exhibitions at TRB annual meetings and other national/international conferences.

Diversity Objectives

To achieve the center's goals, two diversity objectives are set:

1. To broaden underrepresented minority participation through direct involvement of two minority institutions; and
2. To recruit and retain female and traditionally underrepresented minority students in close collaboration with special programs such as the activities of the Student Diversity, Outreach and Women's Programs office at Missouri S&T.

1.B - What Was Accomplished Under These Goals?

Research Accomplishments

Twelve research projects were awarded in Year 1 to six research-focused partner institutions based on the INSPIRE UTC proposal reviewed by experts outside the consortium. All awarded INSPIRE UTC projects are posted on the Center's website at http://inspire-utc.mst.edu/researchprojects/, and project information is maintained in the TRB RiP Database at https://rip.trb.org/. Although officially started on March 1, 2017, most of these projects progressed at full speed from August, 2017 when participating students were recruited into various academic programs in multiple disciplines.

Twelve research projects were awarded in Year 2. Prior to awards, each project proposal was evaluated by at least one DOT/consulting engineer and one external researcher in the proposed subject area. Every effort was made to avoid the conflict of interest during the review process. Proposals were reviewed with respect to established evaluation criteria. Reviewers submitted their evaluation results to the Center Director, and funding recommendations were made during an executive meeting with the INSPIRE UTC directors and External Advisory Committee members in December 2017. The INSPIRE UTC Director issued final approval of research projects on January 1, 2018. One new project started right away on January 1, 2018. The remaining eleven out of twelve projects represented Phase 2 studies of the Year 1 projects, which will expire on July 31, 2018.

Monthly meetings are scheduled with PIs to provide open lines of communication within the Center, and to share important news and announcements with the research team. PIs provide research progress updates during the monthly meetings, and submit written quarterly reports to the Center.

Table 1 summarizes the progress made in each of the research topics: sensing and nondestructive evaluation (SN), autonomous systems (AS), inspection and maintenance (IM), retrofit and resilience (RR), and workforce development (WD). Progress evaluation is done in terms of major activities, specific objectives, significant results and key outcomes/achievements.

Table 1 A summary of research progress

Topic	Major Activities	Specific Objectives	Significant Results	Key Outcomes
SN	1. Integrate a 3-axis magnetometer into an unmanned aerial vehicle (UAV) and relate the flight speed with sampling rate of the magnetometer. 2. Analyze a strain rosette of three antenna sensors with each designed with a new RT/duroid® substrate. 3. Test thermal influence on the new substrate design in an environmental chamber. 4. Test the performance of distributed fiber optic sensors in large-scale composite beams. 5. Prototype and characterize a long period fiber gratings (LPFG) sensor with graphene and then Fe-C coatings. 6. Prepare concrete specimens with embedded reinforcing bars, evaluate mass loss of bars with electrochemical tests, and microwave scan specimens with corroded bars. 7. Determine appropriate technical specifications for hyperspectral camera with potential vendor.	1. Develop a UAV platform for magnetic field measurement and characterize field performance of smart rocks for bridge scour monitoring. 2. Develop and validate a light antenna sensor that can be interrogated over 30 m distance. 3. Develop a Fe-C coated LPFG sensor for chloride ion and steel mass loss monitoring. 4. Integrate LPFG sensors into a distributed fiber optic sensing system for multi-parameter measurement. 5. Develop and optimize a linear array of microwave probes for bridge inspection on a UAV platform. 6. Prepare a set of reinforced concrete specimens and characterize corrosion effect on concrete surfaces.	1. No UAV motor interference on magnetic field measurement at 0.9 m distance. 2. Accurate empirical formula for the strain effect on dielectric constant of the RT/duroid® substrate. 3. Sensitive measurement of mass loss with Fe-C coated LPFG sensor. 4. Clear microwave images of corroded bars with scanning in X-band. 5. More difficult to detect corroded bars than virgin bars due to high absorption of corrosion products.	1. UAV integrated measurement system with smart rocks. 2. Smart rock localization algorithm. 3. Antenna sensors on RT/duroid® substrate. 4. Graphene-based LPFG sensor with Fe-C coating.
AS	1. Design and test 3 climbing mechanisms for robots using 3D simulations and prepare the first test prototype. 2. Design a CAD model of GPR-Rover prototype II and fabricate parts using 3D printer. 3. Identify bearing cleansing and crack sealing parameters for maintenance work. 4. Test and evaluate a gripper design with a systems integrated sensor test rig.	1. Develop and prototype automated climbing robotic platforms for steel bridge inspection with NDE devices. 2. Design an embedded controller for GPR-Rover and develop methods to eliminate interference between GPR signal and robot circuit. 3. Design and use hyper-redundant serpentine-like limbs for dexterous manipulation.	1. Magnetic wheels carry 8 pounds of load while strongly adhering on steel surface. 2. The robot can transit from one to another surface without falling. 3. The GPR-Rover prototype can scan smooth and rough surfaces for GPR data.	1. First prototype of climbing robot for steel structures. 2. GPR-Rover prototype II with a RGB-D camera. 3. Machine learning algorithm to detect and visualize surface flaws. 4. Co-author the first book on aerial manipulation in the field

Topic	Major Activities	Specific Objectives	Significant Results	Key Outcomes
IM	1. Assess current state of the technology on data fusion, impact sounding algorithms and image processing algorithms.	1. Develop a framework of quantitative bridge inspection using relevant data from the literature and those derived from NDE devices	1. Extract frequency features from impact sounding tests. 2. Select a classifier of support vector machine over neural network.	1. One computer program for power spectral density analysis. 2. One computer program for empirical mode decomposition.
RR	1. Investigate the effect of local crack or corrosion on bridge column capacities both probabilistically and deterministically.	1. Develop and validate a framework of bridge condition assessment and prioritizing structures for repair after an extreme event.	• Corrosion and cracking affect shear, flexure, and other failure modes differently.	1. Fragility curves considering corrosion and crack effects.
WD	1. Develop computational algorithms and analyze video data with human in the loop. 2. Create a virtual bridge inspection scenario in Simulation Training and Control System (STACS) based on Unity3D game engine. 3. Design and implement user interaction and interfaces. 4. Start to design and implement magnetic physics on STACS.	1. Introduce a bridge surface image collection method and a data processing and pattern recognition algorithm. 2. Create visual tools for the analysis of processed data and recognized patterns towards decision-making.	1. Retrieve spatially-correlated frames from a video sequence based on a representative frame selected. 2. Establish a two-way communication between a STACS and robots through ROSBridge package.	1. One computational algorithm. 2. User interaction and user interfaces of STACS. 3. Two-way communication between STACS and robots.

Note: [green] to address the 1st research objective; [dark green] the 2nd objective; [yellow] and the 3rd objective.

Education Accomplishments

Dr. Iris Tien, INSPIRE UTC PI from Georgia Institute of Technology prepared and taught a new course on engineering risk analysis. Main topics include updating structural assessments with measured data, predicting performance of structures including bridges under varying scenarios, and accounting for uncertainty in hazards for resilience. Examples and projects include calculating expected performance of bridges under varying hazard scenarios, analysis of bridge and transportation networks, and using data to update estimates of probability distribution parameters. 20 students were enrolled in the spring semester 2018.

Dr. Hung La, INSPIRE UTC Associate Director from the University of Nevada, Reno, introduced automated infrastructure inspection concepts using robots into the current robotics courses: CPE470/670-Autonomous Mobile Robots; CS791-Special Topics on Robotics, and CS455/655-Mobile Sensor Networks. In addition, Dr. La has organized several lab open day events to generate robotic interests to both local elementary and high school students as well as DOT engineers.

In 2018, the INSPIRE UTC implemented a new Undergraduate Research Scholarship Program to engage undergraduate students in research projects conducted by the center. Missouri S&T provides scholarships for undergraduate research through the Opportunities for Undergraduate Research Experience (OURE) program. The INSPIRE UTC provides up to 4 additional scholarships annually for OURE students participating in research projects that are funded by the UTC and led by Missouri S&T faculty. Participating students will prepare and submit a final research report, and will prepare a research poster and present it at the Missouri S&T Undergraduate Research Conference, Undergraduate

Research Day at the Capitol event, and INSPIRE UTC Annual Meeting. For more information, visit http://inspire-utc.mst.edu/studentprograms/.

The INSPIRE UTC provides two (2) scholarships each year to support Lincoln University undergraduate students for an 8-week summer research experience on the Missouri S&T campus. The purpose of the program is to provide underrepresented undergraduates attending Lincoln University an opportunity to conduct transportation-related research and learn about graduate education opportunities at Missouri S&T. Selected students will participate in a research project directed by a member of the INSPIRE UTC faculty. Participants will devote at least 40 hours a week to their respective research projects and scholarly activities. At the conclusion of the program, students will present their research to their fellow S&T peers, faculty mentors, and guests using a poster format and oral presentation. For more information, visit http://inspire-utc.mst.edu/studentprograms/.

The University of Nevada, Reno (UNR) offers a Research Experiences for Undergraduates (REU) site focusing on Collaborative Human-Robot Interaction (CHRI). The site will develop new autonomous robot capabilities and supporting network and data science technology to address real-world challenges of operating autonomous systems. The University's Robotics Group is made up of faculty specializing in human-robot interaction, assistive robotics, autonomous robots, field robotics, and wireless communication and cybersecurity. Experienced graduate students will help mentor participating undergraduate students. Students will participate in a research project, prepare a written report on their project, and present to the University's undergraduate research symposium. For more information, visit: https://www.unr.edu/cse/research/intelligent-systems/reu.

In January 2018, Matthew Klegseth, a Ph.D. student at Missouri S&T was presented with the UTC Student of the Year Award at the TRB Annual Meeting in Washington DC, and through his participation at TRB, was introduced to various transportation industries and professionals.

Workforce Development Accomplishments
On July 18, 2017, the INSPIRE UTC held a one-day MoDOT Transportation Camp for 30 Missouri high school students (grades 9-12). The INSPIRE UTC showcased driver's behavior simulation, sensor applications in bridge condition assessment, the use of robotics in bridge maintenance, and potential effect of tornados on transportation structures. Following a welcome address, students toured S&T's Virtual Reality (VR) Laboratory, Wind Hazard Mitigation (WHAM) Laboratory, and the System and Process Assessment Research (SPAR) Laboratory. Students also participated in hands-on activities in various laboratories, and attended a demonstration presentation in the Computer Vision and Biomedical Imaging (CVBI) Lab. Of the 30 participants (17 male and 13 female), 21 were underrepresented students.

On September 1, 2017, the INSPIRE UTC held a kickoff meeting at Missouri S&T with representatives from the USDOT OST-R, INSPIRE UTC associate directors, external advisory committee members and Missouri S&T leadership and grant management support staff. Following the business meeting, the Missouri S&T MinerFly research support team demonstrated the unmanned aerial vehicles that will be used for robotic bridge inspection. Participants toured the new INSPIRE UTC office and Applied Microwave Nondestructive Testing, the System and Process Assessment Research, High-bay Structural Engineering Research, and MinerFly Laboratories. A total of 32 people attended this meeting.

On October 14, 2017, Dr. Genda Chen introduced the INSPIRE UTC to the FIRST Lego League (FLL) robotics team and the FLL Junior robotics team at the Kaleidoscope Discovery Center (KDC) in Rolla, MO. Dr. Chen's presentation introduced to the FLL teams the challenges associated with current bridge

inspection methods, and the importance of improving these methods through the use of the advanced technologies, such as non-contact sensing, unmanned aerial vehicles and climbing robots used for bridge inspection and maintenance. Approximately 20 students ranging in age from 6-14 and their parents attended.

On November 17, 2017, the INSPIRE UTC hosted a transportation-related robotics workshop on the Missouri S&T campus. The workshop, entitled "Rescue the Bridge with Robotics" was part of the 2017 Expanding Your Horizons (EYH) Conference. The EYH conference is an annual conference for 7th and 8th grade girls. It is designed to help participants better understand some of the many career choices they can explore in S.T.E.M. (Science, Technology, Engineering and Mathematics) areas. Participants learned that traditional methods used to inspect and maintain bridges are time consuming and costly or even dangerous in some cases. They learned how to use advanced technology to perform inspections and make the process safer and more efficient. For more information visit http://pce.mst.edu/youth/eyh/ and http://inspire-utc.mst.edu/. A total of 30 female students (ages 10-14) were introduced to the transportation industry in a memorable and fun way.

On October 13, 2017, Dr. Hung La and Sushil Louis from the University of Nevada, Reno, introduced 3D simulation and virtual reality technologies during a VR Meetup event (https://events.unr.edu/event/vrar_meet-up). These advanced technologies were applied into automated infrastructure inspection research with the goal of transforming the current holistic visual inspection approach into a data-driven decision process in bridge management.

On January 13, 2018, the INSPIRE UTC participated in the Missouri State Future City Competition, hosted by the KDC in Rolla, MO and Future City Competition- Missouri. The 2017-2018 theme was The Age-Friendly City. Teams identified an age-related challenge that exists in today's urban environments and engineered two innovative solutions to this challenge. The INSPIRE UTC's participation in this event helped to raise awareness among the participants (ages 11-14) of the UTC activities and the advanced technologies that can be used to help preserve our nation's aging transportation infrastructure.

On January 29, 2018, Dr. Genda Chen met with the Missouri S&T student chapter of National Society of Black Engineers (NSBE), and Dr. Suzanna Long met with the Missouri S&T student chapter of the American Society for Engineering Management (ASEM). Drs. Chen and Long presented the research activities of the center and discussed how students can get involved through undergraduate research.

On February 24, 2018, the INSPIRE UTC participated in the National Society of Black Engineers (NSBE) Pre-College Initiative (PCI) Weekend on the Missouri S&T campus. PCI is an on-campus visit program for African-American students who may consider a future career in math, science, computing or engineering. PCI is sponsored by S&T's student chapter of NSBE and the Student Diversity Initiatives Department. Through information sessions and hands-on workshops, students explored a variety of career options and gained a better understanding of college life.

On February 27, 2018, Dr. Genda Chen attended the signing ceremony of a memorandum of understanding (MOU) between Missouri S&T and the KDC, in Rolla, MO. The MOU will allow Missouri S&T to formally support the KDC mission to provide interested children with hands-on exposure to advanced programs in engineering, science, technology, the environment, art and mathematics (ESTEAM), and to grow the next generation of leaders in those fields. The INSPIRE UTC provides robotics outreach support to the KDC to introduce students in the community to the transportation industry, and to raise awareness of the challenges associated with current bridge inspection methods, and the

importance of improving these methods through the use of the advanced technologies currently being developed by the INSPIRE UTC.

On February 28, 2018, the INSPIRE UTC held an exhibit at the inaugural University of Missouri System Legislative Showcase in Jefferson City, MO. Under the theme "*Protecting Missourians*", the INSPIRE UTC demonstrated to over 100 legislators and the general public robot-based advanced technologies that can improve the safety of inspectors and travelers and minimize the interruption of traffic during bridge inspections. The exhibit highlighted INSPIRE UTC's leadership in developing infrastructure inspection and preservation solutions for a sustainable and resilient transportation system.

March 9-11, 2018, Dr. Jizhong Xiao, INSPIRE UTC PI, and his students from The City College of New York are actively supporting robotics education by serving as advisors and coaches to The Titanium Knights 6203, a FIRST robotics team from Bergen County Academies (BCA). The Titanium Knights 6203 recently participated in the 2018 FIRST Robotics Competition (FRC) and garnished the Event Winner title at the Mid-Atlantic District Mt. Olive Event in Flanders, NJ.

On March 9, and March 30, 2018, Dr. Sushil Louis, INSPIRE UTC PI, and his students from the University of Nevada, Reno, attracted approximately 25 local high school students and teachers during two Nevada Bond Tours to showcase their current research work in the Evolutionary Computing Systems Laboratory.

In March 2018, Dr. Hung La, INSPIRE UTC Associate Director, and his students from the University of Nevada, Reno, organized a lab tour and robot demonstration for about 40 visitors of the Nexus in Nevada event. The visitors mainly come from local elementary and high schools in Reno. Fourteen key personnel from Koch Industries, Inc. and the CEO and his senior engineers from Rich Robotics Corp. visited the Advanced Robotics and Automation Lab during robot demonstrations.

Technology Transfer Accomplishments

INSPIRE Webinars - The INSPIRE UTC hosts quarterly webinars. Three (3) webinars were presented in this reporting period, and six (6) professional certificates were issued to attendees. All quarterly webinars are archived and can be viewed at: http://scholarsmine.mst.edu/inspire_webinars.
1. *Lab-On-Sensor for Structural Behavior Monitoring: Theory and Applications* was presented on September 28, 2017 by Dr. Genda Chen, INSPIRE UTC Director.
2. *Drone-Enabled Remote Sensing for Transportation Infrastructure Assessment* was presented on December 13, 2017 by Dr. Colin Brooks of Michigan Technological University.
3. *Microwave Materials Characterization and Imaging for Structural Health Monitoring* was presented on March 15, 2018 by Dr. Reza Zoughi, INSPIRE UTC PI at Missouri S&T.

INSPIRE Newsletters - The INSPIRE UTC publishes a biannual newsletter that has been subscribed by over 2,500 readers. Two (2) newsletters were published in this reporting period and posted on the Center's website at: http://inspire-utc.mst.edu/news/.
1. Volume 1, Issue 1 was published in Summer 2017.
2. Volume 1, Issue 2 was published in Winter 2017.

UTC Spotlight Article - The March 2018 edition of the UTC Spotlight featured the work of the INSPIRE UTC. Led by Dr. Genda Chen, Director of the INSPIRE UTC at Missouri S&T, the *UAV-enabled Measurement for Spatial Magnetic Field of Smart Rocks in Bridge Scour Monitoring* project is part of the INSPIRE UTC Research Program.

Publications/Conference Presentations - INSPIRE UTC faculty disseminate research results and information through numerous publications, presentations and technical reports. A list of those for this reporting period is included in Section 1.D.

Diversity Accomplishments

The INSPIRE UTC broadens underrepresented minority participation through direct involvement with three minority institutions. The University of Nevada, Las Vegas and The City College of New York are major consortium members leading research, education, workforce development and technology transfer initiatives for the Center. Lincoln University, a minor consortium member, encourages student participation in INSPIRE UTC workforce development activities.

Through its education, outreach and workforce development efforts, Missouri S&T has implemented multiple outreach and education initiatives to introduce underrepresented students to the field of transportation, and opportunities to participate in transportation-related research through Center activities and programs. In this reporting period, the INSPIRE UTC reached over 100 underrepresented students.

- In July 2017, Missouri S&T engaged 30 underrepresented high school students from Missouri in a hand-on bridge engineering competition and interactive transportation research lab tour during a one-day MoDOT Transportation Camp on the Missouri S&T campus.
- In November 2017, Missouri S&T engaged 30 young female students (grades 7-8) in a transportation-related robotics workshop as part of the 2017 Expanding Your Horizons (EYH) Conference. Participants learned how to use advanced technology to perform inspections and make the process safer and more efficient.
- On February 24, 2018, Missouri S&T faculty and students led a hand-on bridge engineering competition for 42 African-American Missouri high school students as part of the National Society of Black Engineers (NSBE) Pre-College Initiative (PCI). Participants were engaged in a hand-on bridge engineering competition, and visited the Virtual Reality lab for a demonstration of driver's behavior-related transportation research.

A female graduate student, Xi Liu, performs transportation-related research with Dr. Yang Wang at Georgia Institute of Technology.

1.C - What Opportunities for Training and Professional Development Has the Program Provided?

- The INSPIRE UTC hosts quarterly webinars, as described in the technology transfer accomplishments section above. The three webinars held in this reporting period engaged a total of 207 professionals from industry, government and academia.
- 15 graduate students, 6 undergraduates and 2 postdoctoral fellows are trained in interdisciplinary team environments through various activities in 12 research projects.

1.D - How Have the Results Been Disseminated?

See Section 2.A for journal publications, conference papers/presentations and book.

Newsletters

- A. Gillman, J.M. Stiritz, A. Sherman, and G.D. Chen. *INSPIRE UTC Newsletter*, 1(1), July 1, 2017.
- A. Gillman, J.M. Stiritz, and G.D. Chen. *INSPIRE UTC Newsletter*, 1(2), January 2018.
- A. Gillman, and G.D. Chen. *INSPIRE UTC Newsletter*, 2(1), April 2018.

- G.D. Chen. *Smart Rock Positioning for Scour Hazard Assessment of Bridges*, USDOT UTC Spotlight Newsletter, March, 2018.

Poster Presentations

- Seven Posters, *Presented at the INSPIRE UTC Kick-off Meeting*, Rolla, MO, September 1, 2017.

1.E - What Do You Plan to Do During the Next Reporting Period to Accomplish the Goals and Objectives?

Research Plan

Research projects will continue in the five research topics described in 1.B above. No Change will be made to the approved plan except that a few projects started slowly due to the challenge of recruiting good students after the projects had been awarded in the middle of the semester. Planned research activities are summarized in Table 2 for each of the 13 research projects awarded by INSPIRE UTC.

Table 2 A summary of planned research activities

Topic	Project Title	Planned Activities
	UAV-enabled Measurement for Spatial Magnetic Field of Smart Rocks in Bridge Scour Monitoring	• Conduct field tests to characterize and validate the effects of various measurement-related parameters and environmental factors. • Develop an algorithm of locating two smart rocks, and validate the field test procedure for repeatability of test results.
	Battery-free Antenna Sensors for Strain and Crack Monitoring of Bridge Structures	• Conduct fatigue tests to understand the crack measurement performance of the new antenna sensor made of RT/duroid® 6202. • Complete the parameter updating for the nonlinear constitutive model of adhesive based on strain transfer ratio tests. • Use the updated mechanical and dielectric parameters for more accurate simulation of antenna sensor behavior under strain and temperature effect.
	In-line Long Period Grating and Brillouin Scattering Fiber Optic Sensors for Strain, Steel Mass Loss, and Temperature Measurement in Bridge Applications	• Analyze the test data collected from 42-ft long floor beams to understand the performance of various distributed fiber optic sensor deployment schemes. • Monitor the life-cycle performance of metallic structures and steel reinforcement with Fe-C coated LPFG sensors when enclosed in multiple coaxial thin-walled steel tubes so that the measurement times of corrosion rate can be regulated by wall thicknesses of the tubes.
	3D Microwave Camera for Concrete Delamination and Steel Corrosion Detection	• Image a portion of a pedestrian bridge on campus pending on the university approval. • Improve the Green's function model of layered structures to allow its use on the imaging data collected from bridges.
	Hyperspectral Image Analysis for Mechanical and Chemical Properties of Concrete and Steel Surfaces	• Procure a hyperspectral camera based on the desirable technical specifications. • Cast and test concrete specimens based on the developed metric to understand their surface characteristics. • Collect and establish a library of hyperspectral images of the specimens.
	Mobile-manipulating UAVs for Sensor Installation, Bridge Inspection and Maintenance	• Iterate gripper design to grasp hoses. • Test and evaluate hose spraying impact on flight stability.
	Climbing Robots with Automated Deployment of Sensors and NDE Devices for Steel Bridge Inspection	• Conduct tests and evaluations of the first climbing design. • Start the implementation of the second design of climbing robot. • Compare the two climbing designs and select the best one for prototyping.
	Autonomous Wall-climbing Robots for Inspection and Maintenance of Concrete Bridges	• Design a multi-chamber GPR-Rover to increase the robustness and payload capability. • Advance machine learning based visual inspection of surface flaws on concrete structures.

Topic	Project Title	Planned Activities
IM	Re-Inventing the Bridge Inspection Program	• Secure off-campus non-federal matching funds to meet the center requirements and get this project started.
IM	Quantitative Bridge Inspection Ratings using Autonomous Robotic Systems	• Compare the classification results from power spectral density and empirical mode decomposition methods especially for rough impact surface. • Collect data manually from sound and damaged slabs (test beds) using a hammer and digital voice recorder.
RR	Bridge Resilience Assessment with INSPIRE Data	• Assess fragility from individual column components (for flexure-critical, shear-critical, and lap splice-critical behaviors) to bridge systems. • Model bridge elements including decks, abutments, joints, bearings, and connections with the effects of corrosion and/or cracking taken into account.
	A Training Framework of Robotic Operation and Image Analysis for Decision-Making in Bridge Inspection and Preservation	• Test the image retrieval algorithm for multiple regions (e.g., bridge joints, bearings) from big video data sets. • Expand the ability of the retrieval algorithm by exploring a deeper neural network and using a hierarchical feature representation to better match image features.
	Developing a Robotic Simulator and Video Games for Professional and Public Training	• Start the 3rd iteration of user interface and user interaction design of STACS. • Design a new simulation scenario with Magnetic Physics integrated. • Conduct the first experiment on evaluating a bridge inspection task by human operators on STACS.

Note: ▢ to address the 1st research objective; ▢ the 2nd objective; ▢ and the 3rd objective.

Education Plan

1. One new course CPE471/671-Advanced Robotics is currently being developed and will be offered in 2019 by Dr. Hung La from the University of Nevada, Reno.
2. Summer research exchange programs are being implemented by Georgia Institute of Technology, Missouri S&T, University of Nevada, Las Vegas, and University of Neva, Reno in summer 2018.
3. The INSPIRE UTC is co-hosting two Visiting Scholars Seminars with the Missouri S&T Civil, Architectural and Environmental Engineering Department in April 2018.
4. The INSPIRE UTC will host a distinguished lecture in Fall 2018.
5. Consortium members are currently exploring course sharing opportunities for the 2018-2019 academic year.

Workforce Development/Outreach Plan

1. The INSPIRE UTC will host a Step-Up Workshop on the Missouri S&T campus in August 2018.
2. The INSPIRE UTC will host a one-day transportation camp as part of MoDOT's annual Youth Transportation Conference on July 17, 2018.

Technology Transfer Plan

1. Quarterly webinars will be held in June and September 2018. The June webinar, *Climbing Robots for Steel Bridge Inspection and Evaluation*, will be presented on June 21, 2018 by Dr. Hung La from the University of Nevada, Reno. (http://inspire-utc.mst.edu/webinars/)
2. Volume 2-Issue 1 of the INSPIRE Newsletter will be published in April 2018, and will feature 3 technical articles highlighting the robotics research being conducted by the Center.
3. Volume 2-Issue 2 of the INSPIRE UTC Newsletter will be published in October 2018.
4. The INSPIRE UTC will hold its Annual Meeting on the Missouri S&T campus. Activities will include a pre-meeting step-up workshop for transportation workforce development, research presentations by the INSPIRE UTC faculty, an executive meeting and discussion with the INSPIRE UTC External Advisory Committee, and a graduate student poster session and awards ceremony.

5. On May 31 – June 2, 2018, Dr. Jizhong Xiao, INSPIRE UTC PI, and his associates will deliver a distinguished lecture on *Wall-climbing Robots for Visual and GPR Inspection* at the 13th IEEE Conference on Industrial Electronics and Applications (ICIEA 2018), Wuhan, China.

6. On June 22, 2018, Dr. Jizhong Xiao, INSPIRE UTC PI, and his associates will make a presentation on *Semantic Metric 3D Reconstruction for Concrete Inspection* at the International Workshop on Visual Odometry and Computer Vision Applications Based on Location Clues in conjunction with Computer Vision and Pattern Recognition (CVPR2018), Salt Lake City, UT.

7. In July 2018, INSPIRE UTC Director, Dr. Genda Chen, and INSPIRE UTC Associate Director, Dr. Anil Agrawal will participate by invitation in the 31st US-Japan Bridge Engineering Workshop in Los Angeles, CA. Sponsored by the Federal Highway Administration, the workshop series brings together bridge engineers from the US and Japan to discuss common issues in bridge engineering.

8. On July 8-13, 2018, INSPIRE UTC Associate Director, Dr. Hung La, and INSPIRE UTC PI, Dr. Sushil Louis will make a presentation on *A Genetic Algorithm for Convolutional Network Structure Optimization for Concrete Crack Detection* at the 2018 IEEE Congress on Evolutionary Computation (IEEE CEC), Rio de Janeiro, Brazil.

9. In August 2018, the INSPIRE UTC will participate in the NDE/NDT for Highway and Bridges: Structural Materials Technology (SMT 2018) and the International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE 2018).

10. In September 2018, Dr. Iris Tien, INSPIRE UTC PI, will co-chair the "Resilient and Reliable Infrastructure" session at the 2018 U.S. Frontiers of Engineering Symposium, Lexington, MA.

11. On October 5-6, 2018, Dr. Genda Chen, INSPIRE UTC Director, will deliver a keynote presentation on "*Sensor-enhanced Analysis and Behavior of Steel Beams in Fire*" at the 5th World Congress and Exhibition on Construction and Steel Structure, Los Angeles, CA.

12. On October 28-31, 2018, Dr. Genda Chen, INSPIRE UTC Director, will deliver a keynote presentation on "*Short-time Continuous Wavelet Transform of the Response of Time-varying Systems*" at the 2018 International Conference on Sensor Networks and Signal Processing, Xi'an, China.

2. PRODUCTS

2.A - Publications, Conference Papers, and Presentations

Journal Publications

- G.D. Chen and Y. Huang. "A Hybrid Instrumented/Computational Modelling Framework with Lab-on-sensor Design and Calibration for Structural Behavior Monitoring." *International Journal of Sustainable Materials and Structural Systems* (http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijsmss), 2017.

- D. Connell, and H.M. La. "RRT-Based Dynamic Path Planning and Replanning for Mobile Robots." *International Journal of Advanced Robotic Systems*, January 2018. (accepted)

- S. Gibb, H.M. La, T. Le, L. Nguyen, R. Schmid, and H. Pham. "Non-Destructive Evaluation Sensor Fusion with Autonomous Robotic System for Civil Infrastructure Inspection." *Journal of Field Robotics*, April 2018. (Accepted)

- H.M. La, T.H. Dinh, N.H. Pham, Q.P. Ha, and A.Q. Pham. "Automated Robotic Monitoring and Inspection of Steel Structure and Bridges." *Robotica*, doi:10.1017/S0263574717000601, January 11, 2018.

- B. Li, K. Ushiroda, L. Yang, Q. Song, and J. Xiao. "Wall-Climbing Robot for Non-Destructive Evaluation using Impact-Echo and Metric Learning SVM." *International Journal of Intelligent Robotics and Applications*, 1(3): 255-270, September 2017.
- D. Li, C. Cho, and Y. Wang. "Patch Antenna Sensor Rosettes for Surface Strain Measurement." *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*, 170(2): 39-49, June 2017.
- H.Y. Qu, T.T. Li and G.D. Chen. "Influence Length of Wire Fracture and Wire-to-Wire Interaction in Helically Wired Strands under Axial Loads." ASCE *Journal of Bridge Engineering*, 23(1), January 2018.
- Y.Z. Chen, F.J. Tang, Y. Tang, M. OKeefe, and G.D. Chen. "Mechanism and Sensitivity of Fe-C Coated Long Period Fiber Grating Sensors for Steel Corrosion Monitoring of RC Structures." *Corrosion Science*, 127: 70-81, August 24, 2017.

Conference Papers/Presentations

- G.D. Chen. "SHM Roles in Autonomous Inspection and Preventive Maintenance of Bridges." *Proceedings of the 8th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, Brisbane, Australian, December 5-8, 2017. (keynote presentation)
- G.D. Chen. "Integrated Smart Structure Technologies for Automated Inspection and Preservation of Bridges on Mobile Platforms." Presented at *the 13th International Workshop on Advanced Smart Materials and Smart Structures Technology*, the University of Tokyo, Japan, July 22-23, 2017.
- Genda Chen. "A Strategic Framework to Extend Structural Health Monitoring into Bridge Management." Presented at *the World Transport Convention*, Beijing, China, June 4-9, 2017 (invited presentation).
- S. Gibb, T.D. Le, H.M. La, R. Schmid, and T. Berendsen. "A Multi-functional Inspection Robot for Civil Infrastructure Evaluation and Maintenance." *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems* (IROS), Vancouver, Canada, September 24-28, 2017.
- S. Gibb, H.M. La, and S. Louis. "A Genetic Algorithm for Convolutional Network Structure Optimization for Concrete Crack Detection." Proceedings of *the 2018 IEEE Congress on Evolutionary Computation* (IEEE CEC), Rio de Janeiro, Brazil, July 8-13, 2018.
- C.R. Guo, C.L. Wu, and G.D. Chen. "Graphene Coated LPFG Sensors for High Sensitivity Corrosion Monitoring." Presented at *the 2018 SPIE Annual Symposium on Smart Structures/NDE*, Denver, CO, March 4-8, 2018.
- D. Kim, and P.Y. Oh. "Lab Automation Drones for Mobile Manipulation in High Throughput Systems." Presented at the *IEEE International Conference on Consumer Electronics* (ICCE), Las Vegas, NV, January 2018.
- D. Kim, and P.Y. Oh. "Lab Automation Drones for Mobile Manipulation in High Throughput Systems." Presented at the *Society of Lab Automation and Screening (SLAS) Conference*, San Diego, CA, February 2018.
- M. Klegseth, Y. Bao, G.D. Chen. "Strain Measurement on the Surface of Diametrically Loaded Acrylic Sphere with a Distributed Fiber Optic Sensor." Presented at *the 2018 SPIE Annual Symposium on Smart Structures/NDE*, Denver, CO, March 4-8, 2018.
- T.D. Le, S. Gibb, N.H. Pham, H.M. La, L. Falk, and T. Berendsen. "Autonomous Robotic System using Non-Destructive Evaluation Methods for Bridge Deck Inspection." *Proceedings of the 2017*

IEEE International Conference on Robotics and Automation (ICRA), Singapore, May 29-June 3, 2017.

- D. Li, and Y. Wang. "Strain Sensing Rosettes Using Passive Patch Antennas." *Proceedings of SPIE, Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring*, Denver, CO, March 4-8, 2018.
- H.Y. Qu and G.D. Chen. "Concrete Delamination Detection with Adaptive Wavelet Transform." Presented at *the 2018 SPIE Annual Symposium on Smart Structures/NDE*, Denver, CO, March 4-8, 2018.
- J.Z. Xiao. "Exhibition on Climbing Robots for Vertical Motion." Presented at *the 2017 World Robotics Conference* (WRC2017), Beijing, China, August 2017.

Books and Other One-Time Publications
- M. Orsag, C. Korpela, P. Oh, P., and S. Bogdan. *Aerial Manipulation*, Springer, 2018 (http://www.springer.com/us/book/9783319610207#).

2.B - Website(s) or Other Internet Site(s)

A website is maintained for the INSPIRE UTC at http://inspire-utc.mst.edu. This website serves as an information clearinghouse for all activities related to the grant and a gateway to transportation agencies, end users, technical communities, and the general public. In this reporting period, the website was improved, and the following NEW webpages were added to the site and populated with information:

- Webinars- http://inspire-utc.mst.edu/webinars/
- News- http://inspire-utc.mst.edu/news/
- Events- http://inspire-utc.mst.edu/events/
- Student Programs- http://inspire-utc.mst.edu/studentprograms/
- Advisory Committee- http://inspire-utc.mst.edu/advisorycommittee/

PPPRs are posted to the site as they are submitted and approved. http://inspire-utc.mst.edu/pppr/.

In addition to the main website, INSPIRE recently established a YouTube Channel at https://www.youtube.com/channel/UCi3KZfYuQok7ON3xdvbmYpQ?view_as=subscriber. This channel will be populated with some initial content in the next reporting period.

INSPIRE webinars are archived and made available through the Missouri S&T Scholar's Mine site at http://scholarsmine.mst.edu/inspire_webinars/. Webinar videos are available for viewing and webinar content may be downloaded.

Affiliated research facility websites include:
- Advanced Robotics and Automation Lab (ARA Lab)- https://ara.cse.unr.edu
- Applied Microwave Nondestructive Testing Laboratory *(amntl)*- http://amntl.mst.edu/
- Computer Vision and Biomedical Imaging Laboratory (CVBI Lab)- http://cs.mst.edu/research/researchlabs/computervisionandbiomedicalimaginglaboratory/
- Drones and Autonomous Systems Laboratory (DASL)- http://www.daslhub.org
- Evolutionary Computing Systems Laboratory (ECSL Lab)- https://ecsl.cse.unr.edu/projects/bridge_inspection/index.html, http://cse.unr.edu/~ecsl/
- Highbay Structural Engineering Research Laboratory (HSERL)- https://care.mst.edu/research/facilities/high-baystructureslab/
- Laboratory for Smart Structural Systems (LSSS)- http://wang.ce.gatech.edu/

- Robotics Laboratory- http://robotics.ccny.cuny.edu/
- System and Process Assessment Research Laboratory (SPAR Lab)- http://spar.mst.edu

2.C - Technologies or Techniques

Affiliated research faculty developed the following technologies during the reporting period:
- Dr. Genda Chen enabled a UAV-based measurement of magnetic fields with smart rock technology. The latest development was shared with the transportation community through the March 2018 issue of USDOT UTC Spotlight Newsletter.
- Dr. Genda Chen developed a graphene-based long period fiber grating sensor with Fe-C coating for high sensitivity corrosion rate monitoring. The new technology was disseminated through conference presentation.
- Dr. Jizhong Xiao further developed the wall-climbing robot technology to provide vertical mobility of NDE devices for concrete bridge inspection. Dr. Xiao also developed machine learning algorithms for surface flaw detection and measurement. The technology with the learning algorithms was shared with the research community through technical publications.
- Dr. Hung La developed the wall-climbing robot technology for steel bridge inspection with NDE devices. The latest development was shared with the research community through publications.

2.D - Inventions, Patent Applications, and/or Licenses

- G.D. Chen, C.R. Guo, and C.L. Wu. "Graphene-based Fe-C Coated Long Period Fiber Gratings for Corrosion-induced Mass Loss Measurement," Paperwork for invention disclosure filed to Missouri S&T's Technology Transfer and Economic Development Office, October 2017.
- H.M. La. "Steel Climbing Robot with Magnetic Wheels," U.S. Provisional Patent No. 62/427734, filed in 2017.
- P. Oh. "Aerial Manipulator Design for Drones," Paperwork for invention disclosure filed to the University of Nevada, Las Vegas, Technology Transfer Office, March 2018.
- J.Z. Xiao, K. Ushiroda, G.Y. Yang, S. Saniegepalli. "Robotic Device for Providing Vertical Mobility," U.S. Provisional Patent No. US62/357, 607, filed on July 01, 2016, PCT/US17/40621, July 3, 2017.

2.E - Other Products, Such as Data or Databases, Physical Collections, Audio or Video Products, Software or Netware, Models, Educational Aids or Curricula, Instruments, or Equipment.

Video Products
- The INSPIRE UTC webinars were video recorded. (See Section 2.B)
- A 2-3 minute video clip was produced to share the main activities at the INSPIRE UTC with the general public, which was presented to the legislators and the public at the inaugural University of Missouri System Legislative Showcase in Jefferson City, MO, on February 28, 2018.
- About 2 minutes of video were recorded by Dr. Hung La and posted on YouTube for public view on the latest development of climbing robots with magnetic wheels for steel bridge inspection.

Equipment
- PI 85L SEM PicoIndenter was purchased with non-federal match funds to enable nanomechanical characterization of fiber optic sensors and thin film coatings.
- DASnova™ Series Optical Fiber Distributed Acoustic Sensing System was purchased with non-federal match funds to enable a cost-effective detection of cracks in large-scale bridge structures.

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS

3.A - What Organizations Have Been Involved as Partners?

Participants: The consortium members of this University Transportation Center remain the same as proposed originally, including:
- Missouri University of Science and Technology - Rolla, MO (lead institution)
- City College of New York - New York, NY
- Georgia Institute of Technology - Atlanta, GA
- University of Colorado at Boulder - Boulder, CO
- University of Nevada-Las Vegas - Las Vegas, NV
- University of Nevada at Reno - Reno, NV
- East Central College - Union, MO
- Lincoln University - Jefferson City, MO
- Ozarks Technical College - Springfield, MO
- St. Louis Community College - St. Louis, MO

External Collaborators:
- Jacobs Engineering Group http://www.jacobs.com/
- Kaleidoscope Discovery Center https://thekaleidoscope.org
- Koch Industries http://www.kochind.com
- McClure Engineering Co. http://www.mcclureeng.com/
- Missouri Department of Transportation http://www.modot.org/
- Rich Robotics Corp http://richrobotics.com

Internal Partners at Missouri S&T:
- Department of Civil, Architectural and Environmental Engineering http://care.mst.edu/
- MinerFly https://itrss.mst.edu/minerfly/
- Student Diversity Initiatives http://sdi.mst.edu/
- Educational Technology http://edtech.mst.edu/
- Curtis Law Wilson Library/ScholarsMine http://scholarsmine.mst.edu/

3.B - Have Other Collaborators Or Contacts Been Involved?
An External Advisory Committee (EAC) was established to guide the center for the development and validation of advanced and applied technologies targeted to practical solutions for existing bridges (http://inspire-utc.mst.edu/advisorycommittee/). Some of the EAC members attended the INSPIRE UTC Kick-off Meeting with the USDOT grant management team on September 1, 2017.

In October 2017, a team of 15 external reviewers from government (7) and academia (8) was assembled to review and evaluate Year 2 INSPIRE UTC project proposals.

4. IMPACT

4.A - What Is the Impact on the Development of the Principal Discipline(s) of the Program?
- The findings from the projects led by Drs. Paul Oh, Hung La, and Jizhong Xiao likely have profound impact on robotic research since their tasks represent cutting-edge research activities.

For example, Dr. Oh recently co-authored and published the first book on aerial manipulation in the field. Dr. La has already demonstrated the capability of the 1st generation of climbing robots on steel structures.

- The multiphysics-based lab-on-sensor concept pioneered by Dr. Genda Chen likely has great impact on the innovation and application of sensors in transportation infrastructure. It can not only meet pragmatic needs in practical applications, but also satisfy scientific curiosity through innovative implementation and variation in various disciplines. For example, the Fe-C coated long period fiber grating sensor can measure the loss of Fe-C mass (and thus the mass loss of adjacent steel structures) that can be directly used by civil engineers to assess the remaining section capacity of existing steel members.

4.B - What Is the Impact on Other Disciplines?

- The same lab-on-sensor concept as used in the Fe-C coated LPFG sensor for corrosion monitoring in civil engineering can be introduced to other applications such as the biological measurement of nutrients and enzyme activities in soil science.
- The semi-supervised machine learning algorithms developed by Dr. Ruwin Qin will be useful in multiple disciplines. In particular, how to find representative data for human annotation and how to retrieve similar data for human analysis are common issues in computer vision and machine learning, which are widely used in various engineering applications.

4.C - What Is the Impact on the Development of Transportation Workforce Development?

- The framework developed by Dr. Ruwen Qin will facilitate data analytics and thus the development of toolkits that can help workforce development and training.
- The robotic simulator in video game environments developed by Dr. Sushil Louis will help engineers and Millenniums to grasp the advanced technologies developed by the INSPIRE UTC.
- The interdisciplinary nature of the INSPIRE UTC research projects broadens the experience and expertise of participating graduate students in various engineering disciplines, providing more broad-based workforce for transportation industry.

4.D - What Is the Impact on Physical, Institutional, and Information Resources at The University or Other Partner Institutions?

- The INSPIRE UTC's research projects can add a suite of research hardware to existing inventory in consortium universities. For example, the innovative battery-free wireless strain and crack sensors developed by Dr. Yang Wang can potentially help improve the safety monitoring of transportation infrastructure. The Fe-C coated long period fiber gratings developed by Dr. Genda Chen can provide unique data sets that are critical to the accurate assessment of bridge conditions. The availability of a robotic platform developed by Drs. Hung La, Jizhong Xiao and Paul Oh adds another dimension of inspection capability.
- The Missouri S&T faculty at the INSPIRE UTC designed and manufactured various unmanned aerial vehicles (UAVs) tailored for bridge inspection and collected image data with UAVs in close collaboration with the Missouri S&T MinerFly team, a campus research support service.
- The INSPIRE UTC's research projects can also add a suite of research software to existing inventory in market. For example, a machine learning algorithm was developed by Dr. Jizhong Xiao to detect and visualize surface flaws. Matlab computer programs were developed by Dr. Anil Agrawal for power spectral density analysis and empirical mode decomposition of

measured data series. One computational algorithm was developed by Drs. Ruwen Qin and Zhaozheng Yin to analyze video data with human in the loop.

- The INSPIRE UTC's research projects also add informational resources to various consortium universities. For example, Dr. Sushil Louis introduced 3D simulation and virtual reality (VR) technologies into automated infrastructure inspection research during a VR Meetup event hosted at the University of Nevada, Reno.

4.E - What Is the Impact on Technology Transfer?

- The robotic simulator in video game environment developed by Dr. Sushil Louis will greatly contribute to the simulation and training efforts on automated bridge inspection tasks. It involves a new 3D bridge inspection simulation system for both operator training (in simulation) and operator control of a robot team in a realistic setting during a bridge inspection.
- The research project led by Dr. Sushil Louis will open opportunities to utilizing the computer based simulation with the cutting edge virtual reality and augmented reality technologies on bridge inspection.
- Automatic retrieval of spatially-correlated frames from a large video sequence developed by Dr. Ruwen Qin allows engineers to analyze video images with human in the loop and, thus make more sensible decision in short time.

4.F - What Is the Impact on Society Beyond Science and Technology?

- The findings from the projects led by Dr. Reza Zoughi and Genda Chen on corrosion monitoring and assessment have significant societal impact since corrosion is the main reason for costly maintenance of bridges. In particular, enabling more accurate corrosion assessment of bridges with fiber optic sensing could potentially extend the service life of bridges.
- The successful completion of robotic research projects led by Drs. Hung La, Jizhong Xiao, and Paul Oh will provide a new automated platform that allows the development of traffic disruption-free, safer, faster, and cheaper bridge inspection initiatives.
- The research activities in sensors and robotics will open opportunities to commercialize this hardware and its associated software for inspection applications of bridges and tunnels. For example, Dr. Hung La has already applied for a provisional patent for the design and fabrication of a steel climbing robot.

5. CHANGES/PROBLEMS

5.A - Changes in Approach and Reasons for Change
No Change to Report.

5.B - Actual or Anticipated Problems or Delays and Actions or Plans to Resolve Them
Nothing to Report.

5.C - Changes That Have a Significant Impact on Expenditures
No Change to Report.

5.D - Significant Changes in Use or Care of Animals, Human Subjects, And/Or Biohazards
Nothing to Report.

5.E - Change of Primary Performance Site Location from That Originally Proposed

No Change to Report.

6. SPECIAL REPORTING REQUIREMENTS

Nothing to Report.