MPC-505
January 27,2016

Project Title:
An Intelligent Transportation Systems Approach to Railroad Infrastructure Performance Evaluation

University:
North Dakota State University

Principal Investigator (PI):
Pan Lu, Associate Research Fellow/Adjunct Professor
Upper Great Plains Transportation Institute
NDSU Dept. 2880, P.O. Box 6050
Fargo, ND 58108-6050
Phone: 701-212-3795
Email: pan.lu@ndsu.edu

Co-Principal Investigator (Co-PI):
Raj Bridgelall, Program Director
Center for SMARTSe[SM]
Upper Great Plains Transportation Institute
NDSU Dept. 2880, P.O. Box 6050
Fargo, ND 58108-6050
Mobile: 408-607-3214
Email: raj.bridgelall@ndsu.edu

Research Needs:

Railroads spend billions of dollars on infrastructure maintenance and condition monitoring each year [1]. Federal laws currently specify the type and regularity of full track inspections. Railroad companies deploy relatively slow and expensive methods using human inspectors and automated inspection vehicles to search for possible defects. The expense and labor requirement of these existing non-destructive evaluation (NDE) methods limit their ability to scale for continuous and network-wide monitoring for risk mitigation and safety improvements. Hence, the industry could save billions of dollars if sensors aboard regular rolling stocks could screen the infrastructure for faults automatically and continuously. Such a solution would provide asset managers with an ability to focus inspections on areas of high fault likelihood and severity without closing lines to search for developing faults.

Federal track safety standards require railroads to inspect all tracks in operations as often as twice weekly. However, with resources thinly stretched and the rate of defect formation escalating with traffic load-density, railroads are seeking to enhance the efficiency of inspections and maintenance of way. The current inspection practice not only decrease rail productivity by taking away track time to perform inspection and maintenance but also increase safety risk for railway inspection workers. There were 321 railroad worker fatalities from 2000 to 2015, and 132 were employees or contractors involved in track inspection and maintenance. Fault screening sensors on rolling stock will automatically and continuously provide track condition profile and characterize potential defects. Such a solution would free up more track time and capacity previously reserved for manual inspections while improving safety for railroad workers on duty.

The inertial responses of a railcar are symptoms of possible track or equipment defects. Although not all defects do, a significant majority produce accelerated car movements in all directions [2]. Inertial sensors that monitor vehicle-track interactions (VTI) exist. However, they do not classify fault types or their level of severity [3]. Existing sensors generally produce alerts directly when acceleration magnitudes exceed fixed thresholds. Inspectors must then travel to the estimated locations of every alert event to search for associated faults. Technicians must also pre-configure such sensors with thresholds based on their experiences or intuition. Without an objective and consistent approach to setting thresholds, some significant defects could go unnoticed whereas minor ones could result in unnecessary and expensive inspections. The inertial responses of vehicles will vary with train speed, gross weight, suspension system design, and weather conditions. Therefore, thresholds must adapt to the specific circumstances to improve accuracy and reduce false positives. However, threshold adaptation can be complex and expensive. Adaption that uses complex algorithms on remote servers will require that the sensors support two-way communications, thus increasing their cost.

The method developed in this research will not rely on adapting sensor configurations and will require only a data upload capability. The new sensors will compress and upload their geo-tagged inertial data periodically to a centralized processor. Remote algorithms will combine and process the data from multiple train traversals to identify fault symptoms, rank their severity, classify fault types, and localize their position. Fault classification will enable asset managers to allocate the appropriate specialists to scrutinize the fault location.

Research Objectives:

The primary goal of this study is to research, develop, and evaluate an automated symptom screening system for railroad tracks and equipment. The system will locate and characterize the type and severity of possible defects by analyzing the inertial dynamics of rolling stock. The team will include at least one student who will learn and practice the required signal processing, data processing, modeling, and signal classification techniques. The research output will feed into the development of new curricula in multimodal intelligent transportation systems for Transportation and Logistics (TL) program. Students will be able to use the framework established in this research as part of laboratory exercises and to identify additional research projects that will refine and build upon its initial capabilities. An ability to demonstrate the full solution via smartphone embedded sensors will lead to outreach activities that would encourage manufacturers of ruggedized industrial sensors to engage in technology transfer for the commercialization a dedicated or customized solution. Henceforth, the following summarizes the primary research objectives:

1) Modify a smartphone data logging application (app) to collect data onboard a hi-rail vehicle or/and in-service vehicle.
2) Develop, demonstrate, and validate the signal compression, fault detection, severity ranking, and type classification algorithms
3) Train at least one student on the various theoretical and simulation methods employed
4) Develop publications and associated outreach material suitable for engaging sensor manufacturers and service providers in possible technology transfer activities for product full commercialization
5) Utilize the research findings and techniques developed to draft classroom instructional material, laboratory exercises, and student project plans for new curricula in multimodal intelligent transportation systems for TL program.

These research objectives will further the overall goals of promoting economic development, safety, interdisciplinary education, workforce development, and technology transfer that serves the critical needs of the Mountain-Plains Region.

Research Methods:

The approach will leverage the cost-reduction and availability of advanced VTI sensors capable of providing more accurate inertial and geospatial position data than is currently available [4]. Such devices incorporate the same inertial sensing, geospatial position tagging, and wireless communications microchips that smartphones use, therefore, their further cost and size reduction would be imminent once the business case is established [5]. Manufactures are currently adding vibration energy-harvesting solutions to power such sensors, and they are designing ruggedized packaging for practical deployment aboard commercial vehicles of all types [6]. Therefore, this team will design and produce outreach material to engage select sensor manufacturers in a technology transfer phase. In lieu of purchasing new or prototype VTI sensor kits, this team will use a smartphone app to collect the inertial and geospatial position data needed to develop and demonstrate the fault detection, severity ranking, and fault type classification algorithms. This approach will demonstrate the potential utility of having ruggedized and low-cost devices deployed on every locomotive, and with further cost-reduction, on every car.

For data collection, the research team proposed an on-board or vehicle-based sensor application. Sensors will be mounted on both high-rail vehicle and in-service railway vehicles and the responsive data will be collected. Regional railroad in ND will be asked to participate in the research. The research is focusing on condition monitoring of vehicle suspensions and fault detection by analyzing the dynamic interactions between different vehicle modes.

The data processing algorithms will compress three-dimensional linear acceleration, angular acceleration, and geospatial data for signature classification. The models will utilize some of the data for calibration, and some of it to evaluate the accuracy of the developed models. Signal classification to determine the probable cause of the fault symptom could include a wide variety of data mining techniques. These include machine learning, genetic algorithms, feature correlation, Bayesian analysis, and maximum likelihood techniques. To focus the research scope, the analysis will investigate the performance of at least three different machine-learning methods on three different fault symptoms to prove the general approach. The algorithms will be extensible to detect and classify a wide variety of possible track defects (e.g. broken rail, irregular geometry), the fastening systems (e.g. missing spikes, displaced anchors), the support structure (deteriorated ballast, mud spots, weak sub-grade), and the vehicles (e.g. sticking brakes, wheel wear, suspension system misalignment). Future research will investigate and evaluate additional machine learning and classification methods to understand the boundaries of their accuracy with additional input factors such as equipment type, gross weight, axle spacing, and weather conditions.

A significant aspect of this proposal will involve the training of at least one student in the methods of field data collection, signal processing, data processing, and classification algorithms. The research findings and the simulation frameworks developed will provide a platform to develop classroom lecture and laboratory material for a future course in multimodal intelligent transportation systems. Furthermore, this research team will utilize the research methods and results to prepare publications and outreach material that would encourage further development towards technology transfer and product commercialization.

Expected Outcomes:

The successful validation and adoption of the proposed techniques will lead to enhanced asset management tools. Decision support systems will immensely improve the ability of the railroad industry to characterize potential defects and their rate of progression to focus follow-up inspections. With enhanced situational understanding, railroad companies will be able to optimize inspection and maintenance procedures to reduce the frequency of slow orders and track closures, while minimizing cost and safety risks. Asset managers will possess reliable track and equipment condition information to make informed decisions, leading to resource optimization.

Students will gain experience and knowledge in the multi- and inter-disciplinary aspects of computer science, physics, mathematics, engineering, and transportation concepts while contributing to the study. The literature search and algorithm development will shape new curricula in multimodal intelligent transportation systems. The outreach products will encourage technology transfer to sensor device and service provider organizations seeking to commercialize the solution.

Relevance to Strategic Goals: This study relates to the following strategic goals:

Economic competitiveness – the ability to optimize asset lifecycle with more accurate data without closing railroad tracks will enhance capacity and minimize maintenance costs. The ability to monitor continuously network risks to take remedial action in a timely manner will sustain economic growth.

Safety – the NDE method of monitoring railroad infrastructure continuously using revenue trains will detect a variety of distress symptom formation and mobility obstructions before they contribute to property damage, injuries, or fatalities.

State-of-good-repair – the research products will enable significant advancements in railroad asset management and right-of-way maintenance. The decision support platforms and asset management solutions enabled will provide practitioners with actionable information to optimize asset lifecycle.

Educational Benefits: This project will include at least one student. The broader educational benefits will include curricula development in multimodal intelligent transportation systems.

Work Plan: The main tasks are as follows:

TASK 1: CATALOG EXISTING PRACTICES (Months 1 – 3)
1) Catalog current practices of non-destructive evaluation (NDE) of the railroad infrastructure
2) Identify emerging NDE techniques that are ITS relevant
3) Assess utility gaps relative to the proposed development

TASK 2: MODEL DEVELOPMENT (Months 4 – 12)
1) Develop the method and plan of fault signature data acquisition
2) Develop mechanistic algorithms to compress the signature data for data mining
3) Formulate the empirical analysis framework for fault signature processing and recognition

TASK 3: DATA COLLECTION AND MODEL REFINEMENT (Months 13 – 18)
1) Develop and produce a data collection plan that identifies the railroad site and partner
2) Arrange and conduct field data collection, including ground truth data
3) Assess the empirical model performance when applied to the field data
4) Train the empirical models to maximize the fault detection accuracy
5) Validate the model with data not previously used to train the model

TASK 4: CURRICULA DEVELOPMENT AND TECHNOLOGY TRANSFER (Months 19 – 24)
1) Assess availability and deficiencies of existing training programs relevant to the topic
2) Develop draft curricula content that includes aspects of the research and its outcome
3) Address the potential for developing online courses that incorporate the proposed curricula
4) Produce at least two conference papers aimed at promoting technology transfer to industry
5) Produce a final report that includes the research findings and conclusions

Project Cost:
Total Project Costs: $226,00
MPC Funds Requested: $113,000
Matching Funds: $113,000 (UGPTI)

TRB Keywords: Intelligent Transportation Systems, Multimodal, Railroad, Fault Location, Fault Monitoring, assessment

References:

[1] United States Department of Agriculture, "Grain Transportation Report," USDA, 2013.

[2] Federal Railroad Administration, "Track Inspector Rail Defect Reference Manual," Federal Railroad Administration: Office of Railroad Safety, Washington, DC, 2011.

[3] L. Biess and M. Dick, "Development and Use of V/TI Monitors for Autonomous Track Inspection," in *AREMA 2011*, Minneapolis, 2011.

[4] S. Nasiri, S.-H. Lin, D. Sachs and J. Jiang, "Motion Processing: The Next Breakthrough Function in Handsets," InvenSense, Inc., Sunnyvale, CA, 2013.

[5] R. Bridgelall, P. Lu and D. Tolliver, "Rolling-stock Automatic in-situ Line Deterioration and Operating Condition Sensing," in *TRB 92nd Annual Meeting*, Washington, DC, 2013.

[6] R. Bridgelall and P. Shah, "Integrated Energy Harvesting Systems for Autonomous Energy Aware Multiband Sensor Networks," in *Energy Harvesting Journal*, Chicago, 2010.

[7] R. Bridgelall, "Connected Vehicle Approach for Pavement Roughness Evaluation," *Journal of Infrastructure Systems*, vol. 20, no. 1, p. 04013001, 23 April 2014.

[8] C. M. Bishop, Pattern Recognition and Machine Learning, Cambridge, U.K.: Springer Science+Business Media, LLC., 2006.

[9] R. O. Duda, P. E. Hart and D. G. Stork, Pattern Classification, 2nd ed., John Wiley & Sons, Inc., 2001.

[10] T. M. Mitchell, Machine Learninig, McGraw-Hill, 1997.