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Project Title:
Automated Track Geometry Monitoring System

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Research Needs:
Railroads spend billions of dollars on track maintenance and condition monitoring each year [1]. Federal laws specify the type and regularity of full track inspections. The Federal Railroad Administration (FRA) is responsible for enforcing track safety standards in the United States. Some states (such as North Dakota) employ additional track inspectors, who work in collaboration with FRA inspectors under cooperative agreements. These inspectors must cover large territories with sufficient frequencies to ensure safe operating conditions. Inspection resources (including personnel and hi-rail vehicles) are scarce and subject to government budget limitations. The expense and labor requirement of these existing non-destructive evaluation (NDE) methods limit railroads' ability to scale for continuous and network level monitoring for track geometry.

Although the FRA and certified state inspectors are responsible for enforcement, the railroads themselves are liable for track safety. In practice, railroad inspectors comprise the leading edge of a comprehensive system dedicated to the safety of personnel and cargo and the prevention of hazardous spills. Like federal and state governments, railroads have limited resources. Geometry cars provide essential information about profile, alignment, warp, and other measures of track condition. However, the use of geometry cars is periodic and expensive. Supplemental means of automating track assessments (such as the on-board sensor system described in the research objectives) could increase the cost-effectiveness of track safety programs.

Current Practice

In North Dakota, FRA and Public Service Commission (PSC) inspectors assess track geometry in relation to safety and maximum train speeds. Profile and alignment (two prime indicators) are measured by stretching a 62-foot string between two points along a rail (Figure 1). Other key indicators are runoff at the end of a raise (Figure 2), cross level (e.g., the difference in elevation between the tops of the rails at any point along the track), superelevation (the constant elevation of the outside rail in relation to the inner rail in curves), and warp (the difference in cross level between any two points less than 62 feet apart along a rail line).

Assessing these irregularities means that inspectors must stop their vehicles and lay out 62-foot chords. This consumes considerable time when many segments of a line must be inspected. The situation is complicated by the fact that measured values may vary with the starting point of the chord. Conceivably, warp, profile, and alignment could change from point-to-point along a rail line if the starting position of a chord is advanced one meter at a time. While geometry cars automatically produce these results, it is difficult for track inspectors to measure the many segments that exist within a rail line.

Research Objectives:

1. Develop, debug, and deploy smart phone system to collect rail track monitoring data
2. Develop algorithms to monitor track geometry measures from data collected with smart phone system
3. Develop reporting and mapping system
4. Produce outreach materials (journal and conference papers), and a project report that details the research method and its findings

This study will develop, implement, and evaluate an autonomous track geometry monitoring system to screen the network for faults during normal train operations. The technology performance will depend on the specific implementation and deployment options selected. Therefore, automatic data collection and recording devices will be necessary to gather motion, location, and speed data to evaluate the performance of various system implementation options. Initial data collection will begin with a smartphone that has all of the required sensors. The PIs will develop a smartphone application that will be capable of autonomously collecting and uploading data from hi-rail vehicles, geometry cars, locomotives, and end-of-train cars where power is available. The technology transfer phase will inform commercialization partners about the best approaches to develop a lower-cost and self-sufficient version of the sensor system deployed during the research. This research project will focus on developing the signal processing and machine learning algorithms and models that will transform the on-board sensor data into track geometry equivalents. The research team will also develop a reporting and mapping system to provide decision-makers with a data visualization tool.

Another key objective of this research is workforce development and technology transfer. Therefore, students on the project (Leonard Chia, Bhavana Bhardwaj, and Neeraj Dhingra) will work closely with the PIs to develop and publish at least three conference and three journal papers that summarize the study and its findings. In addition, the research team will publish a project report and incorporate appropriate materials into curricula refinements that focus on intelligent transportation solutions.

Research Methods:

The proposed approach will leverage the cost-reduction and availability of advanced vehicle-track interaction (VTI) sensors capable of providing more accurate inertial, gyroscopic, and geospatial position data than is currently available [2]. 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 [3]. 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 [4]. 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 potential utility of having ruggedized and low-cost devices.

Use of Hi-Rail Vehicles

This research team anticipates that their development and testing of such a sensor deployed on Hi-Rail vehicles will greatly aid track inspectors because it will require only a smart phone and minimal input from the inspector. The automated assessment method will utilize scarce personnel time more effectively and generate a record of the entire line for each trip that a hi-rail vehicle makes. The record will be continuous, much like a “moving chord” that is incremented in small distances along a line.

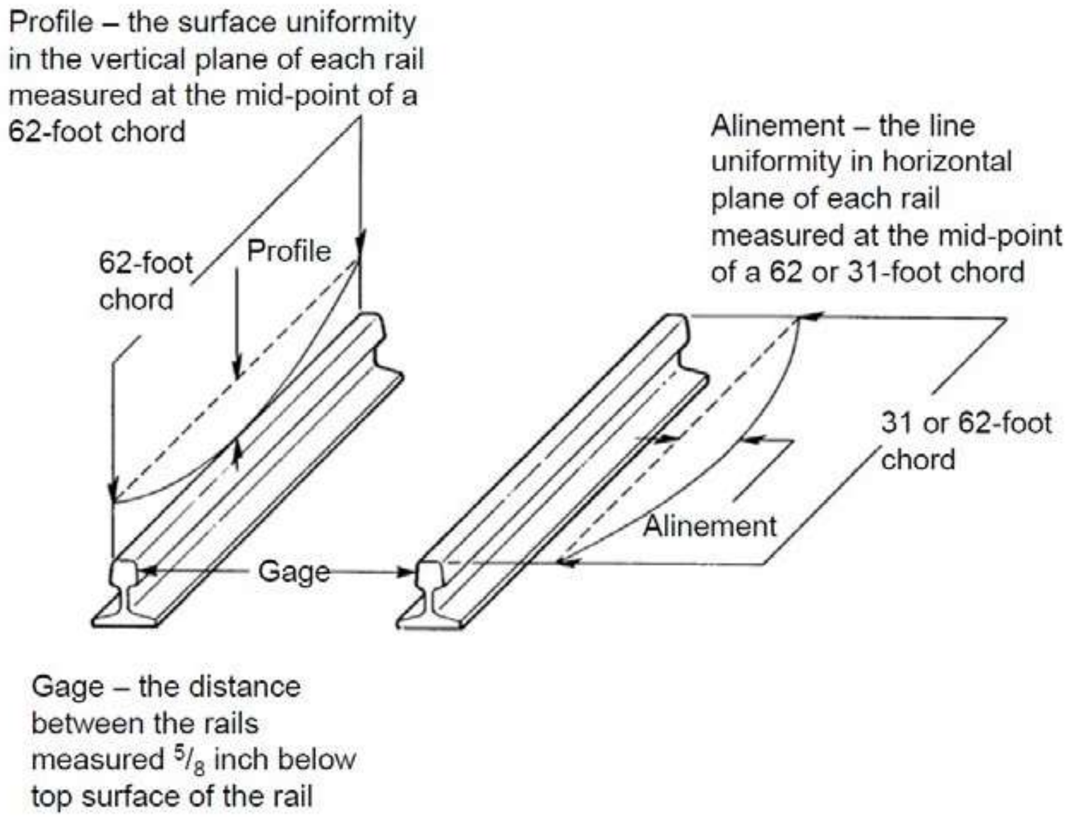

Figure 1 Illustration of Alignment, Gage, and Surface (FRA, 2014)[5]

Figure 2 Measurement of Runoff for a Track Segment (FRA, 2014)[6]

Sensor Data Collected. A rugged smart phone will be placed in each participating hi-rail vehicle at a specific location. The phone's accelerometer will measure g-forces in three dimensions (along x, y, and z axes). In addition, the phone's gyroscope will measure yaw, pitch, and roll in degrees, as well as yaw, pitch, and roll rates in degrees per second. These measurements will have time stamps associated with them (in universal date-time format) and GPS coordinates in decimal degrees. Therefore, speed measurements (in meters per second) can be generated from the phone's data stream.

App and Data Transmission. A smart phone application will be developed to record and upload the measurements to a server. The necessary sampling rate (e.g., the frequency at which the phone's app generates records of each data observation) will be determined in the study.

The app will include power and memory management features and a user interface that allows inspectors to tag mile markers as they pass.

Calibration and Data Analytics. Equations and software algorithms will be developed to translate raw data into changes in track geometry as the hi-rail vehicle moves along a line. The algorithms will be calibrated against the outputs of track geometry cars and field measurements. Once it is calibrated, the hi-rail tool will help inspectors screen sections for detailed field measurements, during and after a trip. Future versions of the smartphone app will issue alerts when threshold changes in acceleration or orientation are encountered, advising the inspector to stop and evaluate the area. After the trip, the record can be reviewed, potentially leading to the identification of additional locations for human assessment. Because the data will be archived, patterns can be analyzed for individual segments over time. Through relational merging, inspector data from FRA's "dashboard" can be combined with data generated from the automated data collection app to provide a rich repository for data mining and statistical analysis.

Automated Track Assessment via Rolling Stock

Hi-rail vehicles are capable of providing frequent assessments of rail lines in a network. However, additional methods are needed to depict railcar responses, which are difficult to infer from hi-rail vehicles. Therefore, a second (parallel) approach will be explored.

The PIs have received preliminary agreement with local railroads such as the Dakota Missouri Valley & Western (DMVW) and the Red River Valley & Western (RRVW) to equip their trains with the smartphones. Placed at various locations on the locomotives, the smartphones will provide multiple data streams from the same consist. The phones will be attached to auxiliary power, requiring little setup or maintenance by train crews. In this way, each locomotive will become a data collection tool, providing additional assessments of track geometry. Moreover, the responses of the locomotives will be modeled from the data stream. In the future, this method (of data collection) could allow software to be developed that monitors the "locomotive's health" based on dynamic responses—which, in turn, would enable the forecasting of truck and axle/wheel maintenance requirements.

Similar methods of equipping railcars will be explored. Potentially, smart phones could be attached to the cars in a train, in which case each car would generate its own location and sensor data. Unfortunately, supplying power to phones on railcars may prove challenging. Alternatively, phone sensors could be attached to the end of train (EOT) device, which is placed on the last car of the train. In the future, it may be feasible to establish local area networks between sensors located on railcars and phones in locomotives.

Expected Outcomes:
The expected outcomes will be educational benefits, workforce development, and technology transfer to advance the state of the art of the railroad industry. Towards the educational benefits and work force development, this project will include three PhD students: Leonard Chia, Bhavana Bhardwaj, and Neeraj Dhingra. All students will invent and explore the impacts of different methods of traversal alignment, digital filtering, feature extraction, and feature transformation to quantify profile, alignment, and warp. The broader educational benefits will be knowledge products and tools that feed into curricula development and laboratories in multimodal intelligent transportation systems.

Towards the technology transfer, the team will utilize the research methods developed and the system solution to prepare publications and outreach material that would encourage further adoption and further development to refine and commercialize the technology for large-scale deployment. Other methods of technology transfer will include journal papers, conference presentations, project reports, web page postings, and other marketing or outreach materials. All publications will acknowledge this award. The PIs will notify the progress-reporting system (PPPR) of any publications generated from this project, as well as technology transfer activities.

Relevance to Strategic Goals:

- State of Good Repair
- Safety

An autonomous track geometry monitoring system could save considerable time for inspectors to frequently stop their vehicles and lay out 62-foot chords to perform the measurement. Furthermore, the system can improve the current practice with continuous track geometry profile rather than discrete 62-foot chord measurements. The research will directly benefit to state of good repair practice and improve rail safety performance. Students trained will be prepared to enter a workforce that can evaluate and help inspectors to enhance railroad safety.

Educational Benefits:

As noted in the expected outcomes, three students will work with the PIs to conduct research that they will incorporate into journal papers and their PhD dissertations. Although all students will develop the data collection, signal processing, geometry measure estimation, and irregularity reporting modules, their dissertations will be different. Each will optimize different portions of the system and evaluate different methods within each module to characterize the performance envelope for the system. Together, this will yield a better understanding that will inform the system design options to maximum both performance and a benefit-cost ratio. The PIs intend to incorporate knowledge and models from this research into curricula focused on intelligent transportation solutions.

Tech Transfer:

As noted in the expected outcomes, the research team will utilize the project findings and models to prepare publications and outreach material that would encourage further adoption in the real world. The team will utilize traditional methods such as journal papers, conference presentations, project reports, web page postings, and other marketing or outreach materials. In addition, the team will engage railroad representatives throughout the project to provide guidance and to achieve buy-in. Furthermore, the PIs will engage with sensor manufacturers to explore the potential for product refinements and cost reduction of the technology. All publications will acknowledge this award. The PIs will notify the progress-reporting system (PPPR) of any publications generated from this project, as well as technology transfer activities.

Work Plan:

1. Deploy smart phone system on hi-rail vehicles
2. Perform initial data analytics
3. Deploy smart phone system on locomotives
4. Develop reporting and graphical mapping system for laptop/notebook
5. Describe results of deployment, potential benefits, and the potential for widespread deployment
6. Develop plan for deployment of sensors and data collection from railcars
7. Develop final research full report

1. Deploy smart phone system on hi-rail vehicles (Jan. 2018 – April. 2018)
    a. Develop and test the smart phone app
    b. Get final participating agreements from railroads
    c. Identify participating hi-rail vehicles
    d. Install phones with apps on participating hi-rail vehicles
    e. Collect data from smart phones over extended period of time
    f. Validate the data collected and request any debugging and improvements required of the smartphone app.
2. Perform initial data analytics (May 2018 – October 2019)
    a. Mine data from hi-rail vehicles
    b. Identify deviation thresholds for phone alerts
    c. Develop alignment algorithms to align traversals
    d. Develop filtering algorithm to clean the raw signal data
    e. Develop algorithms to convert raw data into track geometry measures
    f. Calibrate algorithms against field observations and outputs from track geometry cars
    g. Finalize algorithms
    h. Develop journal papers
3. Deploy smart phone system on locomotives (July 2019 – May 2020)
    a. Get participating agreements from railroads
    b. Adjust app originally developed for hi-rail vehicles for locomotives
    c. Install phones with app on locomotives in participating trains
    d. Collect data from smart phones over extended period of time
    e. Perform initial data analytics (analogous to Task 2 above)
4. Develop reporting and graphical mapping system for laptop/notebook (June 2020 – August 2020)
5. Describe results of deployment, potential benefits, and the potential for widespread deployment (September 2020 – November 2020)
6. Develop plan for deployment of sensors and data collection from railcars (November 2020 – January 2021)
7. Develop final research full report (November 2020 – January 2021)

Project Cost:

Total Project Costs:	$198,302
MPC Funds Requested:	$99,151
Matching Funds:	$99,151
Source of Matching Funds:	NDSU/UGPTI

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