Development of Autonomous Track Geometry Measurement Systems for Overall Track Assessment

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Word Count: 5,639

ABSTRACT

Since 1970 the use of automated track inspection systems have gone from limited use as a quality assurance tool by a handful of railroads to a key element to track asset management and safety assurance. Today some form of automated inspection for track geometry, rail profile and/or gage restraint measurement regularly used on most class one railroads. The data from these systems plays a key role in both safety assurance and maintenance planning. Over the last decade a new generation of autonomous track inspection systems has emerged, most recently exemplified by Autonomous Track Geometry Measurement Systems (ATGMS).

This paper summarizes the history of an ATGMS developed by the Federal Railroad Administration’s Office of Research and Development. Lessons learned and experiences gained during a pilot study conducted on Amtrak’s Auto Train route over CSX Transportation track will be provided. This paper will also describe a vision for the use of autonomous track geometry inspection in overall track condition assessment that will facilitate the identification of track-related issues before they reach levels associated with reportable defects.

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INTRODUCTION

The number of track-caused derailments in the United States has decreased since the 1970s. This overall decrease can be attributed to many factors, including the development and improvement to the wide range of inspection technologies used throughout the industry. To further decrease the number of track-caused derailments, new methods of derailment prevention, including new track inspection methods, are needed. Improved track inspection methods can also provide benefits to railroad operations. In addition to reductions in-service track failures, improvements to inspection practices can lead to more efficient safety compliance programs, resulting in better use of resources and an increase in the capacity of the freight and passenger railroads.

Current methods for track inspection rely heavily on either visual inspection by track inspectors or automated inspection from dedicated inspection vehicles. Automated inspections, for the purposes of this discussion, are those in which key measurements are collected by instrumentation that is attended to and monitored by one or more operators. An inspection vehicle can be a self propelled or towed rail car or can be a hi-rail vehicle; in all cases, the inspection vehicle carries specialized equipment to measure various parameters associated with the track relying on trained operators to run the equipment and conduct the survey. Today, the use of automated track inspection systems has grown to become a key element to track asset management and safety assurance on all Class I US railroads and provides an objective method for the evaluation of track conditions that has contributed to the decrease in the derailments rates. However, methods involving automated inspections typically require scheduled track time, dedicated manpower resources and expensive systems. Emerging technologies relying on remote communication can significantly improve current methods.

Autonomous track inspection is a process in which the track is inspected from revenue trains using unattended instrumentation with minimal direct involvement from operators. Autonomous track inspection technologies have been developed utilizing revenue service trains equipped with data collection equipment that employs wireless communications to provide inspection data with dramatically increased frequency and reduced cost. Since 2000, systems of this nature have been used by Amtrak and
Class I freight railroads (I). By making inspection systems autonomous, data can be collected more frequently without track time being consumed by dedicated inspection vehicles. The use of autonomous inspection technologies will result in earlier detection of track defects and changes in maintenance practices from reactive to preventative, ultimately reducing the number of track caused derailments throughout the railroad industry.

The Federal Railroad Administration’s (FRA’s) Office of Railroad Policy & Development sponsors and conducts applied research as well as develops, tests, and evaluates technologies that support the FRA’s core mission of improving rail safety and supporting national transportation policy. To that end, the FRA Office of Research and Development has undertaken a research program focused on the advancement of autonomous track geometry measurement to improve rail safety by increasing the availability of track geometry data for safety and maintenance planning purposes. This goal can be reached through the development of Autonomous Track Geometry Measurement Systems (ATGMS) that:

1. Reduce the life-cycle costs of geometry measurement operations;
2. Eliminate interference with revenue operations;
3. Increase inspection frequencies and productivity;
4. Provide data of the highest quality possible.

The FRA’s research vision is to create a relatively low cost, self-powering geometry measurement system that can be deployed on standard rail equipment, including freight cars, to collect and distribute accurate track geometry data while running in a standard revenue train. The objective of the program is not necessarily to replace manned automated inspection systems as a quality assurance tool, but to create a more flexible, efficient tool for use in quality control and maintenance planning activities.

This paper will describe the FRA’s ATGMS research program as well as its current development plan for this technology and provide a description of the challenges that must still be addressed to realize the vision for the use of autonomous inspection technology in assessing overall track conditions.
OVERVIEW OF FRA’S ATGMS RESEARCH

Development Plan

Although autonomous technology to evaluate track conditions is broadly accepted in the United States, the use of this technology to directly measure track geometry as part of regular maintenance and safety assurance practices is still in its early stages. Unattended systems that recorded track geometry data and downloaded recorded data to readers located at strategic points throughout a rail network have been utilized in Europe (2). Following the demonstration and implementation of autonomous track assessment systems on Amtrak and other Class I U.S. railroads, FRA took steps to develop and evaluate a track geometry measurement system that reported track issues in near real-time without the need for extensive dedicated data transfer mechanisms to be installed throughout a rail system.

To achieve the FRA’s vision of relatively low cost, self-powering geometry measurement systems that can be deployed on standard rail equipment, a development plan has been created to guide the research and evaluation efforts. This plan is summarized as follows:

- **Stage 1: Long Term Pilot with Standard Inspection Technology** – The initial stage of development centers on the creation of a ruggedized, truck-mounted pilot system using commercial, off-the-shelf equipment to facilitate early evaluation. This activity would be used to develop the basic elements required for a system of this nature, including:
  - Communication software;
  - Processing software, including analysis tools, means to filter exceptions detected by the system that are usually addressed by operators in manned automated systems filtering, and system health monitoring;

This phase employs a long term, pilot system test to facilitate the development of the elements cited above as well the evaluation of operational and maintenance issues that result from long term use of a system of this nature.
Stage 2: Simulation of Standard Revenue Operations – Stage 2 focuses on the evaluation of the system under long distance, revenue service operating conditions. Refinements of hardware and software based on the results of pilot system testing accomplished under Stage 1 are also addressed. This phase of development will compare geometry data collected with the autonomous system to geometry data collected with typical manned geometry systems to identify and address any remaining issues affecting data captured by the autonomous system.

Stage 3: Advancing Measurement Technology – Stage 3 involves the development of sensor technology to allow for installation of autonomous geometry measurement systems on wide range of vehicle designs to facilitate use under a wide range of operating scenarios. Efforts to be conducted during this activity include the development a full carbody-mounted system, improved sensors, non-contact speed measurement and revised processing algorithms to account for new measurement techniques. Movement of the system to the carbody offers several benefits to the ATGMS, including a less severe shock-and-vibration environment compared to truck- or axle-mounted systems, thus prolonging hardware and sensor service life; a location further away from the track, reducing exposure to mud, snow and flying ballast; and less manual interaction with the system during periodic truck maintenance activities. All of these benefits will serve to advance the ATGMS to a point where it can be deployed on a wider range of host vehicles where regular maintenance proves to be difficult. A key element of this stage of development will be the demonstration of this approach in revenue service operations and comparison of data to that collected by standard geometry systems.

Stage 4: Development of Energy Harvesting Technology – Stage 4 targets the development and evaluation of technology that will allow autonomous systems of this nature to be deployed to cars without existing power sources, thus eliminating the restriction of installation of autonomous systems on powered cars such as passenger vehicles and locomotives. This effort involves the optimization of ATGMS power demands to facilitate advancement.
• Stage 5: Demonstration of System in Freight Service – As the issues addressed in the earlier development stages are solved, this technology will need to be demonstrated on freight vehicles operating under typical revenue service operations to establish the vision of the use of this technology for track assessment throughout the industry.

As is the case with the introduction of any new technology, implementation issues must be identified and challenges must be addressed by both operators and regulators if the technology is to have an impact. Therefore, FRA has relied on partnerships with railroads to facilitate this research to date and continues to seek railroad participation in continuing research activities.

Technical Approach

Developed on behalf of the FRA by ENSCO, the ATGMS is designed to detect, locate, and report potential track defects in near real-time to a web-based inspection data management system for review and remedial action. Although the confirmation of defects on the ground and remedial actions still require human intervention, autonomous track inspection provides a significant step forward in maintaining track by increasing the frequency and decreasing the cost of track inspection. The core technologies and approach employed in the ATGMS, as illustrated in Figure 1, includes three major components - an onboard unit, processing servers and a cellular communication link.
Figure 1. General Depiction of FRA’s ATGMS Installation and Web-Based Reporting Application

- **Onboard Unit** – The portion of the system located on the vehicle consists of a series of measurement sensors, a computing platform, and location determination technology.

  A dramatic increase in computer power and reliability, combined with a decrease in processor size, is one of the enabling factors for autonomous monitoring. Onboard equipment has become small enough, reliable enough, and sophisticated enough to conduct most of the operations currently performed by inspection car operators. These operations include recognition of issues with instrumentation, location marking, and exception identification. Although there are still operations where it is difficult to replace a human operator, particularly in exception evaluation, when something
malfunctions or unexpected situations arise, these situations can be identified and handled appropriately within the overall system in an automated fashion.

Global Positioning System (GPS) technologies are critical to autonomous inspection in that they provide location of the detected defects in absence of an operator. Onboard GPS based location systems can have different levels of accuracy and sophistication from regular GPS receivers to Differential GPS (DGPS) to high end DGPS assisted inertial navigation systems. As a result of early evaluations, the ATGMS installed on the Auto Train employs DGPS assisted inertial navigation systems for providing location information. This approach offers the benefit of correcting the shortcomings of standard GPS such as decreased accuracy due to atmospheric conditions and the blockage of signals due to local terrain, dense foliage, overpass bridges, tall buildings and other obstructions. It should be noted, however, that this increased accuracy, which can be as high as 1 foot, comes at a cost in that it is achieved by using more expensive hardware and paying for differential correction services.

- **Processing Servers** – A key element of the autonomous inspection system is a central server to which data is transferred. This facility features data processing capabilities, a database management system, and Geographic Information Systems (GIS) applications to facilitate reporting of areas of interest.

The nature of autonomous inspection systems greatly improves the productivity of inspection operations but can increase the volume of data to be considered. An efficient data management and reporting system is necessary to create uniform data storage and maximize the effectiveness of reporting track issues. GPS coordinates or other location data associated with defects are not sufficient unless there are underlying maps that show information associated with track and other rail infrastructure. This allows for conversion of location data reported by the onboard autonomous systems into standard linear railroad referencing (subdivision, MP, FT, track number). With the impending implementation of Positive Train Control (PTC) in the United States, the accuracies associated with the location of rail infrastructure are expected to increase to a level where track number can be correctly determined. The centralized approach to data processing and reporting will
be able to leverage this improvement in accuracies to the advantage of automated inspection technology.

- **Cellular Communication Link** – The manner in which data is transferred between the onboard units, the central processing servers, and the data recipients is an important feature of any autonomous inspection system. It affects the way in which measured data is uploaded to the central processing servers, and processed information is distributed to inspectors or maintenance personnel.

  Cellular communication is a critical enabling technology used for retrieval of data from the onboard systems and providing remote monitoring and maintenances to the systems. The FRA ATGMS uses publicly available commercial data networks. The bandwidth of available wireless communications continues to increase providing opportunities to collect and upload larger data sets, a key consideration for future enhancements of autonomous inspection technology.

  Data collected by the ATGMS can be made available to stakeholders through a variety of ways including email alerts, electronic reports and dedicated websites and presentation of survey results to outside railroad data management and reporting systems. Figure 2 illustrates the various reporting tools that are made available through the ATGMS-dedicated website.
ACCOMPLISHMENTS TO DATE (STAGE 1 DEVELOPMENT)

The FRA commenced a pilot program in 2008 involving the use of an Autonomous Track Geometry Measurement System (ATGMS) on Amtrak’s Auto Train operating between Virginia and Florida on CSX Transportation track to evaluate such implementation issues. The FRA’s ATGMS, the instrumentation beam of which is pictured in Figure 3, was installed on an Amtrak Superliner II sleeper car in January 2008 and introduced into revenue service on Amtrak’s Auto Train service immediately following installation. Amtrak’s Auto Train runs daily on CSX-owned track between Lorton, VA, near Washington, DC, and Sanford, FL, a distance of 855 miles. From the time of its initial use until its removal in March 2011, the FRA’s ATGMS unit surveyed close to 460,000 miles of track, an average of approximately 153,000 miles per year.
The efforts under the pilot program employing the prototype ATGMS produced several key results that show that this is a viable technology for long-term use in service within the US rail industry. These results are highlighted by the following:

- **Repeatability** – The initial effort demonstrated that the prototype ATGMS was capable of producing repeatable data over time, a key aspect to the reliability of the system and its data products.

  During the initial stages of deployment, the foot-by-foot data collected and stored on the ATGMS for evaluation purposes was compared to foot-by-foot geometry measurements collected by an FRA-owned automated track inspection car over the same territory. Comparisons of the results collected by both systems over selected evaluation zones met reproducibility standards used to confirm the proper operation of track geometry measurement systems on a single platform.

  Repeatable data was a critical aspect of the implementation of the pilot program with CSX. Under the implementation of the initial effort, potential track defects identified for follow-up

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**Figure 3. FRA ATGMS Installation on Amtrak Superliner II in Auto Train Service**
inspection by CSX would have to be shown to be repeated over several consecutive surveys before deploying field personnel; the subject of identification of track issues through repeated detection is an issue to be addressed later in this paper. Defects that were believed to be an imminent threat for derailment were brought to the railroad’s attention immediately.

An example of the type of report created through use of the ATGMS is illustrated in Figure 4. In this example a narrow gage exception was repeatedly measured at the same location over several consecutive runs made in the same month in late 2010. These measurements were assessed for data quality using a method described later in this section and reported to the railroad.

<table>
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</tr>
<tr>
<td>Run 2</td>
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</tr>
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<td>Run 3</td>
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<td>Run 4</td>
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<tr>
<td>Run 5</td>
<td>55.87</td>
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<tr>
<td>Run 6</td>
<td>55.83</td>
</tr>
<tr>
<td>Run 7</td>
<td>55.82</td>
</tr>
</tbody>
</table>

Figure 4. Example of Repeated Narrow Gage Measurement Reported Through Use of FRA’s ATGMS, Fall 2010

- **Automatic Data Filtering** – The FRA ATGMS processes the measured geometry data on the vehicle and provides notification of detected track issues from the instrumented car in near real-time. It was recognized early in the development of the ATGMS that one of railroad industry’s biggest concerns
regarding autonomous geometry measurement was the possibility of a large number of false alarms that would cause the track to be slow ordered when in fact these are no defects.

The subject of automatic data filtering has been focused on throughout the development of the ATGMS. A unique system capable of automatic data editing to remove false exceptions has been developed to address the reliability of results provided by this unattended system. The editing process relies on a proprietary set of software modules to determine the location of the detected event, verify that the measurement in question is valid and make the result available for display and notification. Using the experiences from decades of track geometry data collection and years of developing autonomous track assessment systems, an approach for data validation was developed that employs two algorithms to ensure data integrity. The first is a human-trained decision model, a self-teaching intelligent algorithm that recognizes the patterns associated with the actual experience of human data editors and applies those patterns to potential measured defects. Edited data from thousands of miles of actual survey are used to “teach” the program how to filter out false exceptions. The second is a computational signature analysis algorithm that analyzes frequency components of the measured signals to identify those cases that exhibit higher-frequency components not related to track-geometry that would cause the reported geometry measurement to be questioned.

This two-pronged approach to exception editing has been shown to be effective in removing instances in which certain conditions in the data look like there are defects present when in fact there are none. Examples of the type of reported data that the system is capable of filtering out include signals suffering from dirty measurement optics, gage conditions found at diamond frogs and turnouts as well as profile irregularities that can be observed in crossovers. The two algorithms are continually undergoing evaluation for accuracy. Recent analysis conducted on a set of geometry exceptions identified by the on-board unit on the Auto Train route over many runs indicated that the experienced human operator agreed with results of the automatic data processing algorithms in both the acceptance of valid exceptions and the rejection of invalid exceptions over ninety percent of the time.

It is recognized that these results may be dependent on track features specific to the route over which
the system has been employed to date. The flexible architecture of the editing approach provides for continual updates to improve accuracies as the ATGMS gains additional miles and use throughout the rail industry. This approach to filtering will yield the added benefit of assuring consistency of track assessment by minimizing the impact of individual operator judgment of track issues that can affect automated track inspections.

- **System Reliability** – Maintenance, repair and system reliability are critical aspects of the ATGMS that will have a direct bearing on its use by the rail industry. It is important that the system have a high mean time between failures since the system is unmanned and the intervals between maintenance cycles must be as long as possible.

  The design of the FRA’s ATGMS features critical elements and sensors that have been used either in autonomous technology deployments or in traditional track geometry measurement systems over extended periods of time. To insure safety and long service life, the design features redundant mechanical mounting systems, shock and vibration protection, internal diagnostics, and ruggedized electronics.

  During the time over which the FRA’s ATGMS was running, the system experienced two failures that could be termed critical to the system:

  - One (1) tachometer failure due to issues with fabrication of the mechanical mounting used to attach the sensor to the end of the axle that lead to failure of the mounting bracket. The design of the mounting bracket was changed and system inspection procedures were modified to monitor the condition of this component. No repeat of this issue has been observed.

  - One (1) laser head sensor used to measure the position of the rails in space suffered from poor performance due to the condensation within the laser enclosure. The manufacturer of the laser head sensor has addressed this issue for subsequent deployments.

  Aside from some of the typical troubleshooting that accompanies the deployment of manned geometry measurement systems and the two issues highlighted above, the FRA’s ATGMS was found
to be reliable over the deployment of the system. None of the issues cited above can be attributed to the autonomous nature of the system. The system relies on digital sensor technology for track geometry measurements, eliminating the need for daily calibrations required to address drift in analog sensors. Where reliance on digital sensors is not possible, namely the tachometer located on the end of one of the axles, self-calibration procedures have been implemented to extend the time between system calibrations.

A key aspect of the ATGMS is keeping lenses used in optical sensors clean from dirt and debris to maximize the quality of the data. The FRA ATGMS employed a film-based optic protection system. This approach was shown to be effective, but changes can be made to improve the logic used to advance the film to maximize film service life and the ease at which those changes can be made. These changes are planned for future deployments.

Plans are in place for improving system reliability through the enhancement of health monitoring features deployed within the system. The number of internal checks will be increased and automatically monitored and interrogated in order to provide a more comprehensive look at system health and data quality than was done with the prototype system. In future deployments, reports summarizing any detected system issue will be emailed to key personnel so that the overall operation of the system can be monitored and corrected if required.

CONTINUING DEVELOPMENT OF ATGMS

Current Activities

The removal of the ATGMS from Auto Train service represented the end of Stage 1 development and activities are under way for Stages 2 and 3. A summary of these activities are as follows:

- Stage 2 Development – In August 2011, the FRA’s prototype system was transferred to DOTX 221, a passenger car employed within the FRA’s Automated Track Inspection Program. The system will be
run in parallel with the FRA’s DOTX 220 inspection vehicle to allow for comparison of geometry data collected with the autonomous system to geometry data collected with a typical manned geometry system over a wide range of track conditions for evaluation purposes and additional system development.

One of the main benefits of increased inspection frequencies is the ability for railroads to monitor changing track conditions and identifying issues prior to reaching levels that could lead to track-caused derailments. The vision for ATGMS is one in which railroads deploy multiple unattended systems throughout their network to capture track information during routine movements of revenue service equipment. When used in this fashion, ATGMS must be able to collect, process and deliver overall information on track condition to provide information necessary for detailed trending and degradation analysis. In addition, ATGMS must have the ability to “drill-down” on a section by section basis to allow for observation/reporting on track changes over time as well as the ability to have trending information determined in an automated fashion and delivered to users in a proactive fashion to facilitate preventative action, not reactive action. To realize this vision, FRA will be implementing the following features during Stage 2 development:

- Ability to report track geometry through transmission of “foot-by-foot” data; this feature represents a departure from the current operating scenario in which only exceptions to pre-defined thresholds are communicated in near real-time. ATGMS will maintain the ability to report track exceptions as soon as they are identified;
- The means to automatically conduct reliable and accurate degradation assessments over track that has been traversed during multiple surveys. Results of such degradation analyses will then be able to be reported to project stakeholders for remedial action in a proactive manner;

- Stage 3 Development – In early 2012, FRA plans to deploy a carbody-mounted ATGMS on a typical Amtrak Amfleet car for initial use on the Northeast Corridor. The carbody mounted ATGMS, a concept of which is illustrated in Figure 5, looks to provide the industry a lower cost system design that is more portable, encouraging railroads to consider moving systems of this nature to a variety of
vehicles to maximize the extent of degradation analyses. During this stage, the effectiveness of degradation analyses and comparison of measurements collected with the carbody mounted system and traditional manned inspection systems mounted to trucks will be evaluated.

Figure 5. Early Concept for Carbody Mounted ATGMS for Initial Deployment on Amtrak Passenger Equipment

FRA intends to follow Stage 3 development efforts with demonstrations of fully autonomous inspection systems in freight service and is actively looking for industry participants in this next stage of development.

Technical Challenges

As the FRA ATGMS moves from Stage 1 development into Stages 2 and 3, several technical challenges remain:

- *Automatic Data Filtering* – As cited earlier, automatic data filtering was a major focus of Stage 1 development. It is considered to be a critical aspect of the system for industry acceptance. Even with
the encouraging results generated in the pilot program, it is realized that track features specific to the route over which the system has been evaluated may have an influence on data filtering results. As ATGMS units are run during follow-on demonstrations and evaluations, the creation of efficient and reliable automatic data filtering will continue to be a target for improvement.

- **Location Determination** – A critical aspect to the reporting of suspected track defects, as well as track degradation assessment, is the accurate identification and referencing of track location. Even with use of high accuracy GPS information available in the ATGMS, referencing these track issues with respect to railroad specific features such as Track Number, Track Class, etc., within a given territory presents many challenges. This can be accomplished with the use of highly accurate geo-referenced base maps, which are being developed within the rail industry to meet the needs of Positive Train Control deployments. However, there are many areas throughout the country that this information is not available for at this time and information that does exist is not generally shared for research purposes. FRA is currently assessing methods that can be used to establish specific track location information from existing geo-referenced location information in order facilitate data processing and accurate location reporting in the most efficient manner possible. Whether this detailed geo-reference information is provided via new methods or this information is provided by research partners in the railroad industry, this information will be vital to the accurate identification of location and track class associated with track issues to aide users in taking remedial actions and conducting compliance analyses, as well as degradation analyses, on surveyed track.

- **Data Accuracy Associated with New Technology** – As cited earlier, Stage 3 development will focus on driving technology upon which ATGMS is based towards lower cost and greater portability. As this initiative is undertaken, great care and due diligence must be given to ensuring that sensors, mounting arrangements and other critical elements of the approach result in the same level of data accuracy and reliability as is present with traditional manned automated geometry measurement systems.
• **Energy Harvesting Technology** – To achieve the vision for ATGMS, a system of this nature should be deployable to a wide range of vehicles, including freight cars with no pre-existing means of providing power to the system. To date, the deployment of autonomous inspection technology intended for long-term use has been on cars or locomotives with available power. The FRA is currently evaluating concepts for energy harvesting technologies that can be used in conjunction with an autonomous system that will provide sufficient power for continuous operations for extended periods of service. At this time, it is envisioned that a combination of several approaches, including but not limited to solar, motion generated and wind energy harvesting will all play a part in the Stage 4 development that is crucial for widespread deployment of autonomous inspection technology.

**Procedural Challenges**

Operational issues must be addressed by both potential users and regulators for the introduction of new technology to be successful. Based on lessons learned through the pilot program conducted in Stage 1 development and by railroads that have implemented other autonomous inspection systems, clear maintenance and operational procedures must be established by an operator prior to deployment of an autonomous inspection system. Procedures should be developed for the autonomous system itself to clearly establish the roles of railroad personnel in performing maintenance and calibration activities and safety precautions must be established when lasers (as in the case of the ATGMS) or high voltages are associated with the inspection system. In addition, operational instructions must be created to address any situation in which the inspection system interferes with the operation of systems on the vehicle or the vehicle itself. These considerations, however, are not felt to be major challenges to the use of this technology.

Several key procedural issues associated with the introduction of autonomous track geometry inspection technology remain that still require effort to address:
Data Management and Remedial Actions - The use of ATGMS or other autonomous inspection technology offers many benefits to the railroad industry, including high inspection frequencies, allowing for additional data availability for improved forecasting and trend analysis, and near instantaneous availability of data. This increase in data brings with it several challenges for the railroad, including:

- The increased volume of data resulting from increased inspection frequencies;
- The manner in which information collected with the system will be integrated into on-going inspection practices;
- Validation of events identified by the system given the increased frequency in which data is reported.

Prior to the implementation of ATGMS, a railroad needs to have a clear plan on data usage. As is often done in automated inspection programs, different thresholds are used to identify issues that could grow into exceptions. With increased reporting frequencies, new thresholds may be warranted to identify and monitor issues at earlier stages of development. As was considered with the pilot program discussed here, pilot applications can afford an opportunity for operators to gradually develop response plans, formulate appropriate thresholds where applicable, and grow accustomed to data flow rates. Based on past experience, pilot applications on limited routes can be useful to identify issues and validate the results of the system while minimizing railroad investments.

Confidence in the data reported with this technology can often be bolstered by considering the existence of “repeated events” on consecutive surveys as a validation mechanism. This approach was used in the pilot program conducted under Stage 1 development. Although this represents a logical approach during the initial stages of autonomous inspection deployment, the “awareness” of a potential issue without immediate follow-up action represents a risk. This is an extremely critical issue; it represents the potential for increased liability for the railroad and poses a regulatory issue as well.
• **Regulatory Issues** – Current safety rules were developed based on inspection practices employing visual inspections and automated inspections conducted at intervals that could be considered infrequent when compared to those achievable with autonomous inspection systems. As ATGMS is used as a tool in a quality control process and track degradation is monitored, established practices may need to be reconsidered.

  FRA has acknowledged that current practices and regulations may actually provide a disincentive for implementation of autonomous technology. With an increase in inspection frequency, railroads may be alerted to potential defects with great regularity, and follow-up inspections may prove costly and logistically difficult prior to the next train. Overall improvement in safety due to increased inspection frequency may justify a relief on reaction time or allowance for additional means of validation. A potential solution posed by FRA could involve re-evaluation of appropriate railroad response time and/or action to particular exceptions reported with an autonomous inspection system (1).

  FRA and the railroad industry must work together to develop long-term strategic plans for implementation and use of this technology. FRA continues to work with railroad partners through the various stages of the ATGMS development to address usage issues so that this type of technology can be used to enhance safety and improve maintenance planning with measurable results.

**Closing Thoughts**

The continued development and demonstration of autonomous track geometry inspection technologies is critical to improving efficiency and reducing the number of track caused derailments throughout the railroad industry. FRA looks forward to working with railroad industry members interested in participating in pilot programs or in establishing their own programs centered about this maturing technology to realize the vision of a system for use in quality control and maintenance planning activities.
ACKNOWLEDGEMENTS

The authors would like to thank those in the industry who have supported FRA’s initiatives in deploying autonomous track geometry inspection technology to date. In particular, the contributions and support of Mr. Paul Steets and Mr. Michael Trosino of Amtrak, and Mr. Ronald Bright and Mr. Larry Biess of CSX Transportation in the efforts to develop the FRA’s ATGMS are greatly appreciated. The authors would also like to thank Dr. Magdy El-Sibaie and Mr. Ali Tajaddini for their vision and leadership throughout the ATGMS research program.

REFERENCES


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Overview

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- Vision for Autonomous Track Geometry Inspection Technology
- Overview of FRA ATGMS Research Program
- Accomplishments to Date
- Current Activities
- Continuing Development Opportunities and Challenges
- Closing Thoughts
What is Autonomous Track Inspection?

FRA’s vision is to improve track safety and maintenance practices by enhancing conditional awareness through the use of *autonomous* inspection systems.

Automated Inspection - Technique by which key track measurements are collected by specialized with trained operators.

*Autonomous* Inspection – Process of inspecting the track from revenue service trains using unattended instrumentation with minimal direct involvement.
What is Autonomous Track Inspection?

Benefits of this approach include:

- Timely identification of potential track issues through more frequent inspections;
- More efficient inspections at much lower overall costs;
- Facilitates proactive maintenance, reducing slow orders and emergency repairs.

Every train movement presents an opportunity to assess the vehicle and track system . . . .
Vision for Autonomous Track Geometry Inspection

FRA R&D’s vision for Autonomous Track Geometry Measurement System (ATGMS):

- Relatively low cost;
- Able to collect/disseminate accurate track geometry data while installed on a standard revenue train;
- Self-powered;
- Deployable on wide range of equipment, including standard freight cars.

*ATGMS technology is designed to enhance, rather than replace, traditional inspection methods.*
Overview of FRA ATGMS Research Program

Development Plan for FRA ATGMS research program:

- **Stage 1:** Long-Term Pilot with Standard Inspection Technology to Establish Baseline Performance
- **Stage 2:** Revenue Operations Simulation Test
- **Stage 3:** Develop Advanced Measurement Technology
- **Stage 4:** Develop Energy Harvesting Technology
- **Stage 5:** Demonstrate in Freight Service

*Partnerships with railroads and equipment owners are a critical aspect to the success of the Development Plan.*
Overview of FRA ATGMS Research Program

Technical Approach

Onboard Unit

Location Determination
- HDGPS with Inertial Navigation

On-Board Processor
- Data collection/analysis
- Remote diagnostic capabilities
- Remote software enhancements
- Remote/self-recovery

Geometry Measurement Sensors

Processing Server

Cellular Communication Link

Database

Inspection Results
Overview of FRA ATGMS Research Program

Data Management and Reporting

- Autonomous Track Geometry Measurement System
- Data Selection
- GIS Map
- Foot-by-Foot Geometry
- Google Map
FRA deployed its pilot ATGMS early in 2008 on Amtrak’s Auto Train running on CSX track:

- Remote assessment of track geometry conditions;
- Alert/alarm message with location, time and exception description when specific thresholds are exceeded;
- Periodic status reports and vehicle location information available through secure Web access;
- Advance exception filtering and data correlation and trend analysis.

Through March 2011, pilot system surveyed over 460,000 track miles.
Accomplishments to Date

Stage 1 Development

FRA pilot ATGMS is capable of producing replicable data:

<table>
<thead>
<tr>
<th>Survey</th>
<th>Gage Measurement (in)</th>
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<tr>
<td>Run 1</td>
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<td>Run 7</td>
<td>55.82</td>
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Accomplishments to Date

Stage 1 Development

Advanced data filtering has been a significant effort in Stage 1:

- ATGMS Exception Generated
- Exception-to-Waveform Selection
- Peak-to-Peak ($S_{PK-PK}$)
- Noise (N) and Frequency (F) Computations
- Validity Computation
- Output: ✓ VALID  ❌ INVALID

$f(S_{PK-PK}, N, F)$
Accomplishments to Date

Stage 1 Development

Pilot ATGMS is mechanically safe and reliable:
Current Activities

Targeted improvements building upon Stage 1 success:

- Transfer of foot-by-foot geometry data in addition to distinct track geometry exceptions;
- Implementation of track degradation tools to analyze repeated surveys;
- Improvements to film-based optical protection system;
- Enhanced diagnostic health monitoring to improve knowledge of system operational status and potential data quality issues.
In August 2011, FRA deployed its pilot ATGMS on DOTX 221 for evaluation around the country in revenue service; efforts focuses on:

- Comparison of geometry data collected with the autonomous system to geometry data collected with a typical manned vehicle system over a wide range of track conditions;
- Regular transfer of foot-by-foot track geometry through cellular transmission;
- Establishment of degradation analysis tools.
Stage 3 Development:

In January 2012, FRA is planning to deploy a carbody-mounted ATGMS on Amtrak equipment:
- Lower cost, “portable” system design;
- Data comparison with traditional systems.
Development Opportunities & Challenges

- Improvements to Automatic Data Filtering – Current levels of performance can be improved as algorithms are trained with additional data;

- Location Determination – Location information (e.g. DGPS, etc.) are highly accurate, efficient translation of this data into railroad features (track #, track class, etc.) requires detailed information. **Railroads can be instrumental in meeting this challenge;**

- Data Accuracy Associated with New Technology – Accuracy of data collected with these systems must be on same order as that collected from traditional systems;

- Energy Harvesting Technology – A solution involving multiple approaches may be required to achieve vision.
Development Opportunities & Challenges

Procedural Challenges:

- Data Management and Remedial Actions – Increase in data resulting from autonomous inspection brings several challenges, including:
  - Vast amounts of information that must be considered;
  - How autonomously collected data will be integrated with existing practices and protocols;
  - Field validation of events/observations, especially at the onset of the autonomous inspection program

Clear plans on data usage should be developed that address thresholds to identify multiple defect levels, procedures to monitor growth rates and appropriate remedial actions.

Pilot studies over selected territories will be useful in developing revised procedures.
Continuing Development and Challenges

Procedural Challenges:

- Regulatory Issues – Current regulations present challenges to rapid deployment and long-term usage of systems of this nature:
  - Largely predicated on infrequent but detailed automated and visual inspections;
  - With increases in inspection frequencies, railroads may be alerted to potential defects with regularity, but follow-up inspections may prove to be costly and logistically difficult prior to the next train.

FRA and industry must work together to develop long-term strategic plan for implementation and usage.

Overall improvement in track safety may justify a relief on reaction time or alternate means of validation.
Continued development and demonstration of autonomous track geometry inspection technologies is critical to improving efficiency and reducing the number of track caused derailments throughout the railroad industry.

FRA’s research program is focused on the development of relatively low cost, self-powered systems capable of providing highly reliable data from virtually any rail vehicle to improve safety and enhance awareness.

FRA welcomes the opportunity to work in partnership with the industry to ensure that progress is made in the development and use of this crucial technology.
Acknowledgements

- Amtrak:
  - Mr. Paul Steets
  - Mr. Michael Trosino

- CSX Transportation:
  - Mr. Ron Bright
  - Mr. Larry Biess

- FRA Office of Railroad Policy and Development
  - Dr. Magdy El-Sibaie
  - Mr. Ali Tajaddini