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IMPLEMENTATION OF ADVANCED TRACK GEOMETRY FORECASTING MODELS

SUMMARY

In 2022, the Federal Railroad Administration (FRA) contracted ENSCO to implement previously developed forecasting models for autonomous track geometry measurement systems (ATGMS) into an operational environment. This report describes the improvements to the track geometry foot-by-foot filtering and forecasting methods originally developed under those previous, FRA-funded research efforts (Sandikcioglu, 2024).

To accomplish the objectives, the research team needed to make several improvements. For example, the team optimized the filtering method to increase processing speed and accuracy and then validated its effectiveness. The team also modified the previously developed forecasting methods to deploy them in the production data management environment of the partner railroad. This effort developed logic to determine which segments of interest should be selected for foot-by-foot forecasting. Further, the team modified database structures and data resampling to allow for a more time-efficient forecasting process.

BACKGROUND

Predicting track geometry signatures and, in turn, defects can play a key role in proactively addressing safety issues before they become problematic. Previous FRA research developed and validated advanced analytical models suited for autonomous measurement processes, namely foot-by-foot surface and alignment track geometry.

In this current effort, ENSCO automated the process that accurately predicts long-term track-related issues so it could be implemented in a revenue service environment. This automation expands the capabilities and application of ATGMS and its data products.

OBJECTIVES

The first objective of the research was to improve the effectiveness and applicability of the previously developed filtering algorithm for use in real-time applications. The second objective was to improve and adapt the foot-by-foot geometry forecasting methods for implementation in an operational environment in partnership with a Class I railroad.

METHODS

IMPROVEMENTS IN FILTERING

To achieve the first objective, the research team enhanced the efficiency of the previously developed Hampel-Lowess filter for mid-chord offset (MCO) channels. It is a robust filter for removing signal anomalies. The filter is based on the Hampel identifier (for outlier detection) and Lowess smoothing (for signal reconstruction) techniques. The Hampel identifier uses a statistics-based approach to detect outliers and replace them with a more representative value. The output of the Hampel identifier is then used as an input for the Lowess smoothing filter. The Lowess smoothing filter uses a moving window for local regression calculations and a weighting function to reduce the effect of outliers.

In this effort, the research team revised the existing filter algorithm to improve speed and accuracy, which made it easier to implement the filter into a real-time process.

The research team also assessed the filtering algorithm's impact on track geometry exception reporting through a comparative analysis. For this assessment, they used three surveys from FRA's Automated Track Inspection Program (ATIP), each from a different inspection vehicle. The combined length of these surveys was over 700 miles. The team then compared track geometry exceptions, manually reviewed by ATIP personnel for erroneous values, with exceptions produced after applying the Hampel-Lowess filter on the same raw survey data. The exceptions produced from the filtered data were not reviewed separately for erroneous values. The analysis also included exceptions within the following channels: gage, crosslevel, 62- and 31-foot profile MCO, and 62- and 31-foot alignment MCO. The team assessed the filter's performance using the three metrics, explained in the Results section.

IMPROVEMENTS TO FORECASTING APPROACHES

Forecasting foot-by-foot track geometry is inherently computationally intensive. The implementation of a forecasting process such as this with the railroad's entire network and ATGMS fleet is not feasible due to IT-related limitations. Therefore, the research team developed innovative logic to identify segments of interest where the foot-by-foot forecasting would be of best use. The logic combines three individual approaches to identify such segments:

- The first approach leverages peak data predictions based on a methodology developed under previous research efforts (Einbinder, 2024). The approach identifies locations where peaks in the track geometry signal are predicted to surpass a given threshold within a pre-defined timeframe.
- The second approach identifies locations where degradation between the latest track geometry survey and the preceding survey exceed a pre-determined limit.
- The third approach identifies all locations in the most recent survey exceeding thresholds tighter than the limits prescribed by the Federal Track Safety Standards (2024).

The three approaches were applied concurrently, and the results were combined and clustered into one set of segments for foot-by-foot forecasting. Figure 1 illustrates combining the results of the three approaches into one set of segments for forecasting.

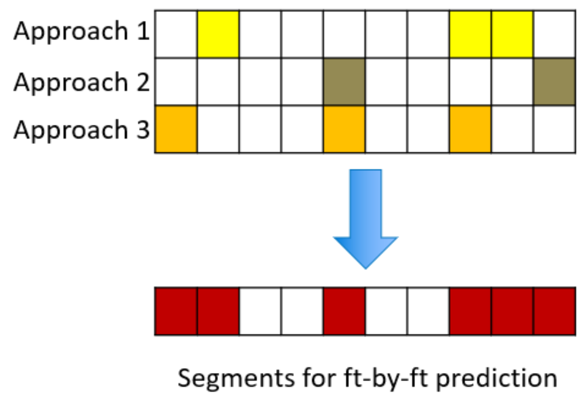

Figure 1. Combining results of segment identification for foot-by-foot forecasting

Another critical aspect of the foot-by-foot forecasting is proper alignment of the survey data. The research team previously developed an automated process for aligning the data under previous FRA research efforts (Einbinder, 2024). However, this approach relies on shifting data and modifying the distance between individual samples to achieve the alignment. This results in data points not having the same linear distances from fixed reference points in subsequent surveys. Therefore, the team needed to implement a resampling method. The method uses interpolation regression to calculate resampled values in all surveys used for forecasting. Location of data points in the most recent survey are used as reference. By design, this process maintains proper alignment across all surveys achieved by the alignment algorithm developed under previous efforts (Einbinder, 2024). Figure 2 shows the resampling process.

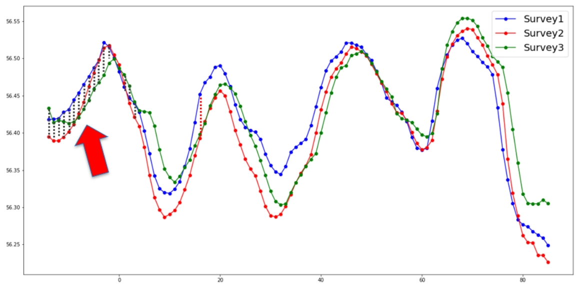

Figure 2. Resampling method maintaining proper alignment

RESULTS

After optimizing and configuring the Hampel-Lowess filter, the research team evaluated its performance using 851 exceptions from the three ATIP surveys, of which 253 were confirmed as valid exceptions, and 598 were manually deleted by ATIP personnel as shown in Table 1. The metrics the team used to evaluate the filter performance were:

1. Number of ATIP manually confirmed exceptions that were incorrectly removed by the filter
2. Number of ATIP manually deleted exceptions that were also correctly removed by the filter
3. Number of ATIP manually deleted exceptions that were not removed by the filter because:
   a) The filter was not designed to remove them
   b) The filter did not perform as expected

The common exceptions that the filter is not designed to remove include the presence of rail lip (for gage channel), incorrect curvature assignment (for crosslevel channel), diverging route in turnout (for alignment channel) and erroneous, longer-wavelength signatures (all channels).

Table 1. Filter Assessment Exception Counts

	Total Unedited Exceptions	Confirmed Exceptions	Manually Deleted Exceptions	1	2	3a	3b
Gage	81	5	76	0	58	16	2
Crosslevel	133	24	109	0	1	108	0
Profile 31 or 62	260	118	142	1	31	109	2
Alignment 31 or 62	377	106	271	0	41	227	3
Total	**851**	**253**	**598**	**1**	**131**	**460**	**7**

The key results are summarized as:

- The filtered surveys did not generate any new exceptions that were not generated as part of the ATIP process.
- One of the 253 confirmed exceptions was removed by the filter. Upon further investigation, the research team determined that this exception should have been deleted by the ATIP operator. Therefore, the filter actually removed this exception correctly.
- The filter did not remove seven exceptions it was expected to remove. This is 5 percent of the 131 cases that were correctly removed by the filter.

The 460 exceptions in column 3a that were not deleted by the filter are not false positives. The filter was not designed to detect these types of incorrect exceptions. The exceptions included section of rail lip, one shallow curve that was incorrectly assigned as tangent and multiple alignments detected in diverging turnout routes. Automatic editing of such exceptions is addressed by separate approaches.

The research team tested the custom logic to resample and identify segments for forecasting in offline mode. The testing modified linear references while still maintaining the required alignment for implementation in the revenue service data management environment.

CONCLUSIONS AND FUTURE WORK

The research team successfully modified the filtering algorithm to ensure its seamless integration into the predictive analytics process. Further, they were also successful in optimizing the Hampel identifier. This resulted in a ten-fold increase in processing speed. The Lowess filter was optimized as well, which doubled its performance speed. Lastly, the research team adjusted the filter threshold and configuration settings to improve the overall accuracy of the filtering process. The evaluation of the improved filter algorithm showed that it correctly edited exceptions produced on the ATIP vehicles in 95 percent of the cases where it was designed to do so.

The next step in the effort is to implement all the methods in the railroad partner's data management system and begin periodic reporting.

REFERENCES

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