



SOFTWARE INNOVATION FOR ADVANCED APPROACH TOWARD MODERN RAILWAY MAINTENANCE PROJECTS

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Abstract

Modern software solutions for rail infrastructure design and maintenance need to match high corporate expectations searching for the ease of use of such solutions with highly reliable results, provided in comparison to an overall financial assessment dedicated to the rail design and maintenance sector. Today's software solutions with complex mathematical tools and advanced algorithms implemented, enable users to design and maintain railway infrastructure faster, more precisely, and with extensive resources saved whilst aiming to obtain or increase overall railway safety.

Within our company's research department extensive effort to design and produce a state of the art regression tool for the alignment position calculation was carried out. The scope of developing the tool was to bind the large amount of data from different corporate database sources as well as the in-the-field data gathering processes into a digitally incorporated design which enables delivering the best alignment layout position calculated with least squares regression method. The use of this tool represents significant savings of time and efforts for achieving the best alignment layouts from different data sources and extends its value with vast connectivity, digital data transfer possibilities and extensive use of designed alignment layout. The tool itself represents a big step forward in alignment design since it manages to calculate and design tangent, curve, as well as all needed spiral characteristics at once for minimal track deviation and realignment needs. Furthermore, updating complex railway databases for the up to date data availability of design changes greatly increases the production of other infrastructure sectors allowing them to use always updated and consistent data. The developed regression tool can be easily applied to other infrastructure design fields such as road design and maintenance, light rail and underground design, GIS (data survey) fields and others.

1 Introduction

Today's railway infrastructure consists of an enormous amount of existing rail tracks that are in use on daily basis. These will continue to be in use for decades more. In order to deliver high capacity and services with high level of security these tracks need to be maintained, realigned and reconstructed following a regular schedule. Therefore continuous work on rail track condition needs to be carried out. Since these works represent significant amount of time and financial assets investment, great effort in providing new technologies to optimize those assets is invested. Common goal of new technologies development is usually a matter in reducing the total cost of ownership while providing same or better results as currently available technology. The essential desire for achieving these goals is to enable fast and accurate design and maintenance works with the establishment of comprehensive digitalized process workflows from data acquisition, surveying projects, through design, analysis and processing of digital data sets, data sharing and managing and maintaining to corporate databases

management. Therefore in order to provide and establish optimized workflow and processes investment in specific/specialized tools for optimizing particular reiterative procedures is continuously going on. One of such specialized tools is a subject of this paper.

Since large survey projects which provide exact and up to date information of a complete (railway) infrastructure involve significant, yet inevitable, investments they still represent only the core data acquisition which involves a large quantity of labor work and time spent with data post processing and management activities. Furthermore with development of new data acquiring technologies the amount of data sets is continuously growing and improved post processing tools and workflows need to be developed in order to master complete data set management.

Within our company's development for computer aided design solutions we have invested great effort in providing a tool that would make some specific tasks much faster and much more accurate. The task was to design an alignment or profile based on existing rail track information in order to achieve the digital alignment information that could be used in design, realignment and maintenance works on the rail track plus adding the ability to update corporate GIS solutions with accurate and up to date alignment information. We based our tool on the subject of constructing the best fit alignment or profile completely automatically with least squares analysis method that would provide accurate results with exceptional amount of time and effort saved. The input data for this analysis tool could be provided from on track surveyed data projects or from existing corporate database rail track position information.

For the purpose of this paper one example of the best fit alignment tool use for the rail track realignment projects where there is no existing digital alignment or profile information available will be presented. The input data for this case are surveyed points (x_i, y_i, z_i) of left and right rail position along an existing rail track. When surveyed points of a longer part of existing rail track (which consist of tangent, spiral and curve elements) are achieved the tool needs to calculate all the given surveyed points data and construct a complete alignment with adequate spiral lengths or profile. The tool uses a method of least squares analysis that would provide most accurate results. All this should be achieved in a significantly reduced time frame in comparison to traditional design methods. An additional benefit of the best fit tool is its use within a common CAD environment that extends the scope of best fit calculation with a graphical representation of the work done. The latest may result in extensive additional editing possibilities while adapting all given results to actual design needs and conditions.



Figure 1 Existing railway track survey.

Although there are already many solutions of best fit tools that calculate and represent graphical results of best fit lines or curves there are very few that enable construction of an entire alignment with correspondent spiral lengths and overall alignment slew diagrams. This evidences that these type of tasks are difficult to achieve. Even more, implementation of these kind of solutions that would satisfy wide civil design requirements worldwide prove to be a demanding task. An example of how this has been overcome is given in an example where a horizontal best fit alignment calculation method (taking in consideration only the x_i, y_i parameters of surveyed points) was used.

2 Task description

A typical data input into our tool would be an unordered set of survey points $\{(x_i, y_i)\}$. These points can either be pairs (easting, northing) when working with horizontal alignments or (station, elevation) in case of vertical profiles.

#	Station	Easting	Northing	PK	DP	PK	DP	PK	DP
445122	477	74215.397	573.621	PK	DP	1216		0	0
445172	980	74216.807	573.587	PK	DP	1215		0	0
445131	028	74222.369	573.925	PK	DP	1201		0	0
445132	412	74231.004	573.925	PK	DP	1200		0	0
445085	900	74240.674	574.295	PK	DP	1193		0	0
445086	522	74251.045	574.293	PK	DP	1192		0	0
445039	602	74266.285	574.667	PK	DP	1184		0	0
445040	166	74269.671	574.666	PK	DP	1183		0	0
444994	450	74286.403	575.029	PK	DP	1176		0	0
444994	893	74287.816	575.052	PK	DP	1175		0	0
444950	827	74303.901	575.423	PK	DP	1169		0	0
444950	274	74302.501	575.372	PK	DP	1168		0	0
444908	146	74314.455	575.711	PK	DP	1161		0	0
444908	117	74313.912	575.759	PK	DP	1160		0	0
444865	132	74323.333	576.088	PK	DP	1152		0	0
444865	358	74324.820	576.090	PK	DP	1151		0	0
444820	290	74329.142	576.392	PK	DP	1144		0	0

Figure 2 Typical data input.

The first task is sorting the points to get a reasonable order where the points follow each other in the most logical way. This task itself is not simple because it is not always obvious what the most logical order would be (e.g. the points can be dispersed around too much, like a cloud). But for the purposes of this article we can assume that the points are already ordered in a list $[(x_i, y_i)]$, $i=0, 1, 2, \dots, N-1$.

The tool also supports two sets of points as input data, which is useful to represent railway tracks or road edges for example. This form of input data can be translated to only one list of points by finding the centre line between both point sequences (assuming that the points in each sequence are already ordered). When the distance between both point sequences is known and doesn't vary too much along the whole length (e.g. railways), the input points can all be passed as one single set and the centreline as well as both point sequences can be obtained automatically, otherwise the user has to specify which points belong to one sequence and which ones to the other. In any case, we can still assume for the purposes of this article that the input to the algorithm is one ordered list of N points.

The goal of the algorithm is to find an alignment made of arcs, lines and possibly spirals that would fit the input points as much as possible - meaning that the overall error e (average perpendicular displacement of all points (x_i, y_i) from the alignment) is as small as possible. Our goal is to minimize the overall error e , where (x_{pi}, y_{pi}) is the closest point on the alignment from (x_i, y_i) .

$$e = \frac{1}{N} \sum_{i=0}^{N-1} \sqrt{(x_i - x_{pi})^2 + (y_i - y_{pi})^2} \quad (1)$$

We have chosen the following way to do this. The entire procedure is based on the least squares analysis in many different ways and several numerical methods are used to perform it, see [1] and [2]. Generally on various steps of the algorithm $y=f(x)$ is a fitting function that we are looking for and that best fits some data (x_i, y_i) . Error $e(z)$ is a function of parameters $z=[z_0, z_1, \dots, z_{m-1}]$ that directly determine the fitting function $f(x)$. Using the least squares regression the algorithm finds the best set of parameters z that minimizes the error e . The condition for $e(z)$ to be a minimum is:

$$\nabla e = \left(\frac{\partial e}{\partial z_0}, \frac{\partial e}{\partial z_1}, \dots, \frac{\partial e}{\partial z_{m-1}} \right) = \vec{0} \quad (2)$$

First it is necessary to determine where the curves and lines are in the input point list. The algorithm calculates the curvature in each point, this way obtaining another list of points $[(d_i, K_i)]$, which is a curvature curve (d_i is the station of the point i calculated as the sum of the distances between all points $(j-1)$ and (j) , $j=1, 2, 3, \dots, i$ from the beginning to the point i). The

curvature K_i of a point (x_i, y_i) and its k neighbouring points ($k>0$) on each side can be calculated by fitting the least squares circle to these $2k+1$ points, where $K_i = D/R$, R is the calculated radius, and D is the orientation of the circle (either $+1$ or -1). Fig. 3 shows an ideal curvature curve calculated from a sampled alignment with 3 curves by taking only two neighbouring points for each point ($k=1$).

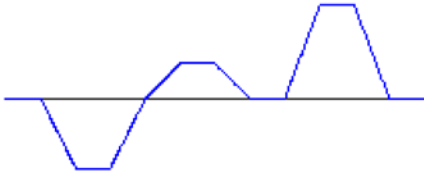


Figure 3 Ideal curvature curve of an alignment with 3 curves.

As one can see in the Fig. 3, it would not only be possible to determine where the curves and straight parts are, but also the spirals, if only the data were ideal. In reality the data are never so accurate. The Fig. 4 shows the curvature curve obtained from a real example. Sometimes even a human eye cannot distinguish circles from lines, let alone spirals.



Figure 4 Curvature curve of a real example.

There are many reasons why the curvature of an existing line can never be ideal, i.e. the original alignment itself might already be distorted, survey points are never entirely accurate, there may not be enough survey points or they are too far away from each other... If there are not enough survey points, entire horizontal elements might be lost between two consequent samples. One can see that three points uniquely define a circle; meaning that the least squares circle regression requires more than three points for each curve. Therefore it is necessary to make sure that the sampling interval is not too long (and not too short as the calculation may be slow). Taking more than 3 neighbouring points to calculate the curvature can improve the results. The algorithm automatically finds the most appropriate number of points on each step that give the best estimate for the curvature, filters the result afterwards to remove spikes and using another form of the least squares analysis it approximates the curvature to get a smooth curve similar to the one in Fig. 3.

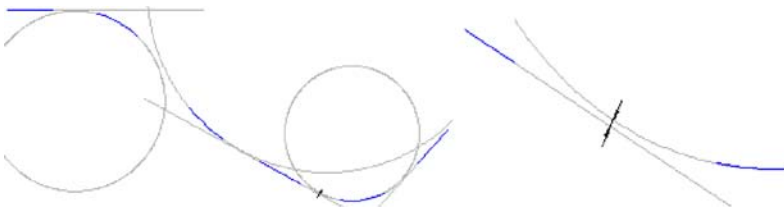


Figure 5 Reconstructed circles and lines in an ideal case and a p-shift.

Now the algorithm has an idea what kind of elements there are and where they are located in the original list of points, so it can start reconstructing them. Using the least squares regression it reconstructs the circles and lines first. Ideally we would get some circles and some lines between them, like in the Fig. 5. If there are spirals in the original alignment, we get p-shifts between lines and circles that uniquely define the spirals. Now it is only necessary to connect the elements in the correct order to get the alignment.

Obviously this only works with ideal or very good input data sets. Otherwise there are many issues that can arise. A number of these are listed below:

- Neighbouring circles can intersect. This is allowed when they have the same direction and the parts that will become arcs in the resulting alignment don't intersect. Otherwise they cannot intersect.
- Neighbouring circles can lie inside each other. This is not allowed at all.
- Lines can intersect one or both neighbouring circles. This is not allowed as the p-shift can only be equal or greater than 0 (0 means no spiral there).
- The distance between a line and its neighbouring circle (p-shift) can be too big, meaning that the calculated spiral would be too long to fit between the neighbouring elements.
- There can be no line between two consequent circles. This is an entirely valid solution as there might be no line or even no spirals between two arcs in the original alignment.
- There can be no circle between two consequent lines. This is not allowed.

The algorithm tries to adjust the elements in order to fix the above issues, but the description of these methods would exceed the scope of this article. In some cases it eliminates the problematic elements, meaning that in the worst case, when all elements are eliminated, the resulting alignment would only be a single line calculated to best fit all the input points. The described method can only reconstruct spirals if there are p-shifts greater than 0 between circles and lines. No line between two circles means that there will be no spiral. The p-shift directly determines the length of such a spiral, which means that the length of the incurve and outcurve spiral will typically be different (or there will even be only one of them). There is another method that produces symmetric incurve and outcurve spirals. The idea is to ignore the lines obtained from the regression analysis in the above procedure and replace them either by tangents or cross tangents between each pair of circles (depending on their direction). This way we get an alignment without any spirals, which can also be useful in some cases. But given a user-defined spiral parameter A it is also possible to calculate a new circle with symmetric incurve and outcurve spirals that best fits the same input points and preserves both tangent directions. Again, a more detailed description of this procedure would exceed the scope of this article. The above algorithm can also work with vertical profiles. A vertical profile with circular arcs is only a simplified horizontal alignment with no spirals where x represents the station and y the elevation of a point and where $x_i > x_{i-1}$ for all i . In case of parabolas instead of circular arcs the regression analysis, element adjusting and everything regarding circles in the above algorithm needs to be done for parabolas instead.

Another difference between vertical profiles and horizontal alignments is that vertical profiles are more likely to have a straight line between all consequent curves and that these lines are longer than the curves and therefore more important to minimize the error. As the above algorithm favours curves, it seems logical to develop another method that would favour lines. The basic idea is the same, except that the circles are ignored and the lines reconstructed. They are extended to intersect their neighbours and the intersections form vertices where rounding's (parabolas or circular arcs) are to be inserted using the least squares analysis on the points belonging to a given intersection between both lines.

3 Tool implementation and use

The field of use of such tool or solution could be very wide and covers specific rail maintenance and design projects, road design and reconstruction projects, traffic analysis tools and other. While computing best fit alignment for rail track design projects based on existing axis data layout position (one set in layout information per station) or existing rail position (two data set layout information; one for left rail position, second for right rail position per station) the tool also works on break line definition (e.g. given road edges information) and other input information. Furthermore with the usage of the tool for designing best fit profiles it enables a creation of complex 3D models of rail or road geometry which extends the applicable field

further on. For example visibility designs checks, simulations and other. The tool enables a fast alignment layout result achievements and offers extensive design edit possibilities which can answer wide design requirement and conditions. In comparison to common design procedures it can save great amount of time while providing same or better results that could be normally achieved by standard user procedures and techniques. It may not substitute design experiences and specific design conditions but it significantly optimizes all alignment creating tasks which are based on existing track layout position. It offers great time and effort savings which may result in more accurate results analysis.



Figure 6 Created best fit alignment result based on existing rail track survey.

4 Conclusion

Currently the tool enables an advanced best fit alignment and profile creation, providing satisfying results which can be improved with the user having the ability to extensively edit automatically designed alignments. With use of the tool in various design offices and receiving positive responses about its use and its results, we found even more space for improvements. With additional artificial intelligence implemented, the tool could produce even more outstanding results in current projects as well as it could also support some more difficult examples of data inputs where it might be able to compute the correct road center line in parts where lateral lines are widened, prioritize tangent creation in data sections where the cant value is zero, consider user defined fixed elements or point through where alignment needs to be designed, implement weighted rule definition for more/less important points or elements, and lastly the best fit tool could check different country standard definition, and prioritize elements creation based on standards minimal and maximal allowed parameters definition.

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