The Recognition of Roadbed Based on Fuzzy Etalons

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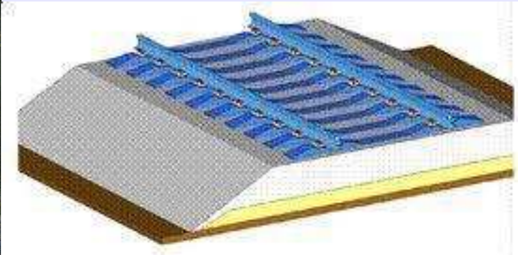
Nowadays there are several program systems that allow to monitor automatically railway roads. These systems give possibility to find defects linked with the track structure, gabarite dimensions, rail cross profiles, etc.



Problem

The development of roadbed profiles recognition system that is then used for detection of roadbed defects, like non-normative breadth of ballast shoulder, non-normative breadth of roadbed shoulder, places of oversized angles of slope.

Outline of presentation

1. Data description: cross profiles of roadbed
2. Fuzzy descriptions of etalon profiles
    - features for describing profiles
    - fuzzy restrictions described by fuzzy numbers
    - the construction of fuzzy sets for etalon classes based on aggregation functions
3. The recognition of cross profiles based on fuzzy etalons
4. The computation of decision functions based on probabilistic genetic algorithm
5. Experimental results
6. Summary and conclusion

Data description: cross profiles of roadbed

This problem can be solved by comparing the measured profile with the normative profile according to the design decision. If the design decision is not known we need to recognize the measured profile using the set of all possible etalon profiles. In this case we have the set of etalon profiles that correspond to different types of roadbed that can be classified as ditch cuts, embankments, tunnels, etc.

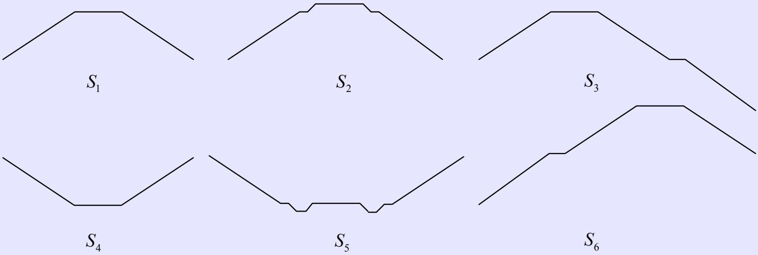


Fig: Examples of etalon profiles.

Fig: Laser scanner on train (http://nipistroytek.ru/).

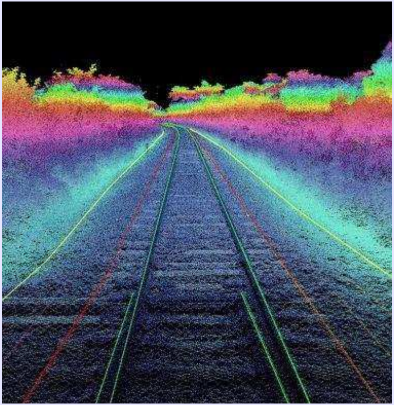


Fig: Points cloud (http://www.artescan.net/).

The results of laser scanning of railway roadbed are the data for recognition and classification.

Fig: Real initial profile of railways roadbed.

Data

- points cloud;
- the 2000-3000 points are in the initial profile of railways roadbed;
- the 6-10 classes of different normative profiles;
- the profiles data are normalized with respect to scale and rotation.

Requirements

- on-line processing on the high speed of movement scanner;
- there are large and lot distortions of profiles.

Feature points of roadbed profile

The analysis of the cross profile of the roadbed assumes that we need to extract feature points, whose positions determine the basic characteristics of the roadbed. The feature points are points corresponding to edges of upper and lower surfaces of embankment (ditch cut) of the roadbed and the ballast section. These points can be extracted by the statistical method of recovering profile.

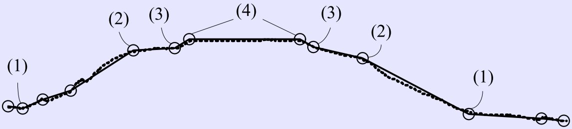


Fig: Profile, polygonal representation and feature points: (1) the edge points of the bottom surface of the embankment edge, (2) the edge points of the upper surface of the embankment edge, (3) the edge points of lower surface of ballast section; (4) the edge points of the top surface edge ballast.

Fuzzy descriptions of etalon profiles

Why we need to use fuzzy sets? - The profiles have dimensions that can vary within intervals, for example, the length of ballast section may be from 2.1 to 2.5 meters, the height of embankment depends on typical designs and may be from 6 to 15 meters.
We assume that profiles, belonged to the same etalon class, can be described by polygonal representations Y_i with the same number M of points. We denote the set of all such polygonal representations by $\mathcal{Y}$.
Then the fuzzy representation of an etalon class is a fuzzy set S defined by a mapping $S : \mathcal{Y} \to [0, 1]$.
After analyzing the normative documentation we discover that each etalon class can be characterized by features that correspond to segments of a polygonal representation. Assume that $Y = \{\mathbf{y}_1, \mathbf{y}_2, ..., \mathbf{y}_M\}$, then these features are the following:

Features for describing profiles

1. $(\mathbf{y}_{i+1})_x - (\mathbf{y}_i)_x$ is the projection of the segment $(\mathbf{y}_i, \mathbf{y}_{i+1})$ on Ox axis;
2. $(\mathbf{y}_{i+1})_y - (\mathbf{y}_i)_y$ is the projection of the segment $(\mathbf{y}_i, \mathbf{y}_{i+1})$ on Oy axis;
3. $\frac{(\mathbf{y}_{i+1})_y - (\mathbf{y}_i)_y}{(\mathbf{y}_{i+1})_x - (\mathbf{y}_i)_x}$ is the tangent of the segment slant.

We will assume next that the system of features has to define the polygonal representation uniquely. It means that for any segment it is sufficient to know two features, the rest one can be easily computed using known ones. After that based on experts opinions and using normative documentation it is possible to describe the possible values of features. It can be done by using fuzzy numbers.

Fuzzy restrictions described by fuzzy numbers

For example, we want to describe the possible values of the ballast section length for a single track. According to the normative documentation this value should be equal to 2.3 meters. But for the real track this value can vary within $[2.1, 2.5]$, and the length outside this segment should be considered as defect of the track structure. The degree of such defect can be described by the fuzzy set $F_i : \mathbb{R} \to [0, 1]$:

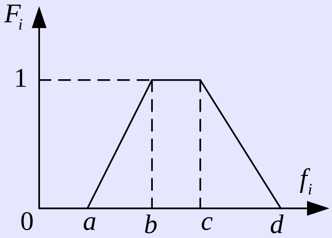


Fig: Fuzzy set representation of possible feature values.

This is so called trapezoidal fuzzy number of $L-R$ type, and it can defined analytically as

$$F_i(x) = \begin{cases} 0, & x \in (-\infty, a] \cup [d, +\infty], \\ 1, & x \in [b, c], \\ (x-a)/(b-a), & x \in (a, b), \\ (d-x)/(d-c), & x \in (c, d). \end{cases}$$

Then for the feature "length of ballast section" we can choose $b = 2.1$, $c = 2.5$. The criticality of the feature value being outside the segment $[b, c]$ is described by parameters a and d. For our example, we can take $a = 1.9$ and $d = 3$, since exceeding the admissible value for the length of ballast section is less dangerous than its dropping below the lower bound.

The construction of fuzzy sets for etalon classes

Let us assume now that for any etalon profile we have build the system $\{f_1, ..., f_n\}$ of features and possible values of each feature f_i are described by the fuzzy number F_i. Then one among general approaches for choosing the mapping $S : \mathcal{Y} \to [0,1]$ is to use aggregation functions. By definition $\varphi : [0,1]^n \to [0,1]$ is an aggregation function if

1. $\varphi(0, ..., 0) = 0$, $\varphi(1, ..., 1) = 1$ (norming);
2. $\varphi(x_1, ..., x_n) \leqslant \varphi(y_1, ..., y_n)$, if $x_i \leqslant y_i$, $i = 1, ..., n$ (monotonicity).

For a given aggregation function φ the mapping $S : \mathcal{Y} \to [0,1]$ is constructed by the formula:

$$S(Y) = \varphi\left(F_1(f_1(Y)), ..., F_n(f_n(Y))\right).$$

The use of linear aggregation function

If features don't interact each other, then the aggregation function is linear and it is defined as $\varphi(x_1, ..., x_n) = \sum_{i=1}^{n} w_i x_i$, where weights w_i, $i = 1, ..., n$, are chosen non-negative and $\sum_{i=1}^{n} w_i = 1$. Let us notice that features that defined parameters of segments in polygonal representations can be perceived as on-interactive, thus, it is possible to choose a linear function for aggregating them.

The choice of w_i is connected with the importance of these features for describing the roadbed. As a rule, the most important features are features that describe the upper road track, but the features that describe the far located objects from the center line of the track can be considered as less important.

The recognition of cross profiles based on fuzzy etalons

The problem statement

We have

- a polygonal representation $X = \{\mathbf{x}_1, ..., \mathbf{x}_N\}$ of the measured profile;
- the set of fuzzy set based descriptions of etalon profiles $\{S_1, ..., S_K\}$.

Using this information we need to construct the decision functions $d(X, S_k)$, allowing us to make a decision "X is belong to the class S_m" by the rule:

$$d(X, S_m) \leqslant d(X, S_k) \text{ for all } k = 1, ..., K.$$

Type of data

- Fuzzy set based descriptions S_i polygonal representations can differ by number of points in corresponding polygonal representations.
- the number of points in a measured profile can be arbitrary.

Solution

Let $X = \{\mathbf{x}_1, ..., \mathbf{x}_N\}$ be a measured profile of the roadbed.
Let $S : \mathcal{Y} \to [0, 1]$ be a fuzzy based description of the etalon profile.
Each $Y \in \mathcal{Y}$ contains M vertices.
Suppose that $\mathcal{Y}_X$ is a subset of $\mathcal{Y}$ that contains all profiles with M vertices such that each vertex of any $Y \in \mathcal{Y}_X$ lay on the segments of profile X.
Let $Y \underset{\leftarrow}{\cup} X$ be a polygonal representation that contains all points of the polygonal representation Y, where $Y = \{\mathbf{y}_1, \mathbf{y}_2, ..., \mathbf{y}_M\}$, and points of polygonal representation X, located between points $\mathbf{y}_1$ and $\mathbf{y}_M$.

Illustration

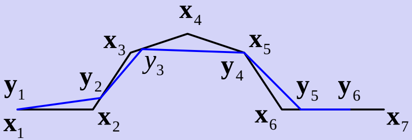


Fig: $X = \{\mathbf{x}_1, ..., \mathbf{x}_7\}$ is a measured profile, $N = 7$,$M = 6$, $Y = \{\mathbf{y}_1, ..., \mathbf{y}_6\}$, $Y \underset{\leftarrow}{\cup} X = \{\mathbf{y}_1, \mathbf{x}_2, ..., \mathbf{x}_6, \mathbf{y}_6\}$.

Solution continuation

The closeness of Y to the etalon profile can be characterized by $S(Y)$. We can measure the quality of approximation using the value

$$(\mu_L(Y \underset{\leftarrow}{\cup} X) - \mu_L(Y)) \Big/ \mu_L(Y \underset{\leftarrow}{\cup} X),$$

where $\mu_L(Y \underset{\leftarrow}{\cup} X)$ is the length of the contour $Y \underset{\leftarrow}{\cup} X$, and $\mu_L(Y)$ is the length of the contour Y.

Solution continuation

Then we define the decision function as

$$d(X,S) = \inf_{Y \in \mathcal{Y}_X} \left(-aS(Y) + b\frac{\mu_L(Y \underset{\leftarrow}{\cup} X) - \mu_L(Y)}{\mu_L(Y \underset{\leftarrow}{\cup} X)} \right),$$

where $a > 0$ and $b > 0$ are parameters that allow us to increase or decrease the priority of approximation quality.

Let us notice that analogous optimization problems are solved in recognition methods based on active contours. In such optimization problems two functionals are used and called inner and outer energies of a contour. The outer energy characterizes the quality of approximation, and the inner energy describes the restrictions on the choice of contour.

The computation of decision functions based on probabilistic genetic algorithm

Preliminary remarks.

Clearly, the computing decision functions is sufficiently hard optimization problem with many local minima, in addition, the differential characteristics of the optimized functional is not good. This does not allow us to use classical optimization methods. Therefore, in this section we introduce the genetic probabilistic algorithm that produces the probabilistic search of local minima.

Assume that the complete and non-redundant system $\{f_1, ..., f_n\}$ of features is chosen for the etalon S, i.e. each profile can be uniquely recovered by values of $f_1, ..., f_n$. Additionally, we have the fuzzy restrictions on the values of features, described by fuzzy sets $F_1, ..., F_n$.

The description of the algorithm

Initial data

To minimize functional:

$$\Phi(Y) = -aS(Y) + b\frac{\mu_L(Y \underset{\leftarrow}{\cup} X) - \mu_L(Y)}{\mu_L(Y \underset{\leftarrow}{\cup} X)},$$

using the following information:

- the measured profile X;
- the etalon profile S defined by the system $\{f_1, ..., f_n\}$ of features and the fuzzy restrictions $\{F_1, ..., F_n\}$;
- for the profile X and each profile $Y \in \mathcal{Y}$ we know the location of the center line of the track.

The description of the algorithm

Step 0

Generate the sample $\{Y_1, ..., Y_N\}$ that satisfies fuzzy restrictions $F_1, ..., F_n$, in a way that the center line of the track for profiles X and $Y_1, ..., Y_N$ have the same location. This is produced by interpretation of fuzzy sets through random sets. (See the paper in proceedings for details.)

Step 1

Profiles $Y_1, ..., Y_N$ are projected on profile X. The sense of this step is in the following. Obviously, each Y_i does not "lie" on the profile X. In order to the above property is fulfilled each profile Y_i is exchanged to its projection $\Pr_X Y_i$. This operation is produced such that coordinates of points along Ox of Y_i and $\Pr_X Y_i$ are chosen the same, but points $\Pr_X Y_i$ should belong to contour X.

The description of the algorithm

Step 2

Compute values $\Phi(\Pr_X Y_i)$, $i = 1, ..., N$, and order the sample such that $\Phi(\Pr_X Y_{i_1}) \leqslant \Phi(\Pr_X Y_{i_2}) \leqslant ... \leqslant \Phi(\Pr_X Y_{i_N})$.

Step 3

Truncate the sample: in new sample we have profiles $\Pr_X Y_{i_1}, \Pr_X Y_{i_2}, ... Y_{i_{N_1}}$, where N_1 ($N_1 < N$) is the parameter of the algorithm. (We can take $N := 100$ and $N_1 := 50$.)

Step 4

The evaluation of feature distributions for f_i, $i = 1, ..., n$, produced by truncated sample $\Pr_X Y_{i_1}, \Pr_X Y_{i_2}, ... Y_{i_{N_1}}$. It is possible to assume that f_i are independent random variables and they are distributed normally.

The description of the algorithm

Step 5

Check the condition of convergence: the value $d(X, S)$ has been computed if the evaluated distribution of each feature f_i, obeying the fuzzy restriction F_i, has been converged to the spotted distribution. If this condition is not fulfilled, then go to Step 6.

Step 6

Generate the sample $Y_1, ..., Y_N$ according to evaluated feature distributions of f_i, $i = 1, ..., n$. Go to Step 1.

Experimental results

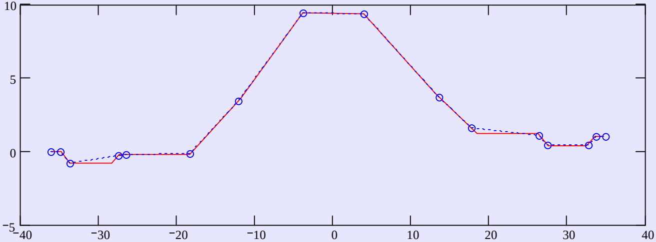


Fig: Processing on simulated data: Red line: initial profile X, Blue line: the projection of constructed etalon profile Y.

Experimental results

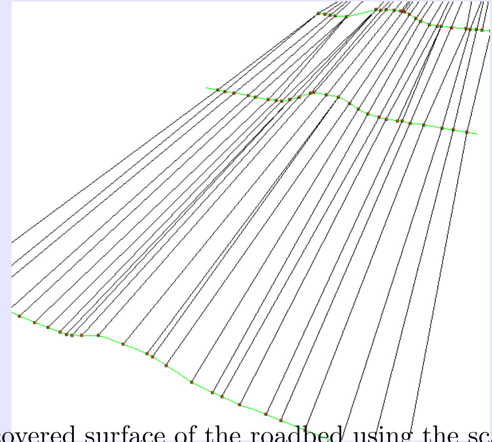


Fig: The recovered surface of the roadbed using the scanning data.

Summary and conclusion

- Tests on simulated data has shown that the method sometimes does not recognize correctly parts of the roadbed located far from the center line of the road track. It is not so crucial because the precision is not so good for recognizing such details using scanning data, where it is possible to have good results by the proposed method for recognizing upper track construction.
- The effective realization of the proposed method depends on the optimization procedure. The features appear to be dependent and the algorithm tries to recognize points of the polygonal representation starting from the center line of the track. If during this recognizing some points are not classified correctly then it recognizes not correctly the next points. Therefore, the next research can be done for improving the optimization procedure which can be realized using pyramid representations.

Thanks for you attention

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