ROAD RESURFACING USING INDUSTRY 4.0 PRINCIPLES

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Abstract

The basic concept of Industry 4.0 is virtualization of reality - creating a digital image of real world and optimizing and planning processes in this virtual environment. The aim is to find the best solutions in a broad relationship with other processes and their realization in the real world.

In the construction industry, Industry 4.0 is only at the beginning phases of utilization, especially the area of a highway reconstruction, which provides an extremely high potential for process optimization. This was confirmed, for example, in the ASFALT project: Advance Galileo Navigation System for ASPHALT's fleet machines (ID: 247976, Funded under: FP7-TRANSPORT).

This paper introduces the methodology of complex robotic and automation process of the pavement repair according to the industry 4.0 principles, which uses Exact Street DNA navigation, patented hybrid GNSS based technology for precise millimetre navigation of road milling machines. The DNA navigation achieves millimetre height accuracy using an inexpensive GNSS receivers. The pavement repair process often takes place in urban canyons areas, which is why the 3D data is enhanced by GNSS Galileo and EGNOS.

Industry 4.0 - road repair process

Highways in the Exact Street innovation are understood as "products" and the whole process of its repair is understood to be the production using the production line. The production line consists of a set of processes that begin with virtualization of 3D reality focus on a worn out products (for example, a highway at the end of its life), digitally prototyping (designing) an optimal repair method, virtualizing the entire repair process, and ending by analyzing (comparing and evaluating) the repair results and the internal and external benefits of this repair with a virtualized initial assumption.

Standart approach to road repair

Road surface repair process known as road resurfacing is generally composed of 4 main sub-processes: current state diagnostics, repair methods design, removing wearied asphalt layer(s) - road milling, and laying down the new layer(s) of asphalt mixes - road paving. Conventional way of milling is based on one specified parameter which is usually thickness of asphalt layer(s) to be removed. The result of newly repaired road then naturally produces inequalities of the previous surface. Roughness and vertical deformations are copied and locally averaged. Given that the operator sets the cutter based on the subjective assessment of the situation, the construction period is significantly longer. The milling machine operator must solve complicated problems on the spot, such as curbs, channels, cross slope tilting of the curves, intersections as well as the surrounding traffic. Operators need to come up with a solution to further proceed with the construction. The principle of conventional and Smart Exact Street milling approach is in following figure 1.

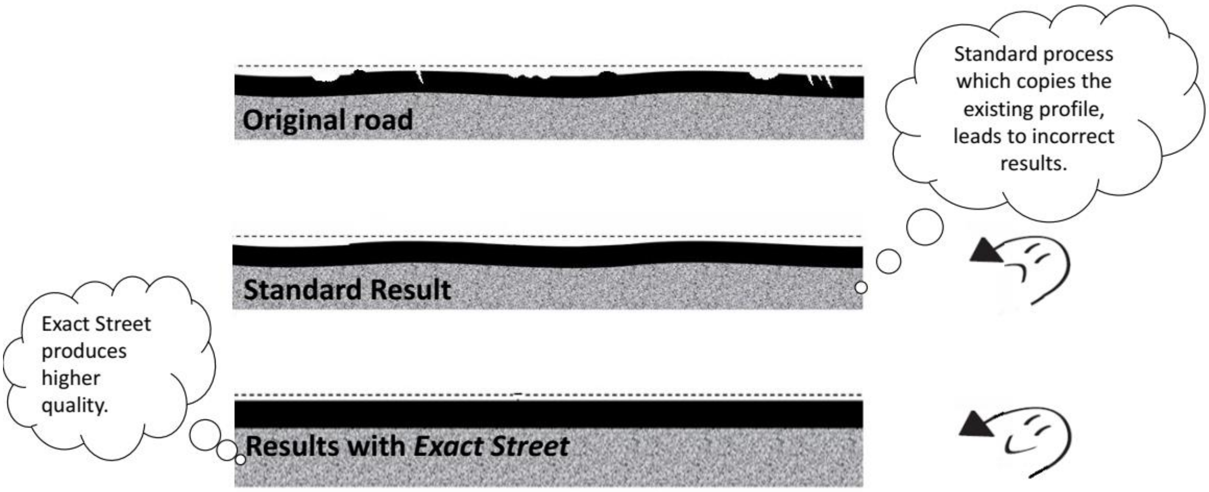


Fig. 1: Conventional vs. Smart Exact Street milling approach, longitudial profile.

Smart way of repairing roads achieving millimeter accuracy

Exact Street DNA smart way of milling navigation is based on a sophisticated digital model of the construction. The parameters of thickness and inclination of milling are automatically modified according to precise milling model resulting in an even and smooth road. The time of milling is significantly shorter compared to the standard process, primarily because all the details are solved during the preparation of digital model.

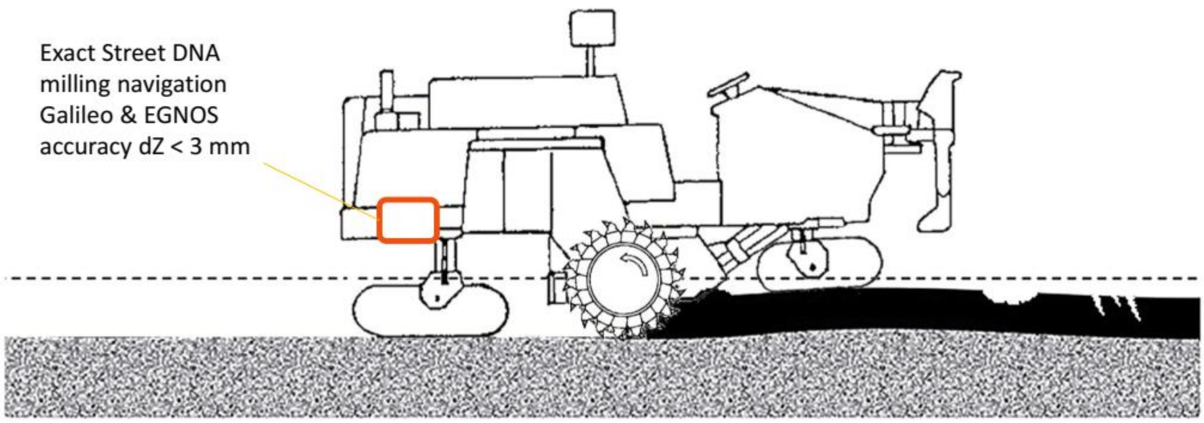


Fig. 2: Exact Street survey and advanced grade information allowed the milling machine operators to control the equipment's grade system to create a much more accurate milling operation to greatly improve longitudinal ride (smoothness, cross slope, super elevation and only remove the minimum amount of asphalt milling material that is required in the correct locations.

The original surface of the road is scanned before milling to create a 3D model of reality, which allows us to address any presenting obstacles and/or complications. From the scanned model the digital prototype of the milled surface is prepared. This preparation is supported by a proprietary software developed to optimize cost and quality criteria of the construction. Based on the 3D model, the designer first analyses all local conditions such as gutters, curbs, slopes, rut depths, pot holes, etc. The software transforms these conditions into mathematical constraints used by methods of convex optimization. The software automatically finds solutions that satisfy construction norms such as maximum/minimum slope and the change of crossfall with the road curvature.

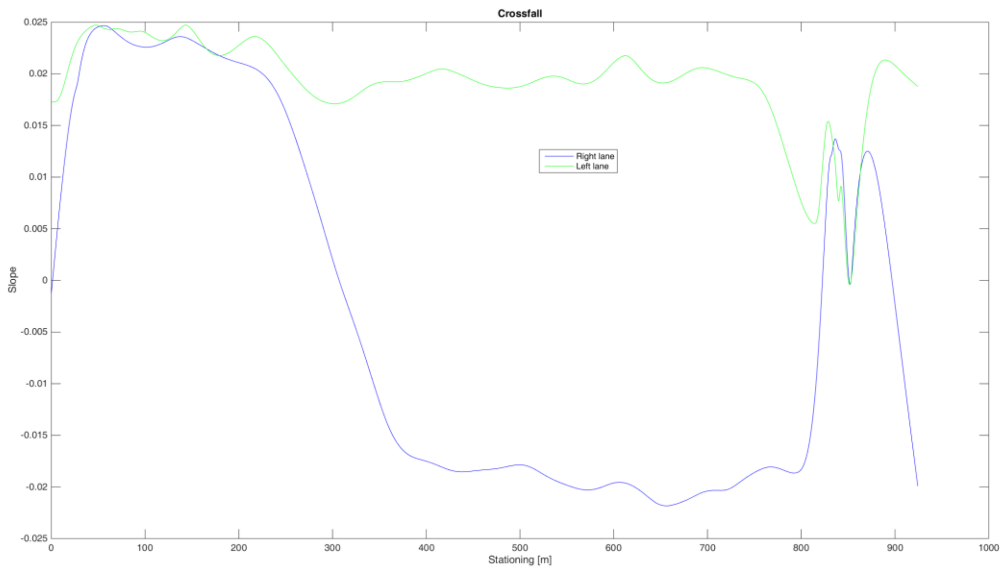


Fig. 3**:** Change of crossfall (X: slope [%]x10^{-2} ; Y: stationing [m])

Designer can analyze how the volume of milled material changes as a function of the required road smoothness, or generate multiple variants and choose the right one by the inspecting of several statistics, including the International Roughness Index, distribution of drainage gradients, height differences between the original and new surfaces, etc.

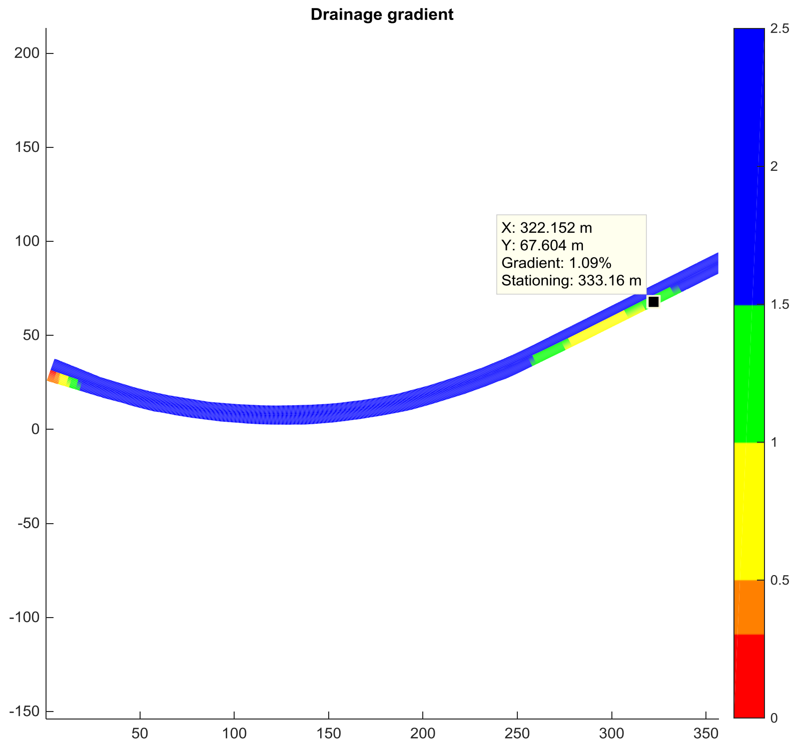


Fig. 4: Distribution of drainage gradients

As a result, a digital model is prepared and formatted in a milling machine readable format. Based on this model, we are able to precisely spray mark the road with adequate parameters for milling or have the milling machine set digitally by low cost GNSS - Exact Street DNA navigation for an automatic milling process. The operator then follows the model and knows exactly how much and where to mill to achieve superior milled surface.

Fig. 5: Exact Street DNA navigation of milling machines using low cost GNSS

Exact Street DNA navigation basically uses one or two GNSS receivers (on the left and right side of the milling machine) which continuously register position information. Afterwards, the driving direction is calculated and predicted for an interpolation from a precise 3D model of the road surface. Given data are then projected on the screen via graphical user interface. The operator of the milling machine reads desired values for current position and predicted direction and appropriately sets the milling machine. The accuracy of interpolated values is obtained as follows. The position is continuously registered with GNSS (+EGNOS) receiver and as the milling machine works slowly and in an almost direct way, one can analyze large amount of data. The most likelihood values of current coordinates are adjusted and the next possible direction is predicted. Accuracy of the estimated position results guaranties millimeter precision in the interpolated data (heights or milling values) from the Exact Street 3D model of the road surface.

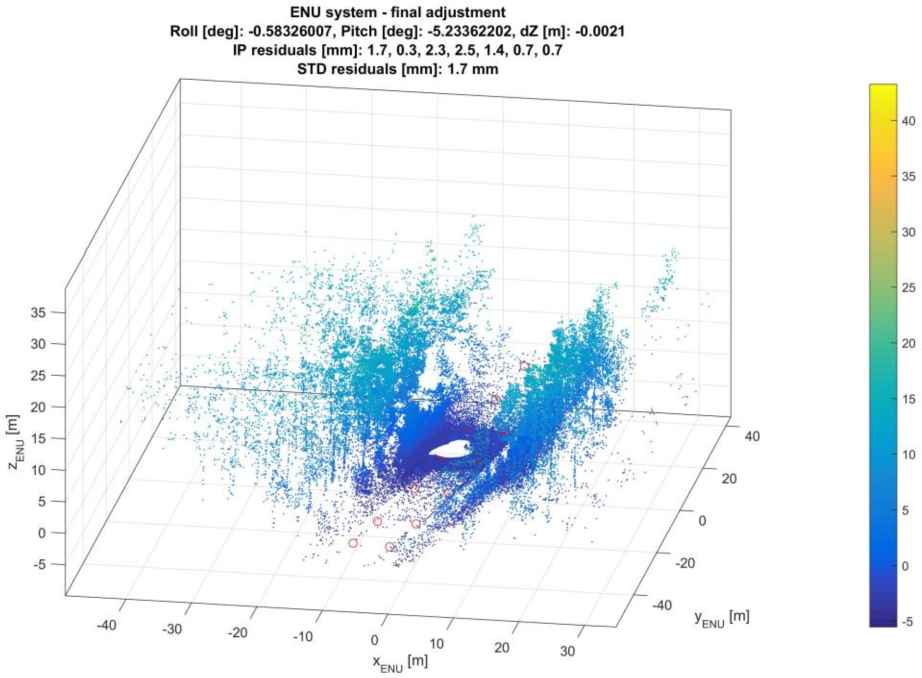
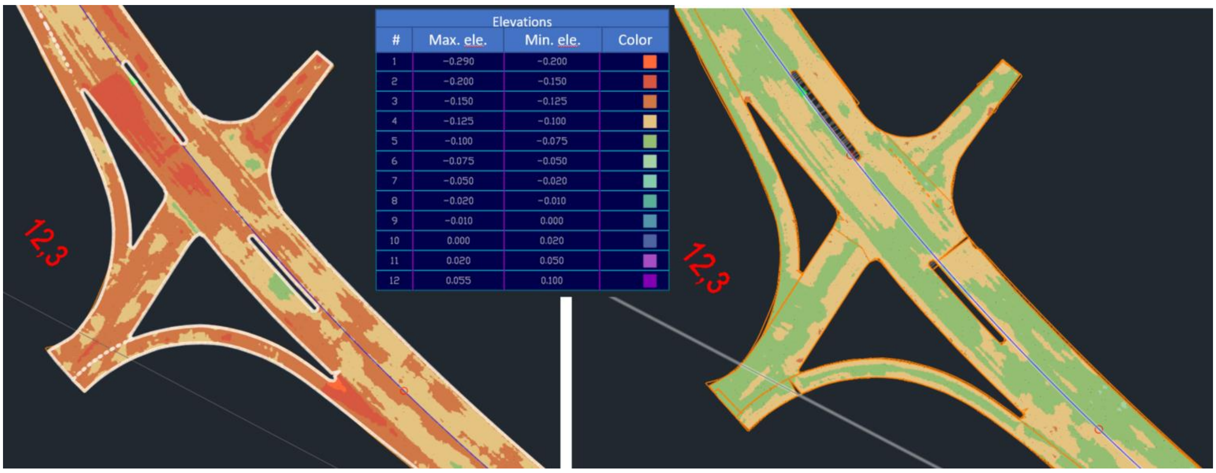


Fig. 6: Analysis of residuals between adjusted network and optimized position of point cloud in ENU system. Standard deviation of residuals (1.7 mm) presents very good accuracy of proposed method.

This way we accomplish an optimal smoothness of the new road, usually expressed as international roughness index (IRI), as well as save time and materials, increase the quality and decrease the closure time of the construction sites. The plan view, comparing conventional constant height milling and prototyped digital model from real project in Canada is presented in following.Fig. 7



Elevations			
#	Max. ele.	Min. ele.	Color
1	−0.290	−0.200	
2	−0.200	−0.150	
3	−0.150	−0.125	
4	−0.125	−0.100	
5	−0.100	−0.075	
6	−0.075	−0.050	
7	−0.050	−0.020	
8	−0.020	−0.010	
9	−0.010	0.000	
10	0.000	0.020	
11	0.020	0.050	
12	0.055	0.100	

Fig. 7: Comparisson between conventional one thickness milling (left) and digital model (right) from section of HW10, Canada reconstruction project.

Socioeconomic impact and the environment

Automation (defined process) works only with defined components (high-quality digital data). The primary task for successful utilization of industry 4.0 communications management methods is to gradually acquire and work with fault-free digital data in individual life cycles. It will then be possible for this recurring activity to be simple and controlled by robot systems or semi-authomatic systems. This will shorten the time of construction site closures needed to repair the "product" of the road. Also, it will allow for more efficient use of recycling technologies due to precise layout of the construction wells and from superior construction quality resulting prolonging the lifespan of the "product". This will lead to a significant reduction of the life cycle cost, which is not only an economic parameter, but also an ecological parameter. Overall, it has less negative impact on the environment by reducing the energy demands associated with repairing the road itself as well as raw materials needed for repair.

Fig. 8: Reducing the negative enviromental inpact

Conclusion

The macro-trends in play here are the digitization and industrialization that are driving GNSS development together with the demand for "easy-to-use" innovative applications. One example is the Exact Street DNA system which provides millimeter-elevation absolute accuracy through low cost GNSS receivers for designers and construction companies involved in road maintenance. In present the easy-to-use version application of Exact Street DNA is already operational.

The future "easy-to-use" application for a larger number of users would represent the use of satellite data with millimeter height absolute accuracy information provided to low cost GNSS receivers. The pre-requisite for industrialization and automation in this area is high quality data. Millimeter-elevation absolute accuracy information is desirable for various applications to increase the overall quality of life.

There are several reasons why the production of millimeter absolute data models should be the subject of GNSS research for their global usability not only in the automation of road repair but also for the creation of a unified technological framework and standard - for example in the area of safe autonomous mobility. It would be interesting, for example, to see different cars using one common reference system in the future - that is the road itself which safely guides them to their destination with the help of millimeter accurate satellite signals in combination with other modern technologies.

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