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The development and application of a global positioning system – based monitoring system for soil stabilization vehicles

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ABSTRACT

The accuracy and efficiency of soil stabilization works are key to ensuring the durability of roads. During the conducted research, a GPS-based (global positioning system) tracking system was developed that can monitor the movement of soil stabilization vehicles in real time, recording the exact location and working width of the stabilized road sections. The system's software solutions enable the conversion of location coordinates from the WGS84 (World Geodetic System) system to EOV (EOV as Uniform National Projection system) format and visualization of the results in AutoCAD. The developed tool can significantly contribute to the improvement of the quality control of soil stabilization works, as the development of road defects resulting from stabilization errors can be reduced with the help of documentation and visualization. During the testing of this system, the development proved to be successful and provides an opportunity to perform soil stabilization processes more efficiently and reliably, thereby improving the service life of road surfaces and traffic safety.

Keywords: soil stabilization, road pavement defects, GPS tracking, coordinate conversion, AutoCAD visualization.

INTRODUCTION

Degradation of road surfaces is a common and significant problem in modern transport infrastructure, which can often be traced back to insufficient and incomplete soil preparation and soil stabilization works. Soil stabilization is essential during road construction, because it increases the load-bearing capacity of soil, reduces water permeability, and minimizes subsidence caused by traffic loads. The most common method is calcareous soil stabilization, which is particularly effective in the case of clayey soils, as it improves soil strength and plasticity through a chemical reaction.

Several studies address the possible causes of road failures, usually involving insufficient stabilization techniques. Such road defects can be, for example, potholes, depressions and protrusions. These road defects mainly arise from uneven material distribution and insufficient stabilization width [Afrin, 2017; Iqbal et al., 2024; Renolith, 2023; Greene, 2016]. The goal of the conducted research was to solve these challenges by developing a tool that tracks the movement of a soil stabilization vehicle and the path it takes, taking into account the operating width of the spreader heads. This tool allows drawing attention to insufficient or incomplete stabilization, thereby reducing the chance of frequent road faults. The novelty of the project is that a solution that can be installed next to the existing systems has been developed, the universal nature of which enables its adaptation to other similar technical tasks.

In the study, different methods of soil stabilization were described, highlighting the importance of proper stabilization in road construction. The hardware and software components of the developed device were presented, and the method of converting GPS coordinates from WGS84 to EOV (EOV is a plane projection system used uniformly for the Hungarian civilian base maps and, in general, for spatial informatics), as well as the visualization of stabilized road sections in AutoCAD were briefly described.

Common soil stabilization procedures

Several soil stabilization procedures are being used in road construction, separately or even in combination in order to achieve the best quality suitable for receiving pavement. These subsoil stabilization interventions can be the following [Kaya, 2021; Kubányi, 2017; Makusa, 2012]:

- mechanical stabilization, where physical methods are used to improve the physical properties of the soil. Two types can be distinguished,
- compaction: soil particles are compacted to reduce porosity and increase density.
- use of geosynthetics: use of geotextiles, geogrids or geogrid systems in the soil to increase stability
- chemical stabilization, when chemical substances such as cement, lime or polymers are added to the soil to improve its mechanical properties. There are 3 procedures for chemical stabilization,
- cementation: adding cement to soil to increase soil strength through a chemical reaction.
- air bubbles: creation of air bubbles in the cement-water mixture, which increases stability.
- lime stabilization: adding lime to soil to stabilize it through chemical reaction.
- temperature stabilization: temperature treatment of the soil, such as the use of antifreeze materials under cold conditions, to increase the stability of the soil.
- electrical stabilization: application of electric field in soil for electrokinetic stabilization, which improves stability by rearranging soil particles and water molecules.
- biological stabilization: the introduction of living organisms, such as plants or microorganisms into the soil, to increase soil stability.
- gas injection: injecting gases, such as foam or specific chemical compounds, into the soil that cause chemical reactions and improve the mechanical properties of the soil.

In order to be able to choose the best possible procedure, it is necessary to do preliminary soil mechanics tests. These tests can be done on site or, for a more in-depth analysis, under laboratory conditions [Nagy, 2019; Szepesházi et al., 2021].

Calcareous soil stabilization

In the conducted study, the main focus was on calcareous soil stabilization, since the machine providing the environment for the empirical validation of the developed system also uses this procedure. Calcareous soil stabilization is an effective geotechnical method widely used in road construction and foundation projects. The essence of the method is to improve the mechanical properties of the soil by mixing lime. Stabilization increases soil strength, reduces drainage and improves soil compressibility [Primusz, 2015; Péterfalvi and Kisfaludi, 2015; Yakub et al., 2020].

Soil improvement with lime takes place is several stages [Negi et al., 2013]:

- soil testing, during which the exact composition of the soil is determined.
- application of lime, to the surface of the soil in the required quantity.
- soil mixing in order for the stabilized soil to be homogeneous.
- wetting and compacting, to start the appropriate chemical reaction and increase the density of the soil.
- aging, during which time the stabilized soil solidifies and sets properly.

Calcareous soil stabilization has several advantages, such as improved load-bearing capacity, reduced plasticity, greater water resistance and cost-effectiveness. In addition to all this, there are also several disadvantages that should be taken into account when using it. These may include environmental concerns, specific soil requirements and weather restrictions. In most cases, the soil improvement process with lime requires post-treatment before the asphalt layer is applied [Fondjo et al., 2021].

Available similar products on the market

Several manufacturers are engaged in the development of similar systems in order to reduce quality issues due to the lack of inspection or control during road construction. Some of the relevant products available on the market are presented in order to place the developed system in their light:

Trimble GCS900: It is a GPS-based machine control system that provides high-precision GPS coordinates using GNSS antennas. It was developed to monitor and control the movement of earthmoving machines. The system provides real-time data on the machine's position and operations, which can be used later for analysis and documentation. The data is not received in

AutoLISP format, so it is necessary to further process the data in order to display it in AutoCAD [Andrew Haupt, 2024].

A Topcon 3D-MC: It also provides the coordinates of the working machines using high-precision GNSS antennas. The system provides an opportunity to document stabilization operations for the purpose of preparing later reports. The latest version allows automating preset depth operations. The vehicle coordinates can be saved in several formats, but the AutoLISP format is not included in the list here either [TOPCON, 2024].

A Leica iCON gps 80: A high precision GNSS receiver designed specifically for construction applications. It can be used as a hand tool for field data collection or can be integrated into machine control systems. Owing to its compatibility, the system can be easily integrated with software from other sources. It can be widely used in civil engineering, road construction and all areas where high-precision positioning is required [Leica Geosystems, 2024].

Overall, it can be said about the systems described above and available on the market that the position of the working machine is provided in the WGS84 coordinate system, as this is the global standard for GPS data. However, for some devices, if necessary, data backup in the EOV system is optionally available. These systems can also be used to control the machine based on pre-written blueprints. The properties of the device presented and developed by the authors are shown in the table below for a better overview (Table 1).

MATERIAL AND METHODS

The main task was to monitor the position and working width of the soil stabilization machine, as well as to record this data, and our final goal was to post-process and plot the recorded data in CAD (computer aided design) software.

Construction of a soil stabilization machine

The stabilizing machine itself is a truck, on which a delivery-spreading system is installed (Fig. 1). The vehicle is capable of applying lime in different working widths, so when processing the data, it was necessary to take into account how many of the 3 spray heads are used at the moment. The spray heads can be switched individually, and their working width is 800 mm each, so it is capable of a total working width of 2400 mm. It was not possible to extract data from the vehicle communication network that would have clearly defined the activity of each sprinkler, so for this purpose a switch box was integrated into the system, with which the driver could switch the active sprinklers.

Hardware structure of the measurement system

A high-precision special GPS with 2 GNSS (Global Navigation Satellite System) antennas was used to determine the location of the vehicle.

Figure 1. Mercedes truck equipped with a delivery and spreader system

Table 1. Main features of the presented and authors' custom device

Aspect	Trimble GCS900	TOPCON 3D-MC	Leica iCON gps 80	Custom device
RTK accuracy	1–2 cm	1–2 cm	1–2 cm	1–2 cm
Orientation	Yes	Yes	Yes	Yes
WGS84 coordinate	Yes	Yes	Yes	Yes
EOV coordinate	Optional	No	Optional	Yes
AutoCAD compatible	No	No	No	Yes
Can be used to control the vehicle	Yes	Yes	Yes	No
Fixing working width	Yes	Yes	Yes	Yes

The used VN-310 GPS is capable of determining the position with an accuracy of up to 1 cm. The use of some kind of computer was essential for the operation of the assembled measuring system, as well as for the recording and processing of data. A Nvidia Jetson Xavier NX microcomputer was used for this purpose, and with authors' custom program code, it could operate the system independently, without intervention, after switching on. The basic structure of the assembled system is shown in the figure below (Fig. 2).

To summarize, a hardware environment that is mobile and able to record and later process location coordinates was created.

Software implementation of the measuring system

The final goal was to plot the data in a CAD software, with which the main problem was the format of the received data. The GPS used sent he location coordinates in WGS84, while the CAD software only supports EOV format. For this conversion, it was necessary to create custom software, for which the Python programming language was used (more detailed presentation of the program code will be presented in another article).

For the sake of easier and immediate data processing, an online database was created where the necessary data can be accessed at any time. This interface is the website called FireBase, on which online data recording is available. After a short registration, different projects can be created, which will later contain the developed database. By creating the project, the site generates a database URL, which can be used to access the developed database. The database can be protected with a password to prevent unauthorized persons from accessing it.

Installation of a measuring system into the vehicle

During the installation, the GNSS antennas were carefully positioned on the top of the vehicle's cab, as this location minimized shading and provided a better contact surface.

Great care was taken to ensure the correct orientation and stability of the antennas to prevent any potential misalignment that could impact data accuracy. The authors aimed to place the GPS IMU (Internal Measurement Unit) centrally on the instrument panel to align the GPS points closely with the vehicle's line of symmetry. Due to the

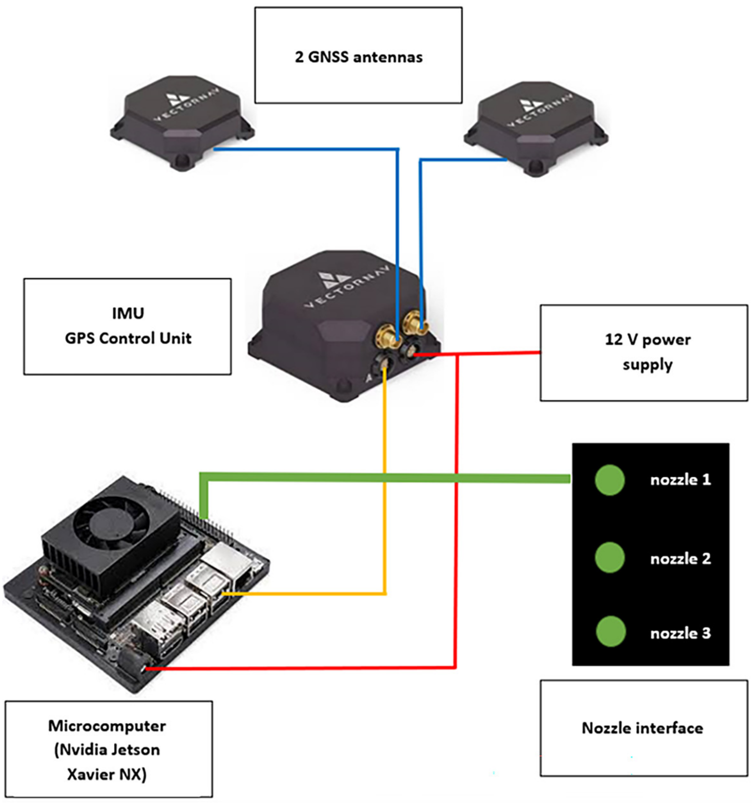

Figure 2. Structure of the employed system

design of the vehicle body, determining the precise relative position of the IMU and GNSS antennas was challenging. The most accurate values were achieved by projecting points onto the side plane of the vehicle and measuring based on those.

The system's control unit was installed in an easily accessible location to enable quick access by the driver (Fig. 3).

In order to ensure safe operation, it was necessary to use a DC-DC converter, since only 24 V power supply came from the vehicle, while the employed system functioned with 12 V voltage.

The measurement area

The device was tested during the foundation works of the new oval track (High Speed Oval) being built at the ZalaZONE Automotive Proving Ground in Zalaegerszeg, Hungary, which was an important step in the proper execution of the road construction. The 4,600-meter oval track under construction (Figure 4.) [AVL ZalaZONE, 2024] consists of two 900-meter straight sections, which are connected by parabolic turns with an inclination angle of 45°. In order for the parabolic curves to withstand the neutral speed of up to 200 km/h without any problems, appropriate ground preparation work was essential at this point. Another special feature of the module is that the paving works are carried out with a bridge finisher with a special technology, of which there are only two in the world [Antal, 2024].

Figure 3. Placement of the system's control unit in the vehicle's cabin

Such specially designed tracks allow vehicles to be tested under various conditions, including high speed and safety tests. This track element is especially useful during stability, handling and aerodynamic tests of cars. In the case of ZalaZONE oval track, stabilization measurements played a prominent role, as such facilities are exposed to increased loads, and any foundation error can have serious consequences in terms of vehicle testing and the lifespan of the track.

RESULTS

After installation, the accuracy of the GPS RTK was checked (Real-Time Kinematic), for which the freely available OpenStreetMap map was used (Fig. 5). In the Figure 5, it can be clearly seen that the section covered completely follows the route shown on the map, so the RTK can be considered adequate.

The additional measurements were recorded on the road sections that were already to be stabilized, and the GPS points were drawn in AutoCAD software. The program required for this was no longer written in Python, but in the AutoLISP language developed specifically for AutoCAD systems. The essence of AutoLISP is that

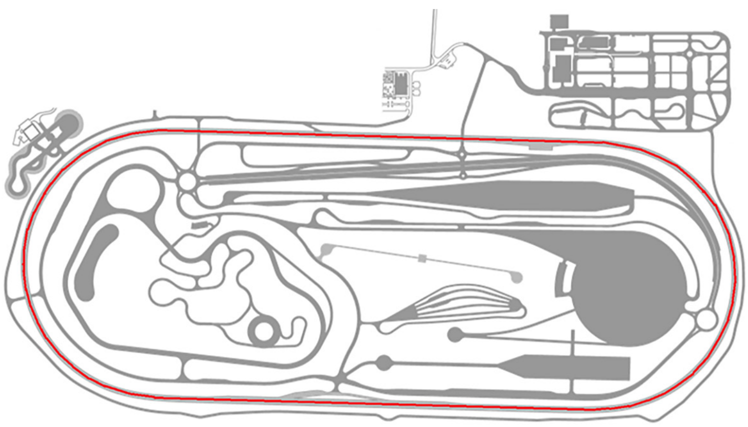

Figure 4. High speed oval under construction at the ZalaZONE Automotive Proving Ground in Zalaegerszeg

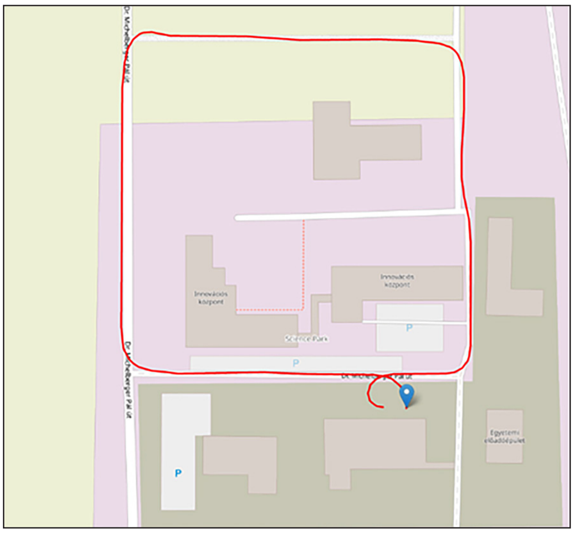

Figure 5. Route drawn by GPS data on an OpenStreetMap

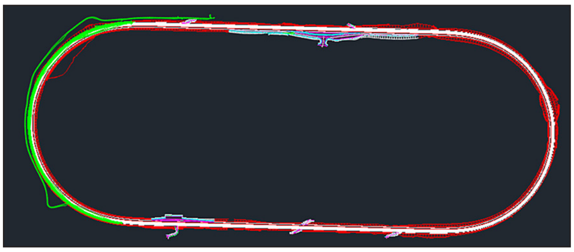

Figure 6. The result of the works done on the designated road section

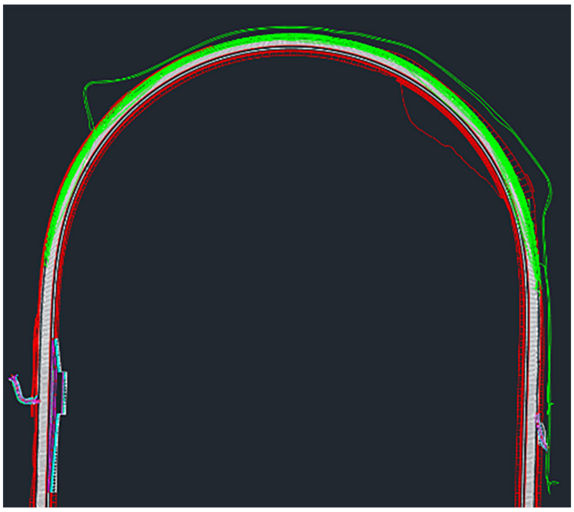

Figure 7. Enlarged image of the designated road section

regularized settings can be run simply by running a single command line, but even lines can be added to the drawing.

Depending on this, the existing program was further developed, which thus created a lsp file. On the basis of the logged GPS coordinates, the developed program wrote the corresponding lsp file, which the CAD software could already handle, so the connected drawing of the important GPS points appeared in the DWG drawing (Fig. 6).

The picture above shows the AutoCAD drawing of the oval track to be stabilized, on which the GPS coordinates recorded during the measurement were drawn in green. For better visibility, the route recorded by the system can also be observed enlarged in Figure 7. In Figure 7, it can be observed that the fixed points completely cover the planned road sections, from which it can be concluded that the coordinate conversion from WGS84 to EOV, as well as the RTK correction, are working properly.

CONCLUSIONS

The device developed as a result of the research described in this article marks a significant step toward monitoring and documenting the soil stabilization works, especially with regard to the working width of the spray heads. By using the device, it may be possible to reduce the risk of road faults caused by inadequate stabilization, which ultimately contributes to enhanced traffic safety and longer road lifespans. While the device is functional, some limitations remain, including its dependence on stable internet access, adequate RTK coverage for precise GPS data, and manual operation by the driver. Further development is underway to automate the system and to refine visualization for accurate working width representation. The goal of these enhancements was to improve the practical applicability and reliability of the device, making it an even more precise tool for monitoring soil stabilization operations.

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