Sensor Fusion
Integration of High-End and Low-Cost Systems for Infrastructure Monitoring and Navigation Purposes

Desislava STAYKOVA, Nico ZILL, Germany

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ABTSRACT

In the recent years the usage of state of the art monitoring systems marks a rapid progress especially in engineering area, for the purposes of the local administration authorities and infrastructure management. For different navigation aims, for monitoring and investigation of big areas the classical geodetic methods are being replaced form a modern mobile and terrestrial scanning systems comprising in itself variety of sensors ensuring continuous and accurate data acquisition. The new age system technologies are symbiosis between hardware and software solutions. The multi sensor integration comprising the combination of the signals from diverse sensors provides more accurate and reliable information. The usage of multiple sensors ensures higher level of data accuracy and reliability in case of sensor damage or failure. The combination of a scanning instrument, DMI and INS system is easy to set up and provides fast way for acquisition of spatial data in large areas without permanent GNSS availability. Using the advantages of combination of different sensors signals can be solved the navigation problems in areas with low or no GNSS signal. Depending on the manufacturer accuracy characteristics and variety of set up combinations this technology can be used for monitoring of surface settlements, in combination with a developed filter algorithm the accuracy of the trajectory resulted from kinematic differential GNNS measurement can be improved up to 2 or 5 cm. With the usage of appropriate post processing software the accuracy of the end results can be raised up to two times. The understanding of the sensors signals and their combination leads to a substantial improvement in the data accuracy and density and higher the speed of data acquisition.

1. INTRODUCTION

For the last ten years is observed fast development in the technology of combination between sensors within diverse common complex systems. The existence of such systems providing different accuracy levels offers the possibility for their usage in application areas of the engineering surveying, railway and automotive industry, land administration and for navigation purposes. The multi sensor integration and fusion is a comprehensive process of reading and combination of sensors signals in order to ensure higher level of data reliability and accuracy. The input information from every sensor and further combination with special developed mathematical algorithms ensures the complete identification of the observed

features which will be impossible only with the information from each individual sensor operating separately.
Because of its flexibility and possibility for fast and continuous data measurement the multisensory integration and fusion rapidly evolved in various applications areas. The object of this paper is to provide an overview for the usage of high-end and low cost system complexes and software solutions for the purposes of the engineering geodesy, transportation and navigation.

2. MULTY SENSOR SYSTMES FOR DEFORMATION MONITORING

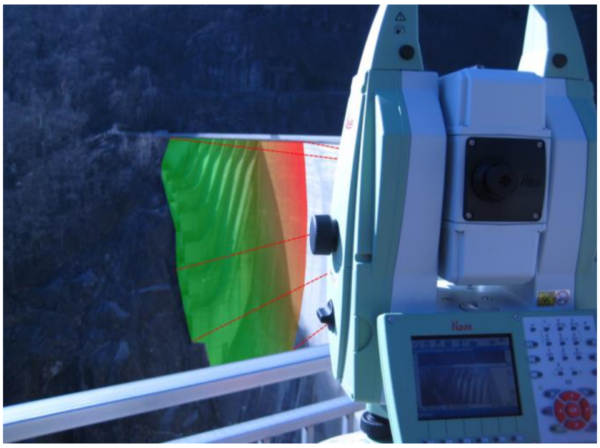
2.1 Geodetic instruments as complex sensor systems

The geodetic measurements for monitoring and displacements analysis of various engineering objects have always played an important role. The long term monitoring of structural objects like bridges, dam walls, building columns, wind power generators, and other constructions requires properly designed network schemes allowing the continuous and high accurate measurements. For such angular and length measurements in the mm area that have to be performed in a minutes, hours or a day intervals the standard total stations are being replaced from the automated one (ATS) comprising precise servomotors, automatic target recognition sensor, electronic inclinometers, self-calibration control system and other sensors. The synchronized process of high accurate measurements (angular accuracy better than one second and distance accuracy better than one mm) and simultaneously adjustment software gives the possibility for real-time or post-processing deformation monitoring and analysis. This type of hardware and software combination is often used during the life cycle of a project for construction and reconstruction of objects and for a regular monitoring of the objects stability.

2.2 Terrestrial Laser Scanning (TLS) for infrastructure monitoring

The need of precise modelling and geometrical characterization of large structures and open areas as dams, mines, landslides and others can not be covered by the traditional surveying methods which require the usage a huge number of points for describing the objects surface. The development of the laser scanning technology in the last decade offers new way for deformations measurements and becomes part of the infrastructure monitoring. The high scanning speed, dense measurement of huge amount of points and high accuracy gives advantage of the terrestrial laser scanning (TLS) in comparison with other technologies used for large structural monitoring. Compared with the technologies using single point monitoring approaches where the displacements detection is limed to specific benchmarks, the TLS provides high data redundancy. Combined with proper software products this technique offers the possibility for high accurate surface modeling and displacement detection in the millimeter area. The scanned object consists of big amount of points which allows the implementation of mathematical algorithms for modeling and analyzing the objects behavior. Another advantage of the TLS as remote sensing measurement technology is the minimized impact of the operator over the observed points and network (Milev and Staykova 2014).

A new method for structural monitoring was presented in the last years. The developed technology comprises the advantages of the TLS, GNSS, geotechnical and meteo-sensors and gives the possibility for wide area coverage and surface monitoring (Leica Geosystems).



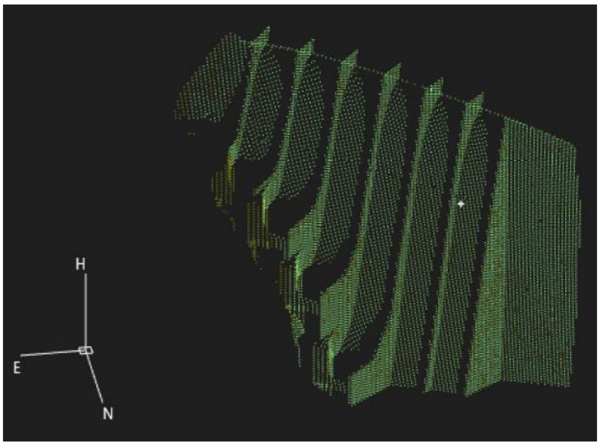


Fig.1 (© Leica Geosystems)

3. MOBILE LASER SCANNING TECHNOLOGY (MLS)

For different navigation purposes, for monitoring and investigation of wide areas the static measuring methods are being replaced form a modern mobile measuring complexes combination of variety of sensors (high-end and low-cost) which ensure fast, continuous and accurate data acquisition. In the last years the MLS experienced a vast development and proved its usage especially in the area of railway and automotive sector, for deformation analysis, for monitoring and documentation of the as-built street and railway network and the correspondent infrastructure objects.

3.1 Application of the MLS in the railway and automotive areas

The advantages of the MLS technique for fast, high accurate and complete scanning of the surroundings make it a substantial part of the modern railway and road conditions monitoring. The continuous way of data acquisition and processing minimizes the operator errors, reduces significantly the time for performance of the surveying work and the a-posteriori data analysis. For decades the localisation and recognition of the infrastructure objects part of the railway and road environment is of a prior importance in the transportation sector.
For determination and documentation of the as-built railway and street network form the acquired data technet-rail 2010 developed software solutions (SiRailScan and SiRoadScan) for point cloud analysis. The integrated mathematical algorithms ensure the high accurate extraction and adjustment of the as-built left rail, right rail and centre line, as well as of the roads border lines. The so adjusted geometry is further the basis for driving speed control tests, determination of the as-built rail and road environment which comprises the clearance detection and documentation, investigation of the catenary wires deviations, ballast and road settlements, signals position and any changes in the existing situation.

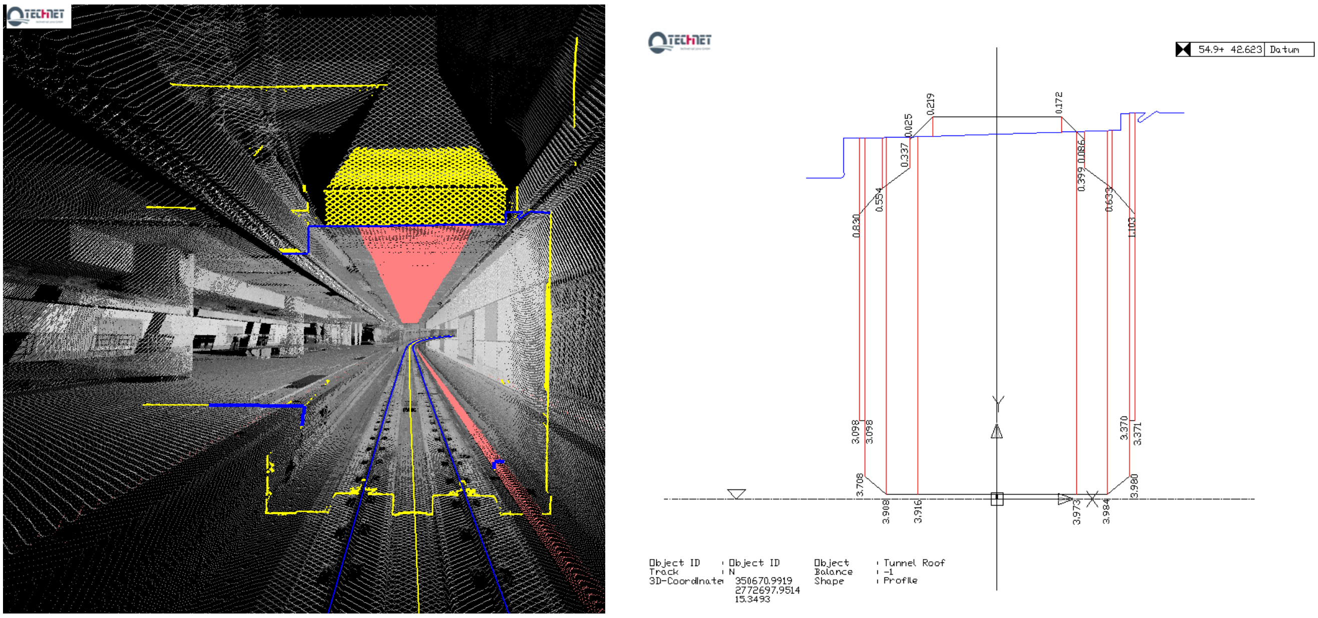


Fig.2.Adjusted as-built rail geometry with SiRailScan used as basis for performance of clearance analysis and documentation in chainage based railway system (© technet-rail 2010)

Fig.3. Adjusted with SiRoadScan road border lines. Detection and recognition of the roads signals. (© technet-rail 2010)

In response of the growing interest to the application of MLS technique and a-posteriori data adjustment for monitoring purposes, were developed additional tools for deformation analysis of the structures as tunnel bodies, railway bridge constructions and road surfaces. The integrated software solutions enable the comparison between the designed and as-built situation, epoch-wise analysis, modelling of the structure, development into 2D followed by color-coded defromation map.

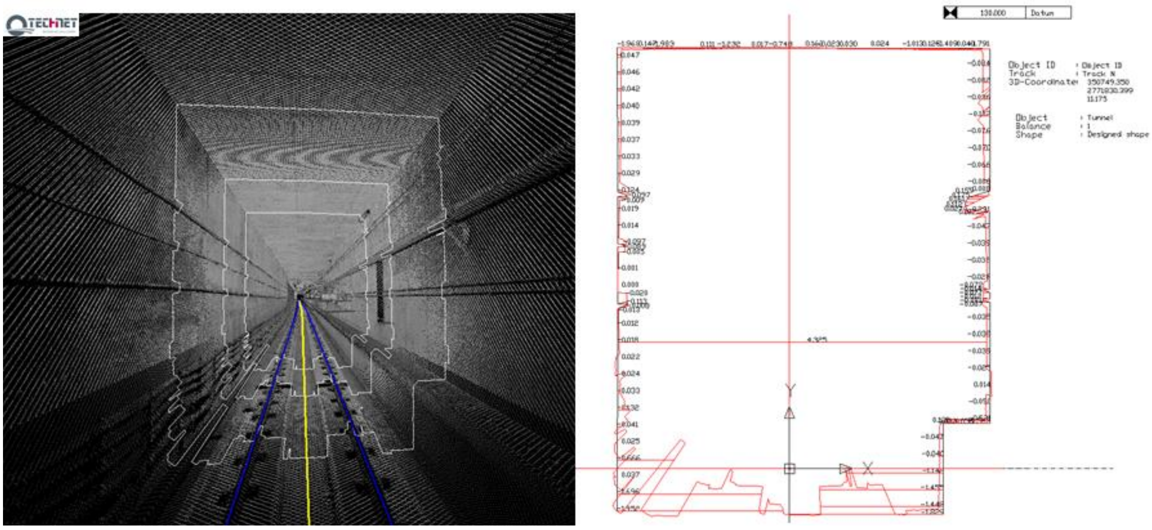


Fig.4 Tunnel deformation analysis performed with SiRailScan based on the as-built rail geometry. Automated calculation of differences between designed and as-built tunnel structure (© technet-rail 2010)

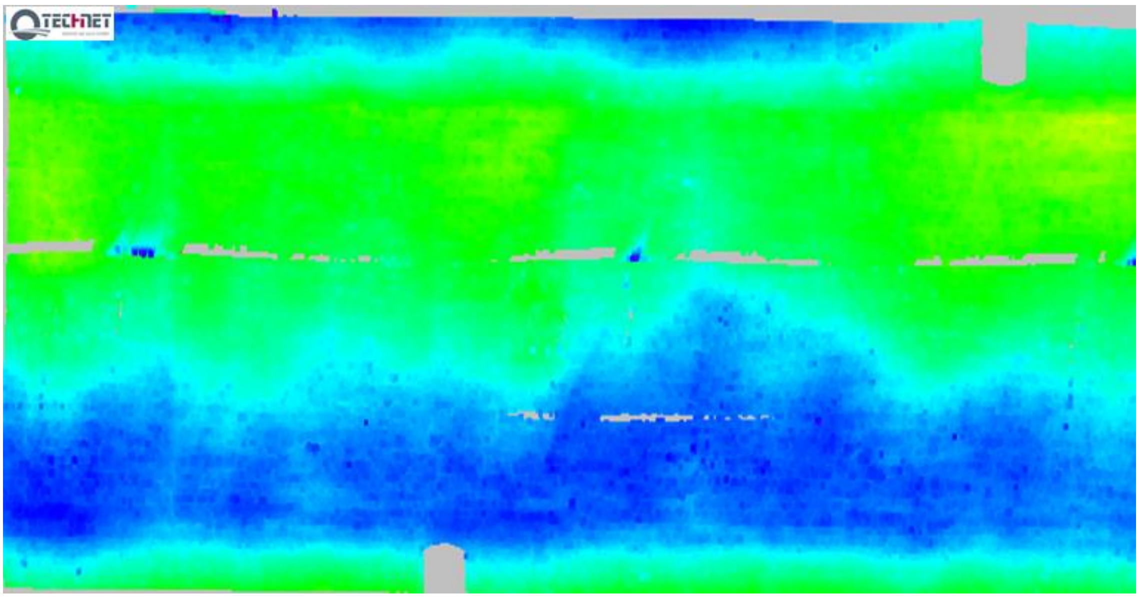


Fig.5 Tunnel deformation analysis with SiRailScan based on a pre-defined form and direction (© technet-rail 2010)

3.2 Application of the MLS for navigation purposes

The multisensory integration is the basis for operation of the moving measuring systems which are combination from hardware devices such as laser scanning devise/s, GNSS, IMU, DMI and specific software algorithms for data synchronization. A milestone in the development of such systems is the measurement and navigation in indoor places or in areas with low or no GNSS coverage. The need of safer and reliable navigation in the transportation systems such as train control system, intelligent vehicle systems, system tracking, in urban environments, underground areas, and other areas with no available GNSS signal initiated many researches in the area of multi sensor integration and fusion. Main scope in the studies (example(Lüdicke,Eßer) and (Pfister,Plank-Wiedenbeck)) is the integration of different sensors delivering information for the attitude, velocity, acceleration such as the IMUs, inclinometers, wheel sensors, and correspondent filtering algorithms in order to achieve the best possible position accuracy without usage of GNSS signals.

CONCLUSIONS

For decades the infrastructure objects such as dam walls, bridges, tunnels, roads and railway tracks, are substantial part of the civil engineering and engineering geodesy. The complicity of their structure requires deep knowledge about the behaviour of these objects and the various methods for their optimal and high accurate monitoring. The fast development evolution of the multi sensor integration in combination with laser scanning technology makes it essential method for accurate, continuous and dense measurement for the purposes of the engineering surveys.

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Leica geosystems: http://www.leica-geosystems.com

technet-rail 2010 GmbH: http://www.technet-rail.de

CONTACTS

Desislava Staykova
technet-rail 2010 GmbH
Goethe Strasse 42, 10625
Berlin
Germany
Tel.:+49 (030)54840785
Fax:+49 (030)54826798
Email: desi.staikova@technet-rail.de
Web site: www.technet-rail.de

Nico Zill
technet-rail 2010 GmbH
Goethe Strasse 42, 10625
Berlin
Geramny
Tel: +49 (030)54840785
Fax:+49 (030)54826798
Email: nico.zill@technet-rail.de
Web site: www.technet-rail.de