Geodetic Monitoring with Prismless Polar Methods

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SUMMARY

Geodetic instruments providing prismless electronic distance measurement – like robot tacheometres and terrestrial laser scanners – show encouraging prospects concerning deformation measurements. Various periodic monitoring tasks to detect movements of constructive parts or of masses can be solved by such polar systems. Here different examples and experiences of practical applications will be reported, mostly within recent monitoring projects of the Chair of Geodesy at Munich University of Technology. These concern deformation measurements at historical churches, motorway bridges and lock gates. An outlook on future developments of an indirect observation approach by means of mirrors to aim at invisible construction parts and of an image-supported tracking technique to determine tower oscillations will be sketched.

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1. POTENTIAL OF PRISMLESS POLAR MONITORING

The term polar as it is used and understood in surveying means to determine a vector originating from the mechanical or calibrated electronic centre of a geodetic instrument to the defined centre of a target. In space this is done by observing the horizontal direction, the vertical angle and the slope distance. Referred to a Cartesian co-ordinate system, these values may be transformed into rectangular components. Adding these to the similar defined co-ordinates of the instrument give the target co-ordinates as a result. This terrestrial approach by tacheometric instruments can also be achieved by satellite supported observations with a pair of GPS receivers, delivering the rectangular components directly. Both methods need a co-operative device placed at the target; in tacheometry a prism, in GPS a rover receiver – which means that somebody has to set up that device there. While GPS cannot dispense with having access to the target, terrestrial polar methods nowadays can with unprecedented accuracy and range. That is the reason why even monitoring has become possible recently.

Starting with the LEICA DIOR3002 (Distanzmessung ohne Reflektor) in 1986, prismless EDM technology evolved dramatically. Hand lasermeters have replaced the measure tape almost completely, up-to-date total stations allow switching from EDM with prism to a mode without co-operative reflector and finally, terrestrial laser scanners appeared, sweeping over objects by millions of rays in minutes. Leading instruments of both kinds attain accuracies of 3 mm, selected ones even better. However, reliable high accuracy represents only one of three decisive features to enable monitoring, the are two being speed and range of operation.

Motorized remote controlled or programmed total stations can now be employed to periodically or continuously monitor structures without fixing prisms on constructive parts. The only condition to be obeyed is that the pointing axis should stand approximately perpendicular to each surveyed object part which means to run coarsely in line with the suspected main movement. This proves necessary, because the total station’s telescope can only be oriented repeatedly into the same spatial direction and cannot use ATR to point automatically at a moving prism. As a matter of fact, optimum set-ups for the instrument must be found to fulfill the condition on average for all spots to be monitored. In some cases one fixed set-up will be sufficient for a permanent monitoring task, in other cases several monuments will be needed to be periodically occupied by an instrument. The economic advantage of prismless polar monitoring increases with the number of surveyed spots, as these no longer have to be fitted with prisms. Not only the costs for the prisms are saved, but also high installation expenses. Where no specific spots are known a priori, the total station can be programmed to create a regular grid on the structure’s surface. This approach can be refined by observing three points per spot and calculating the triangle’s centre of gravity, if the extra effort is justified. The denser the grid becomes, the more the procedure resembles scanning. The important difference is the ability to exactly level and orient the total station so that we may expect to reproduce nearly identical pointing directions in every epoch.

Terrestrial laser scanners show a different behaviour; these instruments manage to guide a laser beam with very high velocity along consecutive profiles over the object. Using efficient step-motors this is accomplished by tilting or rotating mirrors or reflecting polyhedra inside of the scanner or sometimes additionally by rotating the scanner itself. In course of the motion the direction of the tightly focused ray is registered by angle encoders, while the distance is observed by phase or runtime measurements of the respective reflected laser signal. Thus thousands of vectors per profile are created within a second and complete scans of again thousands of profiles are completed in some minutes. Relative to the defined centre of the instrument the vector tips deliver 3d co-ordinates, which as a whole form a spatial point cloud. The point cloud as accurate representation of the surveyed object is available right after the scan and can be visualized and modeled. Larger objects need several different scans; these can be joined by means of distinct natural or artificial targets included in both of two adjacent scans. Single and joint scans can be transformed to a superior co-ordinate system by means of a proper number of pre-surveyed control points also included in the scans (Wunderlich, 2003).

Though for some of the common scanners the accuracy of each single point of a cloud might not be sufficient for monitoring purposes, a further treatment or modeling of regions of interest will increase the accuracy down to 2-3 millimeters. If appropriate, a typical modeling approach would aim at replacing a region by a best-fitting analytical surface on least squares basis. For monitoring translations the computation of the perpendicular distance between the surface position in two different observation epochs may be successful. Nevertheless, the technique will fail in case of pure or additional deformations of the object. As an alternative we could try to apply a shrink wrap technique - usually employed to calculate volume changes - on the two point cloud regions, but the resulting DTMs will not allow to compare identical points. Compared with the tacheometric approach, the basic problem comes from the fact that a laser scanner cannot point at discrete points, but is only able to create a slightly irregular grid, which does not prove perfectly reproducible in successive scan missions. That is the reason why at the Chair of Geodesy of Munich Technical University a different approach has been developed, which interpolates a regular grid in advance (Schäfer, 2004). Then the subsequent deformation analysis shows convincing results.

It is our strong belief that both methods sketched, the tacheometric as well as the scanning one, now have an excellent potential for monitoring missions. This will be demonstrated by practical applications below after a short glimpse on the technological progress which made the instruments applicable to these tasks.

2. TECHNOLOGICAL PROGRESS

Prismless EDM depends heavily on object range and reflectivity and of the beam's incident angle. To get a strong reflected signal small incident angles should be avoided. Hence, reasonable monitoring configurations will obey that condition, which fortunately coincides with the one explained in section 1. Therefore distance measurement will represent the essential component of instrument accuracy. That is the reason why, above all, the improvements of prismless EDM have to be mentioned.

At first we should admire the successful integration of both types of EDM in total stations, which began with the *Zeiss* RecEltaRL in 1993. Immense progress has been made since by applying sophisticated signal processing algorithms to pulsed or continuous distance measurement with visible lasers. In its top class total stations *Trimble* uses a series of numerous pulses to detect the returning pulse's shape before runtime measurement and thus reduces noise considerably while increasing range (DR300+). *Leica* changed from amplitude modulation to frequency modulation and developed a generalized phase measurement technique; for extreme long range and high accuracy (Pinpoint R300) a system analyzer determines optimum evaluation parameters in dependence of the EDM beam and target quality (Ramseier, 2004). The distance definition is confined with 768 meters and till 500 m 3mm + 2ppm distance accuracy is specified. Higher ranges are not possible at the moment.

Laser Scanners have a typical range of up to 100 meters and accuracies of a few millimeters. Most instruments apply distance measurement by runtime measurement of pulses, special ones use phase measurement or triangulation. About a dozen of terrestrial laser scanners, e.g. from *Leica, Mensi, Optech, Riegl, Zoller+Fröhlich* etc. are on the market today. Compared to the first models at the turn of the century, recent products show superior speed of operation. True long-range scanners are not available, but one seems to stand in between total station and scanner, the *Riegl* LPM2K with up to 2500 m range and 50 mm accuracy. It enables distant monitoring of snow or rock masses by scanning procedures (Scheikl et al., 2001).

3. PRACTICAL EXPERIENCES

3.1 Monastery Dome

In spring 2002 cracks showed up in the dome of the monastery church Walderbach. Investigations resulted in immediate closing of the church because of an imminent collapse of the dome. To protect the workers while installing a supporting scaffold, a geodetic monitoring system was ordered. Because of the dangerous situation and missing access possibilities any installation of targets in the dome was impossible. We tried to meet the high demands by means of a prismless polar system based on a LEICA TCRA1101+. A choice of instruments of this type was extensively tested at our laboratory to find out the one with ultimate distance accuracy and to determine the resolution of the selected one. An onboard GeoBasic application was programmed to control an automatic operation schedule. After orientation to a stable prism and observation of a calibration distance in prismless mode distance measurements were executed to six specified spots at the dome (Figs. 1a,b). Each measurement consisted of a waiting period of 30 seconds to allow for compensator stabilization and 10 single measurements to attain an accuracy of the mean better than 1 mm. Internal and external temperature sensors were used for atmospheric correction and studying structural reactions to temperature changes. Distance changes were checked against an alarm threshold of 1 mm to actuate an emergency horn blowing if exceeded. From design to operation only six weeks went by, including testing and improving. During the start phase some false alarms occurred, mostly due to current fluctuations of the energy supply or interference of workers. The complete data was permanently transmitted per Email to our institute and to the responsible civil engineer in order to check, to visualize and to store it.

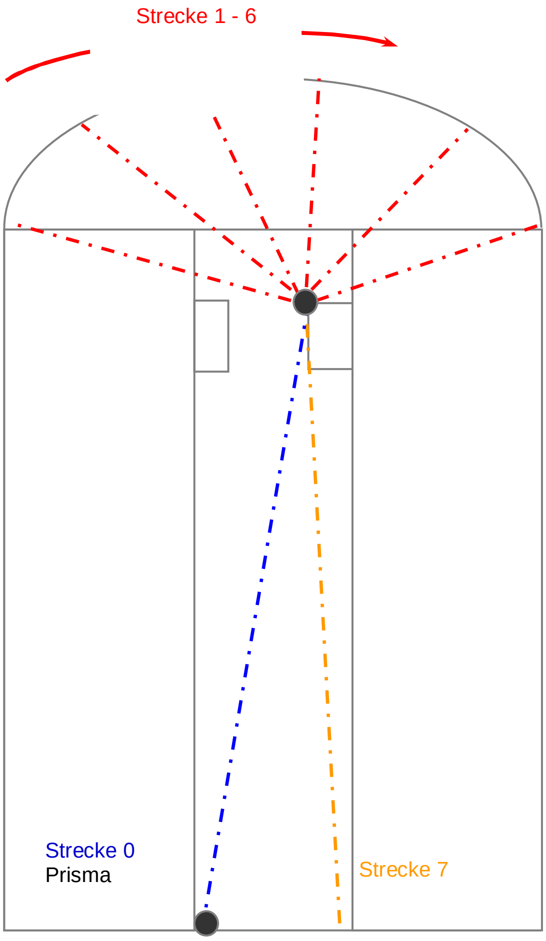

Fig. 1a: Polar monitoring array in church

Fig. 1b: Total station with temperature sensor

3.2 Motorway Bridge

At the outskirts of Munich a highly frequented motorway bridge is suspected of imminent fatigue concerning inner construction parts of the bridge deck. First symptoms would become apparent as local vertical deformations of only 2mm amplitude in maximum. To reveal such contours a project team of the Chair of Geodesy (Dr. Stempfhuber, Dr. Foppe, Dipl.-Ing. Schäfer) has proposed a specific monitoring layout in cooperation with the Chair of Solid Construction. From special consoles (Fig. 2) fixed at the bearing columns a LEICA TCRA1101+ is going to observe the concrete bottom from underneath, using a grid of 2m by 2m meshes. The consoles serve as forced centerings; the instrument's orientation is determined by pointings to prisms at stable locations. The same observations are used to check the stability of the precisely pre-surveyed stations. Three measurements are planned for each grid point. From successive observation epochs possible vertical deformations can be detected. As the bridge runs almost horizontal, translations caused by temperature induced length changes have practically no effect. General vertical translations because of varying traffic load have only to be expected during traffic jams and can be removed in total to discover local deformations.

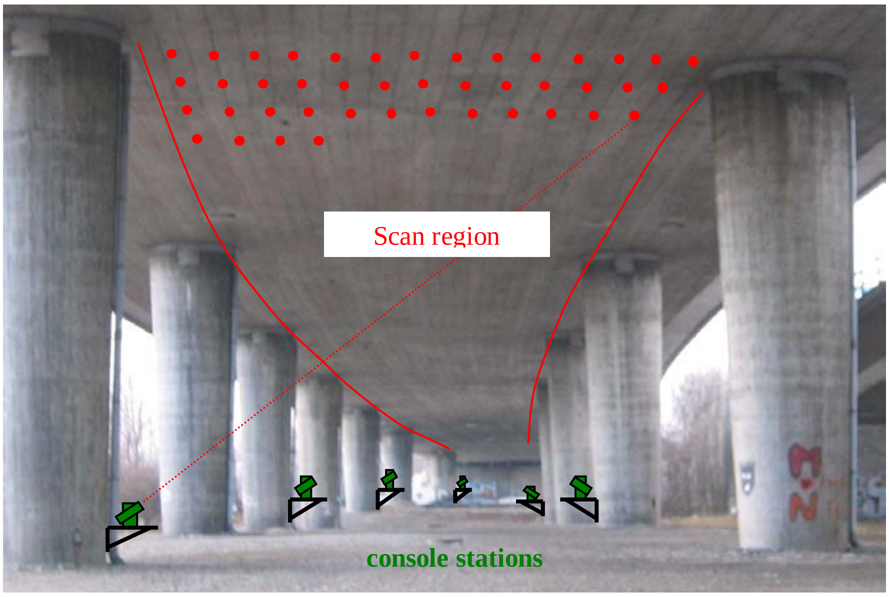

Fig. 2: Scan situation under the motorway bridge

3.3 Lock Gates

Supported by the DAAD and the Slovak Agency of Research and Science, a prosperous cooperation between the Chairs of Geodesy of the Technical Universities of Bratislava and of Munich started in 2003. One of the objectives was to investigate the capabilities of terrestrial laser scanning for deformation measurement purposes. An important test took place in the autumn of the year at the giant locks of the Slovak hydropower plant Gabčíkovo (Kopáčik and Wunderlich, 2004). Here at the Danube, for the first time worldwide, dynamic deformation development of lock gates during filling has been observed by means of a LEICA HDS2500 laser scanner and the methods described in section 1. Details are given in a specific contribution to the present event (Schäfer et al., 2004).

4. FUTURE DEVELOPMENTS

Encouraged by the results of prismless monitoring at the monastery Walderbach and of employing deflected laser beams to hidden prisms at Schäftlarn church (Stempfhuber et al., 2004) we now want to combine the concept for future applications. When numerous points have to be monitored by a permanent polar system in the interior of a church we frequently face two problems. At first, it often proves impossible to see all spots of interest from a single and stable instrument station. As a rule economic reasons prevent providing a second precious tacheometre. So either supplementary sensors must be installed or the invisible points must be caught indirectly via deflecting mirrors as we invented and demonstrated at Schäftlarn. The second obstacle is pure economical: a respectable number of prisms causes additional costs as well as the effort to install them. A hydraulic lifting device has to be rented and the church benches in the nave have to be removed to let it operate. Particularly the latter inconvenience together with the wish to avoid wall damages lets us prefer a prismless approach with only a few mirrors at accessible places.

At the moment we prepare an experiment to determine the amplitudes of wind induced oscillations of the Munich Olympic Tower. During the last years ever increasing wind velocities have been noticed by European meteorologists. The experts suppose the phenomenon relates to climatic change because the big storms coming from the Atlantic ocean force their way steadily deeper and deeper into Central Europe. As highrise buildings and towers were planned and built obeying standards based on maximum wind velocities lower than today, structural behaviour in course of extreme storm forces acting should be watched closely. In case of the Olympic Tower continuous observation by GPS or ATR fails, because no antenna or prism can be attached to the tip. Although the top part could be reached by spiral stairs theoretically, practical access is only possible during rare service breaks due to extreme electromagnetic fields of TV transmitters. That is why we decided to try observing by prismless techniques. We will employ our brand-new LEICA TCRP1201. It disposes of a very capable prismless EDM option called Pinpoint R300 enabling accurate range measurements to distant (up to 750m) non-cooperative targets as e.g. the tower tip (Stempfhuber and Wunderlich, 2004). From an observation pillar in the park area we could determine the line-of-sight component of the oscillation in this way. The transverse component represents a bigger challenge. We aim at adapting an automatic target recognition technique recently developed at the Chair of Geodesy (Wasmeier, 2003) to recognize and track the tower tip's motion. It is based on images of the instrument's ATR-camera and template generation. The possibility to read out the images is a special and unique feature of our total station exclusively granted by LEICA for our research work. In future we will investigate other applications of the camera images and long-range prismless EDM, in particular monitoring of inaccessible landslide areas.

5. CONCLUSION

There is no denying the fact that prismless polar methods have become capable of solving demanding monitoring missions. Both, tacheometric and laser scanning approaches can be used for the determination of structural deformations without co-operative targets. The present instruments' accuracy margins come down to 3mm or even better and can be further improved by strategies discussed here. Prismless polar monitoring should not try to keep up with established high precision solutions, but fill in the gap where prisms cannot be fixed or where their number would be uneconomically high. Moreover the method can solve new tasks like dynamic deformation observation of entire surfaces. With increasing range capacity future applications can also be expected in landslide monitoring, which are already under research and test at different places.

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