Analysis and Compensation of Instrument Orientation Instability in Tachymetric Measurement of Crane Rails

Žiga RANZINGER[1], Gašper ŠTEBE[2] & Aleš MARJETIČ[3]

[1,2,3] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Chair of Geodesy
(ziga.ranzinger@fgg.uni-lj.si)

DOI: 10.3217/978-3-99161-070-0-021, CC BY 4.0

Abstract

Accurate measurement of crane rail geometry is essential for safe and reliable crane operation, as even small deviations in geometry can adversely affect crane performance and structural integrity. Modern tachymetric methods enable high precision surveying of crane rails. However, their accuracy strongly depends on the stability of the instrument orientation during measurement.

This study investigates the stability of a tachymetric measurement setup used for crane rail geometry control, with a particular focus on horizontal orientation drift during long term observations. Based on semi-automated measurements performed on a wide span crane rail simulated system, systematic variations in horizontal directions were observed that could not be attributed to local target movements.

An experimental analysis combining segmented drift evaluation, inclination measurements, and meteorological observations was carried out simultaneously to identify the dominant sources of instability. The results show that the observed horizontal drift is primarily caused by rotation of the instrument tripod around the vertical axis, while the orientation station remains largely stable. Furthermore, the influence of mechanical and environmental factors varies significantly over time, with both immediate and delayed effects detected.

The findings confirm that instrument stability cannot be assumed constant during extended crane rail surveys. Segment based analysis and consideration of time dependent effects are therefore essential for reliable orientation correction. The presented results contribute to improved understanding and mitigation of orientation related errors in high precision crane rail geometry measurements (MARJETIČ, et al., 2012).

1 Introduction and motivation

The stability of surveying instruments during continuous measurements is crucial for achieving the highest accuracy that these instruments enable when monitoring deformations of structures and equipment. Tachymeters can be stabilized in various ways in the field, either on concrete pillars or on a tripod. The instruments are subject to numerous external influences, the most common of which are vibrations of the structure, changing meteorological conditions, and consequent changes in the mechanical properties of the tripod or concrete pillar. Measurements where these changing conditions are present are very difficult to eliminate due to the specific environment where crane rails are installed - on a wide variety of infrastructure structures, especially on hydroelectric power plant dams.

To monitor the correctness of the geometry of crane rail, we use tachymetric measurements with a special metal L-platform (***Fig. 1***) (MARJETIČ, et al., 2012), which we place on the crane rail. The measuring points on the rail are determined by using the polar method, whereby it is important to measure the horizontal direction to the orientation point (e.g. from S_1 to S_2 in ***Fig. 1***). Due to obstacles (structures and equipment, ***Fig. 1***, right), we only take measurements from two instrument setups (S_1 and S_2, ***Fig. 1***, left) – one crane rail from each setup. One point is the setup point and the other is the orientation point. We repeat the orientation several times during the measurement of each rail.

Fig. 1: The principle of measuring crane rail tracks

From the results of repeated measurements to the orientation point, we found out that the value of the horizontal direction at the orientation point changes over the time (several hours). This change is not negligible. ***Fig. 2*** shows an example of the change in the horizontal direction values at the orientation point when measuring the crane rail. The change in mean value of both faces at the orientation point changed by approximately 13″ in about two hours. This means a transverse deviation of the point position on the 200-meter rail of more than 1 cm.

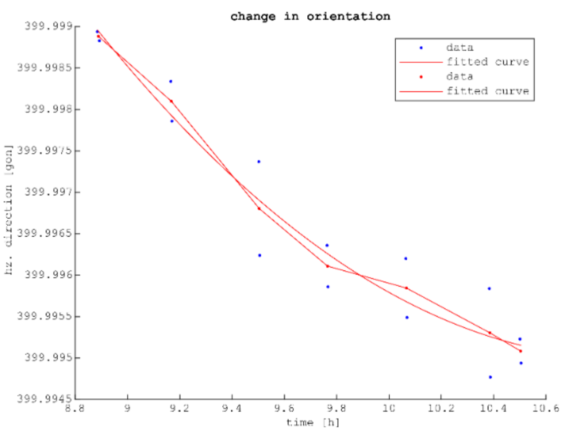

Fig. 2: Example of changing the values of horizontal directions to an orientation point

In the process of calculating the parameters of the rails, these changes are of course taken into account and compensated for accordingly (**Fig. 3**).

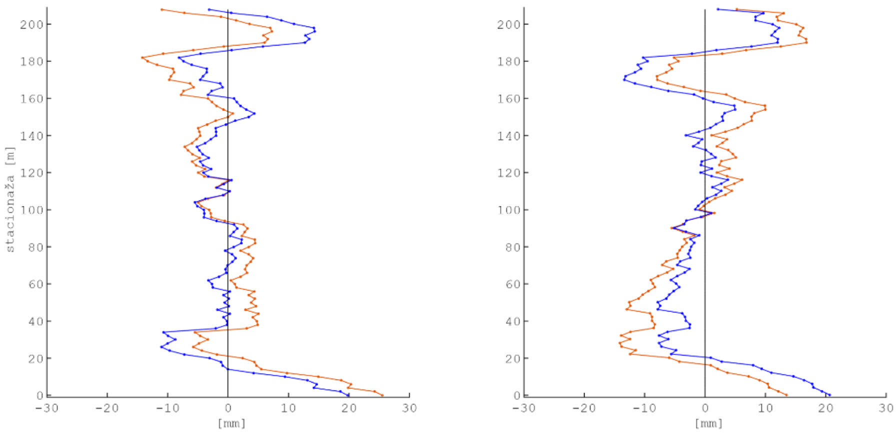

Fig. 3: Compensation for direction change at orientation point when calculating crane rails

The phenomenon of changing the line of sight or horizontal direction to the orientation point was the main motive for the research. We conducted a test simulating the conditions for measuring crane rails in the field, where we use a tripod (Leica Geosystems GST120) for tachymeter and orientation point and using no protection from sunlight.

In some previous studies, the authors have already discussed the influence of the height and torsional stability of tripods (NINDL & WIEBKING, 2010) and meteorological conditions on measurement results and instrument stability, as well as the influence of tripod tilt on changes in measured directions (ODZIEMCZYK, 2018).

All of the above indicates that the system consisting of a tachymeter and a tripod is not rigid, but behave as a mechanically dynamic system that is subject to external influences and has a certain time response.

The aim of the research is therefore to analyze the time-dependent changes in the horizontal directions of the tachymeter, with results that indicate the instability of the tachymeter-tripod system and not the instability of the orientation point. We also investigated the possible connection between the change in orientation direction, the inclination of the instrument, and meteorological factors.

2. Surveying method and data

2.1 Surveying method

The measuring system consists of three measuring devices: a Leica Nova TS60 tachymeter, a Leica Nivel 210 inclinometer, and a Vaisala weather station (***Fig. 4***). The tachymeter was mounted on a wooden tripod (Leica Geosystems GST120). The instrument is usually fixed to the tripod with a screw. For the test, we used a special tray on which the inclinometer Leica

NIVEL210 was placed. We screwed the tray together with the tachymeter to the head of the tripod (***Fig. 4***).

Fig. 4: Test setup

The test was performed on the roof of the Faculty of Civil and Geodetic Engineering, University of Ljubljana. The placement of the targets is shown in ***Fig. 4***. With this setup, we simulated the situation when measuring crane rails. Two targets were placed on a concrete pillar to simulate the targets on the crane rail. Next to the pillar, we placed another target on a tripod, which simulated an orientation point. The standing position and the measured points were approximately 65 meters apart, which corresponds to the dimensions of the situation when measuring crane rails.

The Vaisala weather station enables the collection of various meteorological data. The data includes wind speed, wind direction, air pressure, temperature, and relative humidity. The Nivel 210 inclinometer measures changes in inclination in the X and Y directions. Due to the way the inclinometer is positioned, the changes in inclination in the Y direction are transverse to the line of sight towards the orientation point. This data helped us analyze the stability of the tripod.

We performed the measurements over two longer periods of time using the automatic monitoring function, where the instrument performed measurements periodically at predetermined time intervals. We performed the measurements of meteorological parameters simultaneously and separately and stored the data on a computer.

2.2 Collected data

The data was collected during a two-day test. We performed two sets of measurements within the test. The first set began at 11:56 a.m. on December 9, 2025, and ended at 5:34 p.m. on the same day, while the second set began at 1:55 p.m. on December 10, 2025, and ended at 11:38 p.m. on the same day. Between the two sets of measurements, we only used different methods of data recording, using the GeoCOM protocol in the first set and the Measure Sets function in the Leica Captivate application in the second set. In the first test, we measured a total of 45 sets of angles, and in the second test, 118 sets of angles.

The measurements were obtained from three different devices, which is why these devices also had slightly different time resolutions. The inclinometer recorded data every ten seconds, and the weather station every minute. The tachymeter measured all three points in one set of angles every five minutes. For the final conclusions on the connectivity of the data and their impact on changes in horizontal directions, we performed time synchronization of the measured data.

3 Methodology

With this test, we wanted to analyze the stability or instability of the tripod when performing long-term measurements. Instability can manifest itself in various ways. Given our specific test area, we expected that the instability of the tripod would help us understand the measurements of angles (α and β), horizontal directions (HzT1, HzT2, and HzT3) (***Fig. 5***), and measurements of possible inclinations with an inclinometer and changes in meteorological parameters with a weather station.

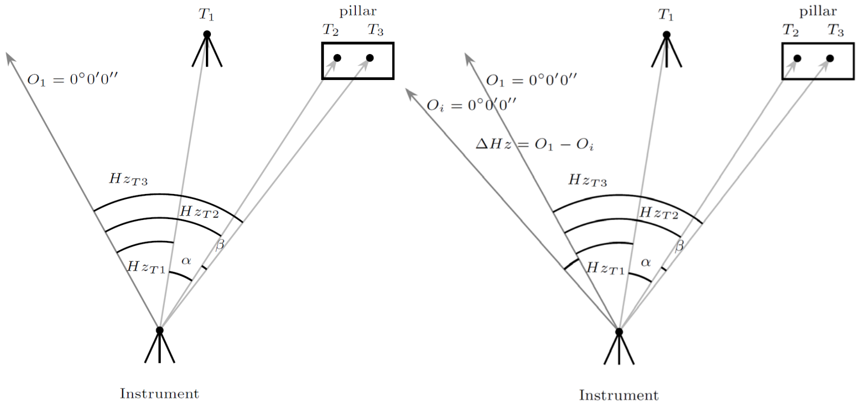

Fig. 5: Measurement system (left) and display of orientation direction change (right)

3.1 Analysis of rotations of the tripod-tachymeter system at a setup point

We assumed that angle β is constant, as it is the angle between two rigidly connected points on a concrete pillar. We assumed that three possibilities could occur with angles and horizontal directions:

- α is constant and horizontal directions do not change during long-term measurements => the system does not rotate.
- α is constant and the horizontal directions change during long-term measurements => the tripod with the tachymeter rotates.
- α is not constant and the horizontal directions change during long-term measurements => the tripod with the target moves and the tachymeter tripod system rotates.

As geodesy experts, we would like the first option to be true, but we have already shown at the beginning, using the example of crane rail calculations on a practical example, that this is not the case. We assumed that one of the remaining two options would occur.

We checked the constancy of both angles using the α and β calculations for each set of angles. From all calculated α and β values, we calculated deviations from the average values. The deviations are graphically presented in ***Fig. 6***. We also listed the maximum deviations in absolute value for α and β (***Table 1***).

Table 1: Table of maximum deviations for α and β

Max. deviation	Measurements 1	Measurements 2
for α ["]	2,3	2,7
for β ["]	3,2	2,4

From the results of changing angles α and β, we can conclude that both angles are constant and eliminate the stability of orientation point.

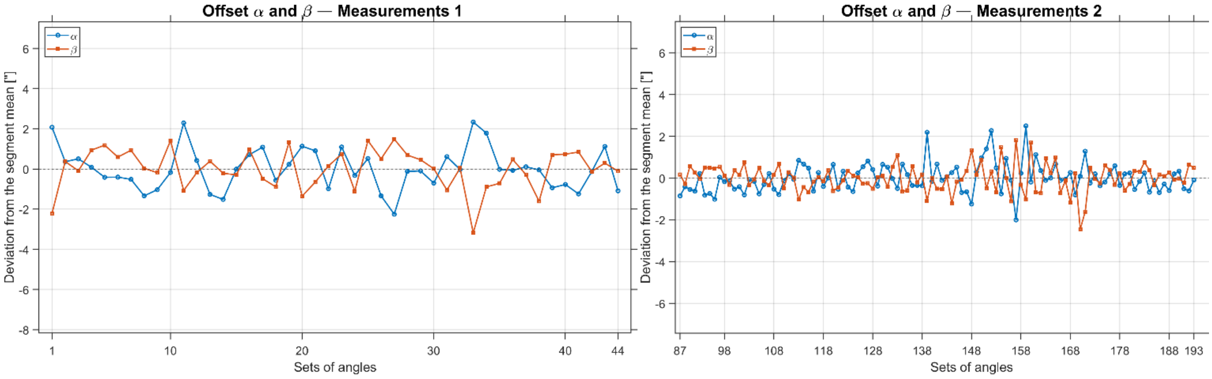

Fig. 6: Display of α and β deviations for the first set of measurements (left) and the second set of measurements (right)

Despite the constancy of angles α and β, the change in horizontal directions to points indicates a total rotation of the entire tripod-tachymeter measuring system. This rotation is the result of the tripod rotating together with the tachymeter around the vertical axis (***Fig. 5***, right). In the horizontal directions, the rotation manifests itself as a systematic effect that is common to all observed points (***Fig. 7***).

The graphs shown in ***Fig. 7*** clearly illustrate the differences in the change in orientation direction, which affects all horizontal directions to the measured points.

We were interested in the rotation, or change in horizontal direction, for each measured point (T1, T2, and T3) separately. For each point, we can calculate the difference between the horizontal direction in a given set of angles and the horizontal direction in the first set of angles. With the calculated difference (ΔHz_Ti) between the direction in the first (Hz_Ti_first_set_of_angles) and last set of angles (Hz_Ti_last_ set_of_angles), we obtained the total rotation for each point. The average of ΔHz_T1, ΔHz_T2, and ΔHz_T3 represented ΔHz_sys.

The representation ΔHz_sys allows us to determine long-term trends related to slow system rotations, as well as short-term changes that occur as a result of mechanical responses to meteorological influences. In this way, we created a time series that we could further analyze and link to inclinometer measurements and parameters obtained from the meteorological station.

3.2 Data synchronization

The data was collected at different time intervals and at different points in time. For this reason, we cannot make a direct comparison. All data sets need to be synchronized in terms of time. A discrete time index (HAMILTON, 1994) with a step size of one minute was defined. All data was then mapped to a common time axis.

Synchronization was performed by averaging the time within each minute interval. This replaced all data within the same minute with their average value and assigned them to the reference time at the beginning of the next minute. This solved the problem of different data frequency and at the same time reduced the influence of short-term noise and individual outliers.

It is important to note that this procedure did not use linear interpolation in the classical sense, but rather time averaging of data (TURK, 2008). The synchronized time series obtained in this way enable a direct comparison of the relative rotation of the system with the inclinations measured by the inclinometer and with selected meteorological parameters, which forms the basis for further correlation and time-shifted analysis (***Fig. 7***, ***Fig. 10*** and ***Fig. 11***).

3.3 Correlation and lag correlation analysis

After synchronizing the data, we performed a correlation analysis. With this analysis, we wanted to evaluate the possible correlation between the rotation of the tachymeter and selected meteorological and inclinometer parameters. In addition to the raw determination of the correlation, we also wanted to investigate possible time lags between the causes and the rotation of the system.

In the first phase, we performed a basic correlation between the parameters. For each pair of variables, we calculated Pearson's correlation (TURK, 2008), where we determine the degree of linear correlation between two time series. The calculated coefficient (***Table 3*** and ***Table 4***) allows us to identify changes in two parameters that occur proportionally and at the same time. Simply put, when one parameter changes, the other changes at the same time. At that moment, the coefficient is elevated, and therefore the correlation between the parameters can be determined.

However, since mechanical and meteorological influences often do not show a strictly linear response, Spearman's rank correlation was also used (TURK, 2008). This correlation is based on rank values and measures the monotonicity of the relationship independently of the form of the relationship between the parameters (***Table 3*** and ***Table 4***). A simple description of this is that Spearman's correlation detects a relationship where one quantity increases or decreases together with another. Even if the relationship is not proportional or uniform, a correlation is detected.

For a more detailed analysis of the temporal dynamics of the system, lag correlation analysis was used (HAMILTON, 1994) (GOUÉDARD, et al., 2008). In this procedure, one time series is shifted relative to another. The correlation coefficient is calculated for each shift. This made it possible to determine whether changes in individual parameters precede or follow changes in the relative rotation of the tachymeter (***Table 5*** and ***Table 6***). A positive time lag means that the changes occurred before the change in relative rotation, i.e., that the rotations are the result of changes in parameters or a response to them. The opposite is true if the time lag is negative. The correlation analysis with lag was performed within a time window of ±180 minutes to check whether the mechanical response of the system in the form of rotation occurs simultaneously or with a time lag relative to changes in meteorological parameters.

4. Results

4.1 Results of the analysis of the rotation of the tripod-tachymeter system at the standing point

This chapter presents the results of the analysis of relative changes in horizontal directions for individual measured points (T1, T2, and T3) and their average, which represents the system component (ΔHz_sys). The analysis was performed separately for each set of measurements in the test.

The analysis focused on these relative changes in horizontal directions at the measured points within each set of measurements.

The results show that in both sets of measurements there is a noticeable rotation of the measuring system that exceeds the expected measuring accuracy of the tachymeter. The shifts in individual directions (T1, T2, T3) are generally similar, which confirms that this is primarily a common rotation of the tripod around the vertical axis and not local shifts of individual targets.

The changes in horizontal directions are shown graphically below. In addition, we show the change in temperature as one of the assumed potential factors for the rotation of the system (***Fig.*** *7*). In a later analysis, when we checked the correlation between other measured parameters and the change in direction, we created graphs for the most correlated elements, which show the connectivity between changes in one quantity and another.

Table 2: Change in horizontal direction from the start to the end point of the measurement set

Measurements	**1**	**2**
Point	Drift ΔHz ["]	Drift ΔHz ["]
Duration [h]	5h 40 min ≈ 5,67 h	8h 52 min ≈ 8,87 h
T1	+27,0	+37,6
T2	+23,9	+38,3
T3	+25,9	+38,7
Average, ΔHz_sys	**+25,6**	**+38,2**
Speed ["/h]	**4.5**	**4.3**

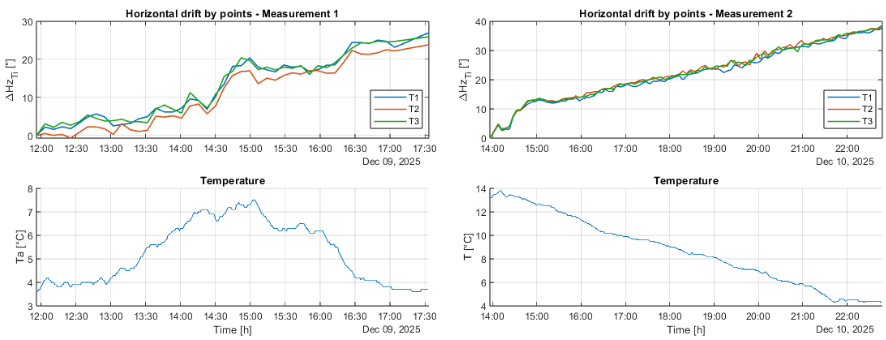

Fig. *7: Changing horizontal directions and temperatures for the first (left) and second (right) set of measurements*

Table 2 shows the change in horizontal direction from the first to the last point in individual measurements. We can see that the largest change occurred in the second set, averaging 38.2". The right side of ***Fig. 7*** also indicates that we can expect a good correlation between changes in horizontal direction and temperature.

4.2 Tripod tilt measurements

The change in direction was in the same direction as the change in tilt in the Y direction of the inclinometer. ***Fig. 8*** and ***Fig. 9*** show how the tilt in the Y direction for the first and second sets of measurements. Quite big changes in inclination of tripod in first set of measurements and in the beginning of second one may be a consequence of walking around the tripod.

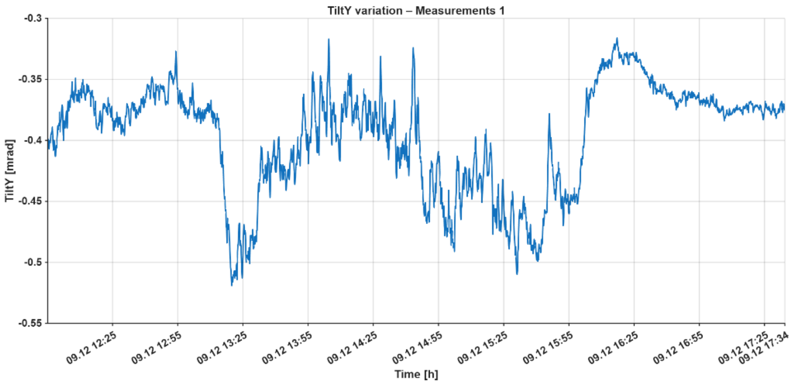

Fig. 8: Change in slope in the Y direction for the first set of measurements

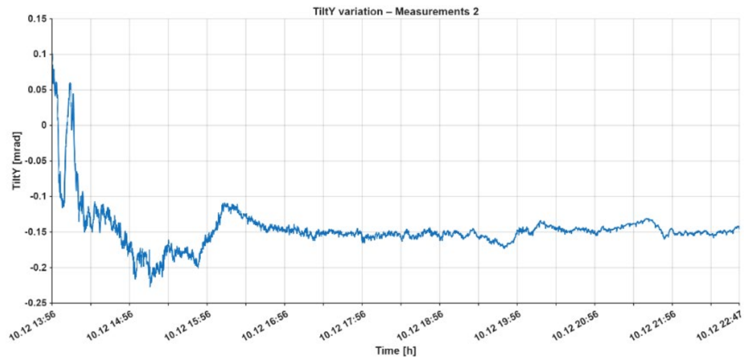

Fig. 9: Change in slope in the Y direction for the second set of measurements

The maximum absolute change in inclination in the transverse direction Y was 0.519 mrad in the first measurement set and 0.227 mrad in the second. With an measured distance of 65 m, approximate height of tachymeter of 1.5 m, this corresponds to a change in the horizontal direction of approximately 2.5″ for the first set and 1.1″ for the second set. Both values are significantly smaller than the actual detected changes in the measured horizontal directions shown in ***Table 2***. Nevertheless, these values are not negligible and should be detected and taken into account in precise measurements .

4.3 Correlation analysis results

Next, simultaneous correlations between relative changes in horizontal directions and selected parameters were analyzed separately for each set of measurements. These were quantities obtained from the meteorological station and the inclinometer. Pearson's and Spearman's correlations were used to assess the relationship (TURK, 2008). In ***Table 3*** and ***Table 4***, Pearson's correlation coefficients are denoted by (P) and Spearman's by (S). The stronger correlation coefficient of the two is marked in bold, and the highest coefficient of all parameters is marked in green.

Table 3: Correlation coefficients for individual parameters in the first set of measurements

Parameters	Correlation coefficient for T1	Correlation coefficient for T2	Correlation coefficient for T3	Correlation coefficient for the system (ΔHz_sys)
P	-0,851 (P)/**-0,865 (S)**	-0,870 (P)/**-0,912 (S)**	-0,847 (P)/**-0,872 (S)**	-0,858 (P)/**0,885 (S)**
D	-0,183 (P)/**-0,203 (S)**	-0,171 (P)/**-0,178 (S)**	-0,174 (P)/**-0,185 (S)**	-0,177 (P)/**0,197 (S)**
TiltY	0,050 (P)/**0,176 (S)**	0,055 (P)/**0,148 (S)**	0,065 (P) /**0,162 (S)**	0,057 (P)/**0,168 (S)**
T	0,163 (P)/**0,167 (S)**	**0,164 (P)**/0,140 (S)	**0,154 (P)**/0,142 (S)	**0,161 (P)**/0,153 (S)
S	0,069 (P)/**0,118 (S)**	0,063 (P)/**0,096 (S)**	0,082 (P)/**0,126 (S)**	0,071 (P)/**0,117 (S)**
U	-0,010(P)/**0,036 (S)**	-0,010 (P)/**-0,015 (S)**	-0,001(P)/**-0,017 (S)**	-0,007 (P)/**0,026 (S)**

In the first set of measurements, air pressure (*P*) proves to be the strongest predictor for all target variables, with a pronounced negative correlation ***Table 3***. Spearman's coefficient values reach magnitudes of approximately 0.87-0.91, which significantly exceeds all other parameters. The calculated values in the last column represent the average of all three points (ΔHz_sys) for each correlation coefficient. ***Fig. 10*** shows how pressure and ΔHz_sys change. We can see that ΔHz_sys increases as pressure decreases.

Correlations with the *TiltY* slope and temperature (*T*) and auxiliary variables are significantly weaker and remain below values of approximately 0.20.

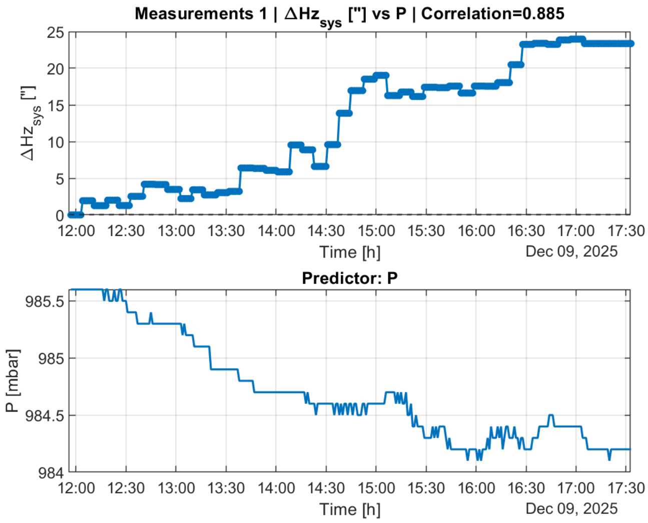

Fig. 10: Correlation between ΔHz_sys and *P* for the first set of measurements

Table 4: Correlation coefficients for individual parameters in the second set of measurements

Parameters	Correlation coefficient for T1	Correlation coefficient for T2	Correlation coefficient for T3	Correlation coefficient for the system (ΔHz_sys)
T	-0,983 (P)/**-0,996 (S)**	-0,984 (P)/**-0,996 (S)**	-0,984 (P)/**-0,996 (S)**	-0,984 (P)/**-0,996 (S)**
U	0,980 (P)/**0,993 (S)**	0,982 (P)/**0,993 (S)**	0,981(P)/**0,993 (S)**	0,982(P)/**0,993 (S)**
P	0,971(P)/**0,987 (S)**	0,973 (P)/**0,986 (S)**	0,972 (P)/**0,986 (S)**	0,973 (P)/**0,987 (S)**
S	-0,555 (P)/**-0,600 (S)**	-0,561 (P)/**-0,603 (S)**	-0,563 (P)/**-0,610 (S)**	-0,560 (P)/**-0,605 (S)**
D	**-0,533 (P)**/-0,476 (S)	**-0,528 (P)**/-0,477 (S)	**-0,526 (P)**/-0,475 (S)	**-0,529 (P)**/-0,476 (S)
Tilt Y	**-0,259 (P)**/0,009 (S)	**-0,260 (P)**/0,013 (S)	**-0,264 (P)**/0,014 (S)	**-0,261 (P)**/0,013 (S)

The second set of measurements showed extremely high correlations between changes in horizontal directions and meteorological parameters *T*, *U*, and *P* (***Table 4***). Spearman's coefficients for meteorological parameters reach values close to 1, indicating an almost perfect monotonic relationship.

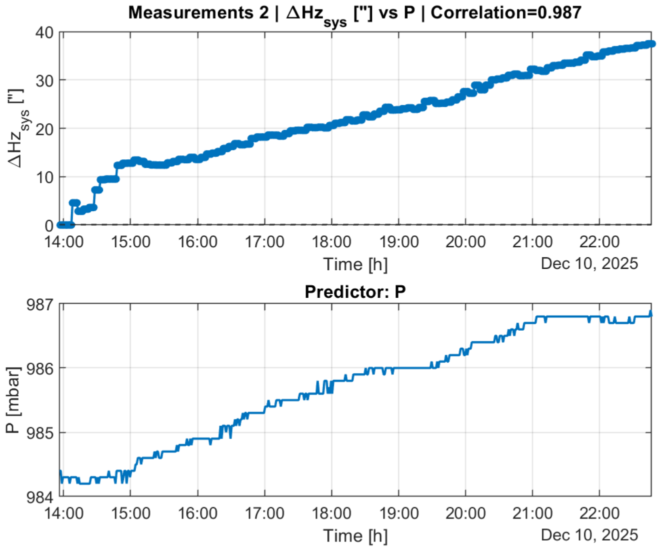

Fig. 11: Correlation between ΔHz_sys and P for the second set of measurements

Fig. 10 and ***Fig. 11*** clearly show why the correlation coefficients are high.

4.4 Lag correlation results

Since the mechanical and thermal responses of the system are often delayed in relation to changes in meteorological parameters, a correlation analysis with a delay was also performed (Statistično društvo Slovenije, 2024). For each pair (ΔHz, parameter), the maximum absolute correlation within the ±180 minute interval and the corresponding time lag at which the correlation is highest were determined (HAMILTON, 1994) (GOUÉDARD, et al., 2008).

Table 5 shows for each parameter the minute at which the maximum absolute value of the correlation coefficient ($|r_{max}|$) between the change in horizontal direction and the individual parameter occurs. In addition to the maximum absolute value of the correlation coefficient, the corresponding time lag is also given.

Table 5: Correlation results with delay for the first set of measurements

Parameters	$\|r_{max}\|$ **for T1**	**Time [min]**	$\|r_{max}\|$ **for T2**	**Time [min]**	$\|r_{max}\|$ **for T3**	**Time [min]**	$\|r_{max}\|$ **for the system (ΔHz_sys)**	**Time [min]**
P	0,851	0	0,870	0	0,847	0	0,858	0
T	0,630	-51	0,633	-51	0,622	-53	0,630	-53
U	0,605	93	0,595	92	0,603	92	0,603	92
Tilt Y	0,492	-92	0,482	-92	0,499	-93	0,492	-92
D	0,192	11	0,192	10	0,193	12	0,192	12
S	0,125	72	0,123	-60	0,125	-60	0,123	-60

Table 6: Correlation results with delay for the second set of measurements

Parameters	$\|r_{max}\|$ **for T1**	**Time [min]**	$\|r_{max}\|$ **for T2**	**Time [min]**	$\|r_{max}\|$ **for T3**	**Time [min]**	$\|r_{max}\|$ **for the system ΔHz_sys)**	**Time [min]**
P	0,983	0	0,984	0	0,984	0	0,984	0
T	0,980	0	0,982	0	0,981	0	0,982	0
U	0,971	0	0,973	0	0,972	0	0,973	0
Tilt Y	0,581	12	0,588	12	0,588	12	0,586	12
D	0,533	0	0,528	0	0,526	0	0,529	0
S	0,259	0	0,260	0	0,264	0	0,261	0

The results of the analysis reveal that the most influential parameters for both sets of measurements are P, T, and U, all of which have the highest absolute correlation coefficient ($|r_{max}|$) above 0,6 (***Table 5*** in ***Table 6***). We can see (***Table 6***) that there are no major delays in the second set, while in the first set (***Table 5***) the delays can be longer than one hour. This fact is also interesting because we used the same equipment throughout the entire test.

5 Discussion and Conclusions

5.1 Interpretation of results

The results of the analysis clearly show that the stability of the entire system tripod-tachymeter during long-term measurements is not constant. In both sets of measurements, systematic changes in the horizontal directions were detected that cannot be attributed to local movements of individual targets or instability of the orientation point. This confirms the finding that the main source of the detected deviations is the rotation of the entire tripod-tachymeter system around the vertical axis.

The analysis of the constancy of angles α and β further confirms that the targets on the reference pillar remain stable throughout the entire observation period, which excludes the possibility that the detected changes are the result of movements of the observed points. Consequently, changes in horizontal directions can be interpreted as a systematic influence that affects all measured directions equally and manifests itself as a zero rotation of the horizontal circle.

Correlation analysis showed that the most dominant influence is air pressure (P). In the second set of measurements, meteorological influences are very pronounced, especially changes in air pressure, temperature, and relative humidity. This shows that the rotation of the tripod cannot be attributed to a single causal factor, but is the result of the simultaneous action of several interrelated processes.

Correlation analysis with a time lag further reveals that influences often do not act simultaneously, but with a pronounced time lag. Such lags are characteristic of mechanical and thermal responses of the system, where a change in external influence does not cause an immediate response, but rather a gradual adjustment of the tripod and instrument. This means that high values of simultaneous correlation do not in themselves imply direct causality, but that the time dynamics of the system must also be taken into account for a correct interpretation.

Overall, the results confirm that the behavior of the entire system under long-term measurement conditions is complex and time-varying. Stability cannot therefore be described by a single variable or a simple model, but requires a segmented approach to the data and consideration of the delayed mechanical and meteorological responses of the system.

5.2 Implication for the stability of the instrument

The results of the study show that the perceived changes in horizontal directions in long-term tachymetric measurements mainly reflect the mechanical behavior of the tripod as a whole and not the instability of the measured targets. The stability of the tachymeter's orientation therefore largely depends on the mechanical properties of the tripod and its interaction with meteorological influences.

In contrast to classical instrument stability tests, which focus on the short-term internal stability of the tachymeter (ODZIEMCZYK, 2018), this study treats the tripod-tachymeter as a time-varying mechanical system. The results confirm that during long-term measurements, the system gradually responds to external influences, which manifests itself as rotation around the vertical axis.

We also measured the inclination changes of the tripod. The analysis showed that even small changes in the inclination of the system can cause measurable changes in the orientation of the instrument, which emphasizes the importance of monitoring inclinations in high-precision measurements. Their effects can accumulate over time and lead to systematic errors in position determination, which is particularly critical in measurements with high accuracy, such as crane rail geometry control.

Meteorological parameters prove to be important accompanying factors, but high correlations with them do not necessarily imply direct causality, but often reflect common temporal trends or delayed mechanical responses of the system.

From a practical point of view, the results indicate that the stability of the entire system cannot be ensured solely by accurate initial positioning. Reliable long-term measurements require appropriate procedures for monitoring and compensating for changes in orientation, as well as careful selection and positioning of the tripod.

5.3 Conclusions

The analysis showed that the stability of the tachymeter during long-term observations is not constant over time, but varies depending on prevailing mechanical and meteorological influences. The detected changes in horizontal directions are predominantly systematic in nature, confirming that they are primarily due to the rotation of the tripod around the vertical axis and not to local movements of the targets.

The results confirm that a uniform treatment of all data is not sufficient, as a comparison of the two sets of measurements reveals some differences in the dominant influences. Nevertheless, meteorological influences and their connection with changes in horizontal directions are the most pronounced in both sets.

The analysis of correlations with a delay further confirms the presence of delayed mechanical and thermal responses and points out that a high simultaneous correlation does not in itself imply direct causality. The stability of the entire system is therefore the result of the intertwining of the mechanical properties of the tripod and time-varying meteorological influences, whereby consideration of the segmental structure and temporal dynamics proves to be crucial for the correct interpretation and use of high-precision geodetic measurements, such as the control of crane rail geometry.

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