TWISTS AND TILTS OF TRIPODS USING ROBOT TACHEOMETERS

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SUMMARY

Robot tacheometers are nowadays used more and more frequently. Due to their motor-controlled axis drives and ATR (Automatic Target Recognition) facility, they are able to independently target and follow points indicated by prisms. However, the motor acceleration and braking processes can cause tripods to twist or tilt. For this reason, the tripod movements have been investigated in comprehensive tests using an electronic autocollimator. Tripods from Nedo, Leica and Crain were included in the investigations. Typical scenarios such as "face change" and "set of angles" were simulated with a Leica TCA2003 robot tacheometer. All measuring scenarios showed systematic horizontal twisting and tilting of the tripod, whereby tilting occurred to a considerably greater extent. It was shown that the twisting and tilting of the tripod remained in the position in which the direction measurements were taken, and that the order of magnitude of the tripod movements was dependent on the position of the instrument. The residual horizontal twisting of the tripod causes a change in direction of the line of sight and thus an error in orientation. Tilting of the tripod has the same effect as a vertical axis error. Using the identified order of magnitude of tripod movements, an estimate can be made as to what extent these errors have an effect on the required accuracy of measurement in individual cases.

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1. INTRODUCTION

Electronic, self-tracking tacheometers (robot tacheometers) are able to independently target and follow points indicated by prisms due to their motorized drives and ATR facility. This therefore raises the question to what extent motor acceleration and braking processes can lead to movements of the tripod, which cause significant residual changes in direction. Greater attention than previously should therefore be dedicated to the choice of tripod to be used with regard to its stability. Amongst other things, the effects of pressing buttons on the deflection of the telescope [Staiger, R. 1998] and oscillations of the tripod [Ingensand, H. 2001] have been presented in previous works. [Schwarz, W. 2001] identifies the possibility of determining tripod movements with a laser interferometer.

The results of comprehensive tests with an electronic autocollimator with regard to twisting and tilting of tripods are presented in the following article. These are mainly concerned with the effects of the acceleration and braking processes of the robot tacheometer on different tripods.

2. TRIPOD

Table. 2.1: Overview of tripods

Design	Nedo 200533 / 513	Leica GST	Crain Tri-Max
Material pillar	Hardwood (ash)	Hardwood	Fibreglass matting impregnated with epoxy resin
Surface pillar	Covered with PVC film or coated (side pillar)	Painted	No separate treatment
Tripod feet	Die-cast aluminium, powder coated, extrusion-coated tripod spike		Plastic injection moulding, extrusion-coated spike
Clamp	Fast-action clamp (200513): Steel clamping straps with stiffening corrugations (stamped) Screw clamp (200533): Die-cast half shell, which is pressed against the side pillar by means of a clamping screw with ball-shaped head	Screw clamp: Small steel plate with thread, which is pressed onto the side pillar by means of a clamping screw.	Fast-action clamp: Clamping straps sawn from aluminium section, open ring strap on the end of the side pillars
Fixing for side pillar in the joint	Clamped by means of a wedge mechanism. Wedge and jaws made from duroplast.	Clamped by means of a wedge mechanism. Wedge and jaws made from aluminium.	Presumably fixed by adhesive
Tripod head	Round shape	Tribrach-shape	Round shape

The following tripods, in new condition, were used for the investigations: Nedo 200533 (Nedo33) and Nedo 200513 (Nedo13), Leica GST and the American Crain tripod Tri-Max. In addition, some tests were carried out with a heavy industrial tripod (self-made by the Geodetic Institute of the University of Karlsruhe), a used Kern tripod, a used Leica GST (Leica used) and a Wild tripod. The table (Table 2.1) shows the differences between the Nedo, Leica and Crain tripods.

3. EXPERIMENTS

3.1 Autocollimator

The autocollimator method was chosen with the intention of recording the effects of the twisting motion of the tacheometer, as far as possible without external influences, while, at the same time, not increasing the weight significantly. On this account a mirror was fixed to the tripod in the hole of the optical plummet with a stress-free mounting. The spatial orientation of the mirror was determined with the Micro-Radian T40 electronic dual-axis autocollimator. The data were monitored by means of a serial interface at about 30 Hz. The autocollimator has a working range of ±1°, a resolution of 0.1'' and an RMS value of 1.7'' for both axes, azimuth and elevation (manufacturer's information over the whole working range). We proved, that the autocollimators accuracy in the reduced working range of ±1' were noticeably better (vertical 0.6'' and azimuthal 0.3'') [Depenthal, 2004].

3.2 Experimental setup

The experimental setup was the same for all tripods. During the measurements in the laboratory, the tripods stood on a weighted tripod star. The instrument was always mounted in the centre of the tripod head. Typical measuring procedures were simulated with a Leica TCA2003 by controlling it by means of the GeoCom command structure [Leica, 1999]. In this way, it was possible to avoid touching the instrument during the measurement process and to eliminate the effects of pushing buttons. The control of the instrument and the monitoring of the TCA and T40 data were carried out using LabView (graphical programming tool from National Instruments) so that an unambiguous time and pair of autocollimator values (azimuth and elevation) could be assigned to each movement of the tacheometer.

3.3 Measuring scenarios

Three different measuring scenarios, namely "set of angles", "face change" and "ATR", were chosen to adapt typical surveying scenarios. In the "set of angles" scenario, the instrument turns horizontally in steps through a certain angle (e.g. 100, 50 or 25 gon), moves to face II after one complete rotation and returns to the starting position with the same step width. Vertical movements are also included. 34 positions can therefore be recorded with a step width of 25 gon. At least one direction measurement was carried out in each position. In the starting position, the lens was located above the autocollimation mirror. The "face change" scenario consisted of several changes between face I and face II and at least one direction measurement per position. For the "ATR" measurements, four prisms distributed in space were recorded automatically in a full set following the learning phase.

4. TEST RESULTS

4.1 General interpretation

Fig. 4.1 shows the results of "set of angles" with a horizontal step width of 100 gon for the Nedo33 tripod. The direction observation was measured 20 times in each position. The effect of acceleration and braking of the TCA2003 showed itself in a predominantly horizontal twisting (azimuth value) of the tripod head at the beginning and end of the positioning movement. A "negative" deflection means that the tripod head is moving in an anticlockwise direction and thus against the direction of rotation of the tacheometer. In face II, the direction of rotation of the tacheometer changes and, as a result of this, also the corresponding direction of deflection. These movements of up to 1 mgon are not critical, as long as the tripod head returns to the original position by the time the measurement is made. For all tripods, the tests show systematic horizontal twisting and tilting, whereby tilting occurs to a considerably greater extent. During the measurement period, in which 20 direction observations were carried out, a continuation of the oscillation of the twisting effects (up to 0.2 mgon in the elevation) could be clearly detected while the TCA2003 was at standstill (cf. Fig. 4.1 and 5.1).

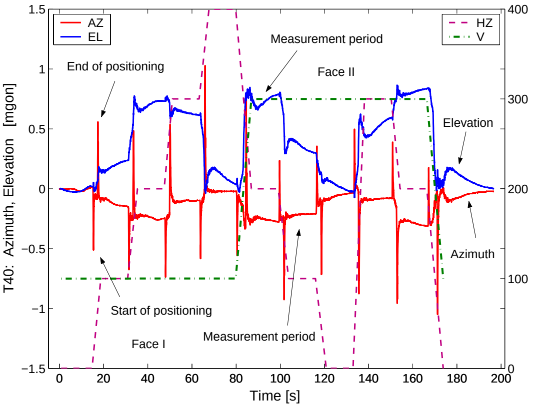

Fig. 4.1: " Set of angles" Nedo33, horizontal step width 100 gon, 20 consecutive direction observations per position ("measuring period")

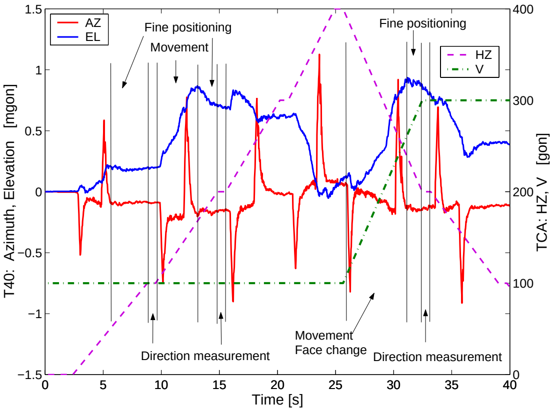

Fig. 4.2: Detail of "set of angles": Nedo33, horizontal step width 100 gon, 1 direction observation

If only one direction is measured, the period of time between the end of coarse positioning and the direction observation – i.e. the time of fine positioning – determines how great the effect of the continued oscillation on the direction accuracy is. This fine positioning procedure is dependent, amongst other things, on the positioning tolerance and, for instance, in the case of the "set of angles" scenario, requires between 1 s and 3 s. Fig. 4.2 shows a detail from a "set of angles" operation with a step width of 100 gon and one direction observation, which lasts almost 1 s.

The differences between the tripods are shown predominantly in the order of magnitude of the movements. Here, it is mainly the short period of the direction observation that is of interest. Fig. 4.3 shows the averaged azimuthal and vertical movements for three consecutive "set of angles" with 25 gon (HZ) and 5 gon (V) step width for a Leica tripod. This shows the stability of the tripod for repetitive measurements. The Nedo tripods show a similar picture while the Crain tripod does not exhibit this stability continuously (Fig. 4.4).

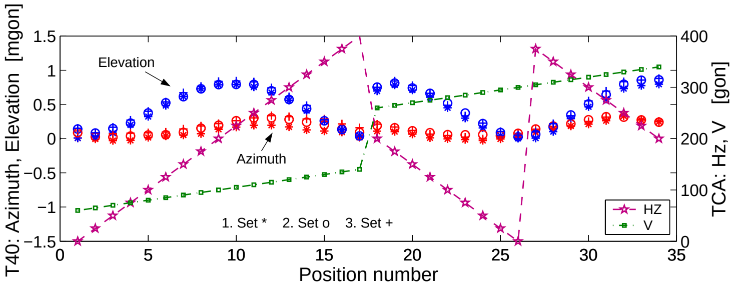

Fig. 4.3: Tripod movements for "set of angles": Leica, averaged AZ and EL values at the time of the direction observation, step width HZ 25 gon V 5 gon, 20 direction observations per position, 3 sets in succession

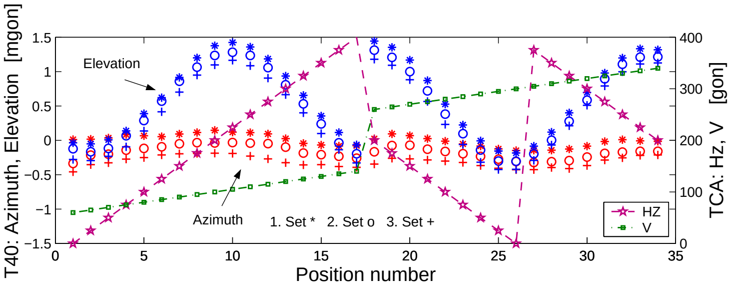

Fig. 4.4: Tripod movements for "set of angles": Crain, averaged AZ and EL values at the time of the direction measurement, step width HZ 25 gon V 5 gon, 20 direction observations per position, 3 sets in succession

Table 4.1: Maximum tripod movements in the "set of angles" test scenario (laboratory arrangement)

Tripod	EL	AZ	Tripod	EL	AZ
	[mgon]			[mgon]	
Leica	0.8	0.3	Kern	0.6	0.2
Nedo33	0.8	0.3	Wild	1.1	0.3
Nedo13	1.0	0.2	Leica used	0.8	0.3
Crain	1.6	0.4	Industry	0.1	0.1

Table. 4.2: Maximum tripod movements in the "set of angles" and "face change" test scenarios (field conditions)

Tripod	EL [mgon]		AZ [mgon]	
	Set	Face	Set	Face
Leica	1.9	1.2	0.9	0.3
Nedo33	1.9	1.2	0.8	0.5
Crain	1.9	2.1	1.0	0.7

An average value can be determined for the maximum twisting or tilting for each individual tripod based on the large number of different test runs (Table. 4.1). The Leica and Nedo33

tripods can be considered as being equal, whereas the Crain tripod gave the worst results. The Kern tripod gave the best results. In this case, the 3 kg greater weight of the tripod and the almost 4 cm wider side pillar certainly played a part. The industrial tripod behaved almost like a pillar but is not suitable for daily field use due to its weight and design.
The results of the tests from the "face change" and "ATR" scenarios are comparable with the results of the "set of angles" scenario (cf. Fig. 5.1).

4.2 Direction-dependent effects

Figs. 4.3 and 4.4 show even more clearly than Fig. 4.1 a tilting and twisting of the instrument foot that is dependent on the instrument position. It must be noted that the second face is included from position 18, whereas on the one hand, the alidade has turned by 200 gon, on the other, the face corresponds to position 1. In consequence, the change in tilt may be due to the fact that the standing axis does not contain the centres of gravity of alidade and telescope. Furthermore, a sinusoidal characteristic can be seen for the elevation and the azimuth. Estimating a sinusoidal function with a linear portion [Depenthal, 2004], a phase shift is evident between the individual sets in the case of the Crain and Nedo13 tripods. The different tripod clamping arrangements might be a reason for this. The fast-action clamp on the top centre pillar, i.e. in the vicinity of the tripod head, presumably produces additional friction between the side and centre pillar, which is not present in the case of a screw clamp on the lower part of the tripod leg, and thus ensures more elasticity in the vicinity of the tripod head.

4.3 Orientation and tilt drift

The residual horizontal twisting of the tripod necessarily causes a change in direction of the line of sight and thus an error in orientation. The rotation of the tripod must not exhibit any drift during a set of direction observations measured only in one face position of the telescope. There was no evidence of any regular linear twisting or tilting of the tripod when estimating the azimuth and elevation values [Depenthal, 2004].
Overall, tilting of the tripod has the same effect as a vertical axis error. With tacheometers, the tilt of the standing axis is measured by means of tilt sensors and the effect on the directions is applied mathematically. For the TCA2003 tilt sensor, there are three different measuring modes using the GeoCom controller [Leica, 1999]: 1. the tilt is always measured under the assumption that the instrument has moved, 2. the tilt is determined from a previous measurement and continually used as a representative correction value under the assumption that the instrument tilt has not changed. In the third option, the system itself decides which mode is used, i.e. the instrument itself checks its own stability. This automatic mode is set by default when using the menu control. The question as to what extent the tripod tilt is detected and dealt with accordingly by the system remains. A further effect remains when determining the vertical index error, as the compensator is switched off in this case and the tripod tilt can thus have the full effect.

5. SPECIAL FEATURES

5.1 Dependence on the subsurface

In order also to test the behaviour of the tripods on a soft subsurface, the "set of angles" and "face change" scenarios were carried out for three tripods (Nedo33, Leica, Crain) in a field with low refractive conditions. The overall results were poor. The maximum deflections for the two test scenarios showed different orders of magnitude (Table. 4.2). The tripod movements for three consecutive sets show variations for all three tripods of up to 0.3 mgon and although they therefore indicate a lower stability in the repeat measurements, they do show a level of reproducibility overall. In the "face change" scenario, only the Crain tripod showed a horizontal drift of max. 0.4 mgon. This experimental setup clearly indicates a correlation between the subsurface and the stability of the tripod.

5.2 Design variations

An important feature of the tripods is the shape of their heads. Nedo, Crain and (the former) Kern generally use round shapes, while Leica prefers a tribrach-shape. With regard to setting up the instrument, all tripods offer a certain action radius, within which the instrument can be fixed. Normally, the instrument is set up in such a way that it is located in the centre of the tripod head. There may however be situations where the action radius has to be fully utilised. Because of this problem, the behaviour of the tripods was also investigated when the extreme position is reached. With the round tripod heads, no difference could be found between the mid-position and an edge position (Fig. 5.1).

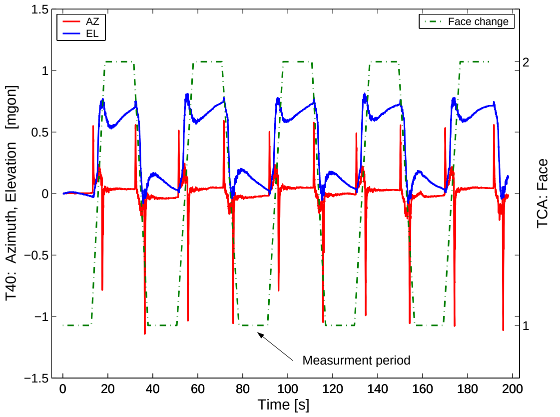

Fig. 5.1: "Face change": Nedo33, 10 face changes, 20 direction observations in each position, TCA2003 extreme position at the edge of the tripod plate

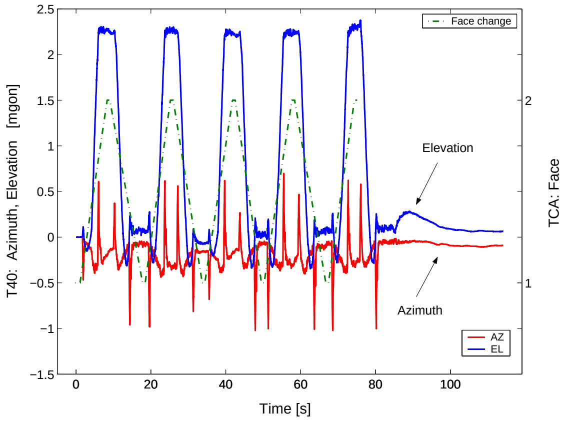

Fig. 5.2: "Face change": Leica, 10 face changes, 1 direction observation in each position, TCA2003 extreme position at the edge of the tripod plate

The situation was somewhat different in the case of the Leica tripod. Here, three different positions were chosen in respect to the three mounting surfaces on the underside of the tripod. In the first uncritical tribrach position, all three surfaces made good contact with the tripod plate. If one mounting surface was completely on the plate and the other two had only very little contact, the tripod tilt reached maximum values of 1.4 mgon. In the worst but theoretically possible position, namely one mounting surface no longer touching the tripod plate, the tripod tilt increased to 2.3 mgon (Fig. 5.2). Although the azimuthal twist is not affected to the same extent, such a setting up the instrument is not to be recommended.

6. SUMMARY

It has been shown by means of comprehensive tests that the tripods (Crain, Leica, Nedo) under investigation exhibit azimuthal twisting and tilting during measurements with a robot tacheometer, which are both direction-dependent. The horizontal tripod movements are maintained during a direction measurement and thus necessarily cause the line of sight to change direction. Tilting of the tripod has the same effect as a vertical axis error. In this regard, consideration should be given to the effect on the determination of instrument errors, especially the vertical index error. The correlation between the subsurface and the type of the tripod should also be critically considered. Overall, the Leica and Nedo tripods can be considered as being equal with regard to tripod movement. The Crain Tri-Max tripod exhibited poorer stability. However, when mounting an instrument on the tripod plate, the mid-position should be preferred in the case of the Leica tripod. From the identified order of magnitude of tripod movements, an estimate can be made as to what extent these errors have an effect on the required accuracy of measurement in individual cases.

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