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Modular Imaging Total Stations – Sensor Fusion for high precision alignment

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Abstract

Initialized in 2009, the Institute for Spatial Information and Surveying Technology (i3mainz), Mainz University of Applied Sciences, forces research towards modular concepts for imaging total stations. On the one hand, this research is driven by the successful setup of high precision imaging motor theodolites in the near past, on the other hand it is pushed by the actual introduction of integrated imaging total stations to the positioning market by the manufacturers Leica Geosystems, Sokkia, Pentax, Topcon and Trimble.

Modular concepts for imaging total stations are manufacturer independent to a large extent and consist of a particular combination of accessory hardware, software and algorithmic procedures. The hardware part consists mainly of an interchangeable eyepiece adapter offering opportunities for digital imaging. An easy assembly and disassembly in the field is possible allowing the user to switch between the classical and the imaging use of a robotic total station. The software part primarily has to ensure hardware control, but several level of algorithmic support might be added and have to be distinguished. Algorithmic procedures allow reaching several levels of calibration concerning the geometry of the external digital camera and the total station. Here the resulting resolution capacity of our sensor fusion and also the accuracy of the system are presented based on examples. We deliver insight in our recent developments and quality characteristics.

The sensor fusion between camera and polar measuring system allows detecting and measuring different types of targets with high precision. MoDiTa is used to calibrate inclination sensors and to control the long-term stability of laser and tripods.

Keywords

Imaging total station, sensor fusion, image processing

1 INTRODUCTION

The combination of polar measurement systems using modern digital industrial cameras keeps growing in the area of measurement technology. Some commercial producers of polar measurement systems like Pentax, Trimble, Topcon or Leica Geosystems now offer this combination as an integrated system, cf. HAUTH/SCHLÜTER (2010). In addition to the aforementioned manufacturers, research institutes also develop solutions and applications of modular imaging total stations, which carry a camera in front of the eyepiece. A prototype of a theodolite combined with a digital camera, developed at the i3mainz, shows the successful use of technical precision measuring SCHLÜTER ET AL. (2009). The MoDiTa – Modulares DigitalkameraTachymeter (modular imaging total station) of i3mainz is a consistent continuation of the previously mentioned theodolite combined with a digital camera on a modular base, which is examined in the BMBF-funded (Federal Ministry of Education and Research) research project "Modulare DigitalkameraTachymeter".

WASMEIER 2009 from the University of Technology München presents the prototype IATS2 based on total station Leica Geosystems TCRA1201. IATS2 replaces the reticule with a CMOS-chip and removes the eyepiece. The camera is fix integrated in the total station and complicates an adaptation for different applications or the changing back to a “classic” total station. An advantage is the good compactness of the system.

BÜRKI 2010 from the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology in Zürich shows with the system DAEDALUS a combination between digital camera and total station, too. This replaces the eyepiece with a CCD-chip and requires no additional optical

components between chip and reticule. The image is no longer imaged precisely in the plane of the reticule but in the plane of the CCD-chip. This small shift is eliminated by the focus of the total station (for objects up to 13 meters) or by adding an additional lens in front of the telescope.
MoDiTa from the i3mainz demand only small changes by the total station. The eyepiece is fitted with a digital camera, which as well as the polar measurement system is controlled by a software module. In this case the digital camera takes images directly from the reticule plane, so no change in the optical path in the telescope prevails. By that modular structure, which requires only a few special products, an easy changing between classical eyepiece and the MoDiTa eyepiece in the field is possible, which causes a large variability (Figure 1). The modular concept of MoDiTa allows replacing several hardware components, e.g. different telescopes (theodolite and total station), several cameras with different resolutions, and various magnifications of the reticule. Thus, this flexible system exploits the respective strengths and weaknesses of each component optimally. Those advantages and application possibilities of the hardware components are discussed in the following chapters.

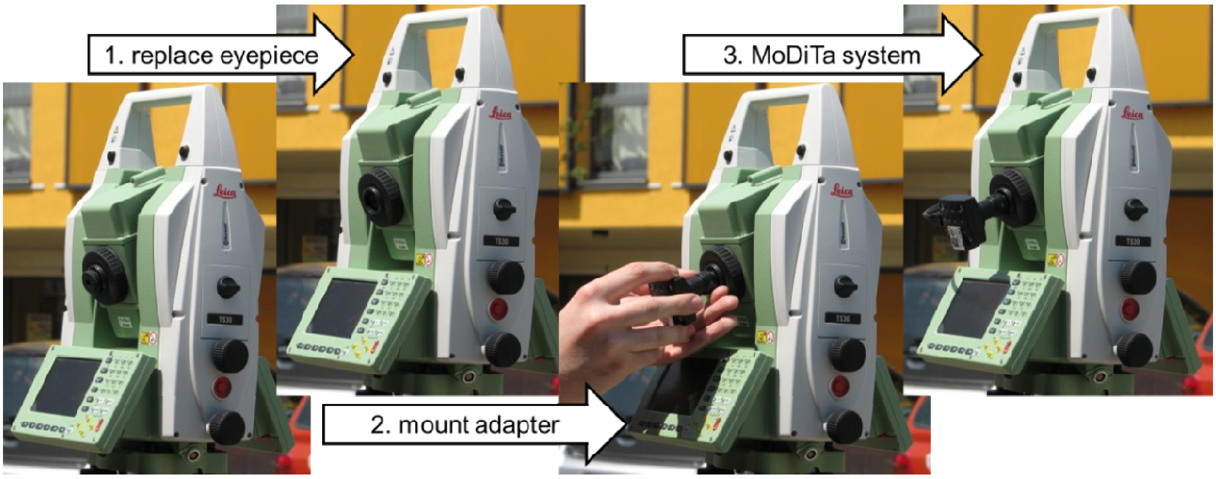

Figure 1: Imaging total station (Leica Geosystems TS30), mounting the adapter

2 THE SENSOR FUSION

The MoDiTa system consists of a sensor fusion between a polar measuring system and a modern industrial camera. The following chapters are describing the configuration and the reachable accuracy and resolving capacity depending on different resolutions of the used cameras.

2.1 Configuration and components of MoDiTa

On the hardware side the specific MoDiTa component is the special eyepiece adapter. This adapter replaces the normal eyepiece and is used as a mount for camera and lens. Camera and optics are standard components and no special developments for MoDiTa. So we use S-Mount and C-Mount ports for camera and optics, and serial ports respective USB for power and data transfer. This offers the advantage that the components are inexpensive to purchase and can be replaced quickly and easily. An optional extension for a focus control is possible. Figure 2 shows the schematic structure of the MoDiTa eyepiece in cross section for mounting the camera and polar measuring system. The standard lens with various fixed apertures is fixed by S-Mount in the eyepiece adapter. This eyepiece holder is connected to the bayonet mount for the eyepiece of the polar measurement system (here Leica Geosystems). The length of the adapter determines the reproduction scale and controls the field of view. The used cameras are producer repetition parts with C- or CS-Mount and data respective power communication by USB 2.0.
MoDiTa can use different polar measurement systems, cameras, resolutions, optics and magnifications of the reticule. This allows to combining the different advantages of the components. At the moment, the MoDiTa adapter can be used with current Leica Geosystems total stations and theodolits and some Kern theodolits. This allows using the Leica Geosystems TM5100 with MoDiTa. TM5100 is an industrial theodolite with high angular measurement accuracy without an EDM. The advantage of a

theodolite telescope is the lack of optical components in the telescope and so less disruptive effects of laser beams. Total stations like TS30 and TCRM1103 are flexible devices with EDM and automatic target aiming.
The adapter of MoDiTa can mount C- and CS-Mount-cameras and so different kind of chips. For most applications colour and monochromatic CMOS-chips are useful, but some tasks requires a special dynamic range. In area of extreme exposure is it helpfully to use a HDR-chip. THIERY (2011) shows a benefit of HDR-cameras by observing laser beams.

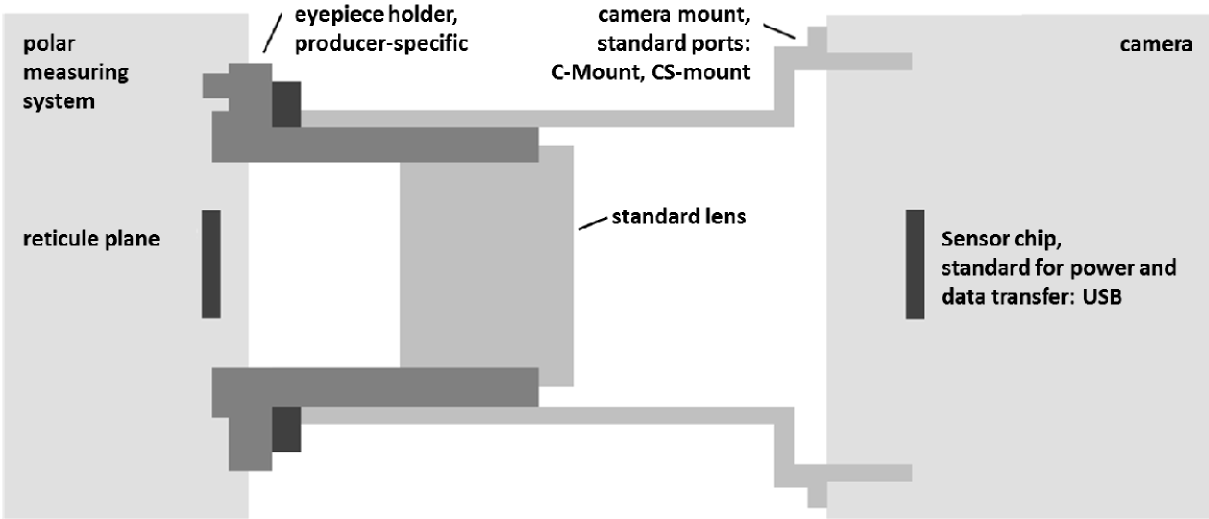

Figure 2: Schematic cross-section of the MoDiTa eyepiece

The resolution can be controlled by chip-size and settings like binning or subsampling. For the maximal accuracy and resolving capacity MoDiTa uses actually a camera resolution of 2560 x 1920 pixels. The disadvantage of this setting is that USB 2.0 limits here the transfer rate and the frame rate. That is no problem by static or slowly moving targets (6 fps). A resolution of 1280 x 960 raises the frame rate of 19 fps, but the resolving capacity and accuracy decrease slightly (chapter 2.3).
Actually MoDiTa provides two kinds of field of views. The full-view images the complete reticule plane and the magnification-view scales up the centre of reticule plane (Figure 3). The difference between full-view and magnification-view is about 76%. In principle the magnification-view has a better accuracy and resolving capacity.

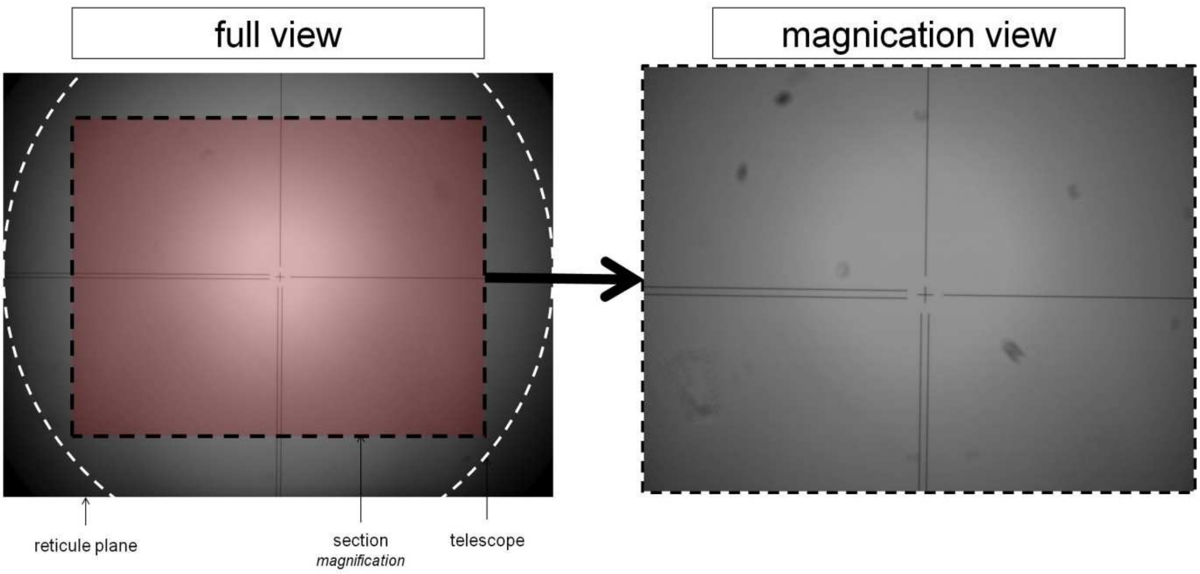

Figure 3: Field of views

2.2 Calibration of field of view

The calibration of field of view allows transforming every pixel coordinate to one angular position. MoDiTa can measure all targets in the field of view without boning with the crosshair (Figure 4 right). The field of view is determined by a self-calibration. The self-calibration scheme using the photogrammetric collinearity relationship in addition of the distortion parameters is conform to SCHLÜTER ET AL. (2009).
For the self-calibration, a fixed target is repeatedly measured, that the target is well distributed over the calibrating area (Figure 4 left). Every measurement is forced angular positions, resulting two correction equations, each new combination of reading and image coordinates. The angular readings following mathematically from the pixel coordinates of the reference cross hairs.

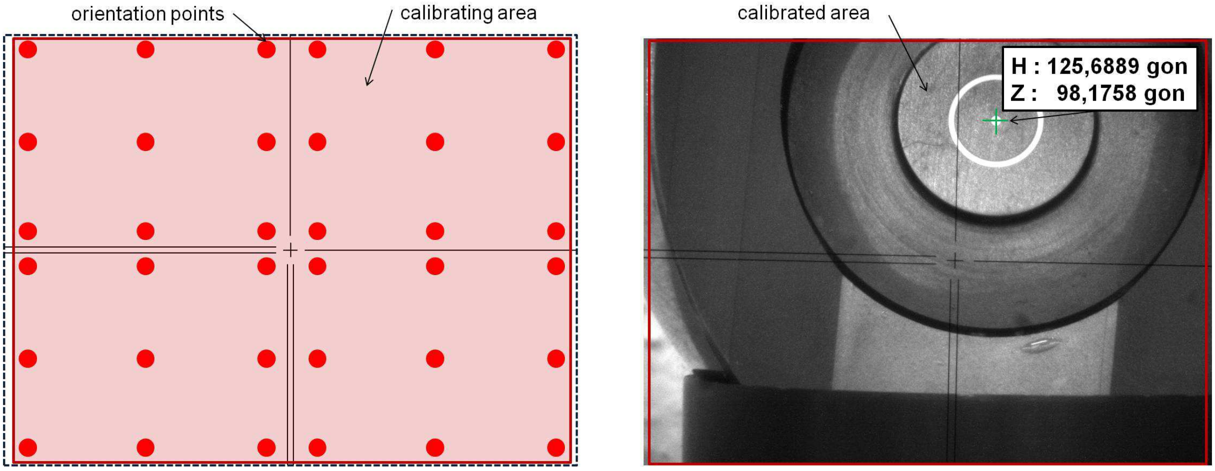

Figure 4: Self-calibration (left) and transforming pixel coordinate to angular position (right)

Beginning with the transition from a levelled local coordinate system to a telescope fixed coordinate system, the parameters are provided solely by the theodolite side compensator and graduated circle read out. The subsequent transition from the telescope fixed coordinate system to the camera system by parameters determining in a self-calibration. The photogrammetric collinearity relationship is chosen as a model for the transformation between direction vectors the telescope system and the image coordinates of digital images. As part of the self-calibration with a fixed scale factor, the angle of rotation matrix (R_K), the camera constant (c_K) and the coefficients of distortion polynomials (Δx, Δy with image coordinates X_B and Y_B) are determined as unknown parameters in a least-square adjustment. Radial symmetric distortion, caused by refraction changes in the lenses of the lens, provides the greatest impact among the mentioned distortions. The radial asymmetrical distortion and tangential distortion be caused by a decentring of the lenses in the lens and is less than the radial symmetric distortion. As the last part of the distortion affinity and angular affinity describing deviations from orthogonality and different scales of the image coordinate axes. The result of the least-square adjustment is a transformation matrix with 13 parameters (3 rotations, 2 image coordinates of the principal point, 1 calibrated focal length, 3 radial symmetric distortions, 2 radial asymmetrical and tangential distortions and 2 affinity and angular affinity).

2.3 Accuracy

The MoDiTa system allows the use of several components. There are two kinds of field of views, different camera resolutions and total stations. The accuracy of MoDiTa-Systems is determined by the self-calibration on two collimators. The self-calibration is measured with 36 observations in two-face-measurements. Exemplary the Table 1 shows the results of the least-square adjustment. The used hardware are a Leica Geosystems TS30 total station with an angular measurement accuracy of 0,5’’ (0,15 mgon, manufacturers' instructions) and a monochromatic CMOS-chip.
The results of Table 1 compare two resolutions (2560 x 1920 and 1280 x 960) and two fields of views.

The standard deviations (std.) of all measurements are not significantly different. But the residuals are larger in the full-view significantly than the magnification-view. The differences between the two resolutions are small. Both the standard deviation and the residuals are in the same range.

Table 1: Results of least-square adjustment (self-calibration), 36 observations

	full-view			magnification-view		
2560 x 1920		dHz [mgon]	dV [mgon]		dHz [mgon]	dV [mgon]
	min	-1,0	-0,4	min	-0,1	-0,2
	max	0,7	0,6	max	0,3	0,1
	std.(1σ)	0,20	0,10	std.(1σ)	0,05	0,05
	1 Pixel = 0,6 mgon			1 Pixel = 0,36 mgon		
1280 x 960		dHz [mgon]	dV [mgon]		dHz [mgon]	dV [mgon]
	min	-1,0	-0,5	min	-0,2	-0,3
	max	0,9	1,0	max	0,3	0,2
	std.(1σ)	0,20	0,10	std.(1σ)	0,06	0,06
	1 Pixel = 1,3 mgon			1 Pixel = 0,7 mgon		

The best accuracy for a single observation is magnification-view and the resolution of 2560 x 1920. The resolution of 1280 x 960 provides a similar good result. The adjustment allows to reach the accuracy of the total station (0,5’’ = 0,15 mgon, manufacturers' instructions). The full-view has a maximum residual of 1,0 mgon and the standard deviation of the adjustment is in the range of the double accuracy of the total station.

3 APPLICATIONS

The flexibility of MoDiTa allows using the system in many different scopes of duties. The possibility of collimation measurements and their detections with MoDiTa or an imaging theodolite build by i3mainz, at both collimator crosses, as well as collimating laser beams offer, with different hardware capabilities of a wide variety of applications. The system enables the directional measurement to a moderately moving target, too. This represented target in this paper is a laserdot and a cross of a collimator.

The MoDiTa allows the use of non-contact measurement techniques including image processing and auto-collimation aiming within a calibrated visible range. Through a rapid self-calibration (ca. 2 minutes), followed by automated analysis of those and immediate readiness for measurement in the calibrated range are special tasks, such as the adjustment and calibration of laser terminals during the manufacturing process, see SCHLÜTER ET AL. (2009), very quickly solved. Azimuth determinations by astro-geodetic observations of stars with the given hardware and software are also available. Classical tasks of geodesy, such as monitoring (here landslides, see REITERER (2009) or the documentation of reference ¬ points for laser scanning and photogrammetry, the sensor-fused system also triggers using image processing. MoDiTa also enables the detection of changes in direction, such as tilting or twisting of various hardware (eg. sensors). In the following exemplary applications which results in projects of the i3mainz, like the calibration of an electronic level and stability testing of a camera tripod through MoDiTa and image processing demonstrated.

3.1 Scale calibration of inclination sensors

Inclination sensors are gaining in importance in the field of geodesy. The electronic collection of data and the high accuracy of small measuring instruments provide in shortest time highly accurate data. The measurement of the slope provides the detection of small movements such as for deformation measurements. The determination of the scale of two inclination sensors (Leica Geosystems NIVEL220 and NIVEL230) is carried out e.g. by AZAR (2009) on behalf of the Wasser- und Schifffahrtsamt Aschaffenburg.

The examination of an inclination sensor, information regarding the producer, takes place in three stages: determining the zero point error, scale error and the detection of the influence of temperature changes. The system of i3mainz is used here only to determine the scale error. The sample is placed on a for flatness granite checked slab, parallel to the axis, compare to figure 6. The combination of sample and collimator is a parallel arrangement of the telescope reaches the level. The granite base is mounted on a tilt table which can be tilted by micrometre screws. With the help of those, putting the sample into the previously determined zero point and gradually tilts the tilt table. Thus, the desired inclination of the level to the actual reading of the level is compared. The MoDiTa-system observes the collimator after every tilt of the table by the micrometre screws. Every observation consists of 36 single observations like a self-calibration (chapter 2.3). This zenith angle performs the tilt angle of the table (inclinometer and collimator).Parallel to the registration of the zenith angle the reading of the inclination sensor (X-and Y-axis separately) is detected.

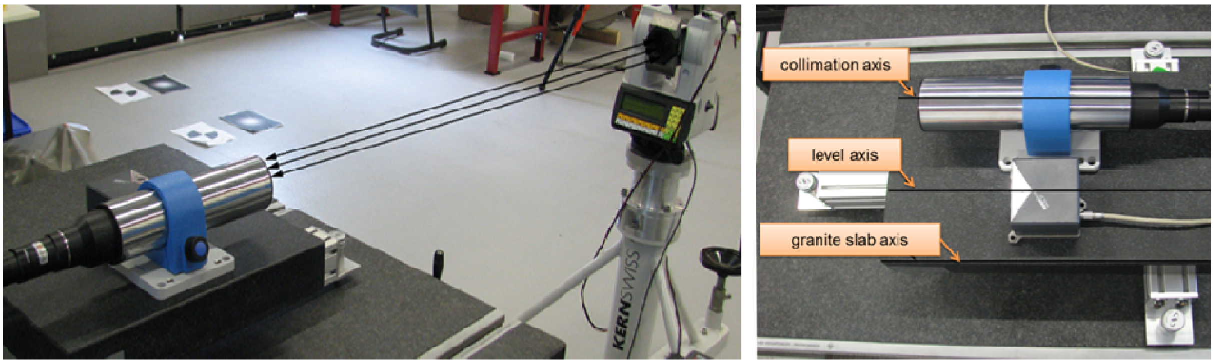

Figure 5: MoDiTa observes collimator (left), collimator and digital level fixed on a tilt table (right)

For this application the MoDiTa-system uses a Leica Geosystems TM5100 theodolite, the camera-resolution 1280 x 1024 and the magnification-view. Magnification-view and resolution is in the range of the angle accuracy from theodolite (0,5'' = 0,002 mrad, manufacturers' instructions). Both test objects (Leica Geosystems NIVEL220 and NIVEL230) have an accuracy of 0,005 mrad (manufacturers' instructions) and thus MoDiTa is suitable for checking the inclination sensors.
The scale is calculated from zenith angle (reference values) and tilt angle of the inclination sensor. The zenith angles are corrected by an average offset, because the collimation axis is not strictly parallel to the surface of the granite base. Figure 6 shows an exemplary result of alignment an inclination sensor Leica Geosystems NIVEL220.

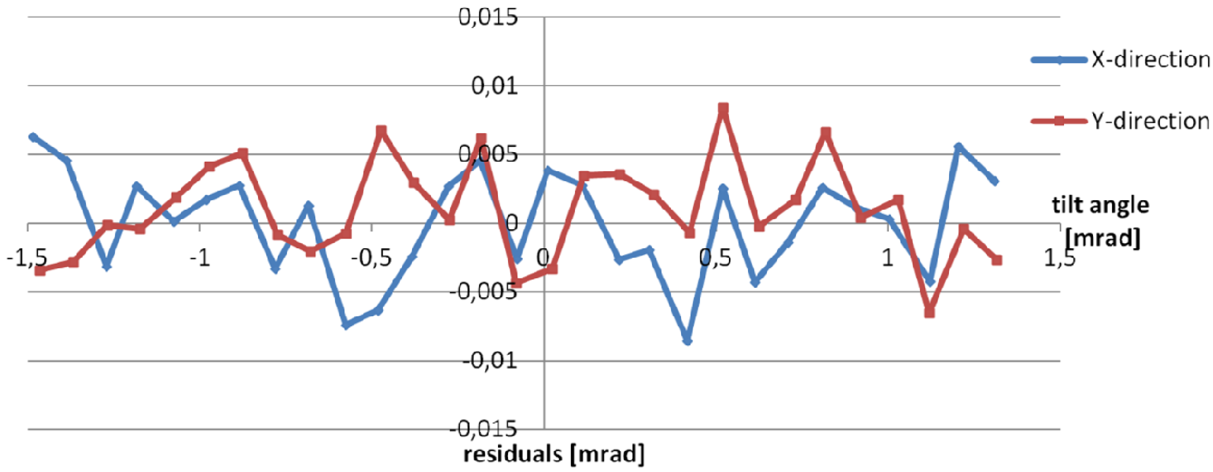

Figure 6: Exemplary result of scale alignment

Here the advantages of MoDiTa are the high repeatability and measurement speed. MoDiTa allows a large number of independent measurements in a relatively short time (36 observation in max. 2 min) with a high accuracy (0,002 mrad corresponds 0,002 mm/m). The measurement has a high degree of automation and a long-term observation is possible.

3.2 Long-term stability of tripods and laser beams

In the precise measurement tripods needed, which have only small drifts in the horizontal direction and vertical angle over a longer period of time, to store testing samples stably. In precision measurement therefore stable tripods made of steel or aluminium are preferred. A long-term stability study intended to show, whether a photo-tripod is suitable for use in precision measurement. Purpose is to detect differences in stability between the tripod head and tripod legs.

Two collimators are used as a target of the imaging total station (Figure 7). On the left a collimator is shown, which serves as a reference and mounted on a stable tripod by KERN. On the right hand a further collimator is displayed, where the sample is fixed (here: tripod including tripod head). A successfully self-calibration of the system, is followed by the actual inspection and sub-pixel registration of the horizontal direction and vertical angle of the collimator cross. The analysis covers for each measurement period in a time period of at least 20 minutes (t_0=0min). Starting with a reference measurement to a collimator on the stable KERN-tripod, the collimator crosshair fixed on the sample is being tracked at different time intervals and concluded with a reference measurement. The evaluation is done by calculating residuals in the vertical direction of the reference measurements for each measurement period in order to detect movement on the instrument.

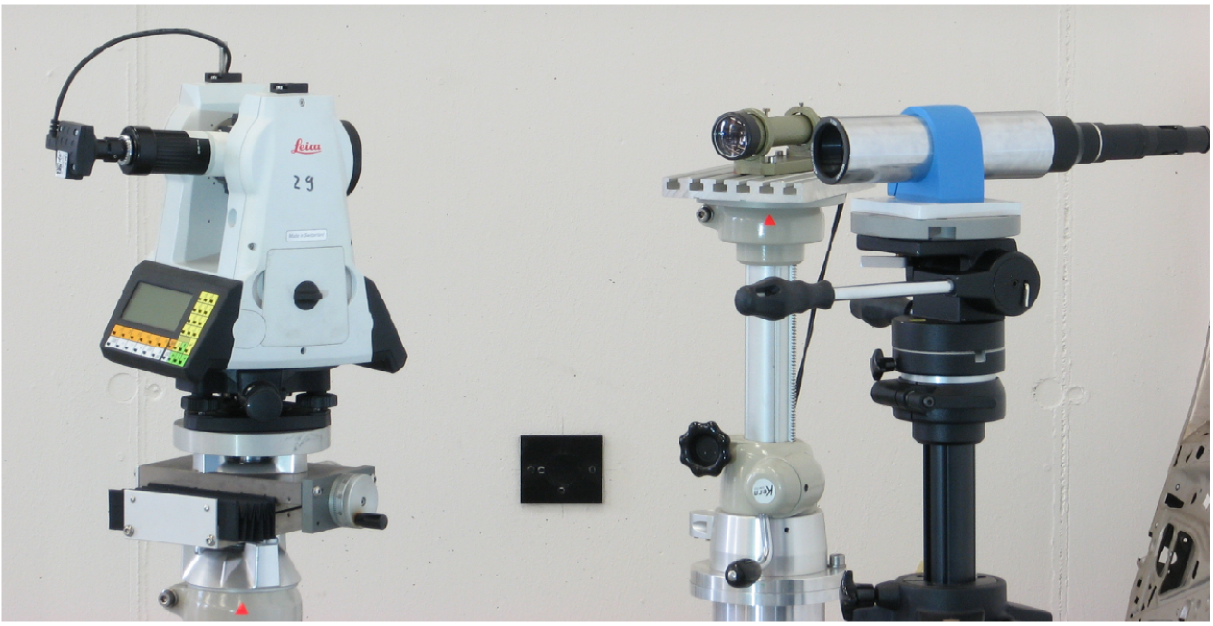

Figure 7: Imaging theodolite aiming a collimator on a Linhof tripod (right)

Based on the results of THIERY (2011) the best configuration for capturing laserdots is a high dynamic range (HDR) camera by using a theodolite without EDM unit to avoid reflections. Theodolite measurements are made only at rest, during a moving target crosses the reticule plane. If the theodolite rests, the direction to the target is registered with high precision, if the target is within the calibrated field of view. For large-scale tracking of a target, the theodolite software supports gradually readjusting. However, in the movement phase, no high-precision measurements are possible. The tracking speed of a moderate moving collimation target corresponds to the recording speed of the used camera.

Figure 8 shows exemplary an image through the eyepiece, along with the recorded measurement collimation image of a laser beam and a resulting image recorded with an HDR camera. If a reference image of the reticule plane is captured and stored, the visibility of that is not necessary to detect the direction. It is only important for detecting movements of the camera. So, matching processes offers the projection of the reticule plane into the image of the laserdot. The centre coordinates of the laser spot can be calculated with subpixel accuracy using digital image processing on an elliptic operator. Out of the centre coordinates, the theodolite and compensator readings and the data from the self-calibration the (virtual) direction can be determined arithmetical to the laser spot centre.

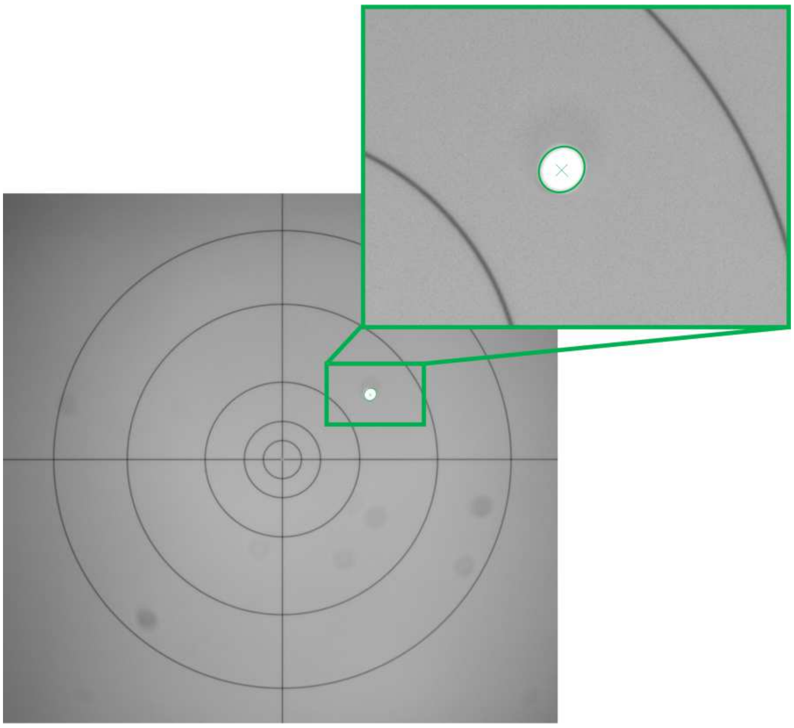

Figure 8: Captured laserdot with reticule

4 CONCLUSIONS

In this paper, we discuss the MoDiTa system, its configuration and some applications. We concentrate on the accuracy and resolving capacity and show that a 1,3 megapixels camera is sufficient to exhaust the angles accuracy of a Leica Geosystems TS30. As the key contribution we present the calibration scheme using the photogrammetric collinearity relationship in addition of the distortion parameters, too. Moreover, we depict that our modular system is able to accomplish and various applications using the best components depending on the problem. In the future, more and more applications for our MoDiTa system should be found. The presented results show a great potential of the given hardware and software.

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