Laboratory Tests of Robot Stations

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SUMMARY

Accuracy characteristics of measured values (lengths and angles) given by producers describe the static conditions by measurement only. Dynamic conditions going by cinematic measurements can be describes by new accuracy characteristics only. Determination of these characteristics by dynamic tests of robot stations. Determination of position of the target moved on 2D trajectory. Mathematical model, instrumentation and series of laboratory tests. Determined and given trajectory comparison. Error distribution.

ZUSAMMENFASSUNG

Genauigkeitscharakteristiken der gemessene Werte (Distanz und Angel), die bei Hersteller gegeben sind, beschrieben nur die statischen Bedingungen der Messprozess. Für die Beschreibung der dynamischen Bedingungen bei kinematischen Messungen braucht man neue Charakteristiken. Dynamischer Test der Robotstationen für Bestimmung der neuen Charakteristiken. Lagebestimmung der auf 2D Bahn bewegtes Prisma. Mathematisches Model, Instrumente und Laborteste. Vergleichung der gemessenen und gegebenen Bahn. Fehlerverteilung.

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1. INTRODUCTION

Motorization and automation of the robot stations starts a new faster and more effective way for measured data obtaining. Development of the automated robot stations with automatic searching and tracking of the reflected system opened new possibilities of their utilisation in all areas of surveying, first of all in the area of the engineering surveying. Robot stations with automatic searching and tracking of the reflected system offer with help of the integrated tracking module a possibility to track and order cinematic processes as movement and deformations of the building structures as well as deformations of the industrial robots and their trajectories, etc.

2. AUTOMATED TARGET RECOGNITION

Characteristic components of robot stations (RS) enable their motorization are stepping motors (eventually servomotors), searching and continually tracking function of the reflected prism Lock-Mode and automated pointing function into the middle of the reflected prism (ATR – Automated Target Recognition). Stepping motors (eventually servomotors) enable instrument rotation round its vertical and horizontal axis.

Automated target searching means identification of the reflected prism in a working area of the searching target function that is represented with the range of the telescope-viewing field (Hennes, 1999). Is concerned RS with the passive reflected prism, searching of the reflected prism carries out by the sequential scanning of the telescope-viewing field in a whole working area. At another principle of the target searching work the robot stations with the active reflected prism. The active reflected prism is equipped with a communication unit with a radio station that ensures a communication between a prism and a robot station.

RS differ also with a principle of the targeting to the reflected prism. Generally it is about determination of the reflection that is sensing with built-in CCD sensor, eventually about a targeting on a principle of the maximal intensity of the reflected prism. Automated targeting starts in a moment of the measurement running.

3. DATA AQUSITION WITH ROBOT STATIONS IN CINEMATIC MODE

Robot stations with automatic searching and tracking of the reflected system in the cinematic mode enable to observe and navigate cinematic processes. It is necessary for the angular and length system to work together. But RS are not constructed like this way, angles and lengths are measured with time slide that size is not known. By the static mode this very short time slide is not a handicap. In a cinematic mode it essentially influences a quality of the measured values because the measured angle and length are associated to the one point by the registration but in fact these are two points. Short time slides between angular and length measurement of the cinematic object effects that measured angle belongs generally to the other point as measured length.

Producers of RS present the accuracy characteristics of the angular and length measurement upon which it appreciates their availability eventually inadvisability for the particular type of the tasks. Also by the producers are presented characteristics of the RS that only for static mode (behaviour). For measurements in a cinematic mode are given only accuracy characteristics of the length measurement. For the utilisation of RS for the measurements in a cinematic mode it is necessary to have more information as for example the accuracy of the angular measurement or a general capability of the instrument for determination of a geometric figure of the measured object eventually trajectory of the object in a space.

For this purpose was made the series of experiments at the Department of Surveying of the SUT in Bratislava, with the aim to verify and supplement the producer information about the accuracy of RS with the automatic searching and tracking of the reflected system.

4. LABORATORY TESTS

Research activities oriented to determination of characteristics of RS under dynamic conditions are at the Department of Surveying started in 2001. The bellow described and presented results of experiments are results of continue realised research projects in this field (Kopáčik et al, 2002, Kadlečíková and Kyrinovič, 2004).

4.1 Test by 2D simulator

For realisation of this experiment was special equipment (2D simulator) used, which was developed for testing sensors of the inertial measuring systems (Fig 1). Its main part is an arm that rotated in a horizontal plane. At the end of this arm there is fixed measurement platform that rotate opposite to the rotating arm (Kopáčik, 1998). It ensures that the measurement platform and also the reflected prism, which is positioned on the platform have always the same azimuth – is oriented always towards the observer. The centre of the platform is moving

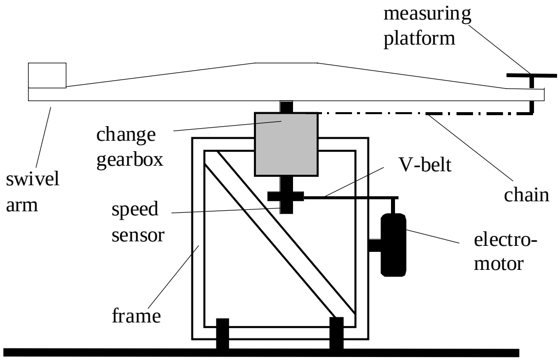

Fig. 1 2D simulator with rotating arm (Kopáčik, 1998)

at the circle trajectory with 500 mm radius. This equipment enables a rotation in various stages of the speed.

The reflected system (prism) was positioned on the measurement platform centre and was moved also in the horizontal plane on the circle form trajectory. The tested RS observe its movement on the trajectory and register the measured values directly to the PC via connecting cable. For the experimetn were used the Leica TCA 1800, Leica TCRA 1101 plus and Zeiss Elta S10 (tab. 1).

Tab.1 Accuracy characteristic of measured values given by producers

	Leica TCRA 1101 plus	**Leica TCA1800**	**Zeiss Elta S10**
Static mode	2mm + 2ppm	2mm + 2ppm	1mm + 2ppm
	$0{,}5^{cc}$	$0{,}3^{cc}$	$0{,}3^{cc}$
Tracking (measuring time)	5mm + 2ppm (0,3 sec)	5mm + 2ppm (0,3 sec)	undefined
Fast tracking (measuring time)	10mm + 2ppm (<0,15 sec)	10mm + 2ppm (0,15sec)	undefined

The trajectory of the moved prism was measured step by step with each RS. The measurement was realised from two various stations that were in different distances from the simulator. Due to limited space conditions measurement of two stations were realised only. Measurement was realised by various angular velocities of the rotation arm.

With comparison of the both trajectories, the measured and given trajectory, the accuracy characteristics of tested instruments are calculated. According the obtained results can be concluded, that the measurement is influenced by certain systematic errors, which are mainly due to the time slide between the angular and length measurement (registration) by RS. According this becomes the geometry of the measured trajectory the elliptic form (Fig. 2). In

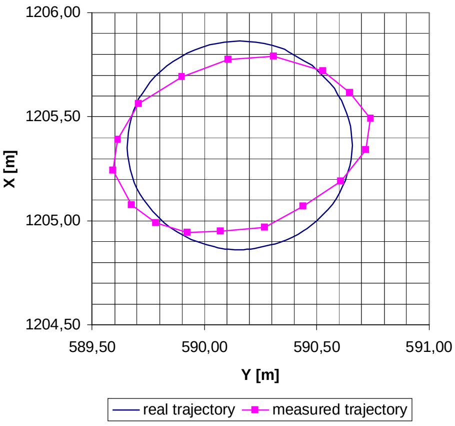

Fig. 2 Prism trajectory determined by Zeiss ELTA S10 (Kopáčik et al, 2002)

table 2 are presented the maximum deviations of measured points from the given circle trajectory for individual instruments and different angular velocity. The deviations are increasing mainly of the angular velocity, but are also other factors there like influences the accuracy of automated target recognition by the higher velocity of target movement.

Tab. 2 Maximum deviations of measured points from the given trajectory

Distance of the instrument from the middle of the circle [m]	**Instrument**	**One swing out lasting** [s]	**Number of the points for one swing out**	**Maximum deviation of the point from the circle** [mm]
11,2	Leica TCRA 1101 plus	5	23	44,3
		7	24	15,0
		18	59	18,0
		48	135	9,9
	Leica TCA 1800	5	16	109,8
		7	21	95,1
		10	30	66,1
		47	144	16,7
	Zeiss Elta S10	10	9	180,9
		18	8	111,6
		53	15	71,9
2,5	Leica TCRA 1101 plus	6	24	50,2
		7	28	39,7
		9	35	34,7
		10	39	27,3
		16	58	19,0
	Leica TCA 1800	6	14	81,0
		7	20	95,5
		9	28	70,5
		10	30	67,0
4	Zeiss Elta S10	30	10	74,7
		32	9	79,6
		3	14	42,6

The smallest deviations are achieved by the Leica TCRA 1101 plus, also this RS was used for the second series of laboratory tests.

4.2 Test by moving platform

The trajectory of the moving prism was simulated by special equipment, which enables the prism movement in horizontal plane and two perpendicular directions. The equipment consists of two parts – the upper movable and the lower immovable part fixed on measuring tripod and pillar in laboratory (Fig. 3). The prism is fixed on the movable part, which movement is realised manually with rotation screws. The measuring range of shifting screws is 25 mm and the accuracy of the position adjustment is 0,05 mm. The maximum distance between the RS and the test equipment (prism) can be arranged to 15,6 m – due to laboratory space limitations.

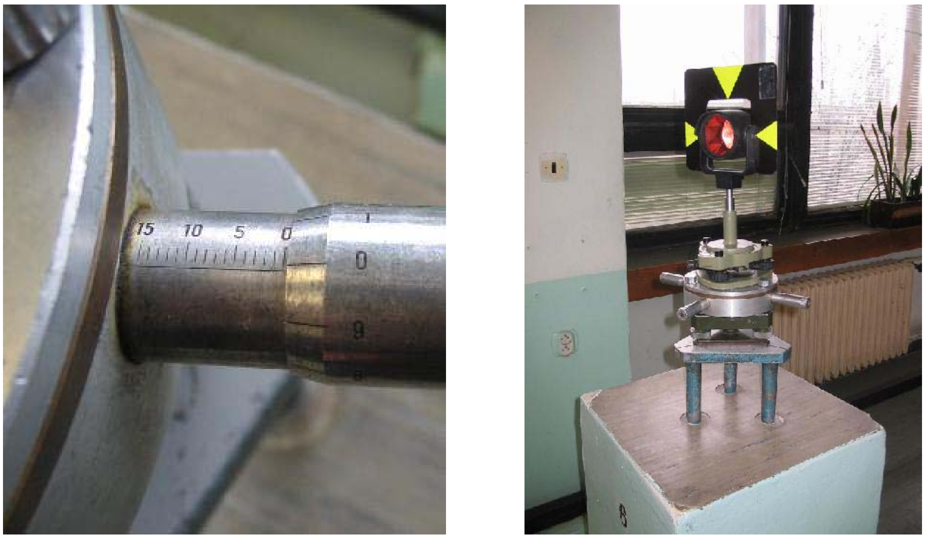

Fig. 3 Detail of the shifting screw and test equipment with prism
(Kadlečíková and Kyrinovič, 2004)

The RS recognised automatically the prism after starting the test measurement and determined its position on the trajectory with the frequency f = 1,25 Hz. The prism was manually moved on the given trajectory, which consists of 7 perpendicular or parallel parts by the shifting screws (Fig. 4). The prism movement was stopped in each 5 mm position given by shifting screw scale (reading) for time of 10 sec, which is equal to 8 measurements (registrations) realised by the RS. The stop positions are marked with cross on the figure 4. During the 95 mm long trajectory was realised 720 measurements, registered the polar coordinates (slope distance, horizontal and zenith angle) for 720 positions. The velocity of the prism moving was calculated, which is between 0,011 mm.s^{-1} and 0,020 mm.s^{-1} (Tab. 3). Average values and relative average values are calculated for each trajectory part. Velocity changes are not influenced the accuracy of the coordination determination.

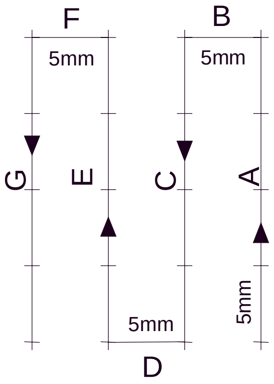

Fig. 3 The given trajectory
(Kadlečíková and Kyrinovič, 2004)

Tab. 3 Trajectory characteristics

Part of trajectory	Length of trajectory [mm]	Number of trajectory points	Average velocity **v** [mm.s^{-1}]	Relative average velocity - **v** /**v**$_A$ [mm.s^{-1}]
A	20	126	0.019	1
C	20	121	0.020	1,04
E	20	192	0.013	0.65
G	20	160	0.015	0.79
A+C+E+G	**80**	**599**	**0.016**	**0.84**
B	5	34	0.018	0.92
D	5	56	0.011	0.56
F	5	31	0.019	1,01
B+D+F	**15**	**121**	**0.015**	**0.78**

According the a priori error calculation is the accuracy of given trajectory more as one order higher as the accuracy of the trajectory determined by the tested RS. The differences between the measured and given position will be seen also as absolute errors of the RS.

4.2.1 Data processing

Processing of measured data consists of calculation of measured trajectory coordinates, transformation (rotation) of measured and given trajectory into one common system of coordinates and the comparison of measured and given trajectory. It is impossible to define and to ensure the parallel orientation of equipment axis with the axis of the chosen coordinate system. Also will be two coordinate system defined with the different orientation, which is given by angle γ (Fig. 5). The given trajectory is transformed to the coordinate system of measured points given by RS and the position of first measured points. Position of this point was determined by repeated measurement.

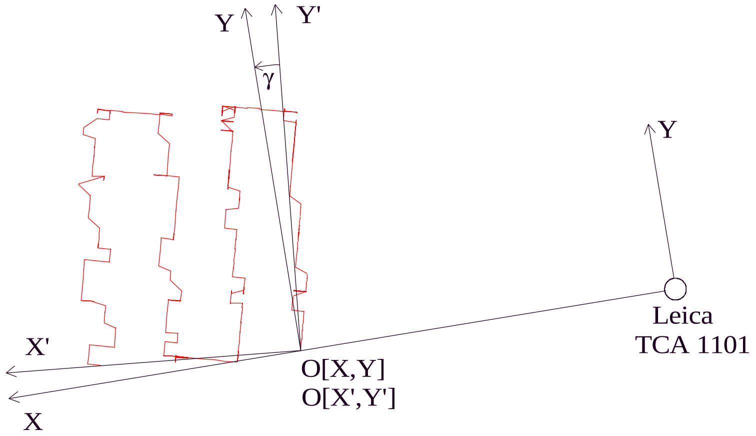

Fig. 5 Coordinate systems (Kadlečíková and Kyrinovič, 2004)

For determination of the rotation angle γ was the average azimuth values determined for the transversal lines (a, c, e and g) of the given trajectory used. These were calculated as azimuth values of the regression lines positioned over the trajectory parts (Fig. 6). In our test was the value γ = 2,5151 gon calculated.

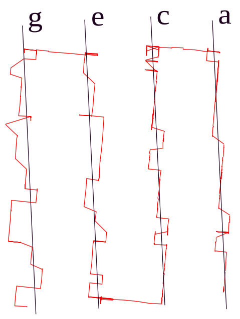

Fig. 6 Regression lines (Kadlečíková and Kyrinovič, 2004)

In next step was the centre of the measuring platform and their position in coordinate system of the RS calculated. Finally the measured trajectory was projected into the given trajectory (Fig. 7).

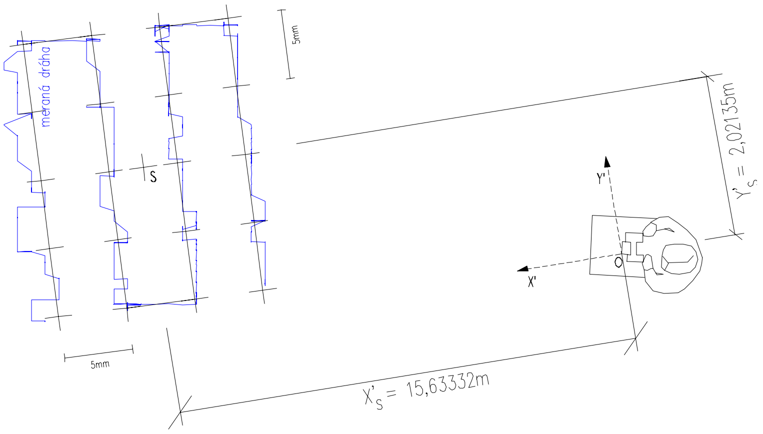

Fig. 7 Common projection of the measured and given trajectory

4.2.2 Accuracy analysis

According the accuracy “conditions” in test the calculated differences between the given and measured coordinates will be seen as absolute errors ε in both directions X and Y. Standard deviations σ_X and σ_Y for each trajectory part (according the figure 3) are calculated by simply formula

$$\sigma_X = \sqrt{\frac{\sum_{i=1}^{n} {\varepsilon_{X}}_i^2}{n}} \quad \text{and} \quad \sigma_Y = \sqrt{\frac{\sum_{i=1}^{n} {\varepsilon_{Y}}_i^2}{n}}, \tag{1}$$

where ε_{Xi} and ε_{Yi} are absolute errors an n is the number of measured points in each trajectory part (Tab. 4). In trajectory parts A, C, E and G (dominant direction – measured length) is the maximum value of σ_X = 1,06 mm. Trajectory parts B, D and F are oriented in direction where is the measured angle dominant achieved maximum value of σ_Y = 0,23 mm. The mean values of σ_X and σ_Y are 0,62 mm and 0,31 mm. For the distance 15,63 m it responds an angle value σ_ω = 1,3 mgon.

Tab. 4

Part of trajectory	Length trajectory [mm]	Number of trajectory points	Stand. deviation σ_X [mm]	Stand. deviation σ_Y [mm]
A	20	126	1,06	-
C	20	121	0.45	-
E	20	192	0.45	-
G	20	160	0.41	-
A+C+E+G	**80**	**599**	**0.62**	-
B	5	34	-	0.23
D	5	56	-	0.31
F	5	31	-	0.36
B+D+F	**15**	**121**	-	**0.31**

5. CONCLUSIONS

The aim both tests are to describe the accuracy characteristics of RS in behaviour of cinematic measurements. Both of presented tests equipments give the possibility to realise the measurements in horizontal plane. The principle of given and measured trajectory comparison are used in both test techniques.

The calculated values of standard deviations (measured coordinates) are different for the trajectory parts oriented parallel to length and angle measurement. For the small distance ca 15,6 m are the angle measurement realised with higher accuracy.

Proportion between velocity and accuracy of coordinate determination was not acknowledged. The prism was moved into the same part of trajectory with different velocity. The standard deviations calculated for the trajectory elements in one part are similar. The standard deviations of trajectory parts measured by static mode are smaller.

According the calculated standard deviations can be concluded that the characteristics determined during the tests are smaller as characteristics given by producers. It certifies that the characteristics given by producers are boundary values and can be fulfilled by cinematic measurement, too. The both tests were limited by existing space structure (walls, etc.). It should be extended for longer distances, minimum to 150 m between the test equipment and the tested RS.

REFERENCES

HENNES, M. 1999: Grundlagende Aspekte zur Bestimmung der Leistungsfähigkeit von Robottachymetern. Allgemeine Vermessungs-Nachrichten, 1999, ps. 374-385 (in German).

KADLEČÍKOVÁ, V. – KYRINOVIČ, P. 2004: Automatic Total Station Testing. In.: INGEO 2004 and FIG Regional Central and Eastern European Conference. Proceedings of the 3rd International Conference of Engineering Surveying. FIG 2004, 10 ps., ISBN 87-90907-34-5, CD-ROM Edition.

KOPÁČIK, A. 1998: Measuring systems in Engineering Surveying. Bratislava, STU 1998, 183 ps., ISBN 80-227-1036-9 (in Slovak).

KOPÁČIK, A. – ČERYOVÁ, I. – KUBÁNKA, P. 2002: Results of Automated Measuring Station Testing. In.: INGEO 2002. Proceedings of the 2nd International Conference of Engineering Surveying. Bratislava, STU 2002, p. 179-186, ISBN 80-227-1792-4.

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