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WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.144192

ARCHIVES OF CIVIL ENGINEERING

Vol. LXIX ISSUE 1 2023

 pp. 627 –644

Research paper

The concept of surveying set for geometrical dimensioning of difficultly accessible objects

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Abstract: While constructing and documenting civil structures, large machines, and industrial facilities, one can encounter a situation where relevant control points are hardly accessible. The instruments with appropriate surveying equipment available on the market provide relatively standard measurements. The limitations mentioned above may transfer into an increased working time (or financial effort) that must be considered while performing the prescribed measuring works. One of the possible solutions (assuming financial capabilities) is utilizing a video-total station (a scan station) with additional supporting equipment. Another possibility would be employing a terrestrial laser scanner (TLS) or close-range photogrammetry. However, such technologies demonstrate significant limitations, especially in the industrial environment.

Regarding that, the authors propose an original measuring set collaborating with a free electronic total station. The main working principle is a known surveying 3D-polar method that can determine XYZ coordinates. The solution presented in the paper facilitates the performance of inventory works, consisting of dimensioning civil structures and rooms with difficult access. Such situations can often be encountered in industrial plants or while documenting architectural or other engineering structures. The device can also be used for dimensioning ventilation ducts, elevator shafts, and other similar facilities. Depending on the configuration of the measuring equipment and the target shapes, the final accuracy may reach a sub-millimeter or millimeter level. Hence, the solution can successfully be applied in civil engineering, industrial surveying, and industrial metrology.

Keywords: civil objects, measuring device, control systems, polar 3D stakeout, object dimensioning, structural monitoring

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1. Introduction

In the tasks of engineering geodesy and industrial metrology, there is often a need for precisely dimensioning hardly accessible objects. Their practical location and mandatory cyclic control measurements sometimes mainly require an individual approach regarding designing control networks and setting out survey stations, including an appropriate measuring cycle program. Such a situation, in many cases, requires applying unconventional solutions explicitly constructed for the needs of a given project. It refers to a newly built instrumentation (measuring sensors, additional accessories) and comprehensive system solutions (measuring sensors with dedicated computer applications). One should add that there is a need to conduct exact measurements in metrological tasks, ensuring their maximum repeatability and reliability. Extraordinary objects and related surveying works are usually beyond the content of generally available standards and instructions [1, 2]. Regarding the needs for such highly specialized jobs, the dedicated methodology is usually elaborated, often based on the experience of similar projects described in the subject literature.

The issues related to ensuring highly accurate measurements have been known since antiquity. A unique synthesis on this subject is presented in [3]. The author of the publication concluded that to provide high accuracies using elementary instruments, it is necessary to develop computational algorithms that adequately identify the error sources affecting the results and effectively minimize them. Following this remarkable line of thinking, one can say that the strength and effectiveness of a given, dedicated solution often stand in line with its simplicity. This conclusion is fundamental in ad hoc solutions – dedicated to the work that needs to be performed. Due to the available hardware and software capabilities, close-range photogrammetry (CRP) is prevalent. It is widely used in metrology and mapping, and its basics relate to image processing [4]. Similar approaches can also be used for precise navigation [5], positioning [6], and the development of plans and maps [7]. Referring to the metrological dimensioning of objects, in the publication [8], the authors presented a newly constructed optical scanner allowing for precise, spatial measurements of things in indoor conditions. Moreover, the project outcomes are based on low-cost solutions, which have become extremely popular [9].

Photogrammetric methods are also used for dimensioning large objects [10]. The authors presented various examples of such solutions. They confronted them with the necessity of the appropriate location of the measuring stations and using proper lenses, thus ensuring the elimination of distortions. These methods are also used in tomography to assess the condition of large objects [11] and small components [12]. Nevertheless, some imperfections are difficult to maintain. Moreover, one can encounter a constant problem of adequately ensuring the relevant camera calibration procedures, which is crucial in such solutions [13]. It is worth mentioning, that except for professional, dedicated photogrammetric cameras used for dimensioning purposes, one can use standard, widely available cameras both for terrestrial and aerial applications (e.g., using unmanned aerial vehicles – UAV's or "drones") [14]. In the mentioned article, the authors presented their experiences with 3D tall object modelling using photogrammetric methods based on popular equipment. The results are promising and credible.

For many reasons, objects are still positioned using classical surveying methods known in engineering geodesy and industrial metrology, especially in modelling displacements [15]. In such a case, besides modern equipment, also sophisticated data processing procedures based on statistical inference play a crucial role. Worth mentioning are also other modern methods utilizing fibre-optical sensors for structural and physical monitoring of structures [16]. Above all, replacing these methods with other approaches is still challenging as it is necessary to perform highly accurate angle and distance measurements [17]. Yet, modern industrial metrology often uses laser trackers due to their offered accuracy and high measurement reliability [18–20]. Moreover, geodetic techniques are successfully used in the dimensioning of industrial facilities, particularly those based on different instruments. In addition to identifying potential sources of systematic, instrumental, and personal errors, the issue of proper data integration [21] and their appropriate combination in multisensory systems [22] is of highly significant importance.

The positioning and monitoring methods in engineering geodesy are mainly based on popular instruments like electronic total stations, laser distance meters, precise inclinometers, or GNSS satellite receivers. Some of the projects may be somewhat challenging like for example relocation of historical buildings [23] or high-rise structures [24]. However, using such devices is subject to many limitations – from proper identification of external conditions affecting the obtained results to eliminating the human factor (personal errors) through automation of measurements or forced centering. What is more, while modeling the captured data, it is mandatory to apply appropriate numerical algorithms. Numerous thematic studies on that problem have been described in many publications, including [25, 26]. Based on the presented state of knowledge, the authors of this research undertook the development of a control system using geodetic instruments, allowing for accurate and reliable dimensioning of places that are difficult to access in closed spaces. Furthermore, when developing concepts and testing their practical use, the increasing need to determine the surface area of industrial facilities and cubature objects (especially in the light of European standards and Building Information Modelling – BIM) was considered.

2. Materials and methods

2.1. Case studies

As already mentioned in the introduction, conditions prevail in engineering objects, making it difficult to conduct direct observation of measurement points invisible from the "traditional" measurement stand, such as a surveying tripod placed over the control point. The difficulty, as mentioned earlier, may result, among others, from insufficiently dimensioned observation space, preventing or limiting access to the instrument, which determines the line of sights to the relevant target points deployed on the object. Figure 1 shows an example of a situation where the dimensions of the niches do not allow for the correct instrument set up when measuring points located inside them (located under the stairs, which is not visible in the picture).

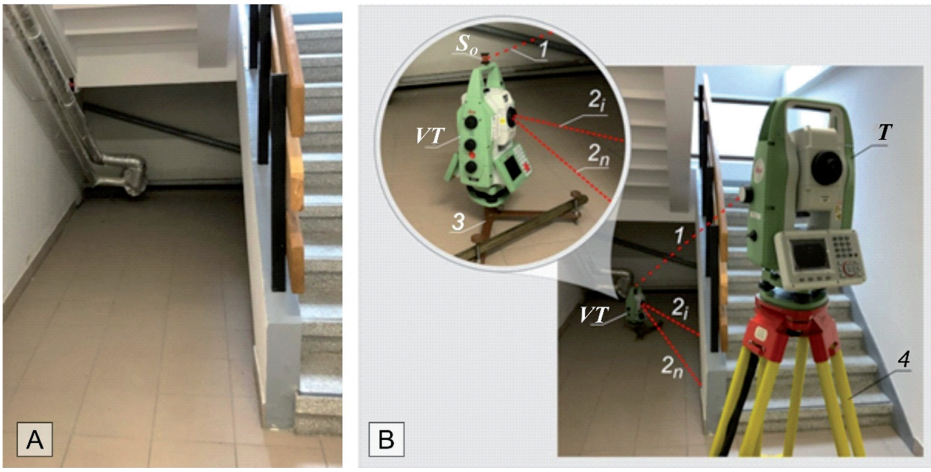

Fig. 1. The example of an object with limited accessibility – A) the surveyed niche; B) possible deployment of instruments and their accompanying accessories (*VT* – video total station/scan station, S_o – orientating prism, T – total station, *1* – angular-distance backside, $2_i \ldots 2_n$ – directions to surveyed points using *VT*, *3* – mini-tripod, *4* – surveying tripod)

Contemporary instrumental solutions make it possible to perform measurements using total stations to the marked points by sticking to additional surveying equipment (e.g., poles with prisms attached) – like in Figure 2. Such a classical, widely used method can be used provided that there is undisturbed access to the characteristic control points.

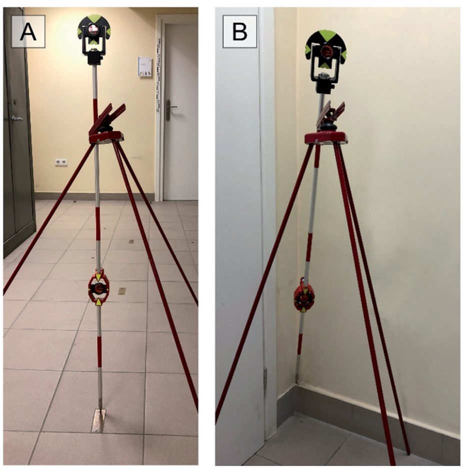

Fig. 2. View of direct signalizing control points by sticking a pole equipped with surveying prisms (A – vertically placed pole, B – slope pole)

If the measuring points are available for targeting from an instrument standpoint, it is also possible to use reflectorless total stations [27]. However, the two measurement methods mentioned above cannot be applied without a direct line of sight to the surveyed points, resulting from the limited operational space (a niche under the stairs – Fig. 1A). In such a case, the measurement can be performed using a modern video total station (scan station) aided by the appropriate accessories (ex. dedicated mini-tripod, aiming signal, and a portable controller allowing for operating the instrument with a keyboard or a touchscreen and stylus) – Fig. 3.

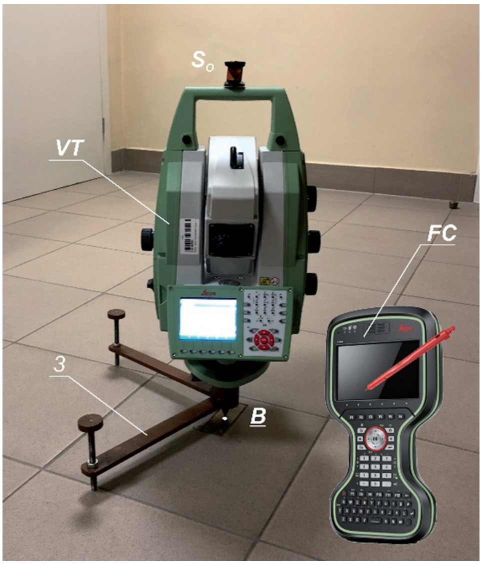

Fig. 3. View of a scan station Leica MS50 with additional equipment and a remote controller Leica CS20 located on a standpoint (*VT* – video total station/scan station; *FC* – functional remote controller, *3* – mini-tripod; S_O – orienting prism/signal; *B* – base point)

In the first stage of our study, we present the low-cost, new-designed measuring sets employing a Leica DISTO laser distance meter (Figure 4). The instrument is used for surveying both distances and the inclination angles of the laser beam (D&LM).

The developed prototypes allowed for conducting experimental tests, based on which their functionality and surveying accuracy were examined. While constructing our measuring set, we made the following assumptions:

– according to the error propagation law [28], the final point positioning accuracy m_{surv} can be expressed in the formula:

$$m_{\text{surv}} = \sqrt{m^2_{S_K - S_o} + m^2_{D\,\&\,LM} + m^2_{\text{exc}}} \tag{2.1}$$

where: $m_{S_K - S_o}$ – error of determining the reference section $\overline{S_K - S_o}$ according to Fig. 4, $m_{D\,\&\,LM}$ – error of distance surveying with the laser distance meter (technical specification the instrument manufacturer), m_{exc} – excentricity error of attaching the distance meter to the $\overline{S_K - S_o}$ section.

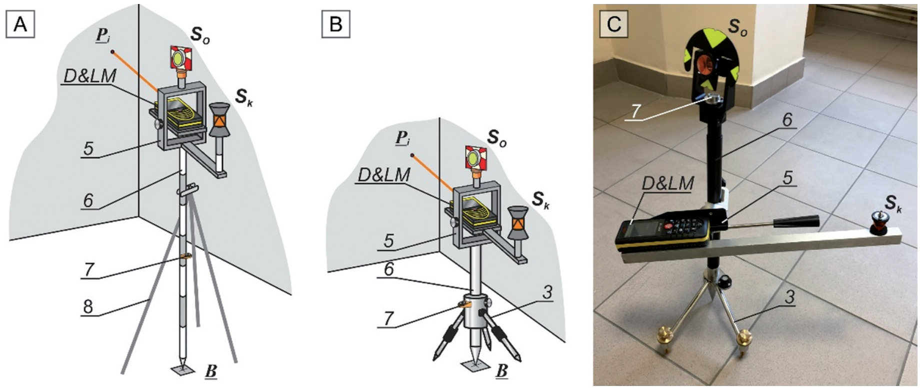

Fig. 4. Schematic variants of the developed measuring system with the assembled prototype (A – scheme of the designed set – mounted on a surveying pole; B – mounted on a mini-pole; C – eccentric set with laser distance meter); *D&LM* – distance and level meter, *3* – mini-tripod, *5* – grip, *6* – pole, *7* – bulls-eye-bubble, *8* – supporting tripod, S_K – directional signal, S_o – orienting signal, *B* – base point, P_i – surveying point

– the designed measuring kit is dedicated to surveying short distances and is rather limited for indoor conditions.

Our prototype employed a laser distance meter Leica DISTO D3, which according to the manufacturer's technical specification [29], offers the standard survey accuracy of ±1 mm for distances up to 10 m. The developed measuring unit is not intended to be used for longer sections. First, precise targeting for longer distances requires special supporting equipment but secondly, in industrial facilities, measuring large distances noticeably increases measurement uncertainty [30]. Hence, we focused on small lengths, barely exceeding a few meters.

According to the literature [31], precise high-end total stations demonstrate excellent accuracies for angular and distance measurements (for Leica MS 50 – we assume ±0.5″ accuracy for angles and up to ±1 mm for lengths, in our case not exceeding a few meters). Using such instruments, we can expect a millimetre-level point positioning accuracy, especially for indoor applications where the influence of systematic errors is significantly limited [32, 33].

Regarding the potential slight eccentricity error – in our example, its effect is negligible for the connection of the distance meter to the frame section exemplified in Fig. 4. Regarding our assumption, the surveying kit is dedicated for short distances. In rooms or staircases, such an offset is often no longer than a few meters – usually 1÷5 m. Considering the solid and thorough execution of the designed set using precise supporting tools aided by vernier controls, such a grip can be performed with maximum ±30″ angular accuracy. It means that for the measured 5m long section, we can expect ±0.73 mm targeting accuracy. Going back to equation 1.1, by substituting the assumed values in place of the variables, we can expect a positioning error of ±1.4 mm, which entirely fulfils our expectations.

2.2. Dimensioning difficultly accessible objects using scan station

For dimensioning hardly accessible object elements, one can use a known 3D polar surveying method, making it possible to determine the *XYZ* coordinates of control points deployed on an examined object. The experiment employed a Leica MultiStation MS50 equipped with CS20 remote controller (Fig. 3). Table 1 presents some selected instrument technical parameters [26]. The mentioned controller has a TFT colour touch screen with a resolution of 800×480 (WVGA) and a diagonal of $5''$ (127 mm), control buttons, and a QWERTY keyboard. The controller is dust and water-resistant. An in-built wireless module can connect to measuring instruments (Bluetooth® and WLAN). Furthermore, the controller allows for the remote operation of robotic total stations using a keyboard and a stylus. This is essential for directing the instrument's line of sight to the individual measuring points.

Table 1. Selected technical data of the instrument MultiStation Leica Nova MS50 [26]

Angular accuracy (according to ISO 17123-3)	$1''$ – horizontal and vertical
Distance measurement accuracy (free surface) (according to ISO 17123-4)	2 mm +2 ppm
A coaxial camera integrated with the telescope	
CCD-matrix	5 MPx CMOS
Matrix resolution	2560×1920 pixels
Angular field of view (Hz, V)	$1.3° \times 1.0°$ ($1.5°$ along the diagonal)
Magnification	30× – zoom; 8× – optical zoom
Sharpness	focusing range from 1.7 m to ∞

Figure 5 shows the essential elements of the measuring set utilized during the observations of hardly accessible objects. The prototype set constitutes of a total station (*T*), a surveying tripod (*4*) above the A base point, a reference signal (*SR*) set with a tripod over the *R* reference point, and a video total station/scan station (*VT*) set out on the B reference point using the self-developed mini tripod (*5*). In the upper part of the total station (*VT*), along its rotation axis $v - v$ in the central part of the handle, an orientation prism (S_o) is embedded. The image captured by the telescope and projected on the CCD matrix is transmitted via Bluetooth® to the remote controller (*FC*). Similarly, all measurements executed by the scan station are performed using the remote controller. Aiming at selected measurement points and recording observation data are carried out by touching the controller screen (*FC*) or using its control keys. The scan station (*VT*) will be able to determine the *XYZ* positions of the inaccessible points after establishing at least one reference point (A, R, R_1). *VT* station *B* is a traverse point.

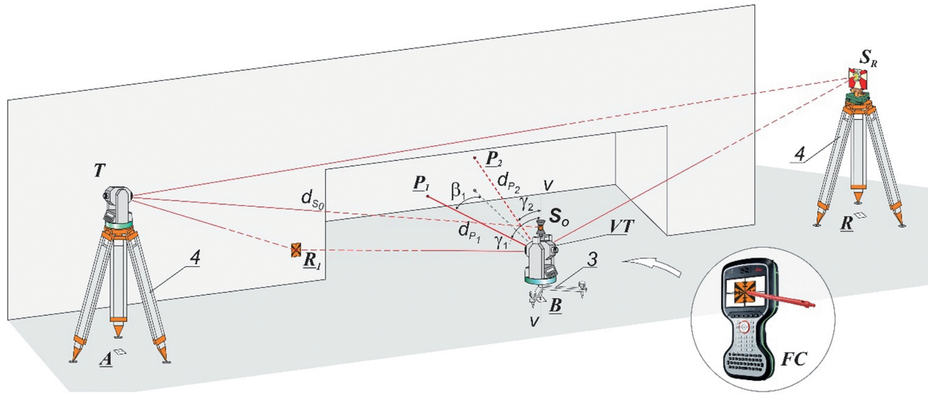

Fig. 5. The idea of surveying control points using a scan station (where: d_{So}, d_{P1}, d_{P2}, β_1, γ_1, γ_2 – observations, *3* – mini-tripod, *4* – surveying tripod, *T* – total station, *VT* – video total station, *A*, *B*, *R*, R_1 – reference points, P_1, P_2 – surveyed points, $v - v$ – vertical axis of the video total station, S_o – orienting signal, S_R – reference target plate, *FC* – field controller)

2.3. Dimensioning difficultly accessible objects using prototype set

The self-designed measuring set presented earlier in Fig. 4 enables carrying on survey works to the control points invisible from the perspective of the instrument stand. Figure 6 shows the main principle of using the developed measuring set in object dimensioning.

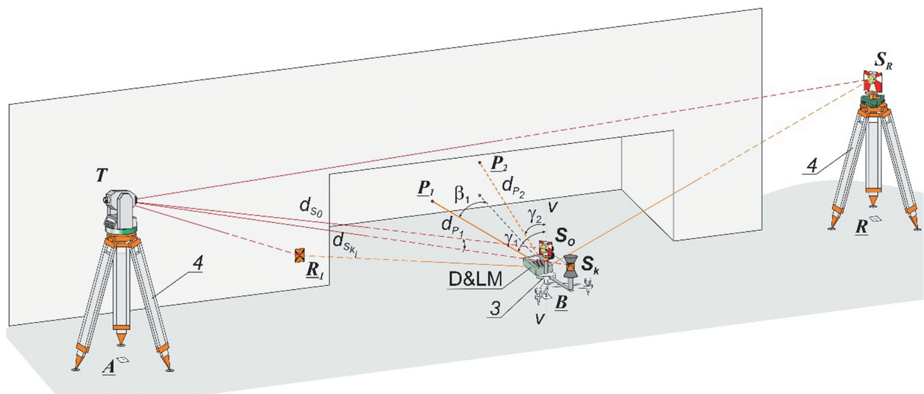

Fig. 6. The idea of surveying control points using a self-developed measuring set (where: d_{So}, d_{Ski}, d_{P1}, d_{P2}, β_1, γ_1, γ_2 – observations, *3* – mini-tripod, *4* – surveying tripod, *T* – total station, D&LM – distance & level meter, *A*, *B*, *R*, R_1 – reference points, P_1 and P_2 – surveyed points, $v - v$ – vertical axis of the measuring set central point *B*, S_o – orienting signal, S_R – reference target plate)

First, a total station (T) should be levelled over the measurement network point (A). The measuring device is then set up over the B point near the observed object and simultaneously in a place visible to the total station (T). Furthermore, the total station (T) is referenced to at least one backside (R, R_1), and then – one should measure horizontal directions, vertical angles, and the distance to the signals (S_k and S_o). Additionally, the laser distance meter (D&LM) fixed to the developed set measures the length to selected measurement points P_i and the relevant inclination angle. To ensure the highest accuracy, the surveys should be repeated.

Figure 7 presents the principle of determining the instrument's orientation constant and demonstrates the necessary formulas for determining the XYZ coordinates of the surveyed point. The measurement and calculation procedure are based on the known polar surveying method. It is vital to set out the device correction constant β_0. For this purpose, based on the direction and distance measurements made by using the total station, the XY position of the direction signal should be derived after aiming with the distance meter (D&LM) at the given waypoint. The bearing values are calculated referring to the defined coordinates of the directional signal and the B point (XY of the orientation signal). Based on the bearing differences, one can establish the β reference constant of the instrument. If the backside is made to several points (e.g. A, R_1), the reference constant β_0 is the arithmetic mean of the calculated constants βA, βR_1.

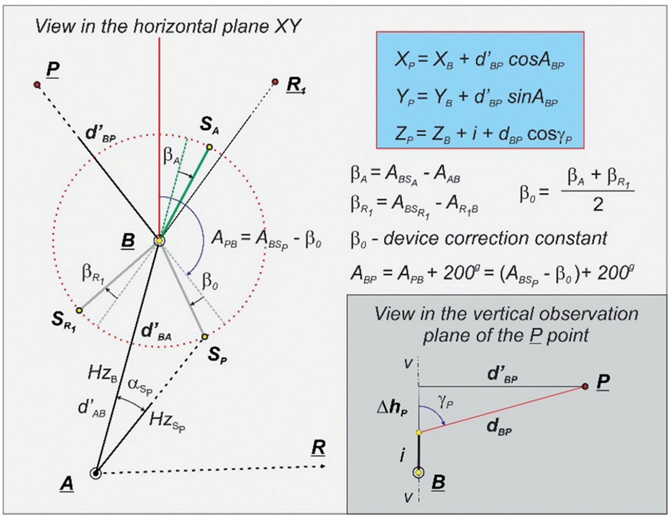

Fig. 7. Scheme of establishing the variables necessary to determine XYZ coordinates of a surveyed point

The variables presented in Fig. 7 have the following meaning:

- A, B, R, R_1 – reference points,
- P – surveyed point,
- $v - v$ – vertical axis of the instrument,
- S_A – direction signal location while measuring with the prototype kit to a reference point,
- A, S_P – direction signal location while measuring with the prototype kit to a surveyed point,

– P, S_{R1} – direction signal location while measuring with the prototype kit to a reference point,
– R_1, d – measured slope distance,
– d' – reduced distance,
– Hz – measured plane angle to a given point,
– γ_P – Zenith angle,
– α_{S_P} – the plane angle between the direction to a reference point B (orienting signal) and the directing signal while measuring with the prototype set to the reference point P,
– i – directing signal height related to the reference point B,
– Δh_P – calculated height difference,
– A – bearing value of a given section,
– β – instrument orientation constant.

3. Experimental works

As mentioned earlier, to determine the measuring accuracy of the prototypes, we performed some dedicated proving tests in a laboratory with stable environmental conditions (Fig. 8). The established test field consisted of 3 observation pillars (St_1, St_2, and St_3) and 4 points signaled with target plates (T_1, T_2, T_3, T_4), constituting a control network. The coordinates of four points T_1, T_2, T_3, T_4 were determined using a precise total station (T) based on multiple angular-linear measurements in the local coordinate system.

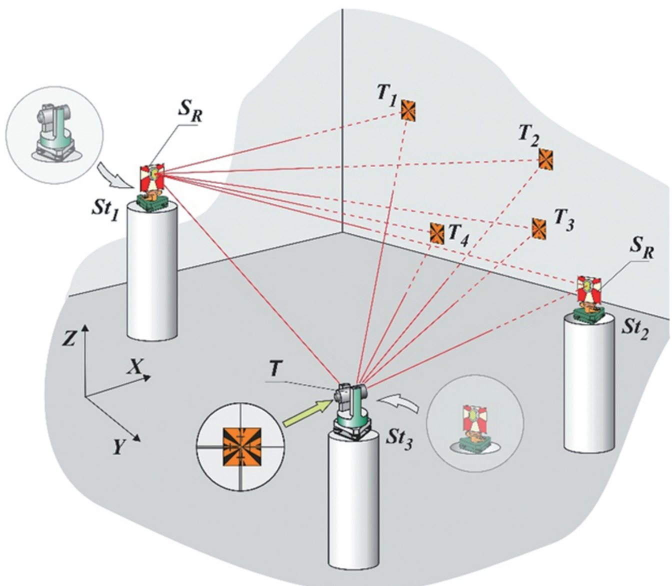

Fig. 8. Scheme of the laboratory test field (where: St_1, St_2, St_3 – observation pillars, T_1, T_2, T_3, T_4 – target plates, T – total station, S_R – reference plate, XYZ – cartesian local coordinate system)

Table 2 summarizes the control point coordinates obtained from the Least-Square-Error (LSE) adjustment of multiple angular-linear observations performed with a total station (T) from St_1 and St_3.

Table 2. Adjusted control point coordinates with their relevant errors

Point ID	X	Y	Z	m_x	m_y	m_z
	[m]	[m]	[m]	[mm]	[mm]	[mm]
St_1	10.00000	10.00000	10.00000	±0.00	±0.00	±0.01
St_2	13.17358	13.16132	10.08580	±0.21	±0.21	±0.15
St_3	10.00000	13.11478	10.02374	±0.00	±0.00	±0.07
T_1	13.51596	10.39772	10.56057	±0.11	±0.07	±0.09
T_2	13.52393	11.29882	10.56428	±0.09	±0.05	±0.10
T_3	13.51891	11.30995	9.88658	±0.09	±0.05	±0.10
T_4	13.51188	11.07251	8.87789	±0.10	±0.05	±0.11

The accuracy measures of the surveyed test network are represented by the mean errors m_x, m_y, m_z of the control points' plane σ_{XY_m} and height components σ_{Z_m}. The reference coordinates' mean error values were calculated using the known formulas (3.1) and (3.2), respectively.

$$\sigma_{XY_m} = \pm\sqrt{\frac{\sum_{i=1}^{n}(m_{Xi})^2 + \sum_{i=1}^{n}(m_{Yi})^2}{2 \cdot n}} \tag{3.1}$$

$$\sigma_{Z_m} = \pm\sqrt{\frac{\sum_{i=1}^{n}(m_{Zi})^2}{n}} \tag{3.2}$$

where: σ_{XY_m} – mean error of the plane coordinates; σ_{Z_m} – mean height error; m_x, m_y, m_z – mean errors derived from the LSE adjustment; n – number of surveyed points.

The obtained error values equal: $\sigma_{XY_m} = \pm 0.08$ mm and $\sigma_{Z_m} = \pm 0.10$ mm.

Figure 9 (A and B) present the view of the video total station (scan station) and the developed measuring set during the experimental and research works carried out in the laboratory.

In the second stage of the experiment, measurements were made using a video total station (*VT*) placed on a pillar – St_3 (Fig. 10), or a mini tripod – station St_5 (Fig. 11). The operation of the *VT* was performed remotely by a field controller (*FC*). The observations executed from the pillar are characterized by high stability, and the distances equal 3.538 m and 4.442 m. On the other hand, the measures made using a mini tripod placed on the floor were exemplified by lower stability, and the target lengths ranged from 1.620 m to 2.973 m.

Table 3 demonstrates the coordinate differences of 4 surveyed points, determined by a video total station (*VT*) placed both on a pillar (ST_3) and a mini tripod (station St_5).

A B

Fig. 9. View of the surveying instruments used in the laboratory tests; (A – total station on a pillar, B – the prototype set on a pillar)

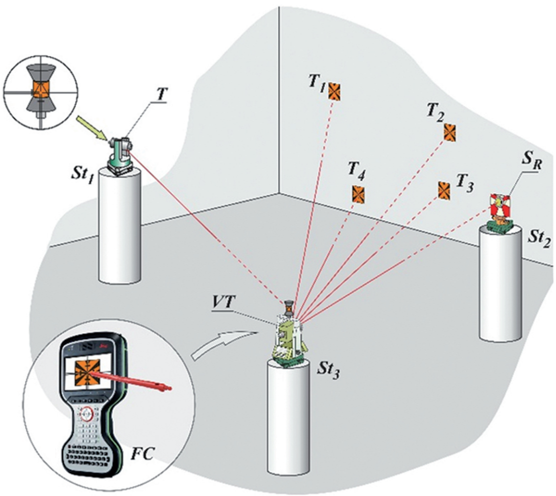

Fig. 10. Surveying with a video total station (scan station) placed on a pillar (where: St_1, St_2, St_3 – laboratory pillars, St_5 – scan station standpoint, $T_1, \ldots, T_4$ – target plates, VT – video total station, FC – field remote controller, S_R – reference plate)

The measurement accuracy derived from the surveys resulting from the video total station and the developed set was determined using the known formulas (3.3) and (3.4).

$$\sigma_{XY} = \pm\sqrt{\frac{\sum\limits_{i=1}^{n}(\Delta X_i)^2 + \sum\limits_{i=1}^{n}(\Delta Y_i)^2}{2\cdot n}} \tag{3.3}$$

Table 3. Coordinate differences for control points determined in different variant surveys performed by video total station

Point ID	Video total station surveys (VT)					
	Observation pillar			Mini tripod		
	ΔX_{VT_p} [mm]	ΔY_{VT_p} [mm]	ΔZ_{VT_p} [mm]	ΔX_{VT_t} [mm]	ΔY_{VT_t} [mm]	ΔZ_{VT_t} [mm]
T_1	–0.53	0.43	–0.08	0.19	–0.07	0.29
T_2	0.23	–0.11	0.00	–0.16	–0.10	–0.07
T_3	0.23	–0.11	0.03	0.24	0.03	0.06
T_4	0.05	–0.02	0.13	–0.02	–0.04	–0.11

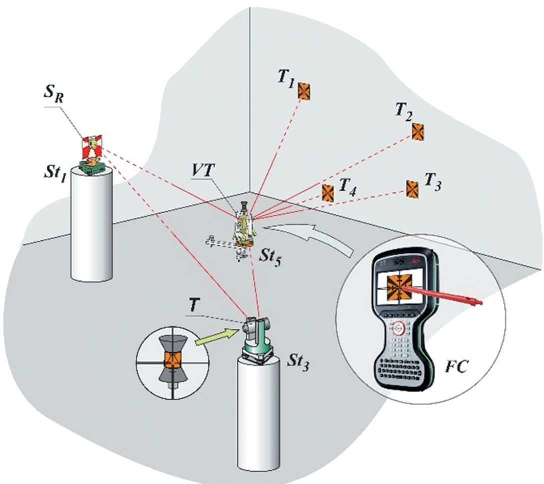

Fig. 11. Surveying with a video total station (scan station) placed on a mini tripod (where: St_1, St_2, St_3 – laboratory pillars, St_5 – scan station standpoint, $T_1, \ldots, T_4$ – target plates, VT – video total station, FC – field remote controller, S_R – reference plate)

$$\sigma_Z = \pm\sqrt{\frac{\sum_{i=1}^{n}(\Delta Z_i)^2}{n}} \tag{3.4}$$

where: σ_{XY} – mean error of XY control point coordinates, σ_Z – mean error of Z control point coordinates, ΔX, ΔY, ΔZ – coordinate differences XYZ determined as the differences between instrument surveying and the reference coordinates, n – number of control points.

Furthermore, based on the coordinates' differences in Table 3, we determined the accuracy of geodetic measurements made with the video total station. For example, in the case of measurements carried out from pillar (an average target distance of 4.10 m), the mean errors equal respectively: $\sigma_{XY} = \pm 0.27$ mm, $\sigma_Z = \pm 0.08$ mm, while in the case of measurements made from a mini tripod (average target distance of 1.66 m): σ_{XY} = ±0.14 mm, σ_Z = ±0.17 mm.

In the third stage of the experimental work, we performed measurements using the developed surveying set placed on the St_3 observation pole (Fig. 12) or a mini tripod – St_6 (Fig. 13). The observations made from the pillar are stable, and the target distances vary

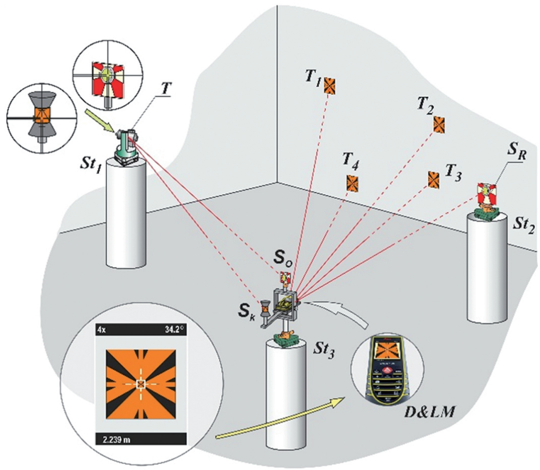

Fig. 12. Surveying with a measuring set placed on a concrete pillar (where: St_1, St_2, St_3 – observation pillars, St_6 – stand of the measuring set on a mini tripod, T_1, T_2, T_3, T_4 – surveyed points, *D&LM* – distance&level meter, *T* – total station, S_R – reference plate, S_o – orienting signal, S_k – directional signal)

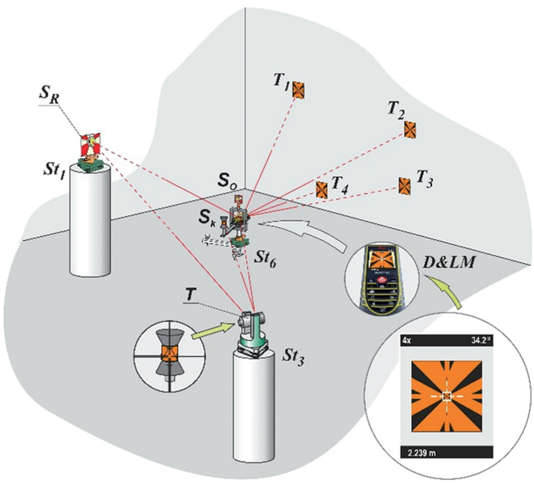

Fig. 13. Surveying with a measuring set placed on a mini tripod (where: St_1, St_2, St_3 – observation pillars, St_6 – stand of the measuring set on a mini tripod, T_1, T_2, T_3, T_4 – surveyed points, *D&LM* – distance&level meter, *T* – total station, S_R – reference plate, S_o – orienting signal, S_k – directional signal)

from 4.221 m to 4.712 m. On the other hand, the observations obtained from the mini tripod placed on the floor are characterized by lower instrument stability and shorter target lengths ranging from 2.394 to 2.857 m.

Table 4 summarizes the differences in the coordinates for four control points determined using the developed measuring set placed on a concrete pillar (St_3) and a mini tripod (St_6).

Table 4. Coordinates differences for control points determined in different variant surveys performed using the prototype measuring set

Point ID	Surveys with the prototype set					
	on a pillar			on a mini tripod		
	$\Delta X_{\mathrm{DEV}_p}$ [mm]	$\Delta Y_{\mathrm{DEV}_p}$ [mm]	$\Delta Z_{\mathrm{DEV}_p}$ [mm]	$\Delta X_{\mathrm{DEV}_t}$ [mm]	$\Delta Y_{\mathrm{DEV}_t}$ [mm]	$\Delta Z_{\mathrm{DEV}_t}$ [mm]
T_1	–5.5	–2.5	–3.3	–0.9	–2.4	1.8
T_2	–2.1	7.0	–3.8	0.7	–2.0	1.9
T_3	–3.5	3.1	4.4	0.6	1.2	–1.2
T_4	4.9	–5.2	4.7	–0.8	0.9	–1.5

Based on the calculated coordinate differences listed in Table 4, we determined the measurement accuracy representing our prototype set. In the case of measurements carried out from the stand on the observation pole, for an average target distance of 4.10 m, the average errors equal respectively: $\sigma_{XY_{\mathrm{DEVp}}} = \pm 4.5$ mm, $\sigma_{Z_{\mathrm{DEVp}}} = \pm 4.1$ mm, while in the case of measurements made on a mini tripod (average distance 2.36 m), are respectively: $\sigma_{XY_{\mathrm{DEVt}}} = \pm 1.3$ mm, $\sigma_{Z_{\mathrm{DEVt}}} = \pm 1.6$ mm.

4. Conclusions

The authors can formulate different conclusions and recommendations for future projects based on the research and experimental works using the prototype device designed for 3D dimensioning of hardly accessible objects. The presented video total station equipped with a field controller can successfully be used during the dimensioning of machines and devices in difficult conditions – in each task, where obtaining the sub-millimeter or single-millimeter accuracy level is mandatory. The desirable accuracy level varies from a few to several millimeters, remembering that the final accuracy mainly depends on target distances. Our set can successfully be used for capturing hard-to-reach architectural details and determining their mutual location, which is crucial in many civil engineering projects. The finding is characterized by portability, simple construction, operationality, and a relatively low cost concerning other professional solutions offered by recognized manufacturers. The device has an ergonomic design and can collaborate with any total station. Moreover, using total stations with automatic tracking and set-of-angle options allows for the automation of surveying works, increasing their credibility and performance. The developed device supports situational and height measurements, especially in construction. Hence, it can be applied in structural health monitoring.

The authors undertook further steps to test the prototype set in dimensioning objects according to European standards considering commercial surface measurements and other BIM applications.

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Koncepcja przyrządu pomiarowego do wymiarowania obiektów trudno dostępnych

Słowa kluczowe: obiekty budowlane, przyrząd pomiarowy, systemy kontrolne, tyczenie 3D, wymiarowanie obiektów, monitoring inżynierski

Streszczenie:

Podczas prac realizacyjnych, a następnie inwentaryzacji obiektów budowlanych, dużych maszyn i urządzeń napotkać można sytuacje, w których występuje ograniczona dostępność do punktów pomiarowych. Oferowane na rynku instrumenty i oprzyrządowanie umożliwiają zwykle prowadzenie pomiarów standardowych. Uzupełnieniem zasygnalizowanych rozwiązań jest opisany w niniejszej pracy oryginalny zestaw współdziałający z dowolnym tachimetrem elektronicznym. Istotą pomiaru jest znana w geodezji metoda pomiaru biegunowego 3D pozwalająca wyznaczyć współrzędne XYZ punktów kontrolowanych. Przedstawione w artykule rozwiązania usprawniają wykonanie prac inwentaryzacyjnych polegających na wymiarowaniu elementów geometrycznych oraz pomieszczeń, do których dostęp jest utrudniony. Z sytuacją taką można się spotkać najczęściej w zakładach przemysłowych, a także podczas prowadzenia prac inwentaryzacyjnych obiektów architektonicznych lub inżynierskich. Opracowany zestaw można z powodzeniem wykorzystać także do wymiarowania przewodów wentylacyjnych, szybów windowych oraz innych podobnych instalacji. W zależności od konfiguracji wykorzystanego sprzętu pomiarowego oraz długości celowych, osiągnąć można dokładność wyznaczenia punktów pomiarowych na poziomie submilimetrowym lub milimetrowym.

Received: 2022-10-11, Revised: 2022-11-29