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INVESTIGATIONS OVER USING MIRRORS AND PRISMS IN GEODETIC MONITORING OF BUILDING STRUCTURES

The paper describes research works over displacement monitoring system based on distance measurements, which could allow the determination of movements of inaccessible points located on the building structure. Due to the dispersion of tested points over large object as well as to existing difficulties with visibility a method has been elaborated that gives access to points via additional optical elements – flat mirrors and/or rectangular prisms. In order to protect against external influences the reflecting area of the mirror and back wall of the prism were Al+SiO_2-coated.

Two optical devices for laser measurements have been planned and purchased for tests. They have been installed in two-hinge brackets to be able to turn laser beam toward the prism mounted at measured place. Flexible research stand was mounted and two tests were performed for the distance up to almost 30 m: a 100-fold and 10-fold with varying distances. Analysis of the results showed that the designed set of devices allows the cyclic displacement measurement of multiple points located within 50 m from the instrument with an accuracy not worse than ±1 mm.

It has been concluded that proposed approach based on distance measurements can be expanded by angles what should give the opportunity to determine three components of the displacement of test points. It is planned to focus further works on the use of the set: robotic total station + mirrors + reflective targets and control its stability in spatial displacement surveys to inaccessible points located on engineering structures or buildings.

Keywords: Structural Monitoring, Total Station, indirect measurement

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1. Introduction

Geodetic survey of displacements of building structures is one of the most popular ways to monitor the geometric state of studied objects because of its high quality confirmed by laboratory tests and various practical applications. Its advantage is the relatively high precision and repeatability of the results. The highest accuracy of ±0.1-0.2 mm can be obtained in vertical displacement surveys by precise geometric leveling. However this method is often being hampered by the lack of accessibility of controlled points by the staff, and sometimes also due overrides or collisions with other objects or parts of the construction. The trigonometric method is then being used. Its advantage is to measure the displacements in both vertical and horizontal directions, as well as to extend this measurement (from one station) to greater number of points.

Generally, the value of vertical displacement is calculated on the base of angular-linear surveys, but – in some unfavorable cases – they may be limited only to distances or only angles. In the past, measurements were limited only to the angles, which was much more accurate than distances [6], but currently linear measurements are comparable in precision and can be taken into account together with angles. This is confirmed by the results of laboratory tests of Total Station Leica 1200 series made by Kirschner and Stempfhuber [3], as well as practical tests of Wojcik et al. [7] concerning surveys of bridges deflections using Leica TPS1203. The results obtained by these authors characterized accuracy (RMSE) of better than 1 mm at 20 m. Similar results were reported by Mazalová et al. [4] and Odziemczyk [5], while on the base on their tests Cosser et al. [1] noticed that TS Leica TCA2003 can be used for bridge monitoring for distances up to 200 m with accuracy of several millimeters.

Measurement of displacements of bridges, roofs or tunnels is being usually made for the distance of several tens of meters, for instance 50, what for angular measurements should guarantee $\mathbf{RMSE} \le \pm 0.5\ \mathrm{mm}$ using 2″-theodolite. The same object can be measured using reflectorless EDM, like Leica Disto, with accuracy of $\pm 2\ \mathrm{mm}$ but the target place has to be flat and clean. First tests on such surveys were successfully applied by Bryś and Woźniak (not published) to measure the deflections of the roof girders using Leica Disto. But their solution needs using many EDMs installed in all surveyed locations and to have clear access to the targeting place. When measure distances with motorized TS to precise reflectors it is possible to reach much higher accuracy compared to the method that the reflectors are pointed by the surveyor. This approach gives the advantages of having repeatedly measurements with highest possible accuracy.

If points of interest are not directly visible it is possible to measure through reflections in mirrors. Such idea was the basis for photogrammetric measurement of displacements of the model of cylindrical tank described in doctor dissertation of Wyczałek [8]. The idea was continued by Janusz J. [2] in his investigations on using mirrors in displacement surveys.

Within studies described here we decided to develop ways to measure distances with changing the direction of the laser beam by mirrors on its way to assess the real possibilities and precision of displacement survey made with the use of Total Station Leica 1201+. Two variants of optical mediums had been considered – mirrors and orthogonal prisms – and they were used in a variety of configurations that might be a response to various types of obstacles. The scope of performed tests have been described starting from the formulation of expected parameters of optical elements through design of measuring network, preparing components of the system, testing it and calculation of displacements. Obtained results fully confirmed, and even exceeded, expectations regarding the precision of such solution. The findings indicated the possibility of its application and announced further work on adding angular observations to measure displacements within proposed approach.

2. The design of the measurement set and its configuration

2.1. The principle of measurement displacements using EDM

Linear measurement of displacements is reasonable in cases where other methods may not be used, for example due to the difficult accessibility to test sites of the structure. In principle it is possible to measure distances in reflectorless mode as is proposed by Bryś and Woźniak, but far more accurate and safe is targeting to the retroreflective prisms. Accurate due to technological reasons of rangefinders, safe, because the return prism is a clear target, specialized for such purposes.

The survey of displacements by EDM is possible when adequate direction of observation is ensured. Thus, the measurement of (vertical) deflection of roof or bridge can be made only when rangefinder is vertically oriented (center line in the Figure 1).

Combined measurement of lengths and angles gives the opportunity to correct the distance, according to known geometric rule. Another problem is the measurement to the prism observed at certain angle, but in the case of displacement surveys initial calibration of the system can be made, and with small movements of the target the observation angle remains essentially unchanged.

Another problem is the visibility of targets on the ceiling or bridge beam. The following describes a solution that enables visibility of the beam on the basis of reflections in mirrors or prisms.

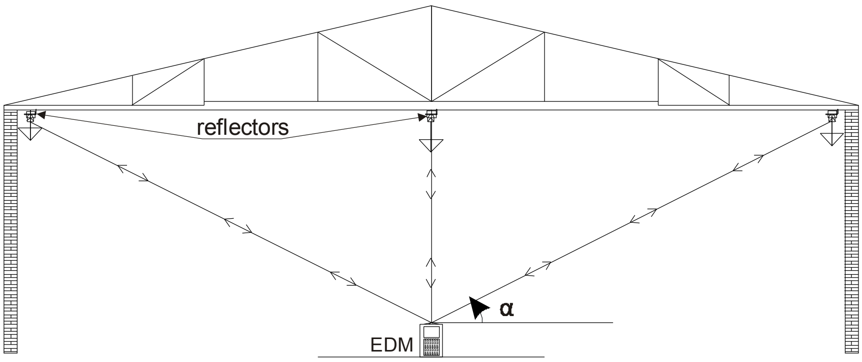

Fig. 1. Configuration of displacement survey of the roof using EDM. Only vertical direction (center line) does not need to measure vertical angles (α)

Rys. 1. Sposób pomiaru przemieszczeń dachu za pomocą dalmierza. Tylko kierunek pionowy (linia pośrodku) nie wymaga pomiaru kątów pionowych (α)

2.2. Using a mirror or prism to measure the vertical displacements

A mirror reflects optical rays in accordance with the known physical principle. To be able to measure joists, the mirror should be mounted in a position which gives the ability to turn the rays toward the target. This can be the place on a pole or pillar supporting the ceiling beams or joists (Fig. 2 on the left). Another solution could be the installation of a rectangular prism on the pole, but in this case the prism would have to be located at the same level as telescope or rangefinder (right site of Fig. 2). Both cases appear to be correct and both are subject of our investigations. It seems, however that it can be easier to make measures with network consisting mirrors.

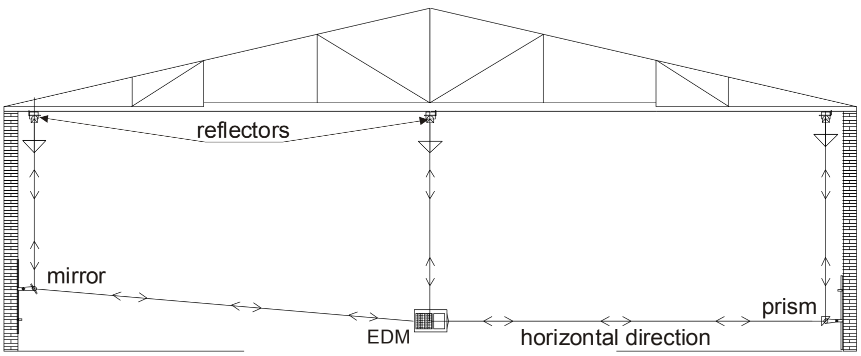

Fig. 2. Considered possibilities of using mirror (left) or prism (right) for measuring displacement using EDM, in comparison with direct measurement (vertical line in the center)

Rys. 2. Rozpatrywane możliwości użycia lustra (po lewej) lub pryzmatu (po prawej) do pomiaru przemieszczenia przy użyciu dalmierza, w porównaniu do pomiaru bezpośredniego (pośrodku)

2.3. Further possibilities of solving measurement network

Survey network that covers changes in the direction of observation can take more complicated forms, including reflections in several mirrors or prisms. Figure 3 shows the planned solution to measure the deflection of ceiling beams of the warehouse from one station of instrument, where not all places of interest are visible directly. In this case, it seems to be necessary to turn the line of sight in horizontal as well as vertical directions. Of course, it is possible to plan more reflections, depending on the situation and the possibilities of the object space.

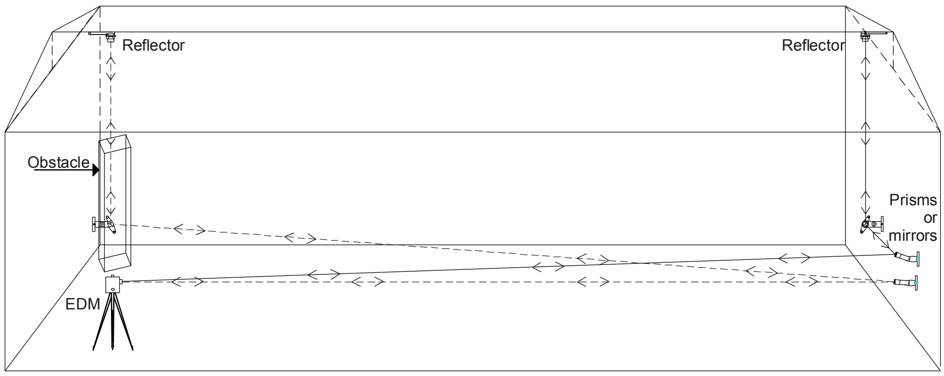

Fig. 3. Expected solution of the net for monitoring the roof from one station of EDM/TS

Rys. 3. Przewidywane rozwiązanie sieci pomiarowej do monitoringu dachu z jednego stanowiska dalmierza/tachimetru

2.4. Design and selection of optical components

It is extremely important that the optical elements do not cause unplanned disturbances in the course of rays. As for the distance, this might not be significant risk to loss the accuracy, but the correctness of reflections should be the basis for operations of such solutions. Moreover, perturbations of the reflections (absorption, scattering of the light) depend on the wavelength. In the case of the use of 'geodetic' rangefinders, it is the best when mirror elements are optimized for the lengths of 600-700 nm. While the passage through the glass (prism) should not cause additional distortions. The best in this regard seem to be elements of laser optics. They are made of a transparent fabric and are coated with an emulsion selected according to the predetermined wavelength.

For our purposes we selected elements made of UVFS (UV Grade Fused Silica) and coated by thin layer of Al. UVFS is synthetic amorphous silicon dioxide (SiO_2) of extremely high purity. It combines a very low thermal expansion coefficient with good optical qualities and excellent transmittance. Transmission and homogeneity exceed those of crystalline quartz without the problems of orientation and temperature instability inherent in the crystalline form. Fused silica can be used for both transmissive and reflective optics, especially where high laser damage threshold is required. For our purpose the optics were optimized to the wavelength of 660 nm. Two types of optics have been used:

- Metallic Coated Round Optics (MCRO) – rings of diameter 25 mm Al-coated at front side and protected by SiO_2,
- Right-Angle Prisms (RAP) with long side Al coated – prisms of 25x25x25 mm with back wall being reflective.

All optical elements were protected by plastic casings and mounted on rotating handles in two-axes (see Fig. 4). This way it was possible to install mirrors/prisms on walls or – as it was used by us – on mounting rails (Al profiles). They provide attachment of the element at desired height and turning it in any direction.

2.5. Analysis of the accuracy of the measurement set with reflections

It is assumed that displacement measurements with the use of mirrors or prisms should be made to reflectors (IR mode). This ensures not only the highest precision of distance measurements, but also enables the automation of measurement and supports targeting (by the use of locking mode). The standard precision of rangefinders being in use in monitoring is ±1 mm + 1ppm. The accuracy for a short distance measurement has slight value of ppm component, however it can be further burdened by calibration errors of rangefinder and reflector, as well as handling errors and the influence of the environment. These errors can be significantly minimized. There remains another factor affecting the distance measurements – targeting to the reflector at an angle other than 90°.

Stempfhuber and Kirschner [3] have shown that a set TS Leica 1200 plus 360°-prism provides accuracy up to 1,5 mm in the plane and 2 mm vertically. Although it is repeatable and by measurements from fixed station errors should also be much decreased. In the case of removal and resetting the instrument by successive series of measurement there is still the matter of repeatability of centering. Ideally, such measurements should be carried out from fixed positions, or distances have to be measured to fixed points of reference. Such control survey is always beneficial, in this case the error of displacement is a function of two distances at beginning state and two for the current, what gives:

$$m_{\Delta D} = m_D\sqrt{2+2} = 2 \cdot m_D = \pm 2\ [mm] \quad (1)$$

Non-parallelism of viewing direction to the vector of movement (as illustrated in Fig. 1) may result in the displacement error:

$$\Delta u = u - \Delta D = \frac{\Delta D}{\cos\alpha} - \Delta D = \frac{\Delta D(1-\cos\alpha)}{\cos\alpha} \tag{2}$$

where: u – vector of displacement,
D – distance from the instrument to the target,
$\Delta D = D\_t_i - D\_t_0$ – measured displacement (difference between distances determined in two moments of time – t_i and t_0),
$\Delta u = u - \Delta D$ – the error of displacement vector caused by viewing target from the angle $\alpha \neq 0$.

The difference Δu resulting from the observation to the point at a certain angle should be negligible small. Counting that the resulting displacement error should not exceed 10% of its length, the angle α should not be greater than:

$$\frac{\Delta u}{u} = \frac{\Delta D(1-\cos\alpha)}{\cos\alpha} \Big/ \frac{\Delta D}{\cos\alpha} = 1 - \cos(\alpha) < 10\% \tag{3}$$

what gives $\alpha < 25°$, and for the maximum permissible error of 1% α should be less than 8°. For distances of 30 m it corresponds to 4-meter offset of the station. Such mild influence of misalignment means relatively big freedom in orientation of the instrument in relation to the observed point.

We conclude that the errors of displacement of points (reflectors) measured only by the EDM should not be greater than ± 2 mm, allowing for a fairly large freedom of measurements.

3. Research tests

In order to evaluate the technical capabilities and the precision of displacement survey using EDM and a set of mirrors a series of tests involving different measurement network configurations have been planned and carried out. The main aim was to redirect the rays by mirrors or prisms in their way to the reflector and automatically measure the distances. The test field covered robotic total station (RTS) mounted on stable frame, two rails for installing optical elements, and typical prisms mounted on tribrach or mounting rails. Tests were made in two configurations – for shorter and longer range of sides. The net was measured few times by different instruments and obtained results proved to be very similar. As representative for this paper was selected two series measured by Robotic Total Station Leica TCRP 1201+.

3.1. Test for short distances

Short test network has been created to see and analyze accuracy of different ways of rays through prisms and mirrors to targets (reflectors). The net is illustrated in figure 4. Total station has been mounted on a solid frame attached to the wall, and racks for optical devices – to the fixed elements of laboratory equipment. The network consists of the following configurations:

1) reflection in a rectangular prism down to the reflector – distance of 3.1 m,
2) reflection in the mirror in the direction of the reflector – distance 5.8 m,
3) reflection from the mirror through the prism to reflector – distance 6.9 m,
4) reflection in two mirrors to the reflector – distance 6.5 m.

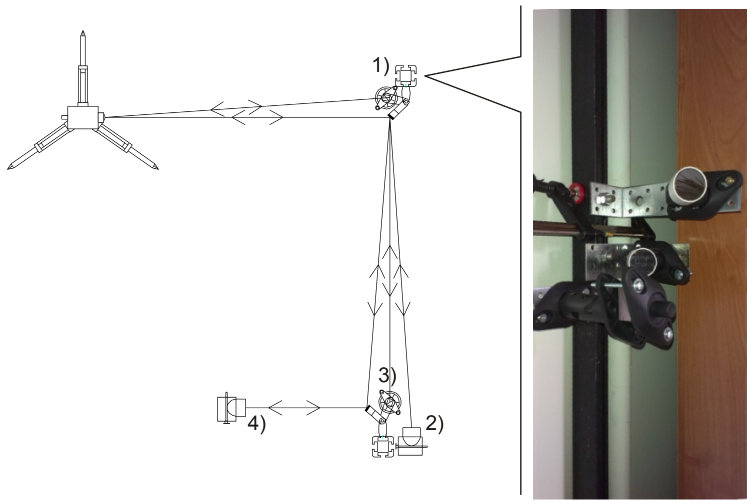

Fig. 4. Four configurations of test survey (as depicted in the paper) – sketch of the net and picture of first node containing two mirrors (upper) and prism (bottom)

Rys. 4. Cztery konfiguracje pomiaru testowego (jak opisano powyżej) – szkic sieci i zdjęcie pierwszego węzła zawierającego dwa lustra (wyżej) i pryzmat (na dole)

The EDM beam was directed so that it run roughly horizontally or vertically, within the limits of non-compliance that ensures no more than 1% loss of accuracy of displacement determination. As targets we used standard reflectors typically used in tacheometry. Prisms and targets were fixed for the time of measurements.

The test was named as ′100×4′, what means that the distances to four targets (reflectors) were measured 100 times. For this purpose in the instrument was set the task for making serial survey and the function for automatic search of signal peaks in the prism (ATR). As a 'zero readings' we have taken average reading of the first 10 series.

Preliminary analysis of the results showed that they have similar accuracies in the whole set and do not change over the time. Consequently, the summary statement was made (Table 1), including the identification of minimum and maximum differences in terms of zero reading, the discrepancy between these differences and the mean error (RMSE).

The spread of the results never exceed ±0,7 mm, wherein the extreme values (ie. greater than ±0,5 mm) are only incidentally found in the whole set of observations. The standard deviations calculated for the entire set of results are not worse than ±0,2 mm and are almost identical in all the blocks of the 20-readings. Similar repeatability – not exceeding 0,1 mm – occurs in all statistics.

Table 1. Summary of results for test '100×4': above – whole set, below – five blocks of 20 readings. Results are written in millimeters

Tabela 1. Zestawienie wyników dla testu ‘100×4’: powyżej – cały zestaw, poniżej – pięć bloków po 20 odczytów. Wyniki zapisane w milimetrach

	1 to 100			
	min	max	**range**	**σ**
3,1	-0,2	0,4	**0,6**	**0,13**
5,8	-0,3	0,4	**0,7**	**0,16**
6,9	-0,4	0,3	**0,7**	**0,18**
6,5	-0,3	0,4	**0,7**	**0,14**

1 to 20				21 to 40				41 to 60				61 to 80				81 to 100			
min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**
-0,2	0,3	**0,5**	**0,15**	-0,2	0,2	**0,4**	**0,10**	-0,2	0,3	**0,5**	**0,13**	-0,2	0,3	**0,5**	**0,14**	-0,2	0,4	**0,6**	**0,14**
-0,2	0,3	**0,5**	**0,13**	-0,2	0,4	**0,6**	**0,15**	-0,3	0,4	**0,7**	**0,17**	-0,2	0,4	**0,6**	**0,16**	-0,2	0,4	**0,6**	**0,19**
-0,4	0,3	**0,7**	**0,16**	-0,3	0,2	**0,5**	**0,18**	-0,4	0,3	**0,7**	**0,19**	-0,4	0,3	**0,7**	**0,19**	-0,3	0,3	**0,6**	**0,19**
-0,3	0,3	**0,6**	**0,13**	-0,3	0,4	**0,7**	**0,15**	-0,2	0,3	**0,5**	**0,11**	-0,2	0,4	**0,6**	**0,15**	-0,2	0,4	**0,6**	**0,17**

3.2. Test in the range up to 28 m

Next test was carried out in a different configuration so as to trace the results of measurement over longer distances. In addition, a control measurement performed on the farthermost mirror observed by three reflections. It was found that each serie of 20-reading will be preceded by a change of position of farthest mirror. For this purpose was used a sliding device made earlier in the laboratory of geodesy at PUT which is shown in the picture below (Fig. 5).

Seven series of measurements were performed (test ′7×20$^{\times}$4′):

1) reflection in a rectangular prism down to the reflector – distance 2,9 m,
2) reflection from the mirror through the prism to the reflector – distance 15,4 m,
3) reflection in three mirrors to the movable reflector – distance 27,3 m,
4) direct measurement to the movable reflector – distance 3,3 m.

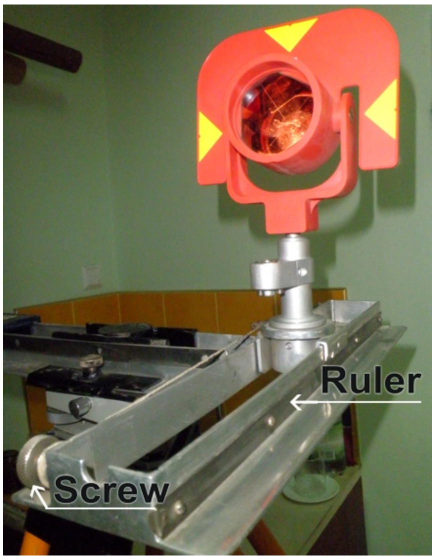

Fig. 5. Reflector mounted on sliding device with screw and the ruler to measure displacements
Rys. 5. Reflektor zamocowany na urządzeniu przesuwnym z podziałką do pomiaru przesunięcia

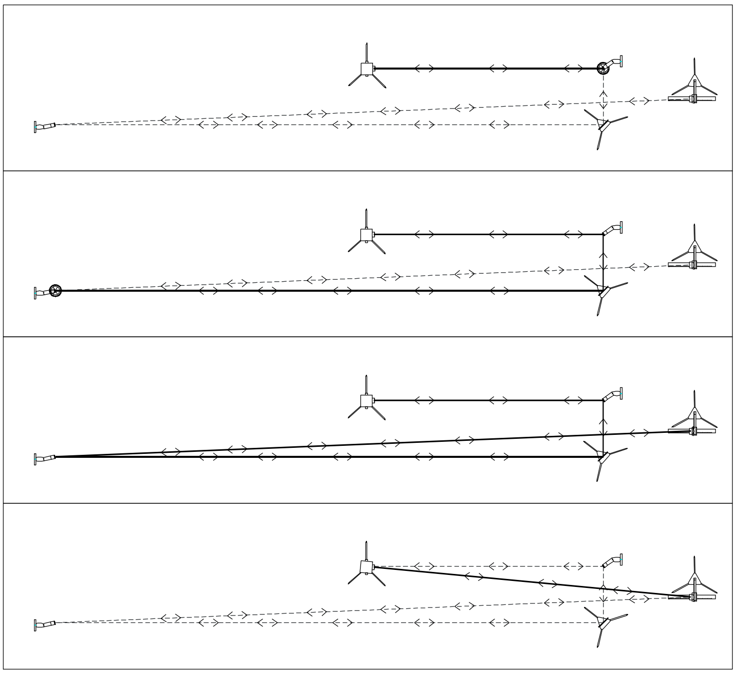

Fig. 6. Four variants of ways of rays in the test 2, as described in the paper
Rys. 6. Cztery warianty przebiegu promieni w teście 2, jak opisano w pracy

Table 2. Summary of results for test '7×20$^{\times}$4' (seven series in two parts)

Tabela 2. Zestawienie wyników testu '7×20$^{\times}$4' (siedem serii w dwóch częściach)

	serie '0'				serie '1'				serie '2'				serie '3'				serie '4'				serie '5'				serie '6'			
	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**	min	max	**range**	**σ**
2,9	-0,2	0,2	**0,4**	**0,13**	-0,4	0,4	**0,8**	**0,24**	-0,3	0,3	**0,6**	**0,22**	-0,4	0,3	**0,7**	**0,18**	-0,3	0,2	**0,5**	**0,18**	-0,4	0,3	**0,7**	**0,16**	-0,4	0,4	**0,8**	**0,20**
15,4	-0,4	0,4	**0,8**	**0,19**	-0,3	0,6	**0,9**	**0,27**	-0,3	0,6	**0,9**	**0,33**	-0,3	0,6	**0,9**	**0,23**	-0,4	0,5	**0,9**	**0,27**	-0,2	0,7	**0,9**	**0,27**	-0,1	0,5	**0,6**	**0,18**
27,3	-0,2	0,4	**0,6**	**0,16**	3,5	4,0	**0,5**	**0,15**	17,2	17,7	**0,5**	**0,10**	23,9	24,4	**0,5**	**0,14**	-15,6	-15,2	**0,4**	**0,13**	-21,6	-21,2	**0,4**	**0,11**	-25,6	-25,3	**0,3**	**0,09**
3,3	-0,2	0,2	**0,4**	**0,11**	3,6	4,0	**0,4**	**0,14**	16,5	17,2	**0,7**	**0,16**	22,9	23,3	**0,4**	**0,11**	-15,0	-14,5	**0,5**	**0,17**	-20,6	-20,1	**0,5**	**0,14**	-24,5	-24,2	**0,3**	**0,09**

3.3. Evaluation of the results

Based on performed tests it was found that:

1) at the range up to almost 30 m and reflection of the beam in two or three mirrors, there is not a significant decrease in accuracy in measuring displacements in relation to the direct measurement,
2) better results were obtained with the reflection from the mirrors than prisms,
3) the average results of 20-fold measurement provides accuracy of designation of displacement – expressed by scattering results – from 0,5 mm (pass through the mirror) to 0,8 mm (prisms) and average errors no more than: ± 0,15 and ± 0,3 mm, respectively.

Similar studies were repeated using the Leica TS15 1203 and Trimble S3 2" Robotic Total Stations, yielding comparable results – more closer when using the other Leica. By reducing the number of series to 10 accuracy (deviations) of measurement shall not decrease accuracies more than to 1,0 mm.

3.4. Extrapolation of the results for long distance measurement

We propose small round mirrors with 25mm diameter to redirect the line of sight. To measure long distances to typical reflectors (diameter 50 mm or 25 mm) this intermediate mirror should lie not far than half a way from instrument to see whole reflector. We made tests which show that this is not necessary – even if the distance between the mirror and the target is as small as 1m, the distance can be successfully measured. So, the maximum range of measurement depends only on expected error of displacement. Based on the results obtained in our tests we can remark, that with the 95% accuracy of ±1 mm it is possible to measure to the distance of about 50 m.

The problem is only when due to the substantial displacement of the target it will not be seen through the mirror. If direction of sight is along the displacement vector this problem should be avoided. Thus, to measure displacements with double change of direction, the main requirement is to ensure that the last section of the course of the beam was consistent with the expected direction of displacement within 8°.

4. Conclusions and future works

The subject of the study was solution and test of a measurement system, which based on distance measurements could allow the determination of the size of movements of inaccessible points on the building structure. Due to the dispersion of tested points on a large object space as well as to existing difficulties with visibility a method to access to points via additional optical elements has been elaborated. Two types of them was taken into account – (i) flat mirrors and (ii) rectangular prisms. Mirrors performs the physical law of specular reflection, wherein the falling and reflected rays lie in one plane. Distance measurements are devoid of effect of specular reflection and appropriate targeting of the beam enables the observation of the test point in the direction of expected movement. For its proper operation the mirror is covered by reflective coating, so it is sensitive to impact of (mechanical and chemical) environment.

Using a prism instead of the mirror is more intuitive for directing beam at right angle, as is in the case of horizontal telescope and redirection of the beam to be vertical. In order to perform the measurement the back wall of the prism is Al-coated, which also allows it to protect against external influences.

In order to implement presented idea two optical devices for laser measurements have been planned and purchased. They have been bounded and installed in two-hinge brackets to be able to turn laser beam toward the prism mounted in measured place. Flexible research stand was mounted and two tests were performed on the basis of it: (i) for a short distance measurement and (ii) for the distance up to almost 30 m – both versions in 4 variants. Two series of measurements have been performed: a 100-fold and 10-fold with varying distances. Analysis of the results showed that the projected suit allows the cyclic displacement measurement of multiple points located within 50 m from the instrument with an accuracy of no more than ±1 mm.

The proposed approach based on distance measurements can be expanded with angles that would give the opportunity to determine three components of the displacement of test points. It is planned to focus further works on the use of the set robotic total station+mirrors+reflective targets in spatial displacement surveys to inaccessible points located on engineering objects or buildings. The next problem to be solved is precision control of stability of the mirrors.

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BADANIA NAD UŻYCIEM LUSTER I PRYZMATÓW W GEODEZYJNYM MONITORINGU KONSTRUKCJI BUDOWLANYCH

Streszczenie

Praca opisuje badania nad systemem pomiarowym bazującym na pomiarach odległości, który pozwoliłby na określenie przemieszczeń niedostępnych punktów na konstrukcji budowlanej. Z uwagi na rozproszenie punktów badanych na rozległej przestrzeni obiektu, jak też z powodu utrudnień w widoczności, opracowano metodę umożliwiającą dostęp do punktów za pośrednictwem dodatkowych elementów optycznych – płaskich luster i/lub pryzmatów. W celu ochrony tych elementów przed wpływem czynników zewnętrznych powierzchnia odblaskowa lub tylna ściana pryzmatu zostały pokryte warstwą Al + SiO_2.

Zaprojektowano i poddano testom dwa urządzenia optyczne do pomiarów laserowych. Zostały one połączone i zamontowane na pochylnych wspornikach umożliwiających przekierowanie wiązki laserowej w kierunku pryzmatu w mierzonym miejscu. Skonstruowano elastyczną podporę i przeprowadzono dwa testy na odległość do niemal 30 m. Wykonano dwie serie pomiarów: 100-krotny i 10-krotny, oba na kilka różnych odległości. Analiza uzyskanych wyników wykazała, że zaprojektowany zestaw umożliwia cykliczne pomiary przemieszczeń wielu punktów zlokalizowanych do 50 m od stanowiska instrumentu, z dokładnością nie gorszą niż ±1 mm.

Stwierdzono, że zaproponowane rozwiązanie oparte na pomiarach odległości może zostać rozbudowane o pomiary kątowe, co powinno sprawić sposobność wyznaczania trzech składowych przemieszczenia badanych punktów. Planuje się skupić przyszłe badania na użyciu zestawy tachimetr+lustra+odblaskowe cele w pomiarach przemieszczeń przestrzennych do niewidocznych punktów zlokalizowanych na obiektach inżynierskich lub budowlanych. Następnym problemem planowanym do rozwiązania jest ścisła kontrola stałości luster poprzez pomiar znaczków kontrolnych na ich obudowie.

Słowa kluczowe: monitoring strukturalny, tachimetr, pomiary pośrednie

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