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LASER SCANNER DATA CAPTURE TIME MANAGEMENT

Ekaterina Aleksandrovna Pravdina and Olga Jurjevna Lepikhina
Saint-Petersburg Mining University, Saint Petersburg, 1st str. V.O., Russia
E-Mail: eanes@yandex.ru

ABSTRACT

Conclusions about an opportunity of laser scanner survey optimization are explicated in the article. It is offered to do this via scanner stations number determination and time spending forecasts. A method of obtaining the number of scan stations for different object patterns (truncated cone, a prism with a trapezoidal section, bounded on two sides by a truncated cone, the L-shaped prism) is shown.The maximum possible survey dump height, depending on the slope angle and the distance between the dump and the scan position was determined for this. Also dependency graphs were plotted for different object forms and various object proportions. In conclusion, the method to identify scan stations number is shown.

Keywords: laser scanner, method of survey, optimization.

1. INTRODUCTION

It is known that any mining company's management is interested in reducing costs and increasing incomes. So it is clear, that mine surveyors are reluctant to spend excessive funds buying expensive outfit. Acquisition of princely equipment that is able to significantly optimize surveyor's work (for example, laser-scanning systems (LSS)), with no straight economic effect is not generally considered as an overriding investment.

In general, mine surveying departments have traditional opto-mechanical gear (theodolites, levels) and modern total stations. Efficiency and precision characteristics of this equipment makes it possible to solve almost all problems faced by mine surveyors. The need for survey with a higher degree of reliability, accuracy and density does not occur so frequently. Furthermore, this problem confronts mainly mine surveying service departments of quarries. Large quarries can afford buying and using photogrammetric survey technology. Modern photogrammetry facilities and software are expensive and therefore the LSS purchase is not often justified. And this is despite the fact that the cost of LSS gradually reduces due to the occurrence of lightweight and quarries' survey adapted scanners (their accuracy is lower and they are several times cheaper) (Janowski, 2006; Mangini, 2015; Integrated system Datamine- Studio and basic techniques for working with it, 2014).

The need for detailed and accurate survey with fastest results as a 3D model of the object (quarry, dump) usually occurs with a total loss of mining and graphic documentation, or when inaccurate and chaotic opencast mining has happened and time is limited. In this case, a laser scanning technology is indispensable. A mine surveying department can exploit this technology by outsourcing a company, specializing in this type of surveys.

The organization works as follows. It acquires several ground-based laser scanners for different run types. For example, a phase scanner for better accuracy (e. g. Imager 5006, FARO LS 880, Leica HDS 6000) and a pulse scanner for distant surveying (e. g. Leica HDS 8800, Leica ScanStation, Optech ILRIS-HD) (Gusev, Naumenko, Volohov, 2007; Seredovich, Komissarov, Komissarov, Shirokova, 2009; Seredovich, 2007; Wester, 2012).

In order to cover costs and make profit, such an organization must constantly make surveys and process data. Increased market competition forces to reduce survey prices and accept any amount of service. This, in turn increases the number of orders. A method proposed below allows properly managing survey time and optimizing the process.

Using laser-scanning systems (LSS) technology set up the following practice of these works:

1) Before the start of survey, the scanner positions (scan position) are roughly outlined keeping in mind a full coverage of the surveying object;

2) Based on the outlined locations a horizontal and vertical justification net of the scan positions is designed taking into consideration coordinate transmission convenience of the project onto the exterior orientation grade marks.

In this case the above criterion for scan positions' selection and their number is not wholly objective. It doesn't minimize the laser scanner run without raw data loss. Keeping in mind that laser scanner produces large amount of redundant data it is actual to optimize the fieldwork data amount.

Thus, on the one hand the number of scan position should be sufficient for full coverage of the object, on the other hand, it should be minimized to reduce the survey time and object data volume.

2. METHODS OF RESEARCH

Research was carried out by theoretical methods: methods of mathematical statistics, theory of measurement errors; experimental methods: analysis of laser scanner data of open pits and tunnels surveys, modeling (by AutoCAD software).

2.1 MAIN PART

2.2 Research objects

To solve the problem of optimizing the laser scanner fieldwork piles of minerals at the warehouses (dumps) were conditionally treated as regular geometric

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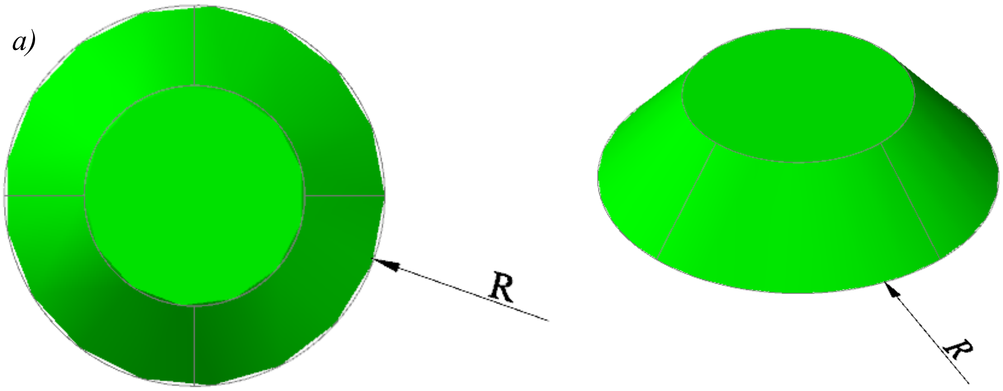
shapes: truncated cone (Figure-1a), a prism with a trapezoidal section, bounded on two sides by truncated cones (Figure-1b) and the L-shaped prism were taken conditionally to solve this problem.

a)



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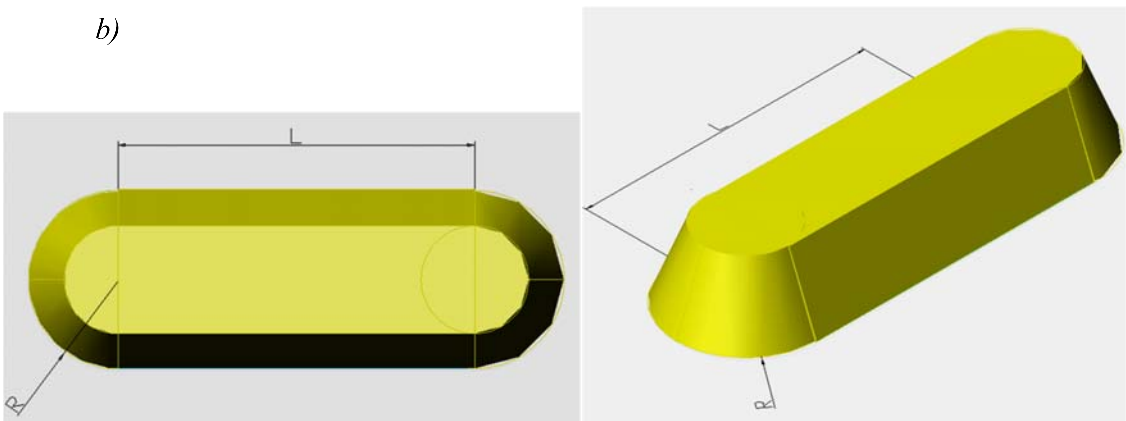

Figure-1. Studied objects: a cone (a) and a prism (b).

While in overview mode the scanning area is a hemisphere of radius r equal to the maximum survey range. For phase rangefinder laser scanners r = 50-80 m, and for pulse rangefinder laser scanners r = 300-1500 m. The measured maximum range of phase scanners is less than that of the pulse scanners, but capacity and measurement accuracy are much higher. Therefore, a method for optimizing the laser-scanning survey was developed for phase laser-scanning systems first.

Therefore, an optimized laser-scanning survey method was first developed for phase scanning systems.

2.2 The maximum possible survey dump height determination

The scanner setting relative to the surveyed object is defined by the parameter l, - the distance to the bottom of the subject (dump) contour. A valid value for this parameter is $r_{min}<l<r$, where r_{min}- a minimum measuring distance for the laser scanner. It is approximately same for different scanners and is about 1.0 m (for Leica HDS6100 - 1.0 m, for the FARO LS880 - 0.6 m).

Specific values for l are selected based on the height of the subject, taking into account the laser beam incidence angle to the dump slope surface.

Laser scanning survey application experience for Zelenchukskaya hydro-electric power station hydraulic tunnels revealed that the optimum distance L from the scanner to the front (rear) exterior orientation marks should be up to 25 m (Figure-2) (Nosov, 2012). For distances greater than 25 m the angle between the laser beam and the tunnel side surface δ is such that laser reflections do not get to the reception path of the rangefinder system.

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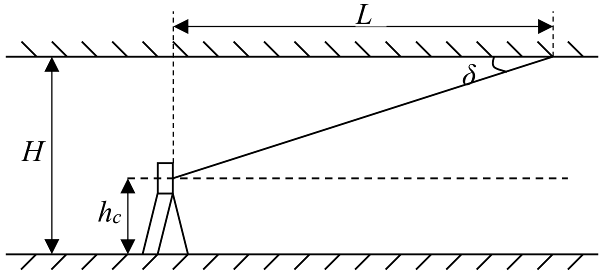

Figure-2. A scheme of defining the angle between the laser beam direction and the tunnel side surface when laser reflections do not get to the reception path of the rangefinder system.

According to the scheme (Figure-2) [delta]angle can be determined by the formula $\delta = arctg\dfrac{H_B - h_c}{L}$. During Zelenchukskaya hydro-electric power station tunnels survey the distance L = 25 m, the tunnel height was H_B=5 m, the instrument setup height was h_c=1,3 m. Thus the angleδ≈8º. This angle allows calculating the maximum dump height H_{max}making it possible to fix reflection points by scanner system rangefinder.

Calculations were carried out according to a scheme of laser-scanning survey of a dump (Figure-3). From this scheme, it follows that:

$H_{\max} = BB' = CB \cdot \sin\alpha$, $CB = L_0 = CD + DB$.

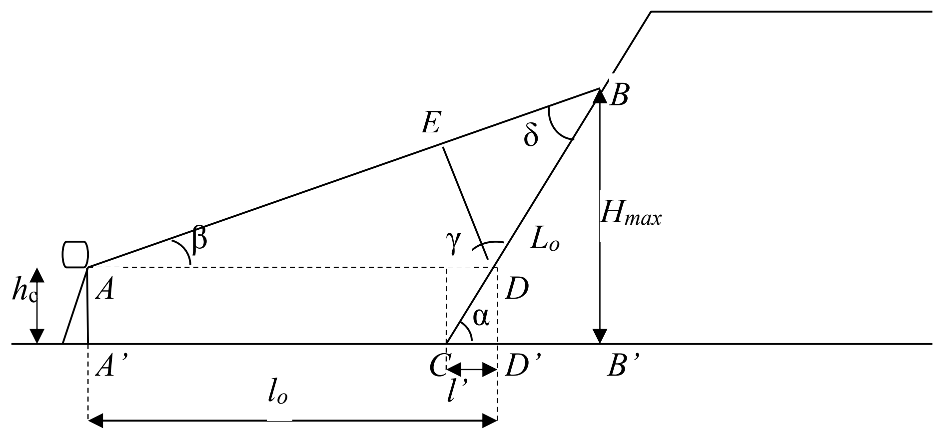

Figure-3. A scheme of laser-scanning survey of dumps.

From the right-angled triangle CDD':

$$CD = \frac{DD'}{\sin\alpha} = \frac{AA'}{\sin\alpha} = \frac{h_c}{\sin\alpha}$$

from the right-angled triangle EDB: $DB = \dfrac{ED}{\sin\delta}$,

[delta] –the angle between the laser beam and the slope surface at which the laser reflection do not get to the reception path of the rangefinder system.

ED can be defined from the right-angled triangle AED:

$$ED = \frac{AD}{\sin\beta} = \frac{A'D'}{\sin\beta}.$$

The angle [beta] can be defined from the triangle ABD:

γ=180º- α; β=180º- γ- δ= α-δ

The angle of the dump slope [alpha] can be found on the basis of the rock type, for soft rock it is ~20º <α <27º, for solid rock ~30º <α<40º. The angle δ is the ultimate angle between the laser beam and the surface slope at which the laser reflection do not get to the reception path of the rangefinder system, δ ≈8º.

The side $AD = A'D'$:

$$A'D' = l_0 = A'C + CD' = A'C + \frac{DD'}{ctg\alpha}.$$

The distance from the scanner to the object $A'C=l=l_o-l'$ is a parameter specified during the survey basing on the object height.

Hence $ED = (l + h_c ctg\alpha)\cdot\sin(\alpha - \delta)$ and

$$DB = \frac{(l + h_c ctg\alpha)\cdot\sin(\alpha-\delta)}{\sin\delta}$$

Consequently, CB is defined by the formula

$$CB = \frac{h_c}{\sin\alpha} + \frac{(l + h_c ctg\alpha)\cdot\sin(\alpha-\delta)}{\sin\delta}$$

And now we can finally determine H_{max}

$$H_{\max} = \left(\frac{h_c}{\sin\alpha} + \frac{(l + h_c ctg\alpha)\cdot\sin(\alpha-\delta)}{\sin\delta}\right)\sin\alpha$$

Hence,

$$l = \frac{(H_{\max} - h_c)\sin\delta}{\sin\alpha\cdot\sin(\alpha-\delta)} - h_c ctg\alpha$$

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The distance l from the scanner to the object at which the dump top is captured by the laser scannercan be defined by this formula.

The maximum dump height was calculated according to the formulaH_{max}, depending on the distance l and the rock type (assumptions made h_c =1,3 m, δ=8º)

Table-1. The maximum possible survey dump height, depending on the slope angle and the distance between the dump and the scan position.

Dump rock type	Dump slope angle	Distance between the dump and the scan position, m	Maximum possible dump height, m
Soft rock dumps	20º	5	5,7
		10	8,2
		20	13,3
		30	18,4
		40	23,5
Solid rock dumps	30º	5	11,1
		10	17,8
		20	31,2
		30	44,7
		40	58,1
	40º	5	17,3
		10	29,6
		20	54,0
		30	78,5
		40	102,9

A formula to find the number of scan positions according to the object shape is derived in the following way.

2.3 The determination of scan positions number defined for truncated cone object

Figure-4 shows an object (piles of minerals at warehouses, dumps) of radius R and mutually positioned scan positions with a measuring distance of r. The distance between the boundary of the object and a scan position is l, the value of l is determined by Table-1.

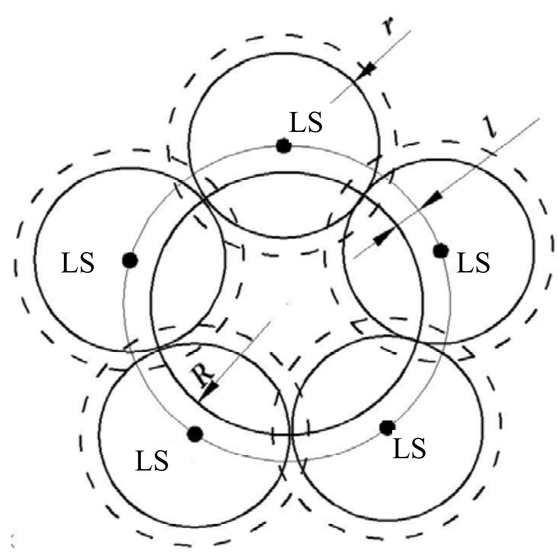

Figure-4. An object and scan positions around it.

The stations must be positioned so that their range (the circle radius of r) completely intersected the object boundary (the circle radius *of R*). It is required to determine the number of stations. This can be done by solving the following geometric problem.

A scheme (Figure-5) of the surveyed subject relative position (the circle *O(R)*) and the circle *o(r)*,

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denoting scanner range was obtained by means of geometric constructions to follow.

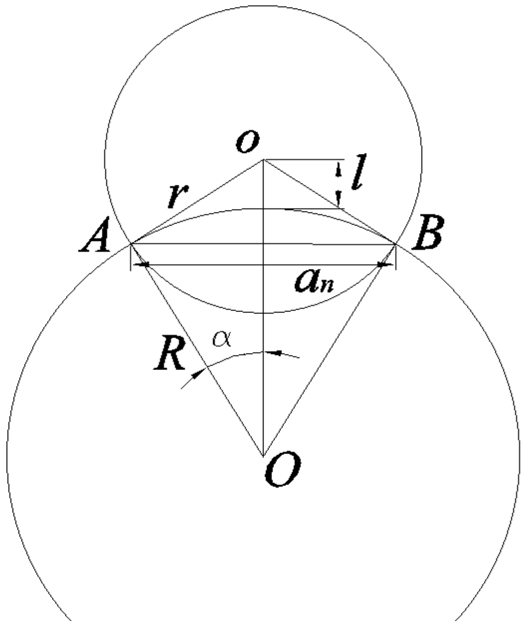

Figure-5. The object and the scanner range.

Since a_n is a side of the polygon inscribed into a circle *O(R)*, the number of sides

$$n = \frac{2\pi}{2\alpha} = \frac{\pi}{\alpha}, \qquad (1)$$

where 2α - the central angle of the inscribed polygon.
[alpha] is expressed through the known side *R* of the *oOA* triangle. According to the theorem of cosines:

$$r^2 = R^2 + (R+l)^2 - 2R(R+l)\cos\alpha. \qquad (2)$$

It turns out that

$$\alpha = \arccos\frac{R^2 + (R+l)^2 - r^2}{2R(R+l)}. \qquad (3)$$

Substituting (3) into the formula (1) the required expression is obtained

$$n = \frac{\pi}{\arccos\frac{R^2 + (R+l)^2 - r^2}{2R(R+l)}} \qquad (4)$$

The this function domain of definition is derived from the following expression

$$\arccos\frac{R^2 + (R+l)^2 - r^2}{2R(R+l)} \neq 0$$

Consequently,

$$\frac{R^2 + (R+l)^2 - r^2}{2R(R+l)} < 1;$$

The solution of this imparity and, consequently, the domain of the function is an expression *r> l*. It proves valid values for variable data given above.

It is necessary to form the overlapping areas, into which exterior orientation marks are to be set during the survey. It is essential to substitute the actual scan range of *r* by 10% less than the maximum into formula 4. Then, while surveying the contact points of lessened scan radii (points A and B in Figure-5) will shape overlapping areas of 0,2*r* width to both sides within which exterior orientation marks will be fixed. They will be uniform to the neighboring scans. As a result, it will be possible to register scans in a single coordinate system.

When planning the dump top survey, laser scan positions relative to each other are determined based on the full coverage and their location relative to the dump contour, but at a distance not less than 20 m with a view to the surveyor’s safety. The number of points depends on the dump top area. Scan positions placing modeling reveals the following pattern.

Taking into account the geometrical parameter *R* as one of the truncated cone parameters (Figure-1 *a*) a total number of scan positions n_O was obtained by modeling. For dump top survey similar in shape to a truncated cone n_O can be defined as follows:

if*R≤r* then $n_0 = n + 1$;

if*r<R≤3r* then $n_0 = 2n - 5$;

if*3r<R≤4r* then $n_0 = 3n - 15$;

if*4r<R≤5r* then $n_0 = 4n - 30$;

if*5r<R≤6r* then $n_0 = 5n - 45$ etc.,

n - the number of scan positions defined by formula 4.

Surveys of individual sections of quarries, mineral warehouses, as well as geometric parameters of buildings’ structural elements, architectural and historical monuments demand higher accuracy and density. For laser scanners with phase-radiation laser rangefinder (Imager 5006, FARO LS 880, Leica HDS 6000) measurement error (m_c) depends on the laser scanner range (*r*) and reflective power of the subject surface (I_{omp}) - $m_c=f(r, I_{omp})$.

This dependency is shown in the technical data sheets of this type of laser scanners. Therefore, one can determine measurement error through setting the scanner range at a certain reflective power of the subject surface.

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Calculations for surveys of objects in the form of a truncated cone at different values of the distance *l*, the radius *R* and *r* were made based on formula 4. And the value of *r* was chosen based on the expected accuracy of the scan, known from the technical data sheet of the laser scanner Imager 5006.

Measurement error power function dependence on the scanner range and subject surface reflective power properties was built. These graphs allow you to define scanning errors beyond the selected radius r limits (shaded area in Figure-6), i.e. with less precision. If you need to get these errors you should take points of curves with the ordinate corresponding larger radius scan. In numerical terms, the increase of measurement error is quite insignificant.

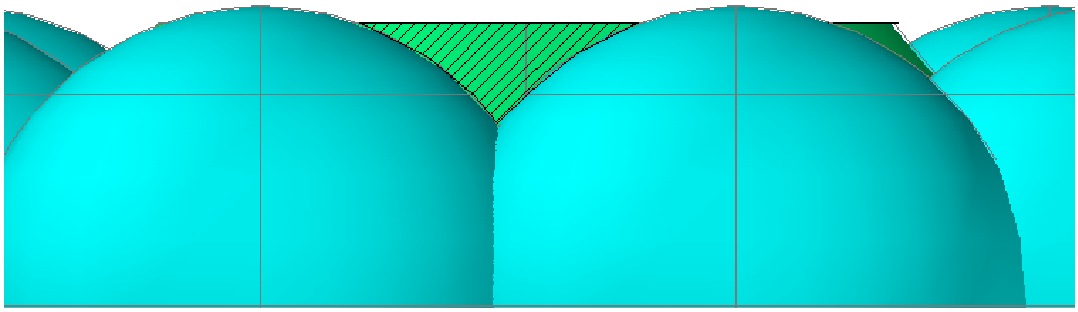

Figure-6. Area of inadequate accuracy.

Calculation results for three different radii *R* of the object are shown in the relevant graphs (Figure-7). The following conclusions according to them can be made:

a) increasing the scan positions number *n* occurs exponentially with increasing distance *l*;
b) the bigger the scanning radius *r*, i.e. the lower the scanning data capture accuracy, the more smoothly is the increase in the number *n* of scan positions;
c) with increasing the object size (radius *R*) *n* increases with other parameters (*l* and*r*) same;
d) increase in the size of the object (radius *R*) leads to a different increase in *n*: the smaller *r*, the faster the difference between corresponding ngrows given the variable *R* and same *l*.

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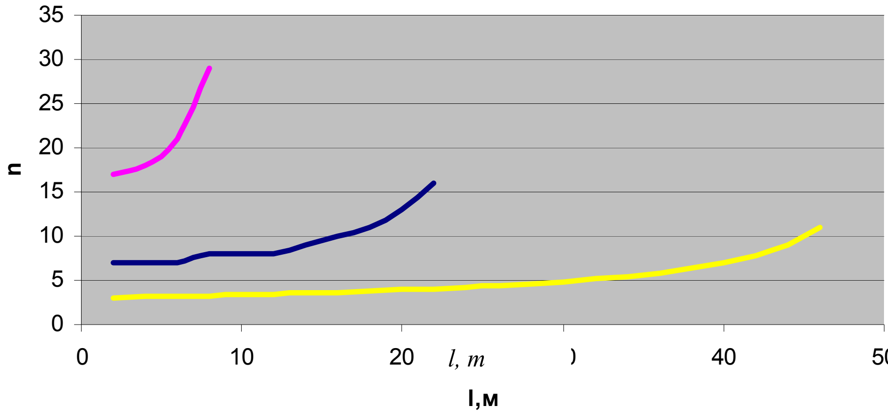
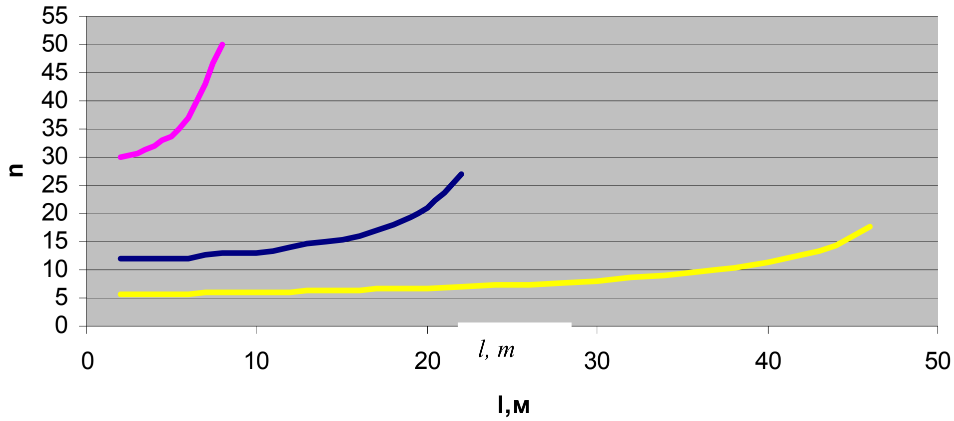


(a)



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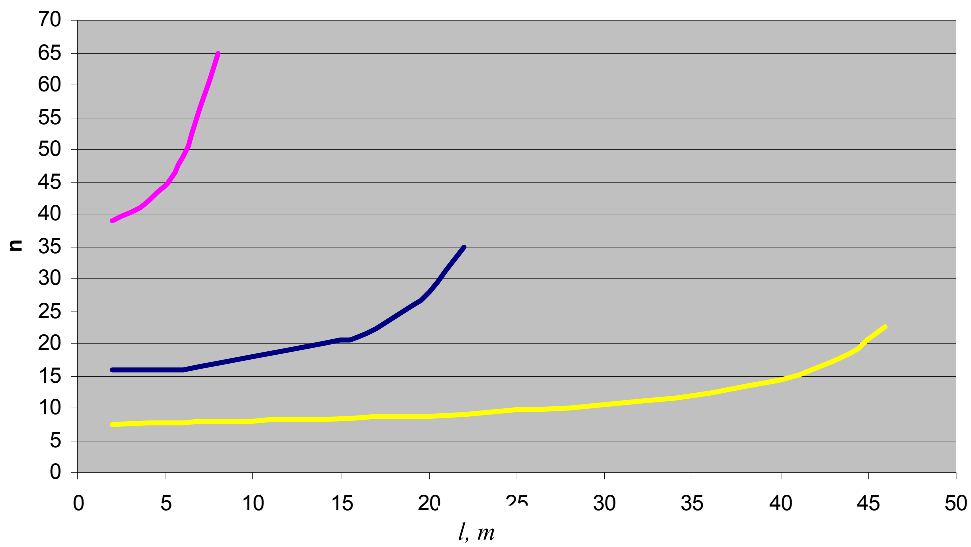

(c)

Figure-7. Dependency graphs $n = f(l)$ for given values r and R: R=50 m (a); R=90 m (b); R=120 m (c);

-at r=10 m; -at r=25 m; -at r=50 m.

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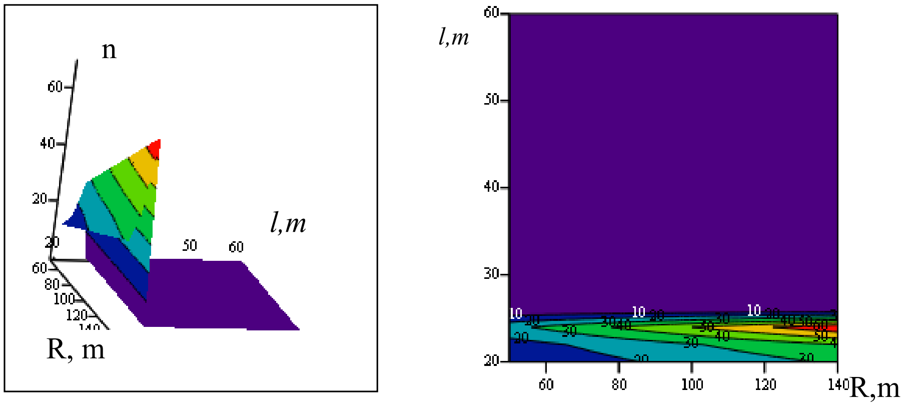
Formula 3 contains three variables: studied object size, scanner range and distance between the scan position and the object (a dump). It is not possible to interpret this dependence graphically. Construction of three-dimensional graphics does not solve the problem completely, because it does not solve the issue of visibility. Only fixing one of the parameters makes it possible.

a)



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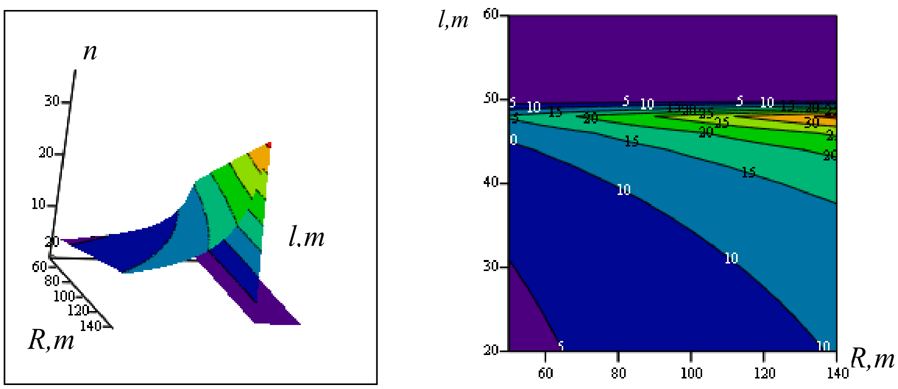
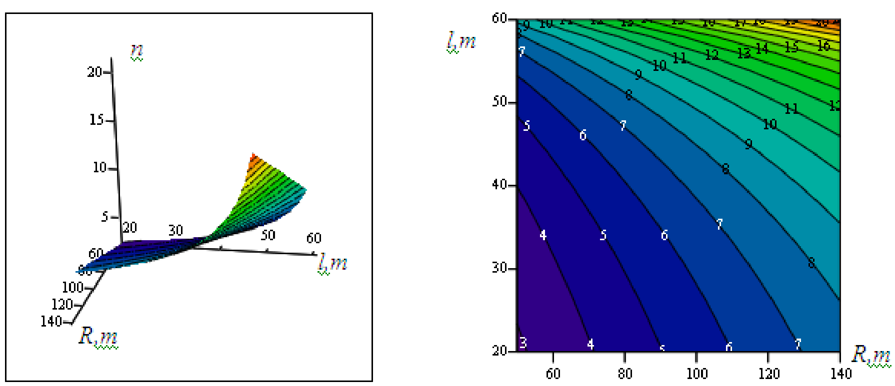


n1

c)



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d)

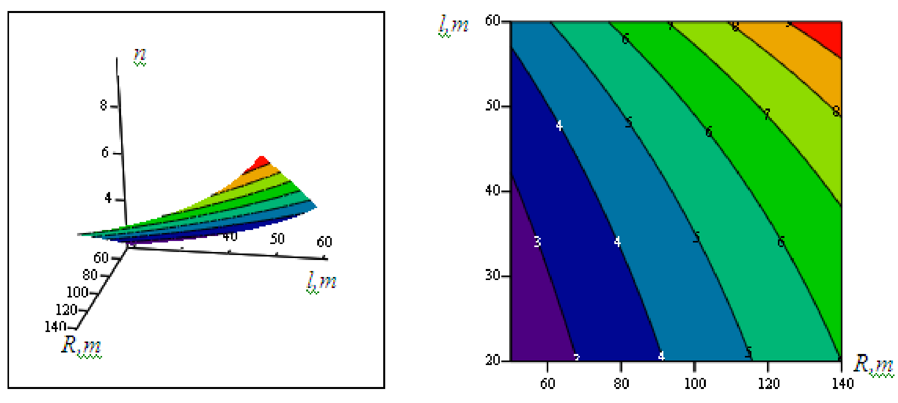

Figure-8. Dependency graphs $n = f(R, l, r)$ at r=25 m *(a)*, r=50 m *(b)*, r=65 m *(c)*, r=80 m *(d)*.

3.3 The determination of scan positions number defined for prism with a trapezoidal cross-section

We can say the following about the prism object with a trapezoidal section, bounded by truncated cones on two sides (Figure-1b).

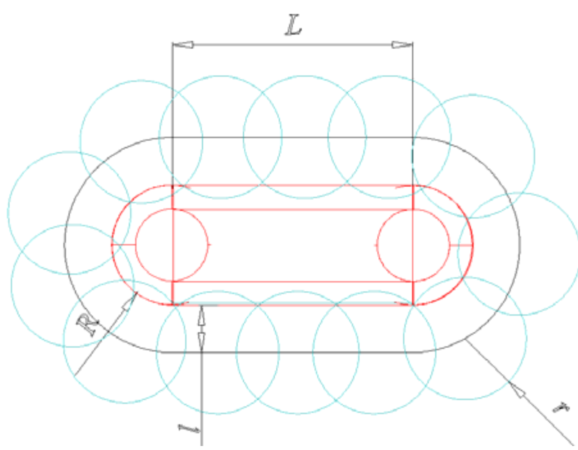

Figure-9. Scheme of the object and scan position alignments.

The lower boundary of this body geometrically has the form of a rectangle and two semicircles (Figure-9) and consequently a formula determining n is:

$$n = \frac{L}{\sqrt{r^2 - l^2}} + \frac{\pi}{\arccos \dfrac{R^2 + (R+l)^2 - r^2}{2R(R+l)}} \quad (5)$$

The domain of this function is an expression $r_{min}<l<r$, r_{min}- minimum range of the laser scanner.

For dump top survey the total number of scan positions n_0 is defined by the formula as follows:

if $R \le 2r$ then $n_0 = 2n - 5$ $n_0=2n-5$;

if $2r<R\le 3r$ then $n_0 = 3n - 15$;

if $3r<R\le 4r$ then $n_0 = 4n - 30$;

if $4r<R\le 5r$ then $n_0 = 5n - 45$;

if $5r<R\le 6r$ then $n_0 = 6n - 60$ etc.,

n - the number of scan positions defined by the formula 5.

For high-precision survey of elongated objects planning formula 5 analysis has been implemented. It was determined by analogy with the previously discussed surveys of truncated cone shape objects planning. The object shape determines the dependence type. The lower boundary truncated cones configuration on the sides leads to non-linear exponential dependence. While the lower border as a rectangle sets a linear relation between the scan positions number and the size of the relevant dump part, and the distance between them.

Graphs constructed at variable values of L for different scanning ranges (radii r) (Figure-10) demonstrate that coefficients a and b in the above linear dependence of $n(L) = aL + b$ increase in power dependence with decreasing r. In other words, the line inclination angle tangent to the Y-axis increases with the scanning range decrease. It follows therefore that for large values of L (i.e. for 200-300 m dump sizes) it is advisable to survey at the maximum scanning range to save time and not to seek to obtain a scan with the least error values.

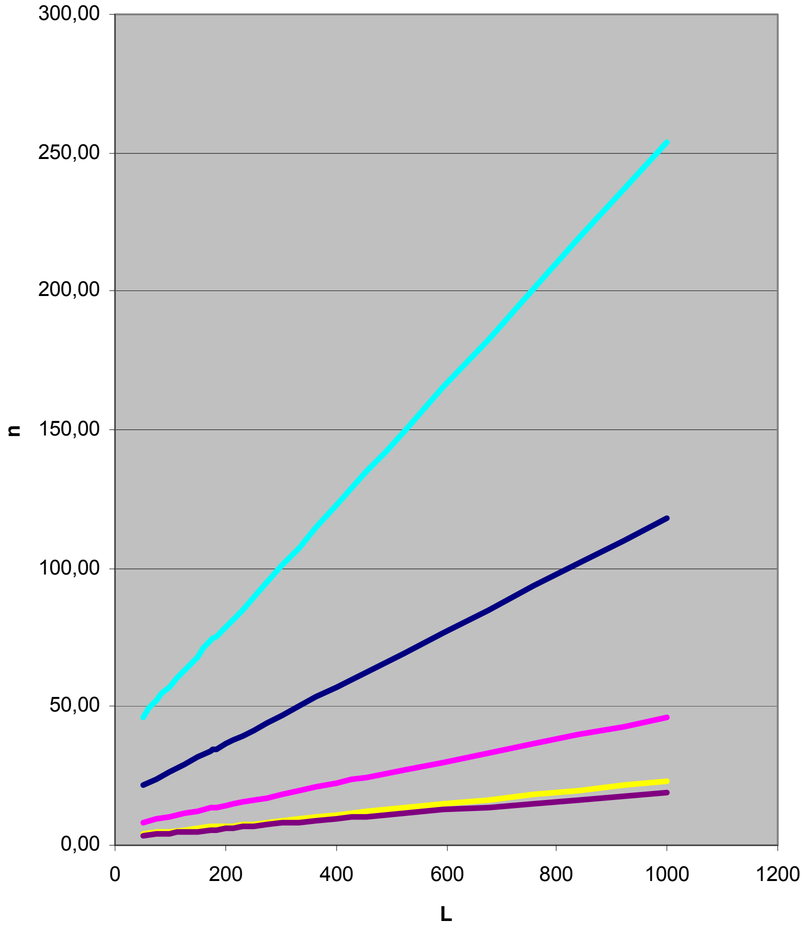

Figure-10. Dependency graphs $n = f(L)$ at R=50 m иl=2 m at different r.

-at$r$=5 m; -at$r$=10 m; -at$r$=25 m;
-at$r$=50 m; -at$r$=60 m.

3.4 The determination of scan positions number defined for L-shaped prism

While open pit mining a variety of complex shapes dumps are produced. One of the simplified dump forms was considered for the study of the optimal number of scan-position. It was conventionally called the L-shaped. These dumps can be studied as two trapezoidal prisms with rectangular bases, limited on both sides with parts of truncated cones (Figure-11).

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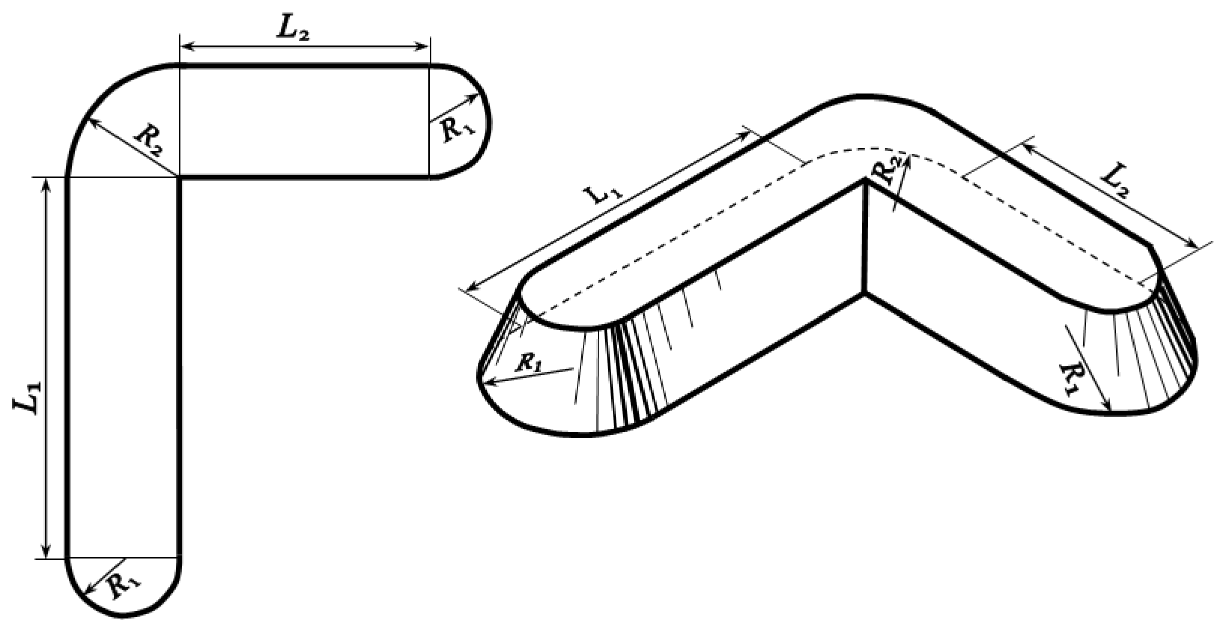

Figure-11. Schematic representation of the studied object

Then, in the composing a formula to find the stations number following geometric shapes will be analyzed: rectangle with the greatest side L_1, a rectangle with the highest side L_2, two semicircles of radius R_1 and quarter circle of radius R_2. Hence, there is formula 6.

$$n' = \frac{L_1}{\sqrt{r^2 - l^2}} + \frac{L_2}{\sqrt{r^2 - l^2}} + \frac{\pi}{4\arccos\dfrac{R_2{}^2 + (R_2 + l)^2 - r^2}{2R_2(R_2 + l)}} + \frac{\pi}{\arccos\dfrac{R_1^2 + (R_1 + l)^2 - r^2}{2R_1(R_1 + l)}} \quad (6)$$

For dumps, similar in form to an L-shaped prism, the total number of scan positions n_0 is defined by the following pattern:

if $R_1 \le 2r$ then $n_0 = 2n - 5$;

if $2r < R_1 \le 3r$ then $n_0 = 3n - 15$;

if $3r < R_1 \le 4r$ then $n_0 = 4n - 30$;

if $4r < R_1 \le 5r$ then $n_0 = 5n - 45$;

if $5r < R_1 \le 6r$ then $n_0 = 6n - 60$ etc.,

n - the number of scan positions defined by formula 6.

From Figure-11 it follows that $R_2 = 2R_1$. Hence, formula 6 takes the form

$$n' = \frac{L_1}{\sqrt{r^2 - l^2}} + \frac{L_2}{\sqrt{r^2 - l^2}} + \frac{\pi}{4\arccos\dfrac{R_2{}^2 + (R_2 + l)^2 - r^2}{2R_2(R_2 + l)}} + \frac{\pi}{\arccos\dfrac{R_1^2 + (R_1 + l)^2 - r^2}{2R_1(R_1 + l)}} =$$

$$= \frac{L_1}{\sqrt{r^2 - l^2}} + \frac{L_2}{\sqrt{r^2 - l^2}} + \frac{\pi}{4\,arccos\dfrac{4R_1{}^2 + (2R_1 + l)^2 - r^2}{4R_1(2R_1 + l)}} + \frac{\pi}{arccos\dfrac{R_1^2 + (R_1 + l)^2 - r^2}{2R_1(R_1 + l)}}$$

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The domain of this function is the expression $r_{min}<l<r$, r_{min}- minimum range of laser scanner.

4. CONCLUSIONS

Method of obtaining scan stations number

The method of obtaining required number of scan stations is as follows:

a) determine the distance *l* from the scanner to the object in which the dump top is captured during survey by the formula

$$l = \frac{(H_{\max} - h_c)\sin\delta}{\sin\alpha \cdot \sin(\alpha - \delta)} - h_c ctg\alpha \ ,$$

H_{max} height at which it is possible to fix reflection points by scanner system rangefinder;
h_c - height of the instrument setup;
[alpha] - angle of the dump slope;
[delta] - angle between the laser beam and the slope surface at which the laser reflection points do not get to the receive path of the rangefinder system;

b) determine the subject shape of (dump, quarry): hemispherical shape;

elongated prism - in apparent predominance of any side length;

L-shaped prism (regarded as an elongated prism if one side visually dominates the other)

c) make measurements of the object by a tape measure or a laser measure whichever at hand:
make approximate measurements of the dump height;

(*for elongated prism* - measure the larger side of the object and subtract twice the smaller side length - it will be *L*, half the length of the smaller side *R*;

for L-shaped prism (Figure-11) - measure S_1 and S_2; measure D_1 and calculate R_1=0,5 D_1; measure the distance from the object edge to the expected rounding (R_2); calculate L_1 and L_2 as $L_1=S_1-R_1-R_2$ and $L_2=S_2-R_1-R_2$);

d) calculate the scan positions expected number by the respective formulas

Hemispherical shape of dump or quarry:

$$n = \frac{\pi}{\arccos\dfrac{R^2 + (R+l)^2 - r^2}{2R(R+l)}}$$

n - number of scan positions;
r - measuring distance, m;
R - object radius, m;
L - distance between the boundary of the object and the scan position, m.

Elongated prism of dump or quarry:

$$n = \frac{L}{\sqrt{r^2 - l^2}} + \frac{\pi}{\arccos\dfrac{R^2 + (R+l)^2 - r^2}{2R(R+l)}}$$

n - number of scan positions;
r - measuring distance, m;
L - the length of the rectangular part of the object, m;
R - radius of truncated cone, m;
l - distance between the boundary of the object and the scan position, m.

L-shaped prism of dump or quarry:

$$n' = \frac{L_1}{\sqrt{r^2 - l^2}} + \frac{L_2}{\sqrt{r^2 - l^2}} + \frac{\pi}{4\arccos\dfrac{R_2{}^2 + (R_2+l)^2 - r^2}{2R_2(R_2+l)}} + \frac{\pi}{\arccos\dfrac{R_1^2 + (R_1+l)^2 - r^2}{2R_1(R_1+l)}}$$

n' - number of scan positions;
r - measuring distance, m;
R_1 - radius of truncated cone, m;
R_2 - turning radius, m;
L_1 - length of the object larger side, m;
L_2 - length of the smaller object side, m;
l - distance between the boundary of the object and the scan position, m.

e) While planning a dump top survey the number of scan positions is determined based on the comprehensiveness and location relative to the dump top and at a distance not less than 20 m for surveyors' safety. Number of scan positions depends on the area of dump top (Nesterenko, Gusev, Naumenko, Volohov (2009); Nesterenko, 2010, 2011).

Presented laser scanner surveying method helps optimize data capture due to the scan positions number determination and accordingly, time consumption forecast at the survey planning stage. The number of scan stations is determined based on the shape and size of the object.

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