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Point-Clouds as Photogrammetric Representations of Linear Objects Surfaces: The Impact of Extrinsic Shooting Parameters on the Change of Roughness-Quality of Their Textures

This paper investigates the impact of various extrinsic shooting parameters regarding change of roughness-quality of surface textures of linear objects/elements when presented in the form of unstructured photogrammetrially created point-clouds. To perfom this scientifically-wise, two types of specific quality-descriptors are identified: process-quality descriptors and smoothness related quality descriptors. Then, they are precisely defined, computed and mutually correlated.

It can be generally concluded that for a fixed focal length, shooting directions perpendicular to the axis of targeted object/element, station-points uniformly radially distributed around it (at a circle of 360 deg.) and obtained process-quality descriptors values that belong to satisfying /recommended ranges, the performed photogrammetric digitalization is declared highly precise and satisfyingly accurate regarding roughness /smoothness and barely prone to object-to-camera distance.

Keywords: *close-range photogrammetry, point-cloud, roughness-quality, precision, accuracy*

1. INTRODUCTION: PREVIOUS WORK AND RESEARCH GOAL

The previous research in this field was focused on investigating several tasks that refer to:

- -comparative analysis of achieved accuracy of two terrestrial/close-range photogrammetry processes: semi-automatic and automatic, based on analysis of deviation of distances between control points defined on a chosen 3D-object from distances between their digitalized representations [12],
- -finding an efficient reverse engineering method /algorithm which can be used for precise and accurate recognition of surfaces from corresponding structured point-clouds, when those surfaces are primarily represented by elliptical segments (consisted of elliptical cylinders and ellipsoids, including spheres, rotating cylinders and cones) but, also, represented by higher-degree surface-segments, such as elliptical tori [10],
- -quantifying the accuracy of dense surface (and terrain) modelling (herewith: "DSM") obtained using a broad spectrum of photogrammetric packages [4,6,8,9],
- -quantifying the metric quality of unstructured linear objects point-clouds - obtained for horizontal shooting directions as a function of object inclination angles [1],
- -quantifying the density quality of unstructured linear objects point-clouds - obtained for horizontal shooting directions as a function of object inclination angles [1],
- -quantifying the metric quality of unstructured linear objects point-clouds - obtained for shooting directions perpendicular to those objects as a function of shooting-distances and number of camera positions shooting-directions [2],
- -quantifying the density quality of unstructured linear objects point-clouds - obtained for shooting directions perpendicular to those objects as a function of shooting-distances and number of camera positions shooting-directions [3], and
- -comparing the accuracy of professional and consumer grade 3D-printers in complex models production [13], that enables all results of the previously mentioned research to be synergically used for precise and accurate 3D processing of linear objects surfaces in the whole (complying thus with complex needs of contemporary engineering praxis).

Bearing in mind that high-quality photogrammetric point-cloud creation of linear objects/elements, especially the thinner ones (like pillars, beams, tree-branches, various types of pipe-lines, etc.) is generally more complicated than that of planar and volumetric entities (like terrains, walls and other, even amorphous, surface and 3D structures), a further research into this topic is inevitable. Obtained results will broaden not only the existent theoretical knowledge related to close-range photogrammetry, but will give a useful contribution to digitalization practice that is closely connected to a broad spectrum of inquiries required by contemporary

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architecture/urbanism, landscape architecture/forestry, civil- and mechanical engineering.

Therefore, the following tasks ought to be scientifically tackled as well:

-quantification of the achieved level of smoothness-related quality of linear objects/elements surfaces (herewith: "S-R-Q"), based on identification of descriptor types that are assumed both: as relevant for qualifying S-R-Q in related sense and responsible for the achieved levels of that S-R-Q,
-identification of obtained smoothness deviation levels (from the original ones - present in reality), and
-recognition of possible causes of previously identified deviations.

All of the above mentioned will be theoretically investigated in this paper. Additionally, given answers will help professionals to digitalize surfaces of linear objects/elements more efficiently from a practical point of view (more easily, precisely, accurately and photo-realistically - without any special extra needs to subsequently refine obtained results).

This research will use a variety of extrinsic shooting parameters, such as: (a) variable number of camera positions/object-to-camera distances (chosen according to recommendations that refer to adequate shooting-angle separations), (b) proper movement-paths geometry adjusted to concrete geometry of related elements (linear ones here), and (c) adequate shooting directions (perpendicular to those axes directions) [5,9,11].

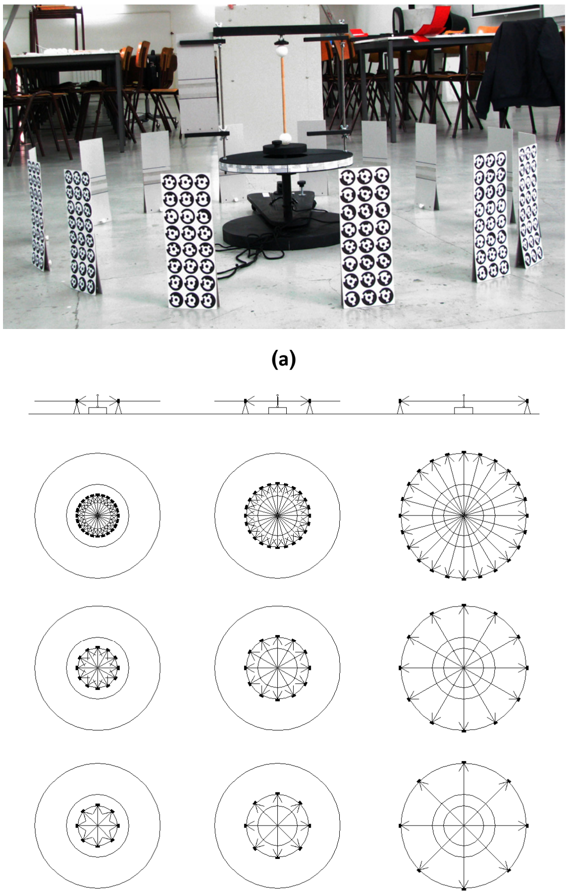
In general, the aim of this paper is to investigate the impact of previously mentioned types of extrinsic shooting parameters on the changing of roughness-, namely, smoothness-related quality of surface textures of linear objects/elements when they are presented in the form of unstructured photogrammetrically created point-clouds. To do so scientifically, two types of specific quality-descriptors are identified as relevant: process-quality descriptors and smoothness-related-quality descriptors. Then, they are precisely defined and computed. Conclusions are based on analysis of subject-related correlations of the previously obtained values of those descriptors.

The importance of this study is in the fact that linear objects/elements of various types are broadly applied in architecture/urbanism, landscape architecture/forestry, civil and mechanical engineering.

2. TEST-FIELD SETUP

Since the nature of this experiment is identical to that of the initial experiment [2] (herewith: "IE"), the test-field setup is directly inherited from the IE (Figures 1(a) and 1(b)). This fact relates to the applied artificial light source, used experimental vertically positioned object /stick (L=25cm, Diameter=10mm / Figure 2(a)), chosen number of camera positions and their mutual spatial inter-relations, chosen number of used vertical RAD-target panels and their spatial distribution Figure 2(b)).

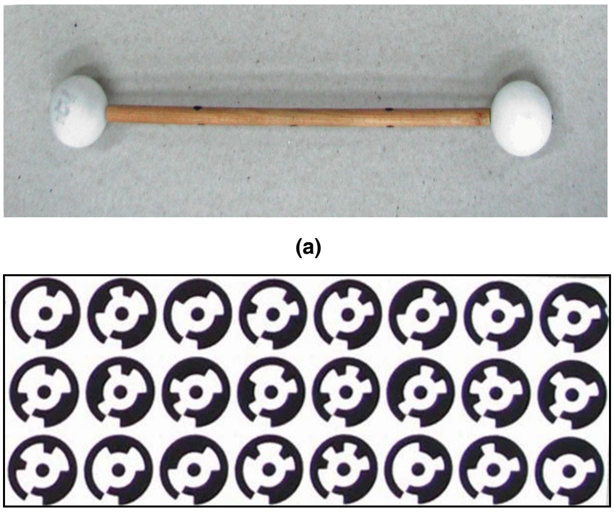
Hence, there are station-points placed at three different horizontal circle-paths, with radii of 70 cm, 110 cm and 220 cm – varying in number: from 24 (determined by 15deg camera radial-movement angle), via 12 (determined by 30deg radial movement) to 8 (determined by 45deg radial movement).



(a)

(b)

Figure 1. Photographed test-field equipment (centrally positioned stand with stick-fixing accessory and radially positioned vertical RAD-target panels) (a), and schematic representation of the Test-field setup used to create all nine experimental cases (b)



(a)

(b)

Figure 2. Experimental object: cylindrical wooden stick (L=25cm, Diameter=10mm) (a), and printed RAD-target panel (W=15cm, H=35cm) (b) (both pictures directly taken from the IE)

Consequently, the same nine experimental cases as in the IE could have also been used here, as subject-related (including their outputs). These cases are desig–

nated as: "70/15", "70/30", "70/45", "110/15", "110/30", "110/45", "220/15", "220/30" and "220/45".

3. EQUIPMENT AND TECHNOLOGY USED

Photogrammetric outputs presented in the IE are also relevant here because of the previously mentioned reason and, thus, they are directly inherited. Those outputs were obtained in the IE by using the following equipment and technology: computer Acer Aspire Timeline X (with IntelCore i5 - 45DM processor and 8GB DDR3 RAM), professional photogrammetric software: PhotomodelerScanner (“PMS”), produced by EosSystems Inc. (version: 2014.0.2.1338/64-bit) [7], mesh-analysis and comparison software: CloudCompare (“C2C”), produced by D. Girardeau-Montaut (version 2.5.3/64bit) [7], and semi-professional camera: PowerShot S5 IS, produced by Canon Corp. with 8MP Image-sensor (relevant technical characteristics of that camera are: physical sensor size (‘Format-size”): .7260mm.2926mm 8 MP sensor-size (“Image-size”): 3264 pxl x2448 pxl, and sensor pixel size ("SPS"): 0.001754289 mm/pxl x0.001753531mm/pxl.

4. SHOOTING AND PROCESSING PARAMETERS

Photogrammetric outputs were obtained as such by using adequate shooting parameters [4],[5],[9],[11] and adequate processing parameters (such as: camera and image-processing settings as well as pre-sets of the Eos' “Multi-view Stereo” technique /“MVS”/ used for unstructured point-cloud creation). Because of the mentioned reason they are inherited here from the IE

Table 1. shows chosen “DSM/MVS” parameters (data are directly taken from the IE).

Table 1. Chosen input “DSM/MVS” parameters (directly taken from the IE)

DSM/MVS parameters	Setup/ ref. value	DSM/MVS parameters	Setup/ ref. value
Min. Visible Images	3 (max.10)	Max. Group Size	20 (>0)
Min. Angle of Point	10 (>0)	Window radius	3 (>0)
Texture Strength	0.1 (max 1)	Number of iterations	1 (max.10)
Down-sample Level	1 (>0)	Curvature Factor	0.5 (min. 0)
Point Spacing	2 (>0)		

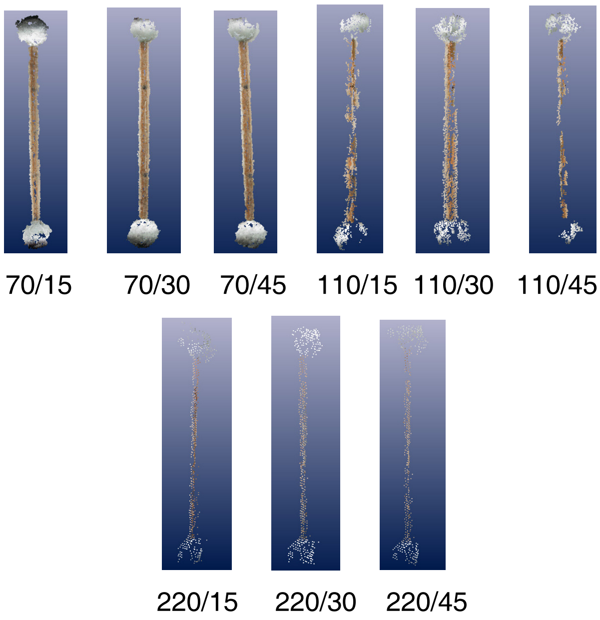
5. METHODOLOGY

Experimental outputs of performed DSM/MVS-procedures are in the form of nine different unstructured point-clouds (Fig. 3.). They could also be taken from the IE due to the same reason.

Each point-cloud is separately processed by PMS-software (as described in the IE) by using corresponding group of photos; intrinsic and extrinsic camera parameters (related to each specific case) are solved together with corresponding point-cloud DSM/MVS-creation - in two successive processing stages:

(a) during so-called “Smart-matching” procedure (used for natural targets identification and 3D-reconstruction of the test-field), and

(b) during 3D-reconstruction re-processing proce–dure (so called “RAD-targets matching” - used for final refinement of obtained results: automatically, semi-automatically and manually).



70/15 70/30 70/45 110/15 110/30 110/45

220/15 220/30 220/45

FIGURE 3. Obtained DSM/MVS results: nine unstructured point-clouds relevant for each experimental case (pictures are directly taken from the IE)

As all preconditions for quality 3D-reconstruction processes were met in the IE (there were no project-status reports with problem notifications and possible suggestions, as pointed out there), performed DSM /MSV procedures could only be responsible for the achieved levels of point-clouds S-R-Q [4],[5]. So, S-R-Q of linear objects/elements (represented by those experimental point-clouds) will be analyzed here - by investigating characteristics of specific, newly defined Smoothness-related quality descriptors-sets (herewith: “S-R-Q-D-Sets”).

Thus, two S-R-Q-D-Sets ought to be newly introduced here (whose values refer to each separate point-cloud):

- Achieved abundance-percentage of specific (smoothness-related) cloud-points, calculated according to the total number of generated points: accurately generated, precisely+accurately generated, precisely but inaccurately generated and imprecisely+inaccurately generated points - as a function of chosen object-to-camera distance and camera radial-movement angle (station-points number), and
- Achieved difference between previously found abundance-percentages of those specific points and their statistically acceptable number - as a function of object-to-camera distance and camera radial-movement angle (station-points number).

Specific values of those S-R-Q-D-Sets will indicate the achieved levels of smoothness-related quality for each generated point-cloud, separately (as a function of chosen object-to-camera distances and camera radial-movement angles/station-points number).

Each S-R-Q-D-Set is the result of comparison between its corresponding point-cloud and chosen reference-mesh (reference-mesh is a cylindrical primitive created by AUTOCAD 14 and identical to the real experimental stick).

That comparison is done by running C2C software (and performed for each of the nine experimental cases). But, to increase calculation precision (by decreasing distance-threshold used in calculation), "Octree-level" is set to 8 (instead to 5, as default). Also, to achieve better alignment between those mutually compared entities (as an additional precaution), they are registered using "Fine registration" by running so-called "Iterative Closest Point Procedure" ("ICP") - not only by running a procedure named as "Match-bounding-box centers" [14]. Additionally, to avoid any changes while adding each element of the image to its local neighbors, smoothness evaluation is performed by doing a convolution between an image and a kernel value of 1.

This comparison is based on identification of Gaussian Normal Distribution characteristics (that is on corresponding statistically calculated Gaussian para–meters: Mean and Sigma/Standard deviation values).

Regarding the statistical meaning of the Gaussian Normal distribution in this subject-related context, there are several terms that also ought to be pre-defined here:

- "Referral smoothness": the smoothness of the surface of the reference-mesh (CAAD-modeled cylinder); that cylindrical surface being created as very smooth (in order to be identical to the experimental/real one), referral smoothness can be declared "absolute/total" with zero-roughness (all mesh points completely lay on that cylinder).
- "Smoothness-related deviation" of a specific cloud-point ("Surface-error"): the achieved level of its deviation from the referral smoothness (such deviation is represented by a concrete distance between this point and the best fitting referral entity computed on its nearest neighbors).
- "Smoothness-related accuracy" of a specific cloud-point: the statistical assumption of its smoothness-related deviation level.
- "Smoothness-related precision" of a specific cloud-point: the statistical assumption of "closeness" between its concrete smoothness-related deviation value and calculated/estimated Gaussian Normal Distribution characteristics of the overall "spread" of that deviation. (see Section 6).

Only unusual photogrammetric output-data charac–teristics of DSM/MVS-procedures assumed to affect the S-R-Q (if any), will be discussed later on - by analyzing the behaviour of process-quality descriptors responsible for it.

On the other side, process-quality descriptors refer to accuracy and precision of identified (calculated) intrinsic and extrinsic camera parameters as well as to quality of subsequently performed photo-matching and referencing procedures. Process-quality descriptors ana–lyzed in the IE as relevant are also relevant here: Final/Last Error, Point Marking Residuals/in pixels ("Overall RMS", "Min. RMS" and "Max. RMS"), Point Tightness/in cm (Min. and Max.), Point Precision/in cm ("Overall RMS" Vector Length, Min. and Max.) and Point (Surface) Angle (Max., Min. and Average) [4-6].

6. EXPERIMENTAL RESULTS

"C2C" output data are in the form of newly created smoothness-related quality Histograms (herewith: "S-R-Q-Histograms" / Figure 4.).

S-R-Q-Histograms are gradually colored/shaded (from yellow/the lightest shade on the right - to blue/the darkest shade on the left[1]) representing gradient of achieved Point-cloud-to-Reference-mesh surface devia–tion (surface-error) as a variation of that smoothness deviation (yellow/the lightest shade shows the strongest, while blue/the darkest shade - close to Origin, the sma–llest level of that deviation/variation). The thin white curve (as a part of each histogram) represents calculated statistical law of that smoothness deviation distribution.

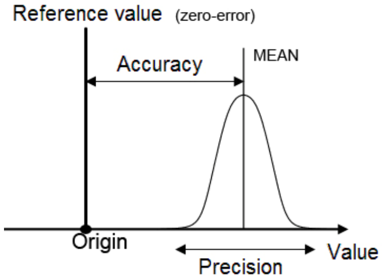


Figure 4. Graphic representation of achieved smoothness-related accuracy and smoothness-related precision according to the meaning of Gaussian Normal Distribution Curve (picture is directly taken from the IE)

This law is based on Gaussian Normal Distribution characteristics values of calculated Mean and Gaussian Standard Deviation (Sigma), visible at the upper part of each histogram (the vertical reddish bar/thin dark-gray[1] bar marks the approximate position of the concrete Mean as an average value of smoothness deviation based on its overall distribution).

Regarding the meaning of Gaussian Normal Distri–bution curve, graphic representation of achieved smoot–hness-related accuracy and smoothness-related precision is given on the Figure 4.

From the smoothness-related point of view, vertical Chart-axis (through the Origin) represents the actual number (percentage) of generated cloud-points that have the same level of the achieved smoothness deviation (surface-error). Horizontal ("Value-line") is a gradient norm scale of the achieved deviation (surface-error). The origin point marks the position of the "reference value" that corresponds to zero smoothness deviation, namely, zero surface-error (representing, thus, the pre–sence of "absolute/total" smoothness).

In accordance with both: the described meaning of smoothness-related accuracy/precision and explanations given above, concrete cloud-points can be characterized as "precisely generated" (with a statistically acceptable precision) if they are positioned symmetrically from the

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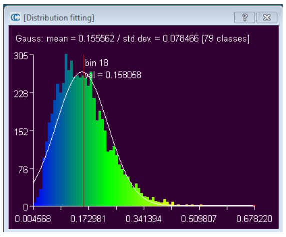
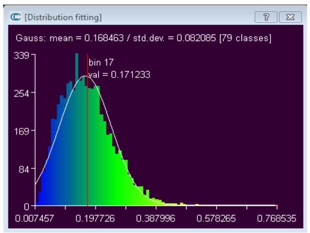
[1] This dual visual description of presented S-R-Q-His–tograms` elements is a consequence of the fact that printed version of the Journal is not in color mode (Authors` remark)

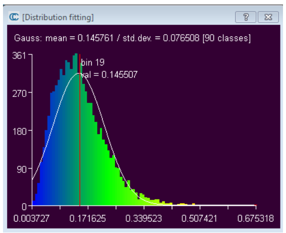
central (vertical) “tendency-line” (from the Mean) and belong to the “chart-field” whose maximal width is 6xSigma ((+-)3xSigma from the Mean toward both Value-line directions). On the other hand, points described as “accurately generated” (with a statistically acceptable accuracy) are those positioned in the chart-field between the Mean and the Reference-line.


Gauss: mean = 0.155562 / std.dev. = 0.078466 [79 classes]

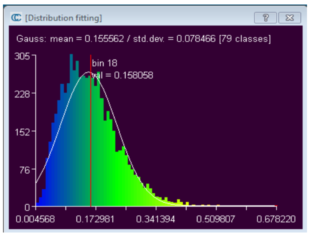
70/15


Gauss: mean = 0.168463 / std.dev. = 0.082085 [79 classes]

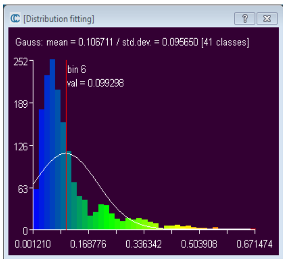
70/30


Gauss: mean = 0.145761 / std.dev. = 0.076508 [90 classes]

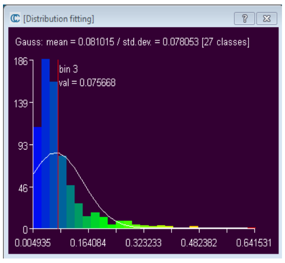
70/45


Gauss: mean = 0.155562 / std.dev. = 0.078466 [79 classes]

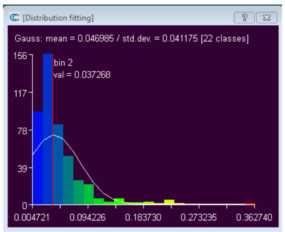
110/15


Gauss: mean = 0.106711 / std.dev. = 0.095650 [41 classes]

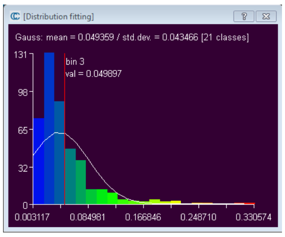
110/30


Gauss: mean = 0.081015 / std.dev. = 0.078053 [27 classes]

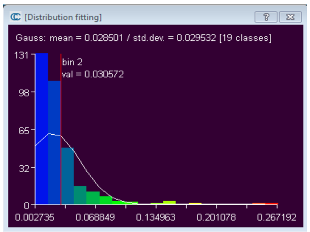
110/45


Gauss: mean = 0.046985 / std.dev. = 0.041175 [22 classes]

220/15


Gauss: mean = 0.049359 / std.dev. = 0.043466 [21 classes]

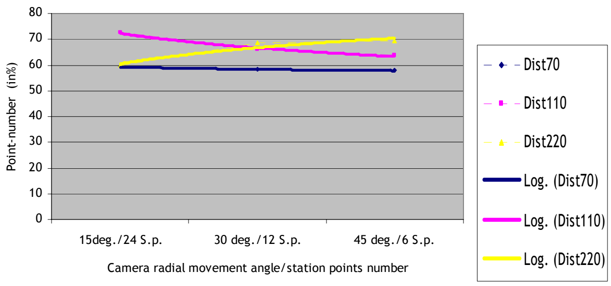
220/30


Gauss: mean = 0.028501 / std.dev. = 0.029532 [19 classes]

220/45

Figure 5. Achieved levels of Point-cloud-to-Reference-mesh smoothness deviation / Surface-error distribution histograms (S-R-Q-Histograms) and corresponding Gaussian Normal Distribution Curves, related to each experimental case (white ones)

(a)



(b)

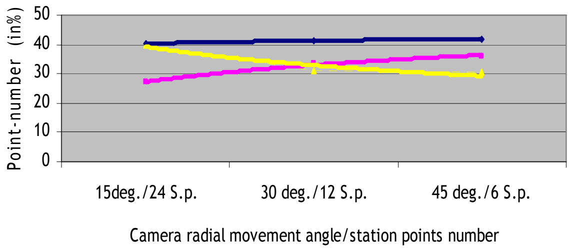


Figure 6. S-R-Q-Charts-1 (First S-R-Q-D-Set): Abundance-percentages of relevant cloud-points (with regard to all created points) as a function of camera radial-movement angle/station-points number. Values refer to smoothness-related: accurately+precisely generated points (a), and precisely+inaccurately generated points (b)

It is obvious that the expected cloud-points smoothness-related distribution is the one strictly obtained with respect to the mentioned Gaussian Normal Distribution: provided that all generated points are “covered” with

Gaussian Curve and that there are about 50% of smoothness-related “precisely+ accu–rately” generated points and about 50% of smoothness-related “preci–sely+inaccurately” generated points. But, one has to bear in mind that each deviation from such Normal Distribution – obtained by increasing either the number of smoothness-related “precisely+accurately” generated points (in favor of others) or the number of smoothness-related “precisely+inaccurately” generated points (in favor of “imprecise+inaccurate” points) can not be considered an important smoothness-related quality asset.

Based on data extracted from presented histograms (regarding values of all nine calculated Mean and Sigma parameters), it is possible to obtain values of studied S-R-Q-D-Sets and to graphically represent them in the form of smoothness-related quality charts (shown below), created by Excel software (herewith: “S-R-Q-Charts”). To generalize the results, each chart-line represents not only actual abundance-percentages of generated Cloud-points (dotted lines) but also their logarithmic Trend-curves (wider/continuous lines).

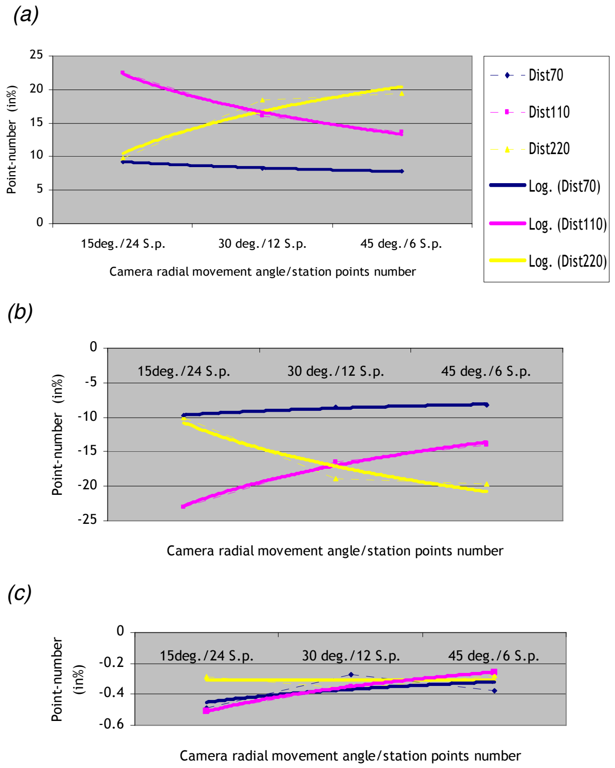


Figure 7. S-R-Q-Charts-2 (Second S-R-Q-D-Set): Difference between abundance-percentages of analyzed cloud-points and their corresponding statistically acceptable percenta–ges as a function of camera radial-movement angle/station-points number (estimation is based on calculated Gaussian Normal Distribution characteristics). Values refer to smoot–hness-related: accurately+precisely generated points (ref. = min. 50%) (a), precisely+inaccurately generated points (ref. =min. 50%) (b), and imprecisely+inaccurately generated points (ref. =0%) (c)

7. DISCUSSION

Globally comparing S-R-Q-Histograms which refer to the smallest shooting distance (70cm), it is obvious that Point-clouds-to-Reference-mesh surface deviation distribution (by means of smoothness), generally fits the corresponding Gaussian Normal Distribution. It means that the majority of cloud-points are precisely generated in a statistically acceptable number (as they are “covered” with the Gaussian Curve) and there is a similar number of precisely+accurately generated poi–nts and precisely+inaccurately generated ones. Also, for all experimental cases related to that distance (three cases), there is an insignificant number of precisely +accurately generated points with zero (or almost zero) surface-error.

Contrarily, six remaining S-R-Q-Histograms (that refer to experimental shooting distances of 110cm and 220cm), generally indicate a significant number of precisely+accurately generated points with zero surfa–ce-error! Also, those histograms show mutually similar surface-error distribution which can be treated as affirmative. Namely, there are many bluish/the darkish shade points significantly outcoming Gaussian levels of acceptance (due to their under-curve positions). Because their locations are from the Mean left side and belong to distances from the Mean less than corres–ponding -3*Sigmas, those points are to be characterized as accurately+precisely generated. Accordingly, six analyzed experimental cases show an absolute domi–nance of these points in favor of others. So, an evident emptiness in under-curve zones (positioned on the right sides from the vertical thin reddish/dark-gray Mean-lines - up to the corresponding values of +3*Sigmas) can not be treated as excessive and, thus, considered a surface-error alert (as smoothness-related quality warning). Additionally, rare clusters of yellowish/the lightest shaded points – present in all nine experimental cases, can neither indicate lower S-R-Q, because they are positioned right from the corresponding Mean values - out of +3*Sigmas and their numbers are insignificantly small (there is a minority of inaccu–rately+imprecisely generated points).

The described affirmative characteristics of all nine S-R-Q-Histograms are strong indicators that it is possible to declare generated point-clouds satisfyingly accurate and highly precise.

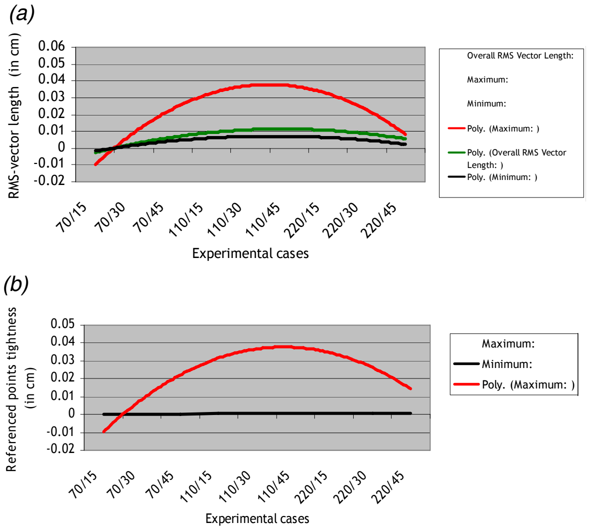


Figure 8. Charts-3 (Subject-related Process-Quality Desc–riptors): Achieved values of RMS-vector Lengths as a function of camera radial-movement angle/station-points number (a), and achieved values of Point-Tightness as a function of camera radial-movement angle/station-points number (b).

Because of a majority of precisely generated points in all nine experimental cases, further output data analysis will primarily include: precisely+accurately and precisely+inaccurately generated points.

Data taken from analyzed histograms are cross-referenced and as such more clearly represented by corresponding S-R-Q-Charts.

Having in mind the achieved abundance-percentage values of both precisely+accurately and precisely +inaccurately generated points related to each separate point-cloud (calculated with regard to all of its created points in the function of camera radial movement-angle/station-points number), the following can be concluded (see S-R-Q-Charts-1/First S-R-Q-D-Set):

(1) For all three experimental distances there are differences between achieved abundance-percentages of precisely+accurately generated points (S-R-Q-Chart-1(a)). Regarding the smallest shooting distance (70cm), there is almost an insignificant decrease of abundance-percentage values of analyzed points (from approx. 59.27% via 58.23% to approx. of 57.84%) as camera movement angle increases/station-points number decreases. The same but more significant trend-line down-slope is characterized by the case of dist110: from approx. 72.5% of analyzed points obtained for radial shooting separation of 15deg. (for 24 station-points) via approx. 66.0% of those points - for 30deg. (12 station-points) to approx. 63.7% - for 45deg. (6 station-points). Such "flow" of those trend-lines is to be assumed as a consequence of behavioural characteristics of related process-quality descriptors (of their corresponding polynomial trend-lines): "RMS-vector Length" and "Point-tightness" (Chart-3(a) and Chart-3(b)).

Namely, by increasing the shooting distance: from 70cm to 110cm, trend-lines of both RMS-vector length and point-tightness show continual rising - up to the distance of 220cm. Such permanent increase of those descriptors values underlines the increase of achieved levels of imprecision and inaccuracy of automatic point-matching and point-referencing procedures as the camera movement angle increases the station-points number decreases. The outcome of such tendency is the said decrease of abundance-percentages of precisely+accurately generated points (dependent on camera-movement angle/station-points number). On the other hand, the abundance-percentage trend-line referring to the case of dist220 shows a slight increasing ("involutory") tendency as shooting angle increases (station-points number decreases): from 59.8% - for 15deg. (24 station-points) via approx. 68.4% - for 30deg. (12 station-points) to 69.3% - for 45deg. (6 station-points). For the same reason, it is possible to conclude that such trend is a result of decreasing tendency of analyzed process-quality descriptors values that causes the increase of achieved levels of precision and accuracy of automatic point-matching and point-referencing procedures - as camera movement angle increases: from 30deg. to 45deg. (namely, as station-points number decreases: from 12 to 6). Additionally, abundance-percentage trend-lines that correspond to the cases of dist110 and dist220 intersect each other for radial separation angle of approx. 30deg (for used 12 station-points). This can be explained by the fact that the angle of approx. 30deg (related to station-points number of 12) corresponds to values of both RMS-vector length and point-tightness that are almost identical in the cases of dist110 and dist220 [4-6].

(2) As there is a small (although insignificant) presence of inaccurately+imprecisely generated points in all nine experimental cases (those yellowish/the lightest shaded), the abundance-percentage trend-lines of precisely+inaccurately generated points logically are not only nearly "supplemental" to those that refer to precisely+accurately generated points but also "involutory" (S-R-Q-Chart-1(b)). Thus, as regards dist70, corresponding abundance-percentage trend-line shows a slight increase of abundance-percentage values of analyzed points (from approx. 40.23% to approx. of 41.78%) as the camera movement angle increases/the station-points number decreases. Other shooting distances are characterized by abundance-percentage trend-lines that are much more dependent on camera radial movement angles (station-points number). So, in the case of dist110, corresponding abundance-percentage trend-line shows a slight increase (from approx. 26.9% of analyzed points - for radial shooting separation of 15deg. (for 24 station-points) via approx. 33.6% of those points - for 30deg. (12 station-points) to approx. 36.0% - for 45deg. (6 station-points)). On the other hand, the trend-line that refers to the case of dist220, shows a slight decreasing tendency as shooting angle increases (station-points number decreases): from 39.8% of analyzed points - for 15deg. (24 station-points) via approx. 31.1% of - for 30deg. (12 station-points) to 30.3% - for 45deg. (6 station-points).

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S-R-Q-Charts 2(a, b, c) (Second S-R-Q-D-Set) underline the following:

(1) Concerning precisely+accurately generated cloud-points (S-R-Q-Chart-2(a)), all shown S-R-Q-D values are positive. This refers to the fact that abundance-percentages of this point type are higher than their statistically acceptable percentages, regardless of shooting distances (of station-points number). Such (positive) difference is to be considered a "surplus" of analyzed points and, thus, a significant S-R-Q asset. Logarithmic trend-line which relates to the case of dist70, shows the smallest but important surplus of precisely +accurately generated cloud-points (according to their statistically acceptable abundance-percentage of min. 50% of all generated points): this surplus slightly decreases as the camera radial-movement angle increases/the station-points number decreases (from approx. 9.2% via 8.2% to 7.8%). Contrarily to that experimental case, there is a different behaviour of trend-lines related to shots from dist110 and dist220: these lines are much more inclined, but in opposite way (as a natural consequence of the behaviour of corresponding trend-lines represented by S-R-Q-Chart-1(a)). Namely, in the case of

dist220, its logarithmic trend-line rises up intensively (from approx. 9.8% via 18.4% to 19.3%) – demonstrating an affirmative tendency (represented by significant and permanent surplus-increase of precisely+accurately generated points according to their statistically acceptable abundance-percentage of min. 50% of all generated points). Contrarily, in the case of dist110, the main characteristic of its trend-line behaviour is an intensive and continual decrease of achieved abundance-percentages of analyzed points as the camera radial-movement angle increases (the station-points number decreases): from approx. 22.5% via 16.0% to 13.7%. The smallest surplus of precisely+accurately generated points in the case of dist70 as well as described behavioural characteristics of trend-lines referring to the cases of dist110 and dist220 can be explained by the already underlined influence (and behaviour) of the two previously mentioned process-quality descriptors (RMS-vector length and Point-tightness).

(2) Concerning precisely+inaccurately generated cloud-points (S-R-Q-Chart-2(b)), the case of dist70 shows a small but important deficit of analyzed points (calculated according to their statistically acceptable abundance-percentage of min. 50% of all generated points). As there is a slight decrease of this deficit (from approx. -9.7% via -8.5% to -8.2%) which additionally exists in favor of precisely +accurately generated points, such trend can be declared affirmative. On the other hand, deficits that correspond to the last two experimental distance-cases are much higher than in the case of dist70. Namely, trend-line of dist110 demonstrates an intensive deficit decrease of achieved abundance-percentages of analyzed points - as the camera radial-movement angle increases (the station-points number decreases): from approx. -23.0% via -16.3% to -13.9%. This is a positive occurrence because, as mentioned, such decreasing deficit also exists in favor of precisely+accurately generated points. On the contrary, the case of dist220 shows significant deficit increase: from approx. -10.1% via -18.8% to -19.6%. But, that trend can be declared slightly negative only, because the maximal value of such increasing deficit actually refers to shooting angle separation of 45deg. (to 6 station-points) which is characterized by a presence of maximal abundance-percentage of precisely+accurately generated points.

(3) Concerning imprecisely+inaccurately generated cloud-points, a most balanced behaviour of their logarithmic trend-lines related to all experimental distances can be noticed (S-R-Q-Chart-2(c)). The fact that all mentioned abundance-percentage values are negative (larger than the calculated statistically estimated abundance-percentage of max. 0% of all generated points), indicates the presence of surpluses of analyzed type of points, which are obviously not affirmative in this situation. But, such surpluses can not be treated as S-R-Q warning, because their values are insignificantly small (comparing to significant levels of abundance-percentages of precisely generated cloud-points - especially of its sub-set: precisely+accurately generated ones). Namely, there is a surplus of imprecisely+inaccurately generated points (of approx. -0.3%) which refers to the case of dist220. It is almost constant independent on camera-movement. The remaining two cases are characterized by the presence of slightly inclining trend-lines to the right: each of them increases as the camera radial-movement angle increases/the station-points number decreases. Thus, the trend-line related to the case of dist110 is slightly more inclined to the right (from approx. -0.4% to -0.3%) than that referring to the case of dist70 (that rises up from approx. -0.5% to -0.2%). These tendencies are to be declared positive because, in both cases, there is a noticeable surplus decrease of imprecisely+inaccurately generated points in favor of other, much important points from the subject-related point of view.

8. CONCLUSIONS AND OUTLOOK

According to all facts underlined in the previous chapter (related to both precisely+accurately generated cloud-points), and to the fact that necessary preconditions for accurate and precise DSM/MVS-processing were met [4-6], one ought to draw the following conclusions:

- For a fixed focal length, shooting directions perpendicular to the axis of targeted linear object/ element, station-points uniformly radially distributed around the object (at a circle of 360 deg.) and process-quality descriptors values belonging to satisfying/recommended ranges, regardless of the level of object-to camera distance, all digitalized surfaces consist of majorities of both precise and accurate points. Hence, the performed photogrammetric creation of those surfaces/textures can be declared highly precise and satisfyingly accurate as regards roughness/smoothness.
- Separately, in the case of Dist70cm, digitalized surfaces possess a satisfying smoothness-related quality (regarding levels of achieved both precision and accuracy) which is not dependent on camera-movement angle (station-points number). On the other hand, according to separation angles from 15deg. to 30deg. (obtained for 24 to 12 station-points), digitalized surfaces related to the case of Dist110cm have the highest quality as regards smoothness, less quality is present in the case of Dist220cm, while the case of Dist70cm is characterized by minimal but still very acceptable quality. Contrarily, when shooting separation angles range from 30deg. to 45deg. (obtained for 12 to 6 station-points), a digitalized surface has the highest smoothness-related quality in the case of Dist220cm, a smaller quality in the case of Dist110cm, and a minimal but still very satisfying quality in the case of Dist70cm.

Subsequent research into this field will focus to investigate descriptor types which could affect achieved curvature-related quality of created point-clouds surfaces as photogrammetric representations of linear objects /elements broadly applied in contemporary engineering practice (architectural/urban, civil, mechanical and forestry).

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ОБЛАЦИ ТАЧАКА КАО ФОТОГРАМЕТРИЈСКЕ РЕПРЕЗЕНТАЦИЈЕ ПОВРШИНА ЛИНИЈСКИХ ОБЈЕКАТА: УТИЦАЈ ЕКСТРИНЗИЧКИХ ПАРАМЕТАРА СНИМАЊА НА ПРОМЕНУ КВАЛИТЕТА ЊИХОВИХ ТЕКСТУРА СА АСПЕКТА ХРАПАВОСТИ

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Рад истражује утицај различитих екстринзичних параметара снимања површина линијских објеката /елемената, на промену квалитета њихових текстура са аспекта храпавости у случају када су оне фотограметријски генерисане у виду неструктурираних облака тачака.

У циљу увођења научне методологије у предметно експериментално истраживање, идентификована су (као релевантна) два типа специфичних дескриптора анализираног квалитета (дескриптори који описују ниво квалитета софтверског/фотограметријског процесуирања дигиталних снимака изабраног експерименталног објекта /елемента и дескриптори којима се дефинише постигнути квалитет храпавости тј. степен очуваности глаткоће његове дигитализоване површине). Ови дескриптори су, потом, прецизно дефинисани и софтверским путем израчунати. Донети закључци су базирани на анализи циљно-релевантних корелација претходно добијених вредности тих дескриптора.

Закључено је да је за непроменљиву жижну даљину, правце снимања управне на осу линијског објекта-елемента који се фотографише, за позиције фото–апарата и фотограметријске таргете равномерно радијално распоређене око те осе (по кругу од 360°), као и за добијене вредности параметара квалитета реализованог фотограметријског процесуирања (process-qua-

lity descriptors values) које су у прихватљивом/ препорученом опсегу, све дигитализоване површине су представљене облацима тачкама чије генерисање карактеришу висока прецизност (precision) и задовољавајући ниво тачности (accuracy) на које незнатно утиче дистанца са које се врши снимање.