Creating an improved DHM from Lidar data

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Abstract: This paper describes the processing method of the LiDAR data by using the feature characteristic derived from height and position information. The most important factor that everyone care, is the similarity of digital representations with the real terrain surface. The LiDAR data is classified by the neighborhood height effect. The problem occurs when you try to eliminate off-terrain points like manmade objects and trees. Those objects not belonging to the bare earth can be eliminated through different filter methods. In a flat area, an object can be detected by an algorithm which analyses the height of the points in relation to the surrounding area. The same algorithm is not anymore suited to filter off-terrain objects from the area with the same threshold. You can have the surprise that this filter will eliminate points from bare earth surface. And you have to find a different approach to the problem. This paper-work demonstrate the benefits brought by introduction of break lines in filtering the Digital Surface Model to achieve a more accurate Digital Height Model. LIDAR data sets used for demonstrations are from Romania – Prahova Valley. The methods of filtering and generation of DHM we use, were developed,implemented in software and improved in time at Institute of Photogrammetry and GeoInformation at the University of Hannover (IPI).

Key-Words: - DHM, DSM, Lidar, filtering, break-lines, terrain model, interpolation, linear prediction, Rascor.

1 Introduction

A pulsed laser ranging system (LIDAR) is mounted in an aircraft equipped with a precise kinematic GPS receiver and an Inertial Navigation System (INS). The signal is sent towards the ground where it is reflected back to receiver. The receiver captures the return echo. Using precise timing, the distance to the feature can be determined. Knowing the speed of light and the time for the signal takes to travel from the aircraft to the object and back to the aircraft, the distances can be calculated[5]. Using an oscilating mirror inside the transmitter, the laser pulses can be made to sweep through and trace out a line on the ground. Reversing the direction of rotation with pre-selected angular interval, the laser pulses can be made to scan back and forth along a line[5].

Errors in the location and orientation of the aircraft, the beam director angle, atmospheric refraction model and several other sources degrade the co-ordinates of the surface point to 5 to 10 centimetres . An accuracy validation study showed that Lidar has the vertical accuracy of 10-20 centimetres and the horizontal accuracy of approximately 1 meter[6].

After that the point coordinate X, Y, Z is obtained by analyzing the position, attitude, distance and projection transformation. Since this data includes many Non Surface Objects such as buildings, trees and cars, the classification is needed in various applications[4].

This classification is called the filtering process of LiDAR data.

The purpose of this research is to extract DSM (Digital Surface Model) from LiDAR data.

Sometimes the raw data itself is called DSM and sometimes not. In this paper, DSM is defined as following to eliminate complications.

DSM = DHM + Non Surface Objects
DHM (Digital Height Model)

In other words, DSM is the model that includes existing terrain and non-surface objects (e.g. trees, buildings, cars etc.).

This research proposes a method that processes the raw data itself by using the concept of combining the clasification and filtering processes into one, also having the posibility to use semi-automatic detected break lines[3].

2 Obtaining DHM from Lidar data

Points located outside the bare terrain surface can be eliminated through a lot of filtering methods, but a special atention should be paid in order not to eliminate real terrain located points, which can be easily mistaken as located on man made objects. As an example, sudden change of terrain slope can be mistaken for a building roof. As a result, of the first processing of LIDAR data set, the listing is obtained :

352610.000	289170.000	126.394
352660.000	289170.000	125.820
352710.000	289170.000	125.241
352760.000	289170.000	123.333
352810.000	289170.000	123.333
352860.000	289170.000	123.267
352910.000	289170.000	123.197
352960.000	289170.000	121.470
353010.000	289170.000	121.470
353060.000	289170.000	120.748
353110.000	289170.000	120.026
353160.000	289170.000	120.412
353210.000	289170.000	120.412
353260.000	289170.000	120.412

[10]

LIDAR data set contains also a great number of points not located on real terrain surface. All these data represent the Digital Model of Reflective Surface (MDSR). In many studies we only need the Digital Height Model (DHM) which can be obtained after a filtering process. Automatic DSM filtering is an important research topic and have been studied by : Petzold et al. (1999) noted that filtering can be done by applying minimum filter iteratively by changing filter size.

Axelsson (2000) uses TIN. Lohman et al. (2000) use dual-rank-filtering. Vosselman (2000) uses slope as criteria. Briese and Pfeifer (2001) use hierarchical approach, Karsten Jacobsen is using a combination of geometric tests together with linear prediction. [2]

General conclusion is that we need the additional terrain information. In addition to LIDAR data, all geomorphological structures are gathered through clasical photogrametric methods. These elements are considerated important in modeling process for medium and small study areas. Particulary to river banks, lake beaches, dams, mountain peaks, bottom valey, etc. As a general fact, in areas where the LIDAR density is not satisfactory and such areas can not be covered by clasic photogrametric methods, topografic survey must be made. Because of high costs of such kind of surveys, we must keep this at a lower level[2].

Deffinition of a break-line: Digitized lines that define critical changes (natural or manmade) in topographical shape. [2]

Break lines may be selected features previously collected for planimetric purposes, ie: lakes or rivers, etc. or lines specifically digitized to define the change in topography. The most important reason why break lines should be considered in global reconstruction is the demand to keep the number of unknown geometric [3].

As in the least squares adjustment the size and the structure of the normal equation matrix depends on the unknown quantities, and as the object surface elements can be eliminated in the matching, the amount of unknowns depends mostly on the number of DHM grid points. Beside the largest errors of the matching occur due to break lines when a continuous model is used in object surface reconstruction [2].

Thus, if a continuous model is used without considering break lines, the result is not reliable especially at break line locations. These reasons imply that in global object reconstruction break lines should be detected at first so that break line areas could be better modelled [2].

Break lines can be regarded as a discontinuity of the mathematical model if the object surface is modelled without considering break lines and smoothness constraints are used for reconstruction of the smooth object surface. Thus, break lines can be detected by computing one ortho-image per aerial input image and the difference (or deviation image in case of more than two input images) ortho-image at the same image pyramid level, and interpreting large differences between the ortho-images as defects

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in the geometric model originating, e.g., from not modelled break lines[4].

As I said before, LIDAR data is a cloud of points without structure. Without additional information, a digital height model cannot offer the certitude of a real representation. An DHM must contain in his structure information about break lines and not only. Raster data together with vector data shows the model discontinuities in areas with break lines[4].

Among their advantages, these systems afford the opportunity to collect terrain data about steep slopes and shadowed and inaccessible areas (such as large mud flats and tidal areas)[7]. Following the initial post processing and positional assurance, the Lidar data are filtered for noise removal and prepared as a file of x,y,z points[7].

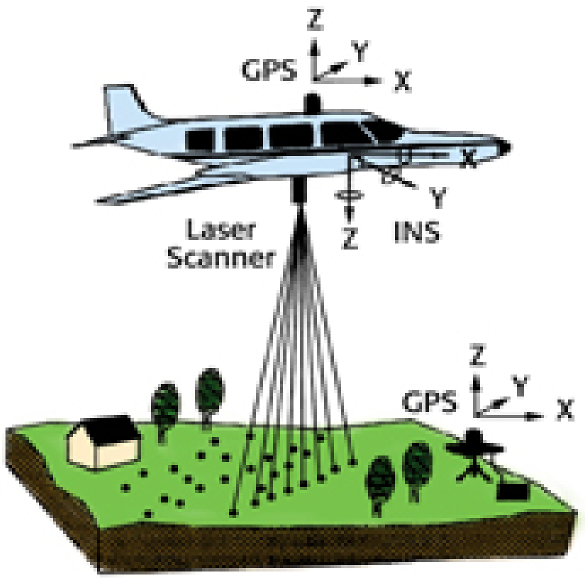

Fig. 1 Theoretical pulse emitted from a Lidar system

The imagery can be used to add break lines to the Lidar data to reveal the terrain more accurately[2].

3 DHM generation from Lidar data and filtering

A method for the generation of DHM from airborne Lidar data presented which was developed and improved at IPI. The method distinguishes itself by using the filter in the same time with interpolation.

The original data obtained by ALS express the surface of ground objects, not only the ground surface but also trees and roofs of buildings. These data are called digital surface model (DSM). It is necessary to distinguish these ground objects and to create a digital height model (DHM) that expresses the ground elevation by removing trees and buildings from DSM[3]. This process is called "filtering.". The manual refinement is time consuming[3]. The strategy for automatic filtering is based on a combination of geometric conditions together with Linear Prediction. The filtering was applied to photogrammetric acquired data via automatic image matching[3].

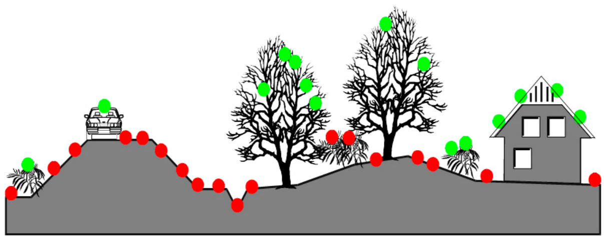

Fig. 2 DSM Gren points belonging to surface of objects; DHM - Only red points – belonging to bare earth surface

The solution found, combines filtering and interpolation of terrain. Is called a robust interpolation or robust linear prediction[2]. The algorithm is embedded in a hierarchical approach, however, the filtering of the laser scanner data on one level will be described first. In this Algorithm a rough approximation of the surface is computed first. Next, the residuals, i.e. the oriented distances from the surface to the measured points are computed. Each (z) measurement is given a weight according to its distance value, which is the parameter of a weight function[2]. The surface is then recomputed under the consideration of the weights. A point with a height weight will attract the surface, resulting in a small residual at this point, whereas a point that has been assigned a low weight will have little influence to the figure of the surface. If an oriented distance is above certain value, the point is classified as off-terrain point and eliminated completely from this surface interpolation. This process of weight iteration is repeated until all

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gross are eliminated or a maximum number of iterations is reached. Program RASCOR use maximum 2 iterations. The reason for this limitation is that more itterations will result in a very smooth earth surface due to the risk of elimination of too many points.

For the interpolation we use linear prediction. In this method the classification and DHM generation are performed in one step, there is no assumption that the terrain is horizontal. It is applied patch wise to the data, which result is an adaptive setting of the shift origin of the weight function. Furthermore, the base are determined for each patch separately, too. The process yields a smooth surface, that means the accidental (random) measurement errors have also been filtered.

However, the algorithm relies on a “good mixture” of ground and off-terrain (vegetation) points, which can also be seen as a high frequency of change from change from ground to vegetation points. This is necessary for a reliable determination of the shift value for the origin of the weight function. In this high frequency is not given, we need to provide the input data in a suitable form. This can be achieved by inserting the robust linear prediction in a hierarchic environment[2].

3.1 Program Rascor for filtering and interpolation

RASCOR is a program developed for automatic improvement of digital surface models to digital elevation models (raster data set) [2].

Program RASCOR can analyze, improve, smooth and interpolate a digital elevation model (DEM) which may be created by automatic image matching or laser scanning (LIDAR) in an equal spacing arrangement[2].

The identification of points not located on the solid ground but on topographic features like vegetation and buildings is possible by a minimal and maximal height in the area, by maximal height differences between neighbored points, by a sudden change of the height level, by a linear or polynomial interpolation in X- and Y-direction, by a minimal and maximal height difference against a local tilted plane or polynomial surface and a local prediction (least squares interpolation) based on the tilted plane or polynomial surface[2].

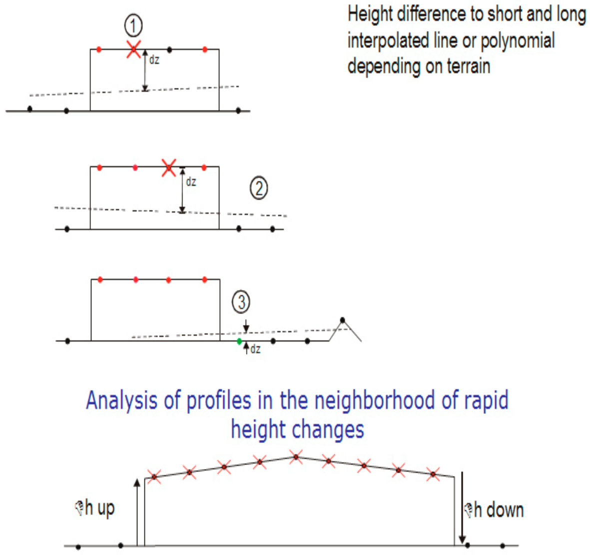

Fig. 3 Different terrain analisys[2]

The interpolated surface in the point P_i is given by:

$$u_i = \underline{c}^T \underline{C}^{-1} \underline{z} \qquad \textbf{(1)}$$

$$\underline{c}^T = [C(P_iP_1) \quad C(P_iP_2) \quad \cdots \quad C(P_iP_n)]$$

$$\underline{C} = \begin{bmatrix} \underline{V_{zz}} & C(P_1P_2) & \cdots & C(P_1P_n) \\ C(P_2P_1) & \underline{V_{zz}} & \cdots & C(P_2P_n) \\ \vdots & & \ddots & \vdots \\ C(P_nP_1) & C(P_nP_2) & \cdots & \underline{V_{zz}} \end{bmatrix}$$

$$\underline{z} = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \end{bmatrix} \qquad C(P_iP_k) = C(0)\, e^{-A\cdot\left(\frac{P_iP_k}{B}\right)^2}$$

u_i **predicted value**
$\underline{c}$ **covariances between point to be interpolated and measurements**
$\underline{C}$ **covariance matrix**
$\underline{z}$ **vector of centered measurements**

RASCOR can respect break lines during data handling. The break lines can be semi-automaticaly aquired and needs a supervisor. They also can be manually imputed or added in the iterative filtering process. Best results have been obtained with the *‚LoG-Operator’* within HALCON, which uses the Laplacian-Operator

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$\Delta g(x,y)$ and a selectable smoothing σ of the Gauss-function[4].

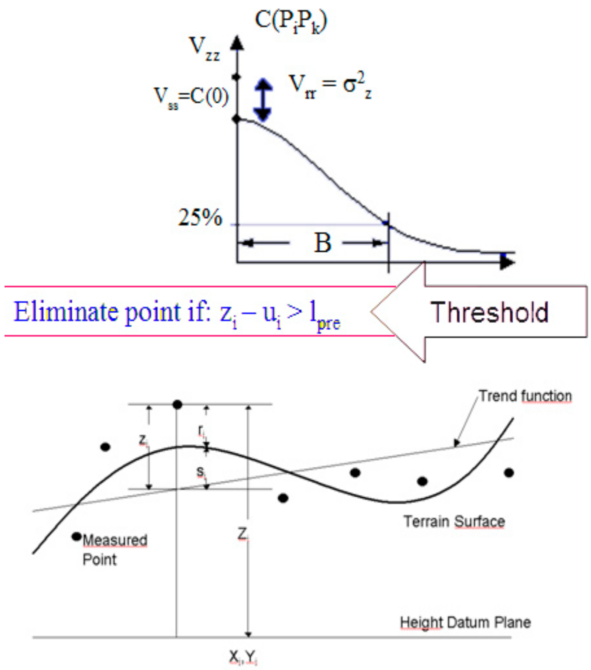

Fig. 4 Interpolation method [3]

Implementation:

$$\Delta g(x,y) = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2} \quad [4]\ (2)$$

The derivates of the LoG are approximated by derivates of the Gauss-function Gσ(x,y). This results in a detection of an ideal edge having a maxima and a minima and a zero crossing (steepest slope of the edge) [4].

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2}\exp\left[-\frac{x^2+y^2}{2\sigma^2}\right] \quad (3)$$

and

$$\Delta G_\sigma(x,y) = \frac{1}{2\pi\sigma^4}\left(\frac{x^2+y^2}{2\sigma^2}-1\right)\left[\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)\right] \quad (4)$$

Top (upper) edge of dike could not be detected because segmentation via thresholds failed[4]. Therefore the mean curvature H is determined from the derivates of the Gauss-function:

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2}\exp\left[-\frac{x^2+y^2}{2\sigma^2}\right] \quad (5)$$

$$H = \frac{a-b+c}{d}$$

$$a = \left(1+\frac{\partial g(x,y)^2}{\partial x}\right)\cdot\frac{\partial^2 g(x,y)}{\partial y^2}$$

$$b = 2\frac{\partial g(x,y)}{\partial x}\cdot\frac{\partial g(x,y)}{\partial y}\cdot\frac{\partial^2 g(x,y)}{\partial y\partial x}$$

$$c = \left(1+\frac{\partial g(x,y)^2}{\partial y}\right)\cdot\frac{\partial^2 g(x,y)}{\partial x^2}$$

$$d = \left(1+\frac{\partial g(x,y)^2}{\partial x}+\frac{\partial g(x,y)^2}{\partial y}\right)^{3/2} \quad [4] \quad (6)$$

A break line will avoid an elimination at locations with rapid change of the inclination like a dam. Program RASCOR is using a sequence of different methods for the filtering of a DSM. Only data sets with raster arrangement are accepted [2].

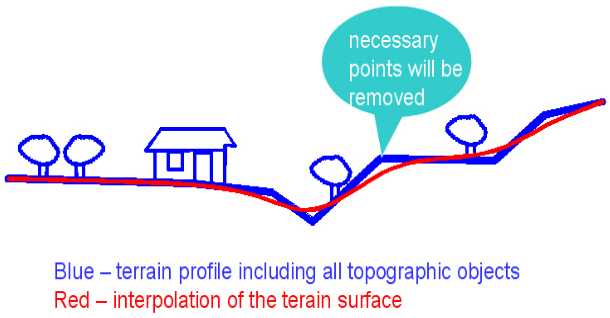

Fig. 5 Interpolation without break lines[8].

RASCOR starts with an analysis of the height distribution itself. This methods requires flat areas, it does not work in rolling and mountainous terrain. It is followed by an analysis of the height differences of neighboured points. The accepted height limit of neighboured points is depending upon the slope and the random errors. With this method only small objects and the boundary of larger elements can be eliminated, but it is still very efficient[2].

Even large buildings can be found by a sudden change of the elevation in a profile to a

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higher level and a later corresponding change down if no vegetation is located directly beside the buildings. This method is used for laser scanning, but it is not optimal for DEMs determined by automatic image matching where the buildings are looking more like hills[2]. Other larger objects not belonging to the bare ground are identified by a moving local profile analysis; at first shorter and after this longer profiles are used. The required length of the moving local profiles is identified by an analysis of a sequence of shorter up to longer profiles[2]. In flat areas the individual height values are checked against the mean value of the local moving profile, in rolling areas a linear regression is used, in mountainous areas polynomials have to be used. It will be combined with data snooping taken care about a not even point distribution caused by previously eliminated points. All these methods are applied in X- and Y-direction[2]. Elements which have not been removed by this sequence of tests are analysed by moving surfaces which may be plane, inclined or polynomial. The size of the moving surfaces is identified by the program itself by checking the data set with a sequence of cells with different size. As final test a local prediction can be used, but it is usually only finding few points not belonging to the surface after the described sequence of tests[2].

In the case of the check for height differences of directly neighboured points, the upper point will be eliminated if the tolerance limit will be exceeded. The other methods are using a weight factor for points located below the reference defined by the neighboured points. This will keep points located in a ditch or cutting in the data set. Usually points determined by laser scanning do not have blunders causing a location below the true position, but this may happen in the case of a DSM determined by automatic image matching, justifying a weight factor[2].

3.2 Results with RASCOR

RASCOR starts with an analysis of the height distribution itself. Based on the structure of the achieved histogram of height distribution an upper and lower limit of the accepted height can be identified automatically. This methods requires flat areas, it does not work in rolling and mountainous terrain. It is followed by an analysis of the height differences of neighboured points. The accepted height limit of neighboured points is depending upon the slope and the random errors. With this method only small objects and the boundary of larger elements can be eliminated, but it is still very efficient[3].

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In forest areas at first only the trees are removed by the program, smaller vegetation is remaining, so a second iteration is necessary. A second iteration in other cases may remove also terrain points leading to a more generalised DEM. This may be useful for the generation of contour lines, but it is not optimal for the correct description of the terrain[3].

RASCOR can be handled in the batch mode or a sequence of batch modes The batch-handling is based on the file rascor.dat which may include a switch for the automatic handling as batch job[2].

Fig. 6 Mosaic of images for the test area (Ialomita Valley – Romania) (Google Earth) [9]

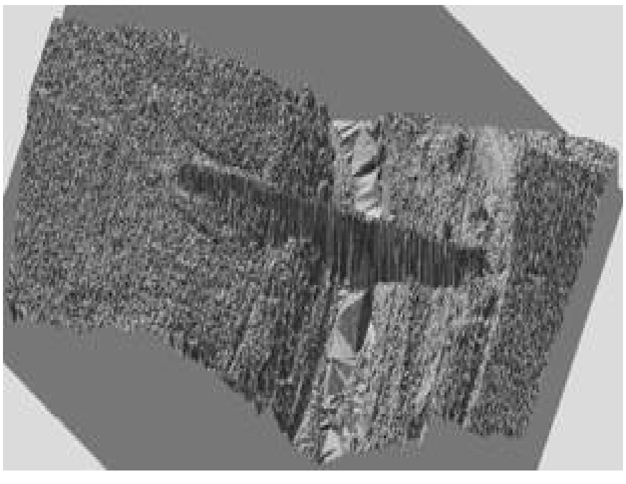

Fig. 7 DSM (Ialomita Valley – Romania) (visualisation with program LISA Basic) [10]

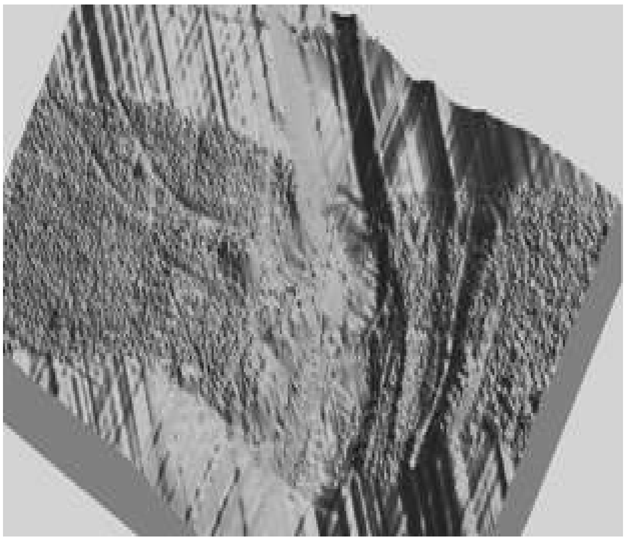

Fig. 8 DHM after filtering with program Rascor (Ialomita Valley – Romania) (visualisation with program LISA Basic) [9]

4 Conclusion

Trying an automatic filtering of a DSM to obtain a DHM without considering the different classes of terrain, shows unsatisfactory. Especially areas of different terrain types or large buildings or forests.

The automatic filtering of a DSM to a DHM without respect of the different structure of the available classes is not leading to optimal results. Most terrain classes do show advantages if they are filtered individually[3].

Very good results were achieved when using break lines for filtering the DSM to obtain DHM. Less points were removed from initial data in comparison with case in which break lines are not used[2]. The example showed in this paper-work is suggestive.

The programs used (RASCOR and Lisa developed at IPI) are very good . The filtering and interpolation works very fast and in a simple to use interface. The results obtained with the programs are satisfactory when we are taking care of the above concluded listed points[8].

The operator must have additional informations about the area being filtered like an image of the area, in order to set correctly the parameters for program RASCOR. Else, the results may be wrong just because of not knowing some details which are very important for the filter process[10].

As a general conclusions, we must say that a Digital Height Model may be improved depending on each one imagination in mathematical methods or algorhitms and additional other data or parameters joined with pure Lidar data, the procedure of filtering will remain a big topic of interest because it can never be left to complete automatisation. There will always be required the human operator to judge the result and by nature, humans will always try to improve it[10].

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