STRIP ADJUSTMENT OFAIRBORNE FULL-WAVEFORM LiDAR DATA

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ABSTRACT: Airborne full-waveform LiDAR is capable of recording complete waveform of the backscattered laser pulse. Due to the capability, it becomes possible to detect more additional objects on each laser travel path compared with traditional LiDAR systems, and therefore has been gradually introduced in applications over forest or vegetation areas. In order to extract information of interest from the scanned point cloud, data processing including pre-processing (such as pulse detection), co-registration, segmentation, classification, etc. are performed in order. From the processing chain, it is realized that quality of data co-registration is one of the key factors affects reliability of processing and analyses performed afterwards. Therefore this paper focuses on the issue may occur at this stage and proposes a method to improve the performance of data co-registration.
Two sets of point cloud collected from adjacent flight strips using Riegl Q680i airborne full-waveform LiDAR were employed in this paper. The scanned data are classified as single, first, last and other echoes in this system. For examining performance of strip adjustment, point clouds of single and last echoes, which were of better potential for representing the terrain, were extracted from the two strips respectively. After the pre-processing and co-registration performed in the proprietary software RiPROCESS, it was found that mis-alignment between the two strips existed when single or last echoes datasets were employed. To address the issue, the technique of 3D surface matching was applied. Moreover, for achieving an ideal co-registration, performance of surface matching using different types of echo data was assessed. The improvement achieved and feasibility of the method are analyzed in the paper.

1 INTRODUCTION

Airborne laser scanning (ALS), also termed as Light Detection and Ranging (LiDAR), has been developed rapidly over the last decade or so (Jenson, 2007). Due to the characteristics of high level of automation, rapidity of coverage and fast delivery time, the technique has been adopted in a wide range of applications (Large and Heritage, 2009), such as geology and topography research (Scaioni et al., 2004; Thoma et al., 2005; Lohani et al., 2006), extracting 3D building model (Haala and Brenner, 1999; Zhou et al., 2004), creation of digital terrain model (DTM) (Kraus and Pfeifer, 1998; Axelsson, 1999; Ullrich et al., 2008), etc.
For the application of DTM production, although LiDAR has shown its great potential to provide accurate and high-resolution terrain model, there are still some limitations when such technique is applied:

(1) The number of returned echo: Traditional airborne laser scanner adopted the discrete echo detection system; it only records the first and last echo of a signal, upmost to 5 echoes recorded. Majority of the received signal is discarded by the analogue detector, so the spatial resolution along the scan direction is limited, causing the ability to differ the objects along the path is also limited (Doneus et al., 2008).
(2) The method of detecting the returned echo: The method of pulse detecting in traditional airborne laser scanner are often relatively simple, such as threshold, peak, center of area, center of gravity, maximum and etc. (Abshire et al., 1994), But when it comes to full-waveform laser scanner, these methods are not appropriate to deal with the complicated full-waveform data for they may lead to range error, besides, using different algorithm may lead to different ranging result (Wagner et al., 2004).
(3) The time interval between two echoes: The time interval between two echoes must shorter than a value, which means if two object is close along the path of a signal, the return echo will fail to distinguish the two different objects.

In order to overcome these limitations, an updated LiDAR system capable of recording complete waveform of the backscattered laser pulse was developed. Figure 1shows an example of the returned echoes recorded along the path of a signal. In which Xs represents the transmitter and the receiver, the blue line indicates the original recorded return echo intensity, and the red line represents the pulse detected. Each peak (X_1, X_2, etc.) of the pulse means a possible object along the path. In addition to the intensity value, the change of the pulse provides information such as slope and roughness of the object surface reflecting the signal. Due to the capability, it becomes possible to detect more additional objects on each laser travel path compared with traditional LiDAR systems (Lin and Mills, 2010), and therefore has been introduced in upgrading vertical resolution of DTM (Lin et al., 2010) and forestry applications (Reitberger et al., 2006; Reitberger et al., 2009). Another important characteristic of full-waveform airborne laser scanning system is the high measuring rate which can reach to 250 KHz. Therefore it enables the scanner to obtain point clouds with density of 20-50 points per m^2 (Volsselman, 2009), and the chance of a signal to reach the terrain is therefore greater than traditional airborne laser scanning can achieve.

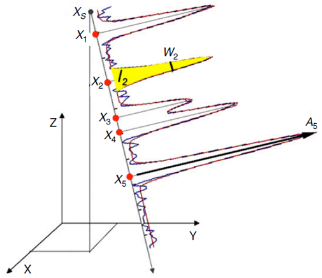

Figure 1: Returned echoes recorded in full-waveform.

Considering the characteristics of the full-waveform airborne laser scanning introduced above, it is realised that the amount of collected point data will largely increased. In order to efficiently extract information of interest from the scanned point cloud, a workflow including pre-processing (such as pulse detection), co-registration, segmentation, classification, etc. are performed in order. At the early stage of the workflow, the quality of co-registration between adjacent strips is critical. If mis-alignment exists in adjacent strips, the performance of processing tasks implemented afterwards is surely influenced. Therefore the main topic of this paper is to investigate the performance of co-registration of adjacent scanning strips. The technique of 3D surface matching is applied to further rectify the alignment of two adjacent strips if there is any discrepancy. Additionally, appropriate types of echo data for implementing surface matching are examined.

2 METHODOLOGY

2.1 Surface Matching

Surface matching is a technique used to carry out co-registration of point clouds and has been applied broadly in the fields of computer vision and geomatics. Its applications can be characterised as (i) registration of objects or surfaces comprised of 2.5D or 3D point feature data, (ii) detection of differences between objects or surfaces, and (iii) integration of datasets generated from different sources (Mitchell and Chadwick, 1999). By far the most common algorithms used in surface matching have been based on some form of least-squares adjustment, minimising the differences in position between the surfaces during iterative computation. Once the matching is finished the transformation parameters are computed and the surface is re-aligned to match more closely the reference surface. Different from traditional method for transformation, on-site arrangement of control points and determination of these points in the point cloud are not required when performing surface matching. Hence it is of great potential to achieve the transformation fully automatically. Examples of the applications of employing surface matching for co-registering multiple data sets can be found in Mills et al. (2005), Gruen and Akca (2005), Waser et al. (2007) and Miller et al. (2008). Due to these features, the surface matching technique is proposed to perform automatic co-registration of point clouds deriving from adjacent strips.

The base algorithm employed in this paper is described by Mills et al. (2003). It was proposed that the surface matching solution is based on a seven-parameter 3D conformal coordinate transformation, which defines the three rotations (ω, φ, κ), three translations (Tx, Ty, Tz) and a scale factor (s) required to relate two sets of 3D point clouds (Wolf and Dewitt, 2000). As no physical control points are given, each point on one surface effectively acts as a control point in height and is contributed to solve the transformation parameters. In this manner, the best fit of two surfaces was found by minimising the surface differences. A surface matching tool developed by Lin et al. (2010) was adopted to implement the algorithm.

2.2 Considerations

The characteristics and quality of the input data would affect the performance of surface matching, not only in the aspects of computing efficiency but also correctness of the transformation result. As waveform scanned data was employed in this paper and it was realised that multiple objects might be recognised on the path of each laser signal, therefore the selection of the data input for a successful surface matching should be considered. To this end, the characteristics of four types of returned echoes after pulse detection were firstly reviewed.

(1) First echo: First echo data is the first echo reflected back to the receiver for a transmitted signal, usually the nearest object surface on the path of a signal.
(2) Last echo: Last echo data is the last echo reflected back to the receiver for a transmitted signal, usually the surface that cannot be penetrated. The ground and the solid object beneath the surface are good examples. Because of the strengthened signal of full-waveform airborne laser scanner, the possibility of a last echo to be a terrain point or an object beneath the vegetation is greater the traditional data.
(3) Other echo: Other echo is the returned echoes between the first and last echo, may be the leaves or any objects between the surface and the ground.
(4) Single echo: Single echo is the signal that only returns an echo, normally a surface uncovered by any objects. The signal travels directly from the transmitter to the surface or objects. There is nothing in the path, so only one return echo for the signal.

In order to achieve a correct convergence in surface matching, surfaces representing solid objects, such as terrain and roof, should be applied. Based on this principle and also considering the characteristics of various echoes, single and last echoes were extracted as the data for implementing surface matching.

3 SURFACE MATCHING FOR STRIP ADJUSTMENT

The test area was near Shihmen Reservoir located in the northern part of Taiwan(Figure 2).The types of land use in the area mainly include forest, grassland, water surface, cultivation land, construction land, road, etc. In this paper, laser scanned data for testing was collected by Riegl Q680i airborne full-waveform LiDAR system. Two sets of point cloud derived from adjacent strips covering the area were acquired on July 2010. After data pre-processing, co-registration of the two sets of point cloud was examined and then updated using surface matching. Details of these tasks are introduced below.

Figure 2: Test area (covered between the two red lines).

3.1 Data Pre-processing

Once the data collected by the Riegl Q680i system was finished, data pre-processing, including positioning and orienting using GPS and IMU data, boresight calibration, pulse detection, and strip adjustment, were carried out in the proprietary software RiPROCESS. In RiPROCESS, RiANALYZE is the module in charge of the pulse detection, which extracts discrete targets from the digitized echo signals by means of the full-waveform analysis. Three methods of pulse detection are provided in RiANALYZE (RIEGL LMS GmbH, 2011):

(1) Center of gravity estimation (COG): COG estimates the target range from calculating the center of gravity of the echo pulse. This algorithm is relatively straightforward thus is simple and fast comparing to the other method. However the accuracy is lower than the other two methods, especially when the range of the two objects is smaller than 2 m.

(2) Gaussian pulse fitting (GPF): GPF tries to fit the full waveform data with one or multiple Gaussian pulse by estimating the temporal position of the pulses, the individual amplitudes of the pulses and also a common amplitude offset. This algorithm results the best accuracy, but requires the longest time for processing.

(3) Gaussian pulse estimation (GPE): This algorithm uses Gaussian pulse estimation similar to GPF but faster in processing, but GPE is an iteration approach rather than solving a linearized set of equations with a constant calculation effort. GPE combines the benefits of COG and GPF, short processing time and high accuracy nearly the same with GPF. Due to the advantages, GPE is used for pulse detection in the data pre-processing stage in this paper.

For performing strip adjustment, RiPROCESS searches tie planes in the adjacent strips for co-registration. The idea of tie plane is similar to tie point in photogrammetric processing. The tie planes are used to calculate the optimal set of parameters or mathematical models for achieving better relative fitting between two adjacent strips. Tie planes can be defined manually or automatically. As the adjustment of the whole strip was examined in this paper, tie planes are defined automatically for timesaving. Figure 3(a) shows the distribution of selected tie planes on one of the strips (indicated by yellow circles). It was observed that the tie planes were uniformly scattered over the whole strip and most of the tie plane is situated at inclined planes, such as roofs or inclined bare grounds (refers to Figures 3(b) and 3(c)).

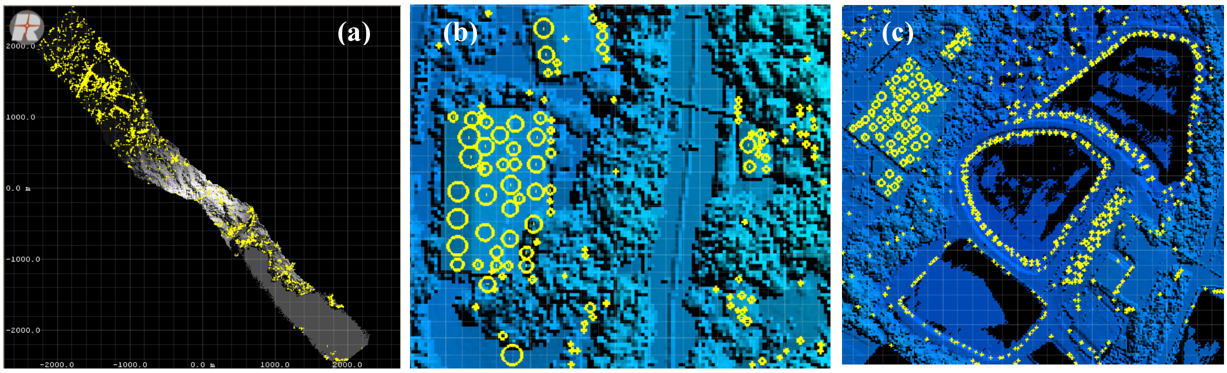

Figure 3: Distributions of tie planes in the strip

Once strip adjustment was accomplished in RiPROCESS, the alignment of the adjacent strips was examined. To this end, elevation comparison over the two whole strips and profiles across the two selected roofs were carried out. As shown in Figures 5 and 6, the vertical differences of the two strips are observed, revealing that mis-alignment after strip adjustment existed. Hence, the alignment of the two adjacent strips was following updated using 3D surface matching technique.

3.2 Implementation of Surface Matching

In order to implement surface matching efficiently, the number of points applied were limited. Two principles for selecting appropriate points in the two strips included:

(1) The points selected should be static, like surface of physical object and ground points. Tree leaves may change their positions due to the wind during data acquisition, therefore they could not be identified as static objects and not applicable in surface matching.

(2) In this paper strip adjustment was proposed to apply on the whole strips. Hence the geometric distribution of the selected points should be considered. To this end, the areas of selected points were uniformly distributed over the strip.

In addition to the principles, considerations described in Section 2.2 were also employed for the preparation of data for performing surface matching. In the scanned data, it was observed that the distribution of single echo normally located on bare ground or object surface that was not covered with vegetation, like road, roof and low grass ground. These were static object surface thus single echo data located in such areas were suitable for surface matching. Compared with single echo, the distribution of the last echo data was more widely, even over forest area. As the last echo might represent the ground surface or object surface under the canopy, last echo data located in uniformly distributed areas were selected. The feasibility of employment of last echo data was also examined. The distribution and magnitude of the selected areas for extracting single (Set 1) and last echo (Set 2) data are respectively shown in Figure 4. Once the surface matching was convergence, two sets of transformation parameters were produced. The parameters were then respectively applied to the single and last echo data over the entire matching strip.

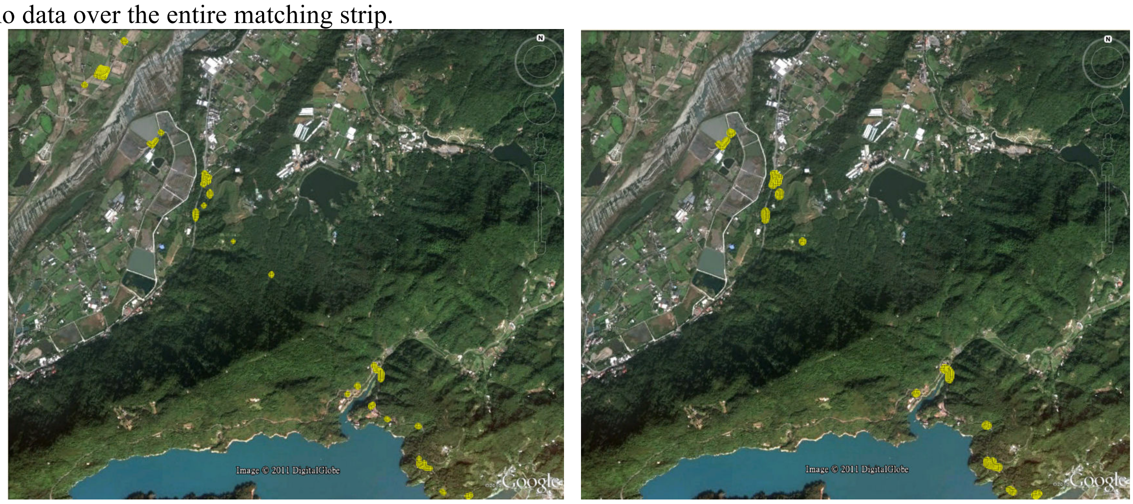

Figure 4: Selected areas (outlined by yellow polygons) of single echo (left) and last echo (right) data for surface matching (shown on Google Earth background).

3.3 Assessment of Strip Adjustment

Assessment of strip adjustment was carried out based on three sets of data, including:

(1) Origin: the first strip of single and last echo data vs. the second strip of single and last echo data;

(2) Set 1 transformed: the first strip of single and last echo data vs. the second strip of single and last echo data transformed using Set 1 parameters;

(3) Set 2 transformed: the first strip of single and last echo data vs. the second strip of single and last echo data transformed using Set 2 parameters.

Strip adjustment was performed through the elevation comparison in the overlapping area. To this end the data listed above were firstly converted to grid data with 1 meter spatial resolution. Height value in each grid was assigned using the lowest elevation of the points located in that grid. The performance of strip adjustment was then assessed through grid computation. Figure 5 shows the distribution and magnitude of difference of grid minus over the whole overlapping area. It is observed that an obvious systematic height offset exists in the Origin set. After applying transformation using Set 1 parameters, the co-registration of the two strips was improved and thus the offset was largely addressed. The height offset, however, was not improved using Set 2 parameters. The same findings are demonstrated in three specific areas and roofs in Figures 5 and 6 respectively.

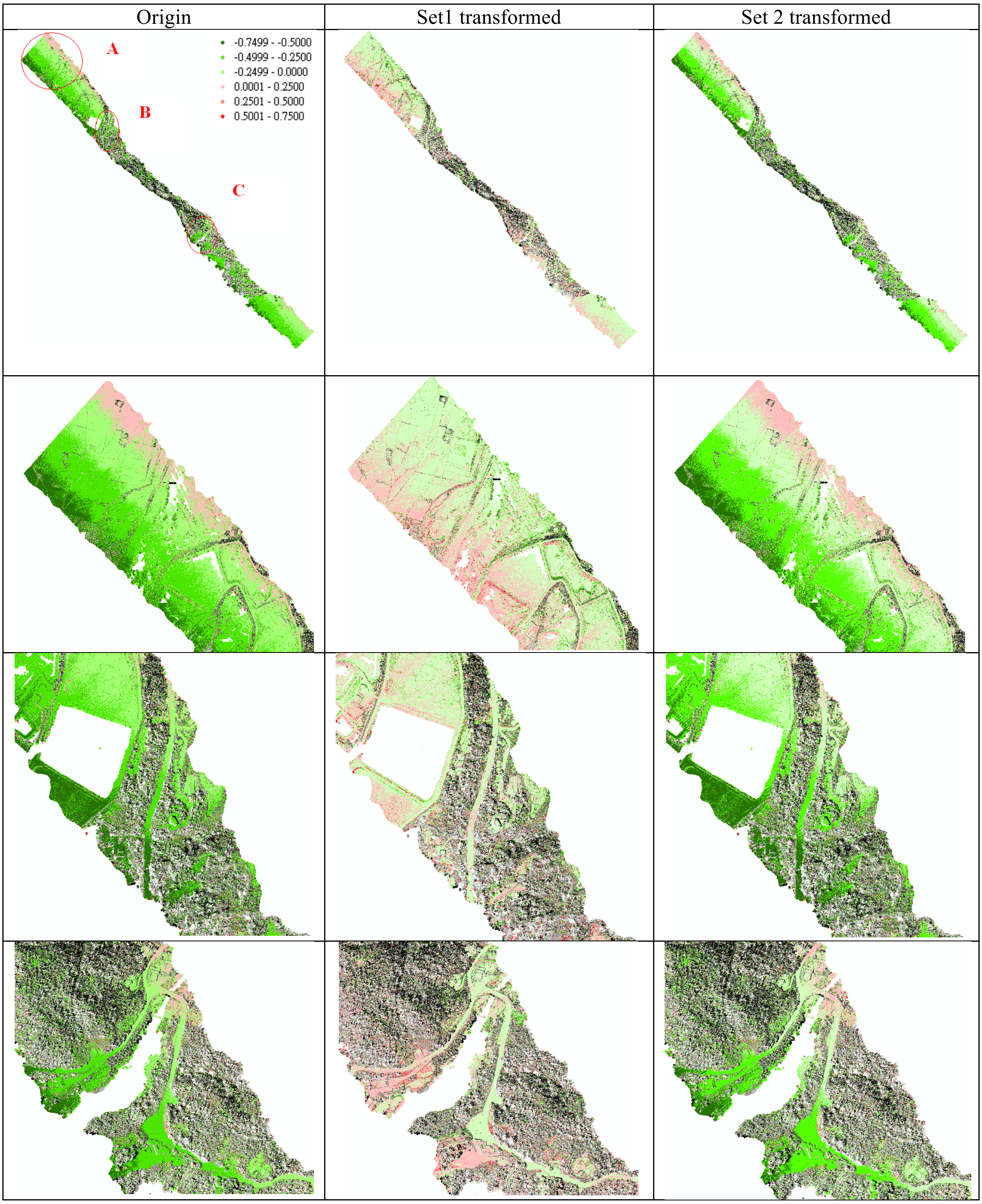

Figure 5: Assessment of strip adjustment after surface matching.

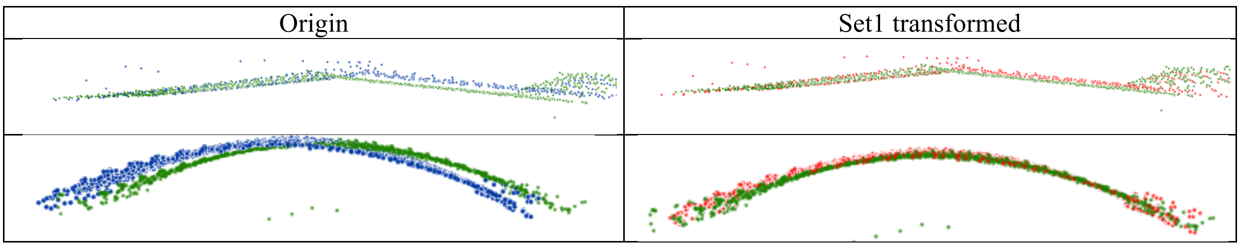

Figure 6: Perspective view of selected roofs in overlapping area (from the same viewing angle). Green, blue and red points indicate points of line 1, the original line 2, and the transformed line 2 with Set 1 parameters.

4 CONCLUDING REMARKS

In conclusion, the application of surface matching was feasible to improve alignment of the overlapping strips. To achieve this, it was noted that the consideration of selecting the points plays an important role in surface matching. In particular, the distribution of the selected points affected the matching results and therefore should be carefully evaluated before implementation.

In this paper the result of parameters derived from the selected single echo points was much better than the set derived from last echo points. One possible reason was that the last echo points were not ground points or at least a part of the last echo points did not really reach the ground. This factor will be investigated in the future work.

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