FULL AUTOMATIC REGISTRATION OF LASER SCANNER POINT CLOUDS

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ABSTRACT

The registration of point clouds that are acquired from different laser scanner standpoints is an essential task in the environment modelling works. In this paper, a full automatic point cloud registration scheme is presented. Special targets attached onto the object(s) are used as landmarks and their 3-D coordinates are measured with a theodolite in a ground coordinate system before the scanning process. The presented registration scheme can automatically find these targets in the point clouds using radiometric and geometric information (shape, size, and planarity). At the last step, targets are labelled using the consistent labelling by discrete relaxation in order to find the actual names of the points in the ground control points list.

1   INTRODUCTION

Laser scanners can measure directly 3-D coordinates of huge amount of points in a short time period. Most of them also provide the intensity or RGB value(s) for each point. This abundant data can be used efficiently to model the scene. In some cases the object has to be scanned from different viewpoints in order to completely reconstruct it. Because each scan has its own local coordinate system, all the local point clouds must be transformed into a common coordinate system. This procedure is usually referred as registration.

In the past, much work has been done on the registration of 3-D point clouds. One of the most popular methods is the iterative closest point (ICP) algorithm developed by Besl and McKay (1992), Chen and Medioni (1992), and Zhang (1994). Several variations and improvements on the ICP method have been shown (Masuda and Yokoya, 1995, Bergevin et al., 1996).

The iterative closest compatible point (ICCP) algorithm has been proposed in order to reduce the search space of the ICP algorithm (Godin and Boulanger, 1995, and Godin et al., 2001). In the ICCP algorithm, the distance minimization is performed only between the pairs of points considered compatible on basis of their viewpoint invariant attributes (curvature, color, normal vector, etc.). Roth (1999) proposed a method that exploits the intensity information supplied by the laser scanner device. It firstly finds the points of interest in the intensity data of each range image using an interest operator. Then, the 3-D triangles, which are constructed by 2-D interest points, are matched. In (Dijkman, van den Heuvel, 2002), a registration method based on parametric model fitting (cylinder and plane) was presented.

In this work an automatic point cloud registration scheme is presented. Special targets attached onto the object(s) are used as landmarks, and their 3-D coordinates are measured with a theodolite in a ground coordinate system before the scanning process. These targets are neither retro-reflective nor made by special materials. But, they have a definite template shape (Figure 1). The aim of the

registration process is to transform each local point cloud into the ground coordinate system using those special targets as common points. Therefore the fundamental problem is the recognition, precise localization and labeling of the targets in each point cloud. The implemented method is fully automatic and does not require any operator interaction/interpretation. To perform the registration procedure, one must supply those information: coordinates of the all target points in the ground coordinate system, the shape and the dimension of the targets, and the angular scanning resolution.

Each local point cloud can be displayed as a 2-D image, in which each pixel is colored according to its intensity value provided by the laser scanner device. Each pixel also has the x-y-z coordinates defined in the local scanning system of the laser scanner viewpoint. The operations are performed on such image files, i.e. the intensity images.

The algorithm starts searching the most probable target candidates all over the intensity image using a cross-correlation matching method. The template used in the cross-correlation procedure is generated artificially according to the real target shape. Only candidates that have cross-correlation values bigger than a predefined threshold value are defined as probable targets. This stage of the algorithm uses only the intensity information provided by the laser scanner, and generally accepts 10-20 times more target candidates then the actual number. The following stages of the method use the object space geometric constraints (the dimension and the planarity of the target) in order to eliminate wrong target candidates.

The dimension of each candidate target must be similar to the real dimension of the target. In order to compare these two dimensions, the image space size of each target candidate is calculated using an adaptive cross-correlation scheme that increases the template and search patch sizes while the correlation coefficient is greater than a predefined threshold value. The actual dimension and the calculated dimension of each candidate target are compared in the image space. The candidates that do not satisfy this condition are rejected from the candidate targets list.

The second condition that could be used efficiently is the planarity of the target surface. The planarity test is applied to all target candidates using Least Squares Adjustment. In order to suppress the noisy points, median filtering is performed before the adjustment calculus and afterwards the candidates that do not satisfy the planarity test are discarded from the candidate targets list. At this stage, the candidate targets list can still include approximately 5-7% wrong candidates in many cases.

To finally remove the wrong candidates, a labeling procedure is carried out. The space angles and the distances among a given set of points are translation and rotation invariant parameters among the different laser scanner viewpoints. These two certain conditions can be used both to label the target points and to eliminate the wrong target candidates completely. These aims are achieved using the consistent labeling by discrete relaxation. With this final procedure, we are able to eliminate all wrong candidates successfully. All the presented registration procedure does not need any operator interaction either to identify or to number the common points for the following 3-D transformation. In the final step a 3-D similarity transformation is performed to transform all the point clouds into the ground coordinate system. The identification and labeling of the special targets are carried out in the point clouds separately, but the final absolute orientation of the local point clouds into common/ground coordinate system is performed simultaneously.

The implementation details are given in the following section. The experimental results of the proposed method are given in the third section. The used data set in the experimental part of the work is provided by Zoller+Froehlich Laser Scanner Company. In the last section, the results and the future work are presented.

2   THE REGISTRATION METHOD

The fundamental aim of the presented registration method is recognition, precise localization, and labeling of the special shaped targets in the laser scanning point clouds. This process is applied to each point cloud in the data set separately. Afterwards, the simultaneous 3-D similarity transformation is performed in order to transform all the local point clouds into the ground coordinate system. The identified special targets, whose coordinates are known in the ground coordinate system, are used as common points in this calculation. The method has four process steps: cross-correlation, the dimension test, the planarity test, and the point labeling by discrete relaxation.

2.1   Cross-correlation on the Intensity Image

In the first step, the probable target candidates are searched all over the intensity image using a cross-correlation template matching method. A sub-sampled version of the intensity image is used to decrease the computational expense. The template used in the cross-correlation procedure is generated artificially according to the real target shape (Figure 1). The window size is selected as 9x9 pixels. Only pixels that have cross-correlation values greater than a predefined threshold value (selected as 0.7) are defined as the target candidates. The aim of this step is to find as many as possible candidates, in which also contain the correct target points. In the following steps, the wrong target candidates will be eliminated step by step using the object space geometrical constraints.
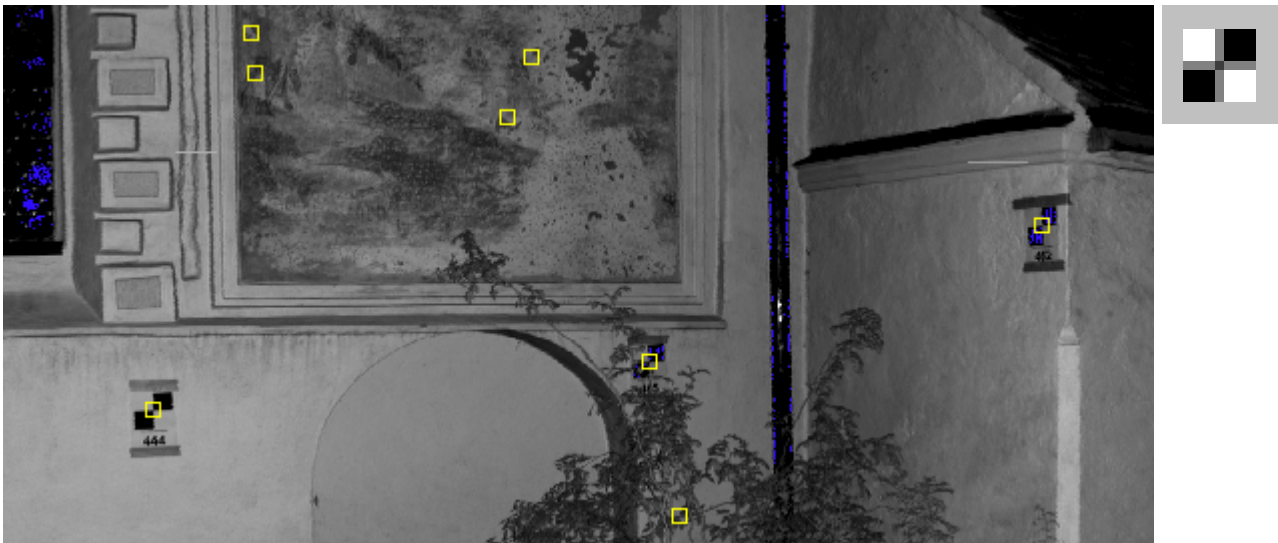
Figure 1: Target candidates from cross-correlation, and the synthetic template (upper right).

2.2   The Dimension Test

The dimension of each target candidate must be similar to the real dimension of the target both in the intensity image space and in the object space. In this work, this comparison is performed in the intensity image space. In order to compare the dimensions, the image space size of each target candidate is calculated using an adaptive cross-correlation scheme that increases the template and search window sizes until the correlation coefficient goes below a predefined threshold (selected as 0.75) value (the bright rectangle in Figure 2). The actual dimension of the target for each candidate can be projected onto the intensity image space using those values, which are the angular resolution of the scanner and the scanner-target distance (the dark rectangle in Figure 2).

Depending on the orientation of the target candidate surface with respect to laser scanner viewpoint, at least one dimension of the target (width or height) must be similar to actual one in a predefined tolerance (selected as 25%). The candidates that do not satisfy this condition are rejected from the candidate targets list.

2.3   The Planarity Test

Since the used targets are planar, the planarity test is applied to each target candidate, which passes the dimension test. The most important error sources of the time-of-flight based laser scanners are reflectivity character of the surface and the incident angle between the surface normal and the

Figure 2: The dimension test.

signal path. Since the most of the signal does not return to the laser scanner device at the extreme incident angles, such an object-laser scanner viewpoint configuration can produce erroneous measurements (Figure 3).
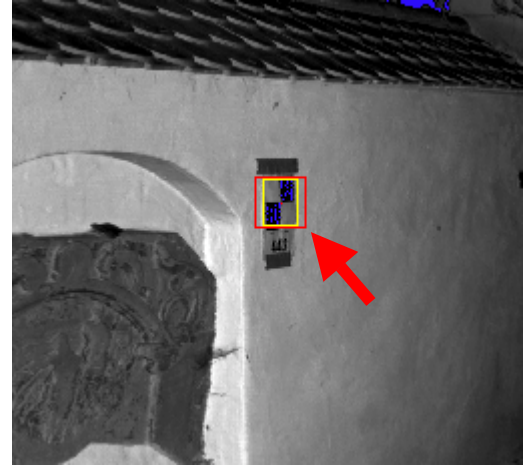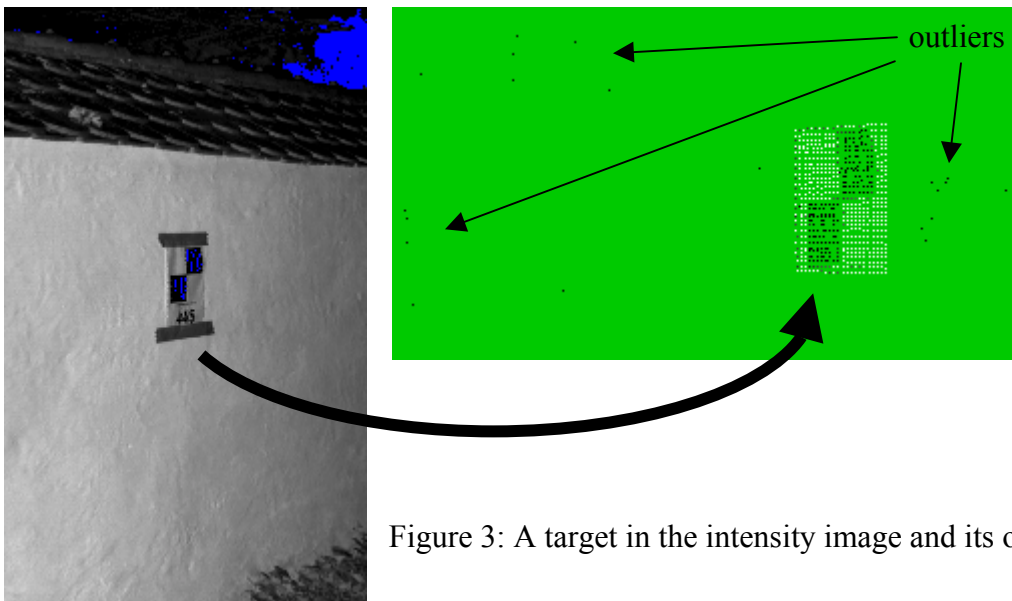

Figure 3: A target in the intensity image and its outliers.

In order to suppress the erroneous points, 3x3 median filtering is performed to the points of each target candidate according to the point-laser scanner distance. Only the points that pass the median filtering procedure are involved to the least-squares plane fitting, whose functional model of the adjustment is given below.

$$v_i = \mathbf{A}\, x_i + \mathbf{B}\, y_i + \mathbf{C}\, z_i + \mathbf{D} \qquad\qquad P = I \quad , \quad \mathbf{D} = 1.0 \ \text{(constant)} \qquad\qquad (1)$$

After the adjustment calculus, the distance from the plane to each point on the target candidate is calculated. If 75% of the points are in-plane according to a predefined threshold (selected as 15mm) value, the target candidate is accepted. Otherwise, it is rejected from the candidate list. At this stage, the candidate targets list can still include approximately 5-7% wrong candidates in many cases.

2.4   The Consistent Labeling by Discrete Relaxation

In order to perform the 3-D similarity transformation, one must define/label the homologous points between the two coordinate systems, i.e. the candidate targets in the laser coordinate system and the targets in the ground coordinate system. To solve the point correspondence problem between two laser scanner point clouds before the 3-D similarity transformation, a method was proposed based on the assumption that the Z axis of the two scans are vertical (Bornaz et al., 2002). The idea is to search the homologous points based on two spherical coordinates (range and elevation), whose the systems are constructed in both sets of points choosing a point as origin. In this work, the space angles and the distances are used as comparison measures (Figure 4). The space angles and the distances among a given set of points are translation and rotation invariant parameters among the different laser scanner viewpoints. These two certain conditions can be used both to label the target points and to eliminate the wrong target candidates completely.
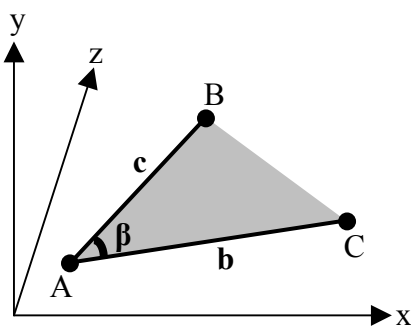

Figure 4: The space angle (β) and the distances (b, c) for point A.

In order to search homologous points, all of the possible space angles and distances are calculated in both point sets, i.e. in the candidate targets list and in the ground control points list. The total computational expense for the distances and the space angles is given below.

$$C\binom{\mathbf{N}_T}{2} + C\binom{\mathbf{N}_G}{2} + \mathbf{N}_T\, C\binom{\mathbf{N}_T - 1}{2} + \mathbf{N}_G\, C\binom{\mathbf{N}_G - 1}{2} \quad (2)$$

where $\mathbf{N}_T$ is the number of points in the candidate targets list, $\mathbf{N}_G$ is the number of points in the ground controls list, and C( ) stands for the combination operator.

Every space angle (β) and two distances (b, c) combinations for each point in the target candidate list is searched in the ground control points list in a predefined angle/distance tolerance values (for angle <0.3°, for distance <30mm). Three of the angle/distance elements, in which at least one of them must be distance, can exactly define a triangle. Therefore the presented search scheme is same as to find the equal 3-D triangles in the both point sets. If a point does not has a compatible 3-D triangle in the ground control points list, this point does not has a label, namely this point is a wrong target candidate, and must be discarded from the candidate targets list. Controversially a point might have more than one label. This ambiguity indicates that more than one equal 3-D triangles are found in the ground control points list. This circumstance is rare, but theoretically it is possible.

In this work, ambiguity problem of the labeling process is solved by discrete relaxation. The previous step assigns all of the possible labels to the each target candidates or discards the incompatible target candidates. The discrete relaxation iteratively removes all the ambiguous labels, which may not be assigned to a target candidate without violating the constraints. A detailed survey of discrete relaxation techniques, their properties, and technical limitations were given by Hancock and Kitter (1990).

The only constraint used here is the 3-ary constraints, which are based on space angle/distances. The implemented relaxation algorithm chooses and updates the target candidates iteratively, until a consistent labeling is found. For each target candidate and its label(s), the labels of the other two points (points B and C in Figure 4) on the 3-D triangle is searched considering their 3-ary relations with the other points. In the case of existence of 4 or more ground control points in the candidates list, it is able to eliminate all the wrong candidates and label the correct ones successfully. But in the case of 3 ground control points in the candidates list, it may give ambiguous results.

3   THE EXPERIMENTAL RESULTS

The presented method was tested using 4 overlapped laser scanner point clouds (Figure 5) provided by Zoller+Froehlich Laser Scanner Company. The data set acquired using IMAGER 5003 Laser Scanner (Z+F) as 4000x660 points in horizontal and vertical directions respectively. The scanner is based on time-of-flight principle, and also it supplies 16-bits intensity information for each point (Z+F 3D Laser scanner).
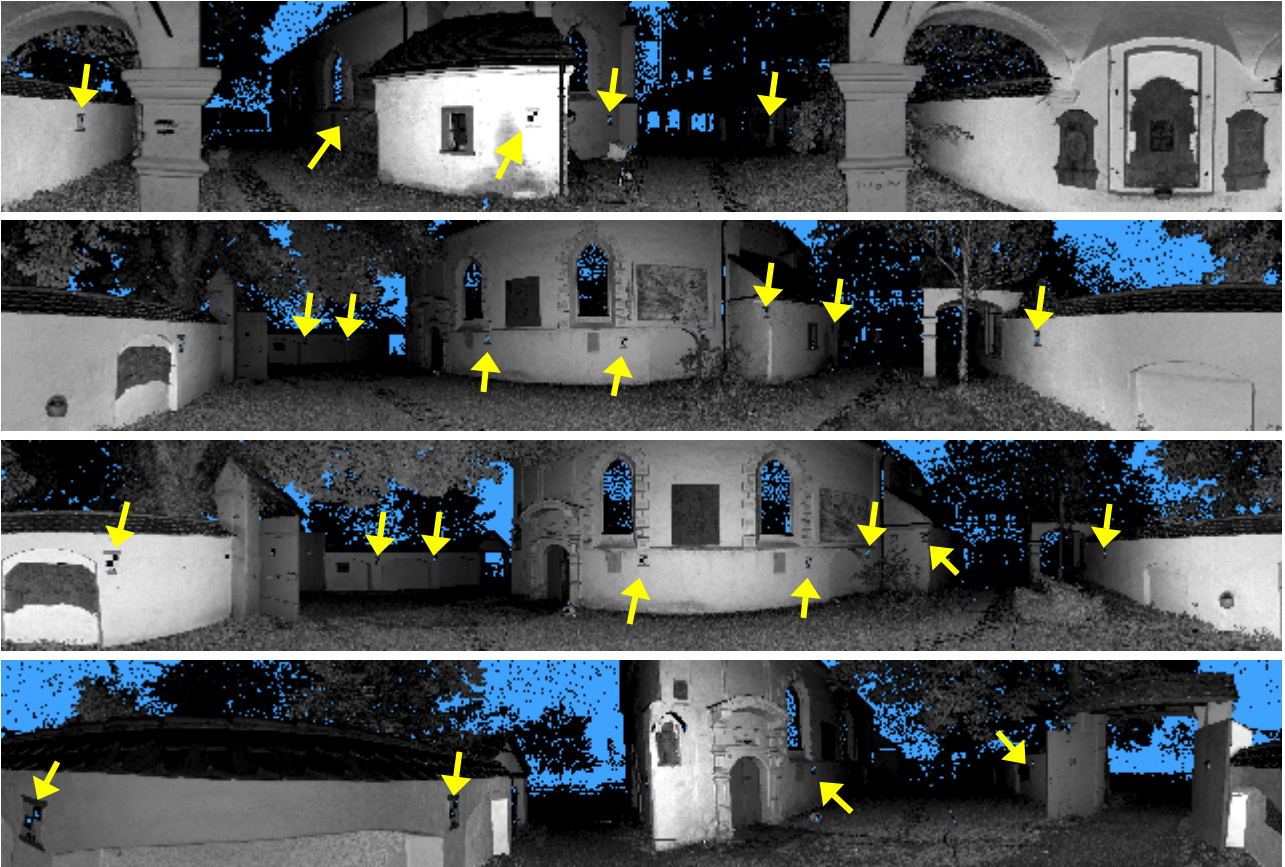

Figure 5: The intensity images of the test data set. Every scan is 360^0 in the horizontal axis. The arrows indicate the targets that were automatically found in each point cloud by the presented method.

The presented registration scheme is performed to those 4 point clouds separately. In Figure (5), the arrows indicate the targets that were found and labeled successfully. 5, 7, 8, and 4 targets were found in the point clouds respectively. The identification and the labeling processes for each point cloud took 25-27 seconds on a PC whose configuration is Intel P4 2.53 GHz CPU, 1 GB RAM. Afterwards absolute orientations of the all point clouds were carried out simultaneously using the same functional models as in the case of block adjustment by independent models. The given ground control coordinates were treated as stochastic quantities with proper weights.

$$v_L = A_1 \mathbf{t} + A_2 \mathbf{x} - \ell_L \quad ; \quad P_L \tag{3}$$
$$v_C = \qquad I \mathbf{x} - \ell_C \quad ; \quad P_C$$

where $\mathbf{t}$ and $\mathbf{x}$ are unknown vectors of absolute orientation parameters and object space coordinates respectively. The obtained results are given in Table (1). In the table, SX, SY, and SZ columns show the mean theoretical precision of the related axes.

	σ0 (mm)	SX (mm)	SY (mm)	SZ (mm)
Block Adjustment by Independent Models	9.2	5.2	5.2	5.5
Generalized Procrustes Analysis	--	1.6	2.4	1.2

Table 1: The results of the absolute orientation of the point clouds.

In the block adjustment by independent models solution, all points (totally 11) were treated as control points. This solution strongly depends on the quality of the ground control coordinates and their stochastic properties. One should carefully design the stochastic model of the adjustment, since the units of measurements (laser coordinates) and the ground control coordinates are same, as well as the a priori precisions should be very similar.

In order to investigate the internal precision of the laser scanner point clouds, the generalized Procrustes analysis was carried out. The Procrustes analysis is a set of mathematical least squares tools to directly estimate and perform simultaneous similarity transformations among model point coordinates matrices up to their maximal agreement. The generalized Procrustes analysis is a free solution; in other words, it does not involve the control information to define the datum.

$$\text{tr} \sum_{i<j}^{M} \left[\left(\mathbf{c}_i A_i \mathbf{T}_i + J \mathbf{t}_i^T \right) - \left(\mathbf{c}_j A_j \mathbf{T}_j + J \mathbf{t}_j^T \right) \right]^T \left[\left(\mathbf{c}_i A_i \mathbf{T}_i + J \mathbf{t}_i^T \right) - \left(\mathbf{c}_j A_j \mathbf{T}_j + J \mathbf{t}_j^T \right) \right] = \min \qquad (4)$$

where $\mathbf{J}$ is unit vector, and $\mathbf{c}$, $\mathbf{T}$, and $\mathbf{t}$ are unknown transformation parameters, i.e. scale factor, orthogonal rotation matrix, and translation vector respectively. The solution of the problem is the search of an unknown "consensus" matrix, which is related to every $\mathbf{A_i}$ model points matrix by a proper unknown similarity transformation that satisfies the Equation (4). In (Beinat and Crosilla, 2001), mathematical background of Procrustes analysis, implementation details, and an application to registration of laser scanner point clouds were given. In Table (1), the values, where are given in the SX, SY, and SZ columns are standard deviations of the related axes with respect to consensus matrix.

4   CONCLUSIONS

An automatic point cloud registration scheme using the template shaped targets has been presented. The method exploits the radiometric and the geometric information that are supplied by laser scanner device. All the presented registration procedure does not need any operator interaction either to identify the targets or to label them. Also, it does not need retro-reflective or other special material based targets. In the final step, simultaneous absolute orientation of the point clouds was carried out. Two different methods were employed; simultaneous 3-D similarity transformations by mean of conventional least-squares adjustment, and the generalized Procrustes analysis. The generalized Procrustes solution reveals the high internal precision potential of the laser scanner data due not to involve the control information to define the datum.

In the future works, it is planned to perform the dimension test using the least-squares template matching instead of the presented adaptive cross-correlation method. The least-squares template matching method should give more information in order to diagnose the wrong target candidates. Furthermore, future research will focus on the registration of the laser scanner point clouds without landmark targets.

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