Application Research of Real-time Integrated Module and Engineering Measurement System Design for Airborne 3D Laser Scanning

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Keywords: 3D laser scanning; Engineering Measurement System; WGS84; Real-time Integrated

Abstract: As a branch of measurement, engineering measurement is the study of the theory, techniques and methods of measuring buildings in measurement, planning, design, construction and operational management. In this paper, the real-time integration technology of airborne 3D laser scanning is deeply studied. The DTM obtained by the airborne 3D laser scanner first includes a surface model of the ground feature and the canopy height. The surface model data is a set of discrete coordinates of the approximate rectangular lattice grid, usually a Gaussian projection in the WGS84 coordinate system, and the data can be used directly as a product. Secondly, through the system, the overall design of the system and the application research of related modules are completed and the framework of the engineering measurement integration system is established, and the positioning and data processing are elaborated and improved. Finally, it is verified by experiments that 3D laser technology will be widely used in the field of surveying and mapping, the work efficiency will be further improved, the equipment will be further miniaturized, the data processing will be more rapid, and the drawing quality will be further improved.

1. Introduction

The three-dimensional laser scanning technology is a modern measurement technology that uses optical non-contact measurement methods to quickly and truly acquire three-dimensional information of space features [1]. The ground 3D laser scanning system has greatly reduced labor intensity and significantly improved work efficiency and results due to its advantages such as non-contact, high scanning speed, large amount of information acquisition, high accuracy, real-time performance, full automation, and adaptability to complex environmental measurements [2].

The three-dimensional laser scanning technology has shown strong advantages in high-precision real-time acquisition of large-scale digital elevation models, three-dimensional modeling of digital cities, and geographic information acquisition in local areas, and has become an important supplement to photogrammetry and remote sensing technology. At present, 3D laser scanning technology has successful application examples in engineering, environmental testing, and urban construction, such as three-dimensional cross-section mapping, road completion measurement, mapping of large-scale topographic maps, archeological heritage, establishment of a 3D urban model, and complex construction, construction of materials, deformation monitoring of large buildings [3].

As a branch of surveying, engineering surveying is the study of the theories, techniques, and methods of surveying construction in surveying, planning, design, construction, and operation management. Its tasks include mapping and testing both. Surveying refers to the use of various measuring instruments and tools, the use of various measurement methods to determine the location of the Earth's surface objects and landforms, according to a certain scale zoom map, that is, the process from the physical to the map. The test is to calibrate the plane position and elevation of the designed objects on the ground according to the design requirements as the construction basis [4]. Obviously, 3D laser scanning technology has inherent advantages for engineering measurement, with high measurement speed, high precision, and easy data processing. This article will use the

  DOI: 10.25236/aisct.2019.060

laser scanning technology as a basis to establish an integrated system for engineering surveys. It will introduce the key technologies in detail and discuss the subsequent processing of measurement data [5].

2. 3D laser scanning measurement

The 3D laser scanning technology is an emerging technology and is another technological revolution that has followed the GPS technology and is one of the most advanced surveying and mapping technologies. The technology integrates mechanics, optics, and computer technology and control theory. It is developed by traditional surveying and mapping technology through the integration of precise and rapid sensing technology and the integration of various modern high-tech means. It is a variety of traditional surveying and mapping technologies integration. The three-dimensional laser scanning technology has the advantages that conventional measurement methods do not have. It does not need to bury the monitoring points in advance, does not need to touch the measured terrain, has high measurement accuracy, and has fast measurement speed. It can quickly acquire high-precision, high-density 3D point cloud data. Through the processing and modeling of the point cloud data, the graphical information of the entire terrain area can be obtained. Through the analysis and study of the measurement results, the topographic map of the measured terrain is generated to better design and plans the terrain. National economic construction and social development provide technical support.

2.1. Three-dimensional laser scanning systems

A three-dimensional laser scanning system generally consists of a scanning system, a control system, and a power supply system.

1) Scanning system: It mainly includes laser ranging system and scanning system. The laser pulse emitted by the laser pulse emitter is sequentially scanned through the two measured areas by two synchrotron prisms, and the distance from each pulse to the measured surface of the object to be measured and then returned to the instrument is multiplied by the laser pulse velocity to calculate the distance. Built-in precision clock control encoder, synchronously measure the observation value of each pulse's transverse scanning angle and longitudinal angle, and calculate the point's space coordinate P and the laser reflection intensity I according to the original control spatial position observation distance of the laser scanner to match the point's color.

2) Control system (calculator): It mainly controls the normal work of the whole scanner, including the input of the station and back-view orientation information, the setting of various scanning parameters, and the division of the scanning area during the point cloud data collection process.

3) Power Supply System: Provides power protection for the scanning system. The initial scanner's power supply system consists of an external power supply, such as the Leica Scan station 2 scanners; the scanner's power system and scanning system have now been combined to provide a compact, lightweight and long-term supply, such as the Leica Scan station C10 scan.

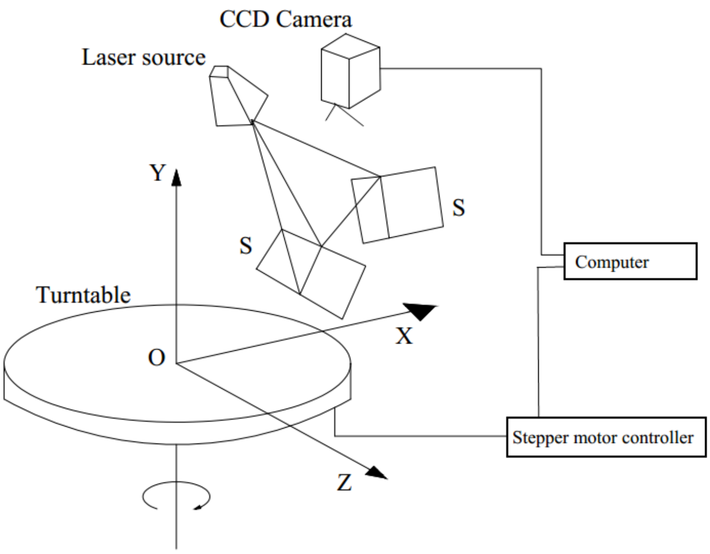

Fig.1 The composition of a three-dimensional laser scanner system

2.2. The working principle of three-dimensional laser scanning system

The three-dimensional laser scanner obtains the distance S from the scanning station to any target point on the surface of the object to be measured through the scanning system, and obtains the transverse scanning angle observation α and the longitudinal scanning angle observation θ of the instantaneous laser pulse measurement, and then obtains the laser angle. The three-dimensional coordinates of the point on the surface of the object:

$$\begin{cases} X = S\cos\theta\cos\alpha \\ Y = S\cos\theta\sin\alpha \\ Z = S\sin\theta \end{cases} \tag{1}$$

The internal coordinate system of the 3D laser scanner is shown in the Figure 2.

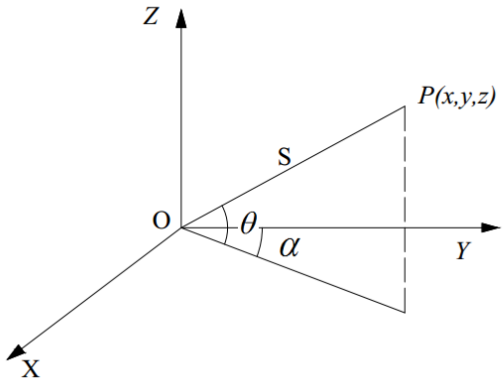

Fig.2 Three-dimensional laser scanner measurement principle

3. System controller and navigation system

3.1. System controller

The system controller controls the laser generator for distance measurement. After the laser generator generates the electrical signal, it starts to drive the optical scanning head. The controller reads the coded scanning angle and GPS time scale, and the data such as the angle and distance are uniformly formatted and recorded [6, 7].

3.2. IMU/GPS navigation system

IMU/GPS is an inertial measurement and GPS compound attitude measurement device mainly used in aviation, aerospace and navigation. The device can output spatial position and attitude data of various sensors such as laser radar and camera. Its core components include gyroscopes and accelerometers. The configuration of the gyroscope can both establish a reference coordinate system and measure the angular velocity of the carrier. Accelerometers are used to compare force measurements to determine carrier position, velocity, and tracking signals. Three gyroscopes and accelerometers can provide three axial angle and acceleration measurements at 200 Hz.

At present, the IMU is widely used abroad in satellite, aviation remote sensing and military fields. For example, IGI's IMU is used on German Leopard tanks. Through its positioning and orientation, a moving tank can launch artillery fire at any time. In addition, IMU has the advantages of sTable deviation and low noise, which can be widely applied to land-sea surveying, and can perform real-time positioning and navigation in the case of poor received signals.

The ultimate goal of adopting GPS/IMU integrated navigation technology is to provide high-accuracy position and attitude information for laser scanning systems. GPS positioning accuracy, the error does not accumulate over time; but the data update rate is low, cannot be output posture information, anti-interference ability is weak (prone to loss of signal lock phenomenon). Inertial measurement unit IMU can provide high data update rate can simultaneously provide information output such as attitude, position, speed, anti-interference ability; but measurement error continues to accumulate over time, that is, error drift. GPS/IMU integrated navigation technology can complement the advantages of GPS and IMU, give full play to the advantages of their respective sensors, and overcome their shortcomings, realizing real-time and high-precision navigation and positioning in the external environment and dynamic interference.

An IMU fixed to a mobile measurement device (such as an airplane, a ship, etc.) is mounted on a sensor stabilization platform. The platform is used to simulate the local horizontal plane and establish a rectangular coordinate system. When measuring the movement of the vehicle, the gyroscope is used to keep the platform tracked. In the local level, the three axes of the local coordinate system always point in the direction of east e, north n and zenith u. Accelerometers are installed on the three axes respectively, and the acceleration components are measured. The integral can be obtained with the speed components:

$$\begin{cases} v_e\left(t_k\right) = v_e\left(t_0\right) + \int_0^k a_e dt \\ v_n\left(t_k\right) = v_n\left(t_0\right) + \int_0^k a_n dt \\ v_u\left(t_k\right) = v_u\left(t_0\right) + \int_0^k a_u dt \end{cases} \tag{2}$$

Then integrate the speed to get the position of the carrier on the earth, expressed as latitude and longitude and height:

$$\begin{cases} \lambda = \lambda_0 + \int_0^k \dot{\lambda} dt \\ \varphi = \varphi_0 + \int_0^k \dot{\varphi} dt \\ h = h_0 + \int_0^k \dot{h} dt \end{cases} \tag{3}$$

In the formula, $\lambda_0, \varphi_0, h_0$ is the initial position of the carrier; $\dot{\lambda}, \dot{\varphi}, \dot{h}$ represents the time rate of change of latitude, longitude, and altitude, respectively, calculated from the speed of motion:

$$\begin{cases} \dot{\lambda} = \dfrac{v_e}{(N+h)\cos\varphi} \\ \dot{\varphi} = \dfrac{v_n}{M+h} \\ \dot{h} = v_u \end{cases} \tag{4}$$

Bring forward the formula to get the instantaneous position of the carrier:

$$\begin{cases} \lambda = \lambda_0 = \int_0^k \dfrac{v_e}{(N+h)\cos\varphi} dt \\ \varphi = \varphi_0 + \int_0^k \dfrac{v_n}{M+h} dt \\ h = h_0 + \int_0^k v_u dt \end{cases} \tag{5}$$

Among them, M is the radius of the meridian circle of the earth ellipsoid, and N is the radius of curvature of the earth's helix circle.

4. Data collecting and processing

The DTM obtained by the airborne three-dimensional laser scanner is a surface model containing ground features and canopy elevations. The surface model data is a set of discrete coordinates of an approximate rectangular ruled grid, generally a Gaussian projection in the WGS84 coordinate system, and the data can be directly used as a product. The data acquired by the three-dimensional laser scanning terrain is a large number of discrete lattice data with no attributes suspended in the air, which is vividly called “point cloud”.

1) From scanner coordinate system to inertial coordinate system

The translational component of the laser emission reference point (scanner coordinate system origin) relative to the geometric center of the inertial measurement unit is $\Delta x_0, \Delta y_0, \Delta z_0$ and the three deflection angles are defined as γ, β, α . By translating and rotating, the scanner coordinate system can be converted to the inertial coordinate system. As shown in Figure 3:

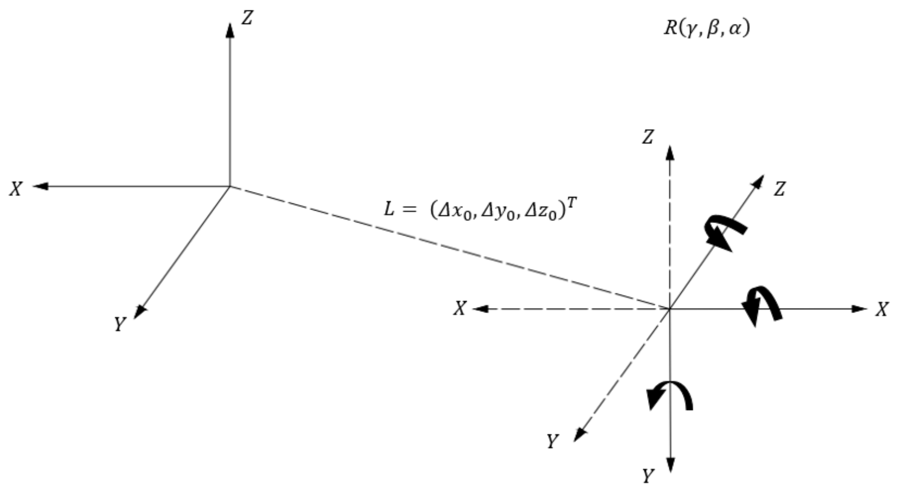

Fig.3 The chart of conversion of laser scanner coordinate system to IMU coordinate system

The conversion relationship between the laser points $(X_0 Y_0 Z_0)$ to coordinate $(X_I Y_I Z_I)$ in the inertial coordinate system of the scanner coordinate system is:

$$\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} = R(\gamma,\beta,\alpha) \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} + \begin{bmatrix} \Delta x_0 \\ \Delta y_0 \\ \Delta z_0 \end{bmatrix} \tag{6}$$

Where $R(\gamma,\beta,\alpha)$ is the rotation matrix $R(\gamma,\beta,\alpha) = R_\gamma \bullet R_\beta \bullet R_\alpha$

$$R_\alpha = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix} \quad R_\beta = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix} \quad R_\gamma = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{7}$$

2) Inertial coordinate system to local horizontal coordinate system

In the measurement process, the posture of the carrier is transformed in real time, so there is a dynamic eccentricity, and the dynamic eccentricity correction of the center of the GPS antenna relative to the inertial measurement unit is:

$$\begin{bmatrix} \Delta x_0 \\ \Delta y_0 \\ \Delta z_0 \end{bmatrix} = R(h,p,r) \begin{bmatrix} \Delta x_I^G \\ \Delta y_I^G \\ \Delta z_I^G \end{bmatrix} \tag{8}$$

Considering the dynamic eccentricity correction, the inertial coordinate system and the local horizontal coordinate system origin are overlapped by the translation, and then the real-time acquired attitude data can be used to convert the laser point cloud in the inertial navigation coordinate system to the local horizontal coordinate system.

The coordinate conversion relationship is:

$$\begin{bmatrix} X_{LLS} \\ Y_{LLS} \\ Z_{LLS} \end{bmatrix} = R(h,p,\mathrm{r}) \begin{bmatrix} X_I \\ Y_I \\ Z_I \end{bmatrix} + \begin{bmatrix} \Delta x_0 \\ \Delta y_0 \\ \Delta z_0 \end{bmatrix} \tag{9}$$

Where $R(h,p,r) = R_h \bullet R_p \bullet R_r$

$$R_r = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos r & -\sin r \\ 0 & \sin r & \cos r \end{bmatrix} \quad R_p = \begin{bmatrix} \cos p & 0 & \sin p \\ 0 & 1 & 0 \\ \sin p & 0 & \cos p \end{bmatrix} \quad R_h = \begin{bmatrix} \cosh & -\sinh & 0 \\ \sinh & \cosh & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{10}$$

3) Local horizontal coordinate system to WGS84 coordinate system

The WGS84 coordinate system is a geocentric spatial Cartesian coordinate system. During the conversion process, the GPS coordinates (B, L, H) of the center of the valley are required. The conversion model is as follows:

$$\begin{bmatrix} X_{WGS84} \\ Y_{WGS84} \\ Z_{WGS84} \end{bmatrix} = R_\gamma(B+90°) R_Z(L) \begin{bmatrix} X_{LLS} \\ Y_{LLS} \\ Z_{LLS} \end{bmatrix} + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \tag{11}$$

Where rotation matrix is:

$$R_\gamma(B+90°) = \begin{bmatrix} \cos(B+90°) & 0 & -\sin(B+90°) \\ 0 & 1 & 0 \\ \sin(B+90°) & 0 & \cos(B+90°) \end{bmatrix} \quad R_Z(L) = \begin{bmatrix} \cos L & \sin L & 0 \\ -\sin L & \cos L & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{12}$$

5. System integration

5.1 The overall structure

The application platform is designed with a mixed architecture of C/S and B/S. Among them, the engineering measurement subsystem and the security management service subsystem adopt the C/S architecture. Based on the Bentley Micro station V8 platform, it has been developed twice. The development language is MDL, VBA, and Del. Phi, C++, C#. The project management service subsystem adopts three-tier B/S architecture and the development languages are JSP and JAVA. Platform architecture and engineering measurement project management system architecture shown in Figure 4.

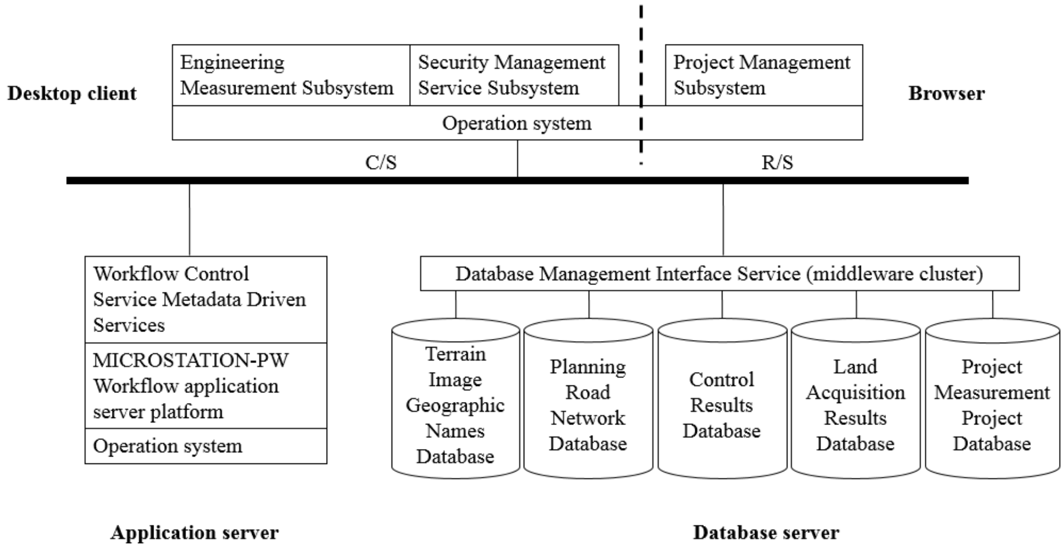

Fig.4 Platform architecture

5.2 System workflow

The scanning system operation process is divided into three parts: pre-planning, field data collection, and internal data processing; as shown in the figure 5:

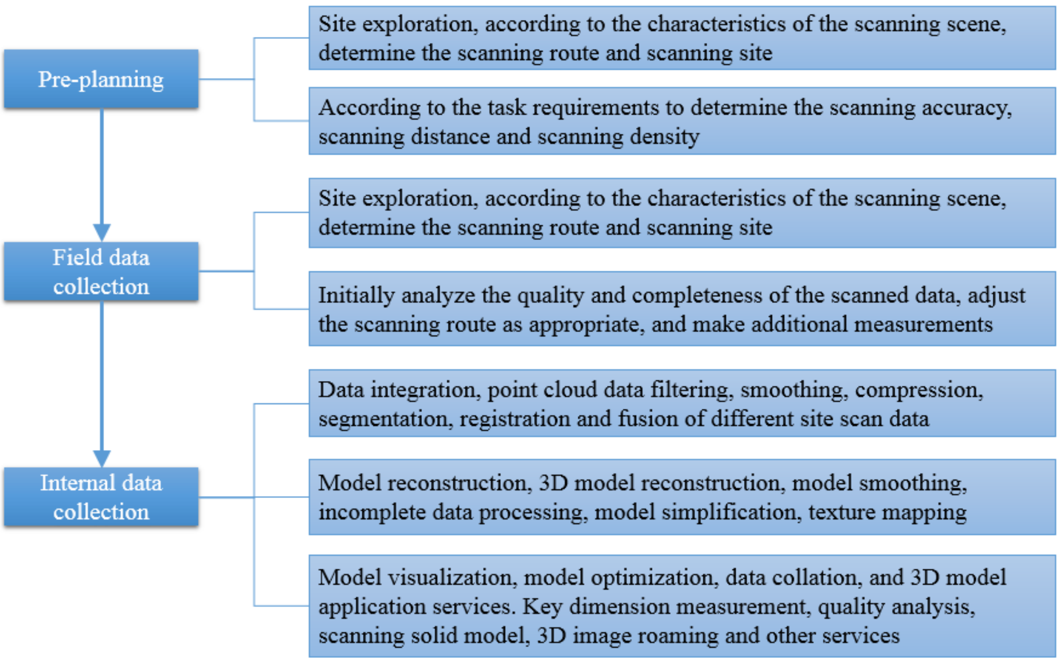

Fig.5 Ground 3D laser scanning system workflow

The pre-planning should be based on different mission requirements to carry out the mission implementation planning, complete the scanning environment, according to the measurement scene size, complexity and engineering accuracy requirements, determine the scanning route, determine the number of scanning stations and the distance from the scanning system to the scanning scene, determine the scanning density.

Field data collection should be based on pre-set scanning routes to set up the site for scanning and photographing. The on-site preliminary analysis of the quality of the data meets the requirements, ensuring that the amount of data collected is neither missing nor excessively redundant. Try to avoid unnecessary measurement of secondary measurements and data processing.

The internal data processing can be roughly divided into three stages: data integration, model reconstruction, and model visualization. Data integration provides reliable and selective point cloud data for model reconstruction, reduces the complexity of model reconstruction, and improves model reconstruction quality and work efficiency. The model reconstruction models the processed point cloud data, selects a reasonable data modelling method according to the modelling quality and characteristics of the scanning scene, and discriminates the rule surface and feature-rich multi-dimensional surface to improve the modelling accuracy and work efficiency. Visualization of the model optimizes the model and data collation, and provides 3D model application services according to user requirements. Such as key dimension measurement, quality analysis, feature line extraction, scanning solid model, 3D image roaming or other visual effects.

6. Conclusion

With the continuous improvement of hardware performance and data processing software capabilities of 3D laser scanners, scanning flexibility, effective distance, point accuracy, efficiency, and data usage have been greatly improved in the process of terrain scanning, making 3D the application of laser scanning technology to the integration of topographical surveys has become a reality.

This article has conducted in-depth research on the real-time integration technology of airborne three-dimensional laser scanning. This research is the application direction of new technologies for surveying and mapping. It has broad application prospects and a huge market space. Through this system, the overall design of the system and related modules the application research has established the framework of the engineering survey integration system, and has explained and improved the positioning and data processing in detail. In the future, 3D laser technology will be widely used in the field of surveying and mapping. Work efficiency will be further improved, equipment will be further miniaturized, data processing will be more rapid, and the quality of mapping will be further improved. There are still more issues in this area that deserve further discussion.

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