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Integrated Algorithm for Multi-Source Data Conversion of Rail Transit Digital Model Based on BIM+GIS

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ABSTRACT

Data formats, data structures and coordinate systems differ across data sources, hindering data conversion and integration. Therefore, a multi-source data conversion and integration algorithm of rail transit digital model based on BIM+GIS is proposed. Based on the B/S architecture of the Cesium open-source map engine, an integrated framework for rail transit digital multi-source data conversion, with BIM+GIS technology at its core, has been developed. In the data layer, tilt photogrammetry technology is employed to collect topographic data of rail transit, vector data is gathered through a tilt model and BIM data is generated in response to the demands of rail transit construction. The GIS model is constructed based on terrain data and vector data, while the BIM model is established using BIM data. The business logic layer handles and publishes multi-source data through BIM servers, GIS servers and other information databases. The transformation integration unit uses a spatial semantic integration algorithm to integrate data transformation from the BIM model into the GIS model, thereby achieving complete transformation and integration of BIM and GIS multi-source data in geometry, semantics and accuracy. Finally, the outcomes of multi-source data conversion and integration are presented to users via the presentation layer. Experiments show that the algorithm can effectively collect the terrain data of rail transit and establish a BIM model and GIS model. We transformed multisource data of an integrated rail transit digital model to improve its comprehensiveness, accuracy and reliability.

KEYWORDS

BIM model; GIS model; rail transit; digital model; multisource data; transformation integration.

1. INTRODUCTION

A digital model of rail transit, constructed in three dimensions, is capable of simulating a rail transit system [1]. This model, with data at its core, utilises digital technology to accurately and efficiently simulate and predict the entire lifecycle of rail transit [2]. The digital model of rail transit can include various components like tracks, subgrades, bridges, tunnels, stations and signal systems. These components can be simulated and optimised by digital technology, offering comprehensive digital support for the planning, design, construction, operation and maintenance of rail transit [3]. In the design of track, the digital model of rail transit can be combined with the three-dimensional (3D) graphics engine to create a 3D digital model of track.

This model not only describes track geometry with high precision but also simulates and predicts track electrical and mechanical characteristics through digital technology [4]. Generally speaking, the digital model of rail transit serves as a tool to comprehensively describe and simulate the rail transit system using digital technology, providing comprehensive digital support for the planning, design, construction, operation and maintenance of rail transit, thereby enhancing the working efficiency and accuracy of the rail transit system [5]. With the acceleration of urbanisation, rail transit systems have been widely adopted worldwide. These complex systems involve many fields, such as civil, electrical and communications engineering. Therefore, it is very important to integrate and share multi-source data in the process of planning and construction. However, because these data come from different sources and have different formats and standards, how to integrate and transform these data seamlessly is an important challenge.

In recent years, many scholars have studied the multi-source data integration algorithm. For example, Lovino et al. explored a multi-source data integration algorithm for multi-cluster samples. This algorithm employed machine learning and statistical techniques to integrate and analyse the similarities and differences among samples of various data types, utilising this information to construct a sample clustering model. Initially, the algorithm gathers sample data from multi-source rail transit data types; subsequently, the sample data is cleaned, standardised and missing values are filled to eliminate noise and outliers. Thereafter, the K-means clustering algorithm is applied to merge multiple datasets into a comprehensive dataset, thereby increasing both the number of samples and variables. The algorithm can integrate the information of various data types and improve the accuracy and stability of sample clustering. The disadvantage of this algorithm is that the dimension and unit differences between different data types may affect the accuracy of clustering results, and appropriate data pre-processing is needed. The efficiency and effectiveness of clustering algorithm are limited by computing resources and time, so it is necessary to optimise the algorithm to improve the efficiency [6]. Ferreira et al. investigated an ontology-based multi-source data integration algorithm. Initially, it is essential to define various entities within the digital model of urban rail transit and their relationships, a task that can be accomplished by establishing an ontology. This ontology can be written in a specific modelling language, such as the Web Ontology Language (OWL), and may include elements like classes, attributes and relationships. Subsequently, data is mapped from different entities to the ontology, allowing it to interpret the data, establish a connection between the data source and the target entity, and update the information in real time as needed. Then, the data is transformed to ensure a consistent format and protocol across all entities. Finally, the transformed data is stored in a unified database to complete the integration of multi-source data conversion. The algorithm boasts good interoperability, which makes it convenient for data sharing and application integration, and it can accommodate more entities and relationships to meet the evolving needs of the urban rail transit digital model. However, the modelling of this algorithm is complex, demanding significant manpower and material resources, and the data conversion is challenging [7]. Lipovetsky investigated a multi-source data integration algorithm based on mixOmics. Initially, the mixOmics pre-processed the multi-source data of the urban rail transit digital model, which includes steps such as data cleaning, standardisation and missing value filling. The PCA dimensionality reduction technology provided by the mixOmics was employed to reduce the dimensionality of the pre-processed multi-source data while retaining the most important information. Using the filtering feature selection algorithm provided by mixOmics, relevant features are selected and irrelevant or redundant ones are removed from the multi-source data after dimensionality reduction. By employing the boosting ensemble learning method provided by mixOmics, the multi-source data are integrated based on the possible correlation and dependence between the characteristics of the multi-source data. This algorithm effectively addresses high-dimensional and high-complexity issues in multi-source datasets, allowing users to better comprehend the structure and characteristics of the data and to complete multi-source data integration. However, in this algorithm, mixOmics primarily relies on the R language for operation, which may entail some learning costs for non-R users, and there are certain limitations in data pre-processing, such as additional work required for data format and special data processing [8]. Wu et al. acquired the original data of the rail transit digital model from multiple sources to ensure the diversity, accuracy and reliability of the data. The collected original multi-source data are cleaned, de-duplicated, standardised and filled with missing values to enhance the quality and consistency of the data. Subsequently, data from different sources are converted into a unified format and structure. The transformed data are integrated using a clustering algorithm to form a unified dataset. This algorithm effectively transforms and integrates multi-source data. However, it may increase the difficulty of data integration for different data formats, structures and semantics [9]. Aggoune et al. pre-processed each data source first, used clustering algorithm to fill the incomplete information, and used probability statistics algorithm to process the uncertain information. Then Apache NiFi was used to map data from different data sources to a common data model. After data mapping, Oracle GoldenGate needs to be used for data conversion and integration to realise interoperability among different data formats. This algorithm demonstrates the feasibility of multi-source data conversion and integration, but its data processing efficiency is low [10]. Biancardo et al. are committed to developing information models that are comprehensive, complete and easily modifiable. In the current available software environment, especially in mainland Europe and the Nordic region, the number of computational codes used by Trimble Novapoint is constantly increasing. Trimble Novapoint collaborates with Trimble Quadri to enhance the efficiency and availability of information sharing. In order to clearly demonstrate the limitations and advantages of Novapoint and Quadri, Italferr S.p.A. provided a detailed description of the development of the BIM model for the "Variant Villammare" railway section in the feasibility study of the Ogliastro-Sapri section. This description provides an important reference for evaluating the performance of the combination in practical applications. This method provides a detailed description of the BIM model development through actual projects, which can intuitively and realistically demonstrate the collaborative operation of Trimble Novapoint and Trimble Quadri in practical scenarios. However, the sample size is relatively limited, and the generalisability and extrapolation of research results are somewhat restricted [11]. Biancardo et al. believe that CBA-BIM is a combination of infrastructure and transportation planning, which involves stakeholder participation as a central planning activity aimed at reducing subjectivity in analysis. The motivation for integrating CBA with BIM is transparency, standardisation and automation of the decision-making process. In fact, from their alliance, the costs associated with stakeholder protests should be reduced, as these protests will not cause unnecessary delays to construction projects. This method demonstrates the application of the framework in BIM based design methods, taking the Naples Bari high-speed railway corridor currently under construction as an example. This method integrates CBA with BIM, aiming to reduce subjective analysis and achieve transparency, standardisation and automation of the decision-making process. However, in real-world projects, stakeholder demands are complex, diverse and constantly evolving, while external factors such as societal, cultural, and environmental influences can also have a significant impact on decision-making [12].

Building Information Model (BIM) and Geographic Information System (GIS) are two powerful tools that play a key role in rail transit planning and management. BIM can create a detailed building model containing rich information [13], such as physical characteristics, functional information and project flow. GIS provides a robust platform for collecting, storing, analysing and displaying geospatial data [14]. Combining BIM with GIS can provide more comprehensive and accurate data support for the digital model of rail transit [15] as well as enhance the fidelity of its three-dimensional digital model. Consequently, an integrated algorithm for multi-source data conversion of the rail transit digital model based on the BIM+GIS is proposed. The algorithm aims to achieve seamless conversion and integration of the BIM and GIS data from various sources and formats, thereby providing comprehensive data support for the establishment of the rail transit digital model. This algorithm not only resolves the issue of data integration and transformation between the BIM and GIS but also provides a new solution for the establishment of the rail transit digital model. It enhances the quality, accuracy and efficiency of data while reducing the error rate, which is of great significance to the planning, design and operation of rail transit.

2. RAIL TRANSIT DIGITAL MODEL MULTI-SOURCE DATA CONVERSION INTEGRATION

Due to the need to handle a large volume of complex and highly fragmented information, effective information communication and sharing are required at every stage of the urban rail transit's entire life cycle. A BIM model relies on lifecycle information management, providing advanced digital tools and an information sharing platform for project management [16]. In addition, it achieves coordinated management of model data at the object level and enhances project controllability. Secondly, varying geological environments, hydrological information and site conditions pose challenges for decision-making in urban rail transit construction. GIS offers a solution to these issues, with the management of large-scale geospatial data at its core [17]. It provides accurate geographic scene information and various spatial information data for urban rail transit projects, enabling the visual application and analysis of BIM in macro-3D GIS scenes, and assisting managers in making correct decisions from a macro and scientific perspective. The BIM model of urban rail transit encompasses numerous professional data, such as underground platforms, ancillary facilities, and mechanical and electrical equipment, whereas the GIS model integrates urban topography, rail transit routes and other data.

Aiming to address the development and demand of the Web platform, a Web-based multi-source data conversion and integration framework is constructed using the open-source Cesium map engine. A rail transit BIM model is built with Revit software, GIS terrain data is obtained through oblique photography technology, BIM model files are parsed and processed by BIMserver [18], and terrain data along with vector data are processed and published by Geoserver. The interface is developed using Vue as the front-end framework, enhanced with ElementUI and Cascading Style Sheets (CSS), and built with programming languages such as

HTML and JavaScript. The Web multi-source data conversion integration framework employs a Browser/Server (B/S) architecture design, facilitating easy development, maintenance, and upgrades.

The multi-source data conversion integration framework consists of three layers from bottom to top: a data acquisition layer, a business logic layer, and a display layer. This integration framework is illustrated in *Figure 1*.

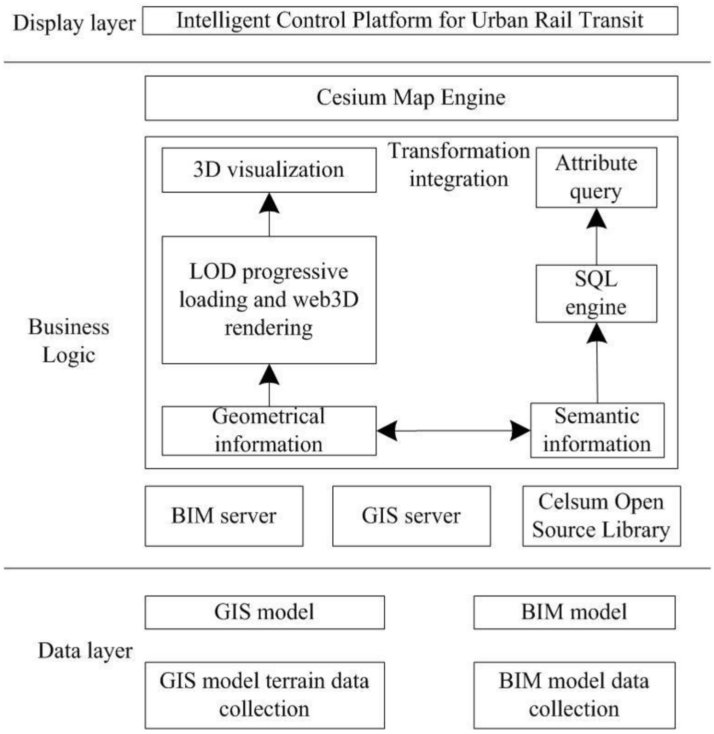

Figure 1 – Integration of multi-source data conversion for digital models of rail transit

As depicted in *Figure 1*, the data layer is tasked with collecting terrain data, vector data and BIM model data for the GIS model, with the terrain data being gathered using tilt photogrammetry technology. Based on the collected topographic and quantitative data, the GIS model for rail transit is established and the BIM model for rail transit is created according to the collected BIM model data [19]. The business logic layer facilitates the processing and publishing of various data through the BIM server, GIS server and other information databases, providing the interface between data and functional business for the display layer. It serves as the logical carrier for realising the entire transformation and integration framework, with its core being the multi-source data transformation and integration between the BIM model and the GIS model. The presentation layer, situated at the top level of the transformation integration framework, displays the results of multi-source data transformation integration and offers users an interactive operation interface.

2.1 Multi-source data collection and model construction of rail transit digital model

Rail transit terrain data collection and GIS model construction

The data layer uses tilt photogrammetry technology to capture topographic data for rail transit. The storage mode of aerial images corresponds to the layout of the Charge-Coupled Device (CCD) array in the camera sensors, maintaining the same direction. As a result, the images produces by the camera differ from the camera's attitude at the moment of exposure. In traditional photogrammetry, it is necessary to determine the camera's installation orientation through photographic flight record reports and manual observation images, followed by rotating the image at a corresponding angle. This approach often necessitates professional operation. Compared to traditional approximate vertical photogrammetry, tilt photogrammetry features a more complex sensor structure. The relative positions of tilt images must be accurately reconstructed from five perspectives at the same moment of exposure. Consequently, a transformation between the auxiliary coordinates of the navigation band space and the camera image coordinate system is established. This recovery forms the basis for efficient multi-view matching and control point measurement. Consequently, by ascertaining the installation orientation of the inclined digital aerial camera, images from other perspectives can be automatically rotated, thereby enhancing the accuracy of data collection regarding the influence of rail transit terrain [20].

The digital image of rail transit topography is a grayscale matrix, where each element of the matrix represents a grayscale value corresponding to a small area of an optical image or entity, known as a pixel. The image plane coordinate system is a rectangular coordinate system within the image plane, used to denote the position of an image point on the image plane. The origin of the image plane coordinate system is the image principal point. The x-axis aligns with the route direction, with the positive direction corresponding to the course direction, while the y-axis is perpendicular to the x-axis, forming a right-handed coordinate system.

The overlapping direction and size of the stereo image pair, composed of the front and rear images from the down-looking camera, will also vary with the different installation orientations of the inclined digital aerial camera. The initial installation position of the inclined digital aerial camera can be characterised by the overlapping direction and average parallax of the stereo image pair from the downward-looking image within the same band. When the installation orientation is 0° and the overlap direction is the same as the positive direction of X, the left and right parallax $dx > 0$. When the installation direction is 90° and the overlap direction is the same as the positive direction of Y, then $dy > 0$. When the installation orientation is 180° and the overlap direction is the same as the X negative direction, then $dx < 0$. When the installation orientation is 270° and the overlap direction is the same as the Y negative direction, then $dy < 0$.

Select any adjacent image from the downward-looking sequence of oblique aerial photography to form a stereo image, and use image matching to automatically measure the pixels with the same name. Since the overlapping direction of the stereo image is unknown, the traditional automatic image matching method cannot be directly adopted. To achieve rapid automatic measurement of the pixels with the same name on the stereo image and enhance calculation speed, an image matching method that combines the pyramid multi-channel image matching strategy with the Scale-Invariant Feature Transform (SIFT) operator is adopted.

Based on the photography direction, any adjacent images within the topographic sequence images of rail transit are selected to form a stereo image pair, and the pyramid images are layered accordingly to create a pyramid image. Due to the slow speed of the SIFT operator in image matching, SIFT feature extraction and feature matching are performed on the highest-level (minimum resolution) image of the pyramid to obtain the initial feature points with the same name. Using these as initial values, pyramid multi-channel image matching and least squares image matching are performed to extract at least six pairs of corresponding image points. To ensure the correctness of the extraction of image points with the same name, coplanar conditions in photogrammetry are employed to constrain the image points with the same name, and the RANdomSAmple Consensus (RANSAC) algorithm is used to eliminate erroneous image points with the same name. The calculation formula is as follows:

$$\begin{cases} d_x = \frac{\sum_{i=0}^{n-1} x_i' - \sum_{i=0}^{n-1} x_i}{n} \\ d_y = \frac{\sum_{i=0}^{n-1} y_i' - \sum_{i=0}^{n-1} y_i}{n} \end{cases} \tag{1}$$

Among them, n is the logarithm of pixel points with the same name. d_x, d_y are the parallax of direction x, y, respectively. Two image points with the same name i have horizontal and vertical coordinates denoted as x_i, x_i' and y_i, y_i', respectively.

Based on the calculation, the stereo images of rail transit terrain provide horizontal and vertical parallaxes x and y (d_x, d_y). The dominant parallax direction determines the overlapping direction of the 3D image pairs: if $|d_x| > |d_y|$, the overlap aligns with the image's x-axis; otherwise, it aligns with the y-axis. Based on the aforementioned interpretation criteria and the calculated average parallax value, the installation orientation of the camera can be automatically determined, which is described in four scenarios: 0°, 90°, 180°, and 270° respectively. The specific judgment conditions are as follows:

When $|d_x| > |d_y|$ and $dx > 0$, the camera installation orientation is 0°.

When $|d_x| > |d_y||$ and $dx < 0$, the camera installation orientation is 180°.

When $|d_x| < |d_y||$ and $dx > 0$, the camera installation orientation is 90°.

When $|d_x| < |d_y|$ and $dx < 0$, the installation orientation of the camera is 270°.

Once the installation orientation of the downward view is determined, the rotation angle of each view image can be established according to the corresponding relationship. After ascertaining the automatic rotation direction of cameras at each view angle, the topographic images of rail transit can be captured based on the set image control points. Upon completion of the image acquisition, the relative position coordinates of the side-looking lens and the down-looking lens are obtained through the automatic matching of the inclined images of rail transit terrain. Control points are then added to adjust the overall regional network, thereby achieving the absolute position acquisition of the inclined images, i.e. three-dimensional encryption.

Applying a mask to resize the rail transit topographic image enhances the success rate and accuracy of its aerial 3D calculations. The mask is created using two colours: pixels corresponding to areas excluded from the operation are filled with black, while those included are filled with white. If the mask is intended for all images within a certain folder, the mask and the topographic images of rail transit should be placed in the same folder and named as 'mask.tif'. Upon loading the topographic image of rail transit, the mask will become effective, thus setting up the mask.

The photographic scale is defined based on the traditional vertical image. In areas where the terrain fluctuates slightly, it is considered that the distance between the camera exposure point and the ground is the same, and the resolution of the rail transit terrain image obtained in this way is also considered the same. The relationship between the resolution of rail transit topographical image and altitude is as follows:

$$G = \frac{\theta * h}{f} \tag{2}$$

Among them, θ is the camera single pixel size, h is the relative height, f is the camera focal length.

Combining with the rotation angle of the main optical axis of the tilt camera, the approximate resolution of the centre point, as well as the closest and farthest points of the tilt image, can be obtained. Let the resolutions of the centre point, the near point and the far point of the oblique image be G_{mid}, G_{top}, G_{hot}, the calculation formula is as follows:

$$\begin{aligned} G_{mid} &= \frac{\theta * h}{f \cos \omega} \\ G_{top} &= \frac{\theta * h * \cos \alpha}{f \cos(\omega - \alpha)} \\ G_{hot} &= \frac{\theta * h * \cos \alpha}{f \cos(\omega + \alpha)} \end{aligned} \tag{3}$$

Among them, ω is the inclination angle and α is half the field of view.

Through the above formula, it can be concluded that the resolution of the topographic image of rail transit is related to the inclination of the camera, in addition to the flying height, focal length and pixel size. The greater the inclination angle, the lower the resolution of the far point and the greater the difference between the topographic images of the near point and the far point. At the edge of the image, due to large deformation and significant resolution differences, it is difficult to perform three-dimensional space calculations, resulting in a low success rate. Therefore, by adjusting the image frame size or the effective image range participating in the operation, the success rate of three-dimensional space calculations can be improved.

After the completion of the three-dimensional solution, the output is Ordnance Survey Great Britain (OSGB) data format, and in order to improve the loading speed of tilt model data, the acquisition software usually establishes an index structure. Therefore, the OSGB data format is converted into data index structure data that can be recognised by the acquisition software.

After importing the 3D spatial results and rail transit vector data into ContextCapture software, the external orientation elements and matching points of all images are obtained. Using the triangular relationships between images derived from the 3D data, a Triangulated Irregular Network (TIN) can then be constructed. The triangular TIN is used to create the white model, onto which the image texture is mapped to build the rail transit GIS model.

Rail transit digital BIM data collection and BIM model construction

The data layer generates BIM data based on the requirements of rail transit construction. To facilitate interdisciplinary collaboration, the rail transit model is divided into modules and modelled, then combined according to the functional, spatial and connection relationships of each module to construct a comprehensive rail transit BIM model [21]. Since it involves multi-discipline collaborative communication and data sharing, and there are differences in data formats, BIM models are difficult to share and integrate across disciplines. In order to realise the collaborative management of various professional models, BIM models need to be converted into a unified format.

Industry Foundation Classes (IFC) is an open data standard proposed by Building SMART for BIM applications, which provides a clear semantic information structure and lays a foundation for the interactive sharing of BIM models. After the BIM model is exported as an IFC format file, the IFC file is processed through the IFCEngine parsing layer in the BIM server, and the model is split according to the attribute category of the component. The IFC file managed and parsed by the BIMserver cannot be directly loaded and has to be converted into 3D Tiles format. The conversion from IFC to 3D Tiles includes four key steps: parsing IFC format file by class, exporting IFC format file to Object (OBJ) format file, converting OBJ format file to Graphics Language Transmission Format (glTF) format file and adding semantic information data to the glTF format file to get the 3D Tiles format file.

BIMserver processes the IFC model by categorising it into building component types (such as walls, doors, columns, stairs, windows, etc.) and generates both IFC model files and JavaScript Object Notation (JSON) semantic files. IFC model files store the geometric shape of the model, while JSON files store the associated attribute information. The conversion of IFC files into OBJ format files leads to the loss of attribute information of model components. However, decomposing the IFC file into components can retain the attribute information of each component. IFCOpenShell is the key open source software library for the BIMserver to parse IFC, and it also provides a framework for converting IFC format files into OBJ format files. Based on the IFCOpenShell framework, the IFCConvert Tool is used to obtain the OBJ format files and mtl material information files of each component.

GlTF is a transit format file for efficient rendering. It is consistent with WebGL rendering, thus being compatible with the WebGL platform. The glTF format file is a JSON text that describes the structure and data configuration of the entire 3D scene, while the binary (bin) file primarily stores fundamental geometry data, such as vertices, materials and external normal vectors. Use OBJ2glTF tool to convert OBJ file into glTF file. The glTF format file supports loading and 3D visualisation of BIM models; however, it does not support querying or reading model component attributes, nor Level of Detail (LOD) loading to reduce client hardware requirements. Therefore, it is necessary to further convert the glTF file into the 3D Tiles format. The 3DTiles format file consists of the JSON format tile set organisation file and the model file corresponding to organisation node. The tile organisation file mainly describes the spatial distribution and Level of Detail (LOD) division of tiles, while the model file determines the displayed objects. The Batched 3D Model (B3dm) is the most versatile and commonly used tile data type in 3D Tiles model files. It consists of a FileHead, a FeatureTable that records rendering-related data, a BatchTable that stores attribute-related data and a Graphics Language Binary (glb) containing the model data. The glb file is a binary glTF format file. Use the open-source program 3D-Tiles-Validator to merge the glTF format file and JSON semantic file into a b3dm format file.

The rail transit BIM model is constructed using Revit software and includes various models such as the pile structure for maintenance, shield, bridge, station structure and tunnel models. The modelling process in Revit involves several steps: first, using the software's Copy and Monitor functions to create the shaft network; then establishing elevation by drawing lines and selecting points; next, creating various equipment components and placing them in their designated positions; and finally, generating the complete BIM model of the rail transit system [22].

2.2 Realisation of multi-source data conversion integration of rail transit digital model

The business logic layer transforms the coordinates of the rail transit BIM model constructed by the data layer into the rail transit GIS model through the spatial semantic integration algorithm, and converts the attribute information of the BIM model into the corresponding attribute types of the GIS model according to the semantic information, thus completing the multi-source data transformation and integration of the rail transit digital model.

The position information of the object within the rail transit BIM model is recorded in ObjectPlacement. PlacementRelTo refers to the local coordinate system that describes the position, whereas RelativePlacement records the position within the local coordinate system and establishes a new local coordinate system. Location represents the origin coordinate, Axis and RefDirection represent the Z and X axis orientations of the new local coordinate frame, respectively.

Hypothetical point Q the coordinates in the local coordinate system and the world coordinate system are (x_1, y_1, z_1) and (x_2, y_2, z_2), respectively; the origin coordinates of the local coordinate system are $Q_r(a_0, b_0, c_0)$. The vectors along the three coordinate axes can be expressed as $X_r(a_1, b_1, c_1)$, $Y_r(a_2, b_2, c_2)$ and $Z_r(a_3, b_3, c_3)$. The transformation matrix Ψ is then constructed using these vectors:

$$\Psi=\begin{bmatrix}X_r & 0\\ Y_r & 0\\ Z_r & 0\\ P_r & 0\end{bmatrix}=\begin{bmatrix}a_1 & b_1 & c_1 & 0\\ a_2 & b_2 & c_2 & 0\\ a_3 & b_3 & c_3 & 0\\ a_0 & b_0 & c_0 & 0\end{bmatrix} \tag{4}$$

Global coordinates can be obtained by *Formula (5)*, namely:

$$[x_2 \quad y_2 \quad z_2 \quad 1]=[x_1 \quad y_1 \quad z_1 \quad 1]\times\Psi \tag{5}$$

Equation (5) completes the transformation from local coordinates to absolute coordinates.

The geodetic coordinate system will produce different projection coordinate systems through different projection methods. Here, the Mercator projection – commonly used in GIS – is taken as an example to illustrate the conversion method from the rectangular coordinate system to the geodetic coordinate system:

Step 1: Extract the geodetic coordinate (L,B,H) of the geographic reference point, and use the Mercator projection forward solution formula to convert the geodetic coordinate into the spatial Cartesian coordinate (X_E,Y_N,H). The plane Cartesian coordinates of the Mercator projection are X-axis in the east-west direction (east is positive) and Y-axis in the north-south direction (north is positive), calculated as follows:

$$\begin{gathered}X_E=\frac{d_1^2/d_2}{\sqrt{1+e'\times\cos^2(B_0)}}\times\cos(B_0)(L-L_0)\\ Y_N=\frac{d_1^2/d_2}{\sqrt{1+e'\times\cos^2(B_0)}}\times\cos(B_0)\ln\left[tg\left(\frac{4}{\pi}+\frac{B}{2}\right)\times\left(\frac{1-e\sin B}{1+e\sin B}\right)^{\frac{e}{2}}\right]\end{gathered} \tag{6}$$

where d_1 is the long semi-axis of ellipsoid, d_2 is an ellipsoid short semi-axis, e is the first eccentric heart rate, e' is the second eccentricity, B_0 is the standard latitude and L_0 is the longitude of the origin.

Step 2: The transformation matrix of IfcSite derived from *Equation (4)* effectively aligns the X and Y axes with true east and true north, matching the orientation of the projection coordinate system. Therefore, only a translation relative to the geographic reference point is needed. The resulting transformation matrix from IfcSite to geodetic rectangular coordinates, denoted as $\widehat{\Psi}$, is:

$$\widehat{\Psi}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ X_E & Y_N & H & 1\end{bmatrix} \tag{7}$$

Then, the rectangular coordinates of the BIM object based on the large ground can be obtained by *Equation (5)*.

Step 3: Transform the rectangular coordinates of geographical space into geodetic coordinates by using the inverse solution formula of Mercator projection, specifically:

$$\begin{gathered}L=\frac{X_E}{\frac{d_1^2/d_2}{\sqrt{1+e'\times cos^2(B_0)}}\times cos(B_0)}+L_0\\ B=\frac{\pi}{2}-2arctg\left(EXP\left(-\frac{Y_N}{\frac{d_1^2/d_2}{\sqrt{1+e'\times cos^2(B_0)}}\times cos(B_0)}\right)\times EXP^{\frac{e}{2}\ln\left(\frac{1-e\,sin\,B}{1+esin\,B}\right)}\right)\end{gathered} \tag{8}$$

Among them, EXP is the base of natural logarithm.

Through the above operations, the coordinates of the rail transit BIM model can be transformed into the rail transit GIS model, while the attribute information of the BIM model can be transformed into the corresponding attribute types of the GIS model by using the spatial semantic integration algorithm to complete the multi-source data transformation and integration of the rail transit digital model.

The spatial semantic integration algorithm maps the entity elements from the BIM model to the GIS model.

The GIS model categorises attribute information into two types: entity attribute and relationship attribute. Entity attributes primarily refer to the attributes based on the object itself, such as the material, volume, fire rating of rail transit components, equipment model, energy consumption, and so on. On the other hand, the related thematic attribute set, known as PropertySet, can be customised according to actual needs. Relationship attribute refers to the relationship between entities, such as spatial inclusion and connection, connection between pipelines and equipment, and so on. The basic attributes of objects in the GIS are mainly recorded by genericAttribute, with no specific attribute classification and limited content. The BIM model contains a wealth of attribute information, but its internally defined data hierarchy is deep and redundant. Therefore, it is necessary to map the attribute information of the BIM model to the corresponding attribute types of the GIS model individually.

3. EXPERIMENTAL ANALYSIS

A railway station within the rail transit system is selected as the experimental subject. The station features a layout where passengers enter at ground level, wait on an elevated platform, and depart via an underground level, incorporating a user-friendly design that separates pedestrians and vehicular traffic. The station includes six floors, namely, the subway floor, the exit floor, the plaza floor and the platform floor, arranged from the lowest to the highest. The station features 26 arrival and departure lines, 12 platforms and an unspecified number of tables. The main design of the station is inspired by its profound history and culture, creating a stable and generous appearance with its solid wall design, symbolising "the thoroughfare of eight roads and the door to access." The waiting hall is spacious and well-ventilated, offering a comfortable environment for passengers. The station has a total floor area of 10,675 square meters follows an unspecified line-side-down configuration. The station building stands 19 meters tall and covers a floor area of 5,998 square meters. The station yard comprises two groups of six lines.

In this paper, the TOPDC-5 manufactured in China is used to collect the topographic data of the rail transit. A total of 33 topographic images of the rail transit are collected. The inclined digital aerial cameras are numbered A, B, C, D and E. These cameras are composed of high-resolution large-format digital cameras, arranged in a Maltese cross formation, with E located directly below the centre of the Unmanned Aerial Vehicle (UAV) platform.

The focal length of the camera with a downward-facing lens (orthographic lens) is approximately 47mm, and that of the other four inclined cameras is approximately 80 mm. Among these, six oblique images are captured from the front, back, left, and right directions, along with nine vertical images. In total, 33 overlapping images provide full coverage of a designated rail transit area. An example of a topographic image of the rail transit is shown in *Figure 2*.

Figure 2 – Results of terrain image acquisition for rail transit

Figure 2 demonstrates that the proposed algorithm successfully captures clear topographic images of rail transit. This indicates that our algorithm can effectively capture detailed terrain and surface information, providing high-quality raw data for subsequent research on multi-source data conversion and integration of the rail transit digital model. As can also be seen from *Figure 2*, the image quality produced by this algorithm is stable. This means that regardless of how the terrain changes, our algorithm can effectively process and produce image data with consistent quality. This is crucial, because in practical application, the terrain conditions are often complex and changeable, so the algorithm needs to be highly adaptable and stable. Therefore, it can be concluded that our algorithm excels in collecting topographic images of rail transit, and the collected images have high definition and stable quality.

Using this method, the rotation direction of each inclined digital aerial camera is automatically determined, and the automatic determination results are shown in *Table 1*, using the first 10 collected images as an example.

Table 1 – Automatic determination results of rotation direction for each tilt digital aerial camera

Image number	X-direction overlap	Y-direction overlap	E Image clockwise rotation angle/°	A Image clockwise rotation angle/°	B Image clockwise rotation angle/°	C Image clockwise rotation angle/°	D Image clockwise rotation angle/°
1	0.1447	0.634	180	90	0	270	180
2	0.1225	0.612	180	90	0	270	180
3	-0.031	0.634	180	90	0	270	180
4	-0.043	0.656	180	90	0	270	180
5	0.124	0.713	180	90	0	270	180
6	0.102	0.691	180	90	0	270	180
7	-0.005	0.669	180	90	0	270	180
8	-0.003	0.647	180	90	0	270	180
9	0.0016	0.732	180	90	0	270	180
10	0.0014	0.711	180	90	0	270	180

According to *Table 1*, it can be concluded that the algorithm in this paper demonstrates remarkable effectiveness in automatically determining the rotation direction of each inclined digital aerial camera, which is conducive to improving the comprehensiveness and image acquisition quality of rail transit terrain image acquisition. During the use of tilt digital aerial cameras, each aerial camera may rotate to varying degrees, which will affect the comprehensiveness and quality of terrain image acquisition. If the rotation direction of each aerial camera is not determined correctly, it may lead to distortion, dislocation or gaps in the collected images, thus affecting the comprehensiveness and quality of image collection. The algorithm proposed in this paper can accurately and automatically determine the rotation direction of each inclined digital aerial camera, enabling precise image mosaicking and enhancing the construction accuracy of the rail transit GIS model. This not only reduces human intervention and errors, but also improves the efficiency and accuracy of stitching, and further enhances the comprehensiveness and quality of rail transit topographic image acquisition. Therefore, it can be concluded that the algorithm in this paper achieves comprehensive terrain information collection by effectively and automatically determining the rotation direction of each inclined digital aerial camera, which provides strong support for improving the comprehensiveness and quality of terrain image collection for rail.

Utilising this algorithm, the collected images are subjected to spatial encryption, and the distribution of image points before and after the improvement of this algorithm is analysed. The analysis results are shown in *Figure 3*.

(a) *(b)*

Figure 3 – Image point distribution before and after algorithm improvement in this article: a) Before improvement; b) After improvement

As can be seen from *Figure 3*, before the improvement of the algorithm, the distribution of image points is dense and the number of matching points is large, which cannot effectively filter out some unnecessary matching points, resulting in low calculation efficiency and accuracy. After the improvement by setting the mask, the number of matching points is significantly reduced, and the matching points are mainly concentrated in the rail transit area. This improved strategy significantly enhances the accuracy of matching points by retaining only those located within the rail transit area, while filtering out points from unrelated regions. At the same time, reducing the number of matching points improves matching efficiency by decreasing the volume of data the computer needs to process. These improvements contribute to an improved solution of the three-dimensional space, as more accurate and efficient selection of matching points can provide more reliable constraints, allowing the three-dimensional space solution algorithm to determine the position and attitude of the camera more accurately. This is significant for the subsequent construction of the rail transit GIS model.

The BIM model of rail transit is constructed by using the algorithm in this paper, and the construction results of some BIM models of rail transit are shown in *Figure 4*.

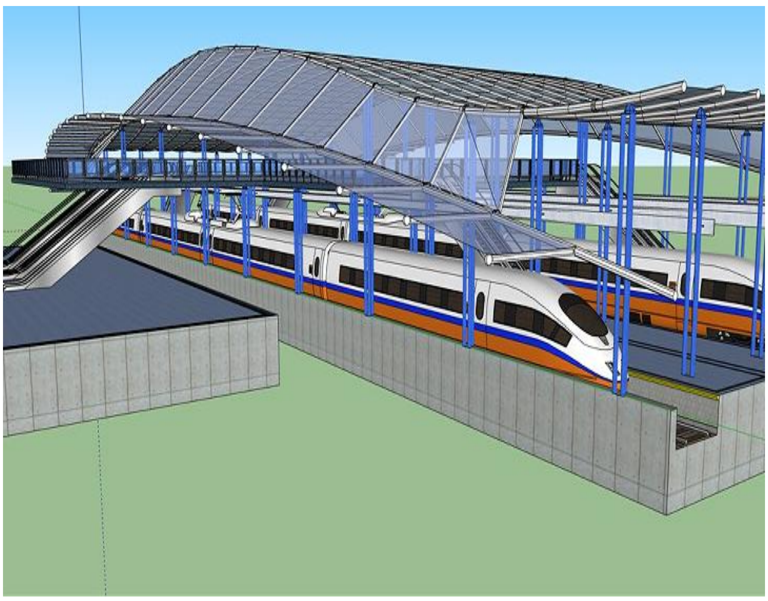

Figure 4 – Construction results of BIM model for partial rail transit

As can be seen from *Figure 4*, the studied algorithm can effectively construct the rail transit BIM model according to the data required by the BIM model, which includes a wealth of detailed information. This ability allows the BIM model to reflect the actual situation of rail transit buildings in more detail, thus better supporting architectural design and construction. However, it is important to note that although the BIM model has a high degree of detail and fidelity, it still cannot fully simulate all the complex factors in the real world. For example, the BIM model cannot simulate the natural environment, weather changes and human behaviour in the real world. This limitation does not stem from technical flaws in the BIM model itself, but rather from the complexity and uncertainty of the influencing factors, which go beyond the descriptive scope of the BIM model. Nevertheless, the BIM model still provides very valuable information and assistance for the design and construction of rail transit buildings. When applying the BIM model, it is important to be aware of its limitations and to combine other tools and methods to better meet the challenges of the real world.

Using the algorithm in this paper, a rail transit GIS model is constructed. *Figure 5* illustrates the construction results of selected rail transit GIS models.

Figure 5 – Construction results of rail transit GIS model

According to *Figure 5*, it is evident that the studied algorithm can effectively construct the rail transit GIS model based on the collected terrain data and vector data. This model can effectively present natural factors such as terrain and traffic, demonstrating that the algorithm can handle and express geographic information well. However, the GIS model has limitations in presenting the detailed information of rail transit building structures. This is because the GIS model is mainly designed for processing and expressing geographic information, not specifically tailored for the design of building structures. Although the GIS model can provide rich terrain and traffic information, it may lack the capability to express the complexity and details of building structures. Therefore, when constructing the rail transit GIS model, it is essential to acknowledge its limitations and consider integrating it with other tools and technologies to more effectively represent and present detailed information about rail transit building structures. For example, integrating the BIM model can leverage its strengths in building structure modelling to enhance the GIS model's ability to represent and visualise rail transit building structures more effectively. Generally speaking, while the GIS model excels in expressing and presenting natural factors such as topography and traffic, it may be limited in expressing and presenting detailed information of rail transit building structures. Therefore, when applying the GIS model, it is essential to understand both its strengths and limitations, and to consider integrating it with other technologies and methods to better address practical needs.

Using the algorithm proposed in this paper, the rail transit digital model constructed through BIM and GIS is transformed and integrated with multi-source data. The resulting model, after multi-source data transformation and integration, is illustrated in *Figure 6*.

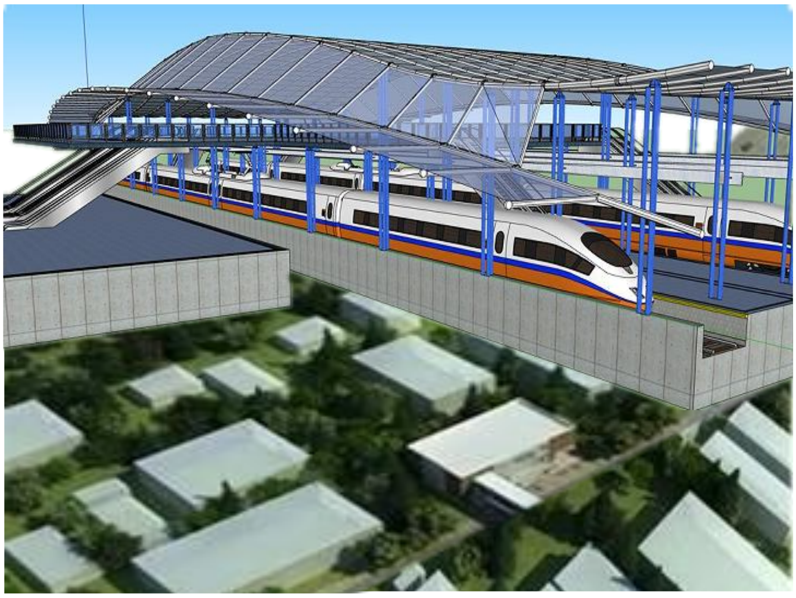

Figure 6 – Digital model of rail transit after multi-source data conversion and integration

As shown in *Figure 6*, the proposed algorithm effectively facilitates the conversion and integration of multi-source data within the rail transit digital model. After conversion and integration, this digital model contains both topographic data and detailed information on the rail transit building structure. This method of multi-source data conversion and integration fully leverages the advantages of the GIS model and BIM model. The GIS model has a strong capability for processing and expressing geographic information, while the BIM model offers high precision and detailed expression in building structure modelling. By transforming and integrating the data from these two models, a comprehensive digital model containing both geographical information and building structure information can be obtained. This digital model can be widely used in various applications of rail transit, such as planning, design, construction, operations and maintenance. In the planning stage, terrain analysis and planning scheme comparison can be carried out using the digital model, which provides a scientific basis for planning. In the design stage, the digital model can be used for detailed design and simulation to enhance the precision and quality of the design. In the construction and operations stage, the digital model can be used to facilitate construction organisation, operational management and emergency planning, thereby improving the efficiency and quality of construction and operations. In the maintenance stage, the digital model can be used to monitor, evaluate and predict the state, identify and address issues promptly, and prolong the service life of rail transit. To sum up, a comprehensive, accurate and reliable digital model of rail transit can be obtained through the multi-source data conversion and integration achieved by the studied algorithm, which fully leverages the advantages of the GIS model and BIM model and provides strong support for the development and application of rail transit.

In order to fully verify the effectiveness of the proposed BIM+GIS based data transformation integration algorithm, the consistency coefficient of the transformed integrated data was used as an indicator to compare it with the multi-source data integration algorithm based on multi omics sample clustering and the ontology based multi-source data integration algorithm.

The digital model of rail transit involves a large amount of multi-source data, and the conversion and integration process is complex, which can easily lead to data inconsistency problems. By conducting data consistency testing, the stability of the algorithm can be comprehensively evaluated. Multiple test results can reflect whether the algorithm can effectively ensure data consistency during each run, timely detect occasional errors or deviations, provide a basis for algorithm optimisation, ensure the accuracy and reliability of the final digital model and meet the high standard requirements of rail transit planning, construction and operation. The data consistency coefficient results of the three algorithms are shown in *Figure 7*.

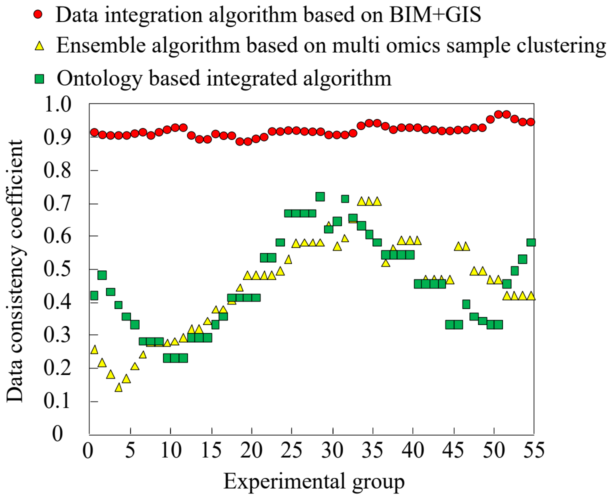

Figure 7 – Results of data consistency coefficient

Figure 7 shows the data consistency coefficient results of different ensemble algorithms. Among them, the integrated algorithm based on the BIM+GIS exhibits high data consistency, with coefficient values remaining stable at around 0.9. This indicates that the algorithm maintains good stability and reliability in data processing. In contrast, the data consistency coefficient results of ensemble algorithms based on multi omics sample clustering and ontology-based ensemble algorithms show significant fluctuations and poor stability. It is particularly noteworthy that the maximum data consistency coefficient of these two comparison algorithms did not exceed 0.8, further highlighting the significant advantage of BIM+GIS integration algorithm in data consistency. The main reason why this article has achieved significant results in the development of a digital multi-source data conversion and integration framework for rail transit with the BIM+GIS technology at the core is its innovative combination of the powerful functions of the Cesium open-source map engine and deep integration of BIM+GIS technology. The Cesium engine not only provides efficient 3D geographic information rendering capabilities, enabling precise presentation of complex rail transit scenes, but also achieves cloud processing and rapid publishing of multi-source data through its B/S architecture support. This technological choice greatly promotes the application of oblique photogrammetry technology in the data layer, ensuring high-precision collection of terrain and vector data, and laying a solid foundation for the precise construction of BIM and GIS models. At the same time, the compatibility of Cesium engine also provides flexible and powerful technical support for multi-source data processing and publishing in the business logic layer, as well as the implementation of spatial semantic integration algorithms in the transformation integration unit, thus achieving seamless integration and efficient integration of BIM and GIS data in geometry, semantics and accuracy.

4. CONCLUSION

Although BIM and GIS technologies are widely applied in many fields their implementation in rail transit engineering still faces certain challenges. To address these challenges, this paper proposes an integration algorithm for multi-source data conversion of the rail transit digital model based on BIM and GIS. This algorithm effectively integrates BIM and GIS data, facilitating coordinated management across various disciplines within rail transit engineering. The algorithm transforms BIM models and GIS data from various formats and data structures into a unified format and data structure for integration. Integrating the converted BIM models with GIS data generates a digital model including terrain data and rail transit building structure data. Using the Cesium map engine to visually display the digital model, the terrain, building structure and other information of rail transit engineering can be intuitively displayed. The experimental results demonstrate that the algorithm effectively accomplishes multi-source data conversion and integration of rail transit BIM and GIS, with the resulting digital model intuitively displaying information such as topography and building structures. This can provide a reference for solving the coordination difficulties in rail transit engineering and improve the construction and management level of rail transit engineering. Although algorithms have achieved significant results in data transformation and integration, their computational efficiency and resource consumption still need to be further optimised when processing large-scale data. With the continuous development of technology, new data formats and standards may emerge, so algorithms need to have a certain degree of scalability and flexibility to adapt to future technological changes.

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