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RESEARCH ARTICLE

Enhanced Combined Techniques for Interval-Valued Intuitionistic Fuzzy Multiple-Attribute Group Decision-Making and Applications to Quality Evaluation of Large-Scale Multi-View 3D Reconstruction

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ABSTRACT With the widespread application of computer vision in many fields, quickly and accurately obtaining the three-dimensional information covered by the target object has become a concern in the field of vision research. Large scale multi view Iterative reconstruction refers to obtaining multiple images of the target object through the camera, then obtaining the corresponding relationship between points and spatial mapping relationship between each image through the pixel information on the image, and then obtaining the 3D information of the target object through the relationship between points and space, finally completing the multi view Iterative reconstruction of the target object. Multi view Iterative reconstruction has a wide range of applications, and has very important applications in medical treatment, industrial detection, space technology, etc. Compared with binocular or multi camera stereo vision, monocular stereo vision has obvious advantages in terms of cost, structure and the way to obtain pictures. Multi view Iterative reconstruction of objects can be completed by processing multiple images to achieve the effect of multi camera stereo vision. The quality evaluation of large-scale multi-view 3D reconstruction is the MAGDM. Recently, the TODIM and EDAS technique has been employed to manage MAGDM. The interval-valued intuitionistic fuzzy sets (IVIFSs) are employed as a useful tool for portraying uncertain information during the quality evaluation of large-scale multi-view 3D reconstruction. In this paper, the interval-valued intuitionistic fuzzy TODIM-EDAS (IVIF-TODIM-EDAS) technique is built to manage the MAGDM under IVIFSs. At last, the numerical example for quality evaluation of large-scale multi-view 3D reconstruction is employed to show the IVIF-TODIM-EDAS decision technique. The main contribution of this paper is outlined: (1) the TODIM technique based on EDAS has been extended to IVIFSs based on Entropy technique; (2) the Entropy technique is employed to manage weight based on score values under IVIFSs. (3) the IVIF-TODIM-EDAS technique is founded to manage the MAGDM under IVIFSs; (4) a numerical example for quality evaluation of large-scale multi-view 3D reconstruction and some comparative analysis is supplied to verify the proposed technique.

INDEX TERMS Multiple-attribute group decision-making (MAGDM), interval-valued intuitionistic fuzzy sets (IVIFSs), TODIM technique, EDAS technique, large-scale multi-view 3D reconstruction.

I. INTRODUCTION

In recent years, with the continuous development of photography equipment and graphic image technology, the collection

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of digital images has become increasingly convenient [1], [2], [3]. The goal of multi view Iterative reconstruction is to obtain the 3D model of an object or scene by calculating the 2D digital image taken from multiple angles, and then digitally save it. It is an important research issue in photogrammetry and computer vision [4], [5], [6]. Multi view Iterative reconstruction technology has a wide range of applications in cultural relics protection, urban planning, remote sensing measurement and other fields. These applications require rapid and accurate 3D digitization of real scenes to meet huge field needs. The methods for reconstructing 3D models can usually be divided into active and passive methods [7], [8], [9]. Multi view Iterative reconstruction is a passive reconstruction method that does not require physical contact with the reconstruction object. Its data acquisition only requires the use of ordinary digital cameras, and is suitable for scenes with different scales. In contrast, laser scanning is a classic active reconstruction method that can achieve high-resolution point cloud reconstruction results. However, devices such as laser emitters are more expensive, and different laser scanners are suitable for different scene ranges [10], [11], [12]. When benchmarking the multi view Iterative reconstruction method, the laser scanning results are usually taken as the true value of the 3D model geometry (ground truth) to evaluate the reconstruction results. The reconstruction objects of the early Middlebury dataset were objects with near Lambertian properties, with a height of about 10cm, and the images were taken in indoor controlled lighting environments. After more than ten years of development, reconstruction methods have achieved significant results [13], [14], [15]. The calculation error on the Middlebury dataset is very close to the resolution of the true value of laser scanning (0.25mm): in the dino scene, 90% of the reconstruction point error is less than 0.34mm, while in the sample scene, 90% of the reconstruction point error can even be less than 0.26mm. However, the scale of the reconstruction 1 scenario today is no longer comparable to the period when the Middlebury dataset was established [16], [17]. The popularity of various cameras and drones has given rise to people's desire for broader reconstruction, and internet image sharing websites can even allow people to obtain a large number of photos of specific areas without leaving their homes. Reconstructing a larger field of view means requiring more photos [18], [19]. Although according to the principle of triangulation, two lines of sight intersect at the same point to determine the position of three-dimensional points, due to the presence of noise, according to experience, the same area should be observed by at least four photos from different perspectives to ensure the accuracy of the calculation. At the same time, the nature of the reimplemented area and the quality of photo collection are also more difficult to control, and weak textures, occluded areas, and changes in lighting during collection are more likely to occur [20], [21]. These changes bring new challenges to multi view Iterative reconstruction. For the reconstruction method, due to its high time and Space complexity, with the increase of the number of images, the computing resources required for direct overall reconstruction are far more than the common hardware level of current single computers. Adopting the divide and conquer method can reduce the scale of the problem and make it solvable. However, due to the interdependence between the sub problems after the overall problem is divided, the final reconstruction quality will vary due to the different fusion methods of the problem, resulting in the inability to achieve the overall reconstruction effect [22], [23], [24]. In situations such as occlusion, weak texture, and changes in lighting, it is often difficult to reconstruct images corresponding to local areas of the scene in accordance with photometric consistency, resulting in defects or voids in local reconstruction results, which seriously affects the quality of reconstruction [23], [25]. On the other hand, the scale of the existing multi view 3D reconstruction benchmark test set cannot match the scale of common reconstruction scenes [26], [27], [28]. For example, when reconstructing large sites, landmark buildings, cities, and other scenes, it is difficult to obtain the true values of the reimplemented scenes through laser scanning and other methods. Moreover, obtaining the true values of camera parameters in outdoor environments is also very difficult, which affects the evaluation of reconstruction effects [29], [30], [31]. In conclusion, although the multi view Iterative reconstruction method has made great progress in laboratory scenes, there are still many problems worth studying for large-scale reconstruction.

Due to the complexity and uncertainty of the decision-making environment, it is difficult to obtain scientifically feasible decision results relying on a single decision expert [32], [33], [34], [35], [36]. In most cases, group decision-making (GDM) based on multiple decision experts is more efficient [37], [38], [39], [40], [41]. Therefore, group decision-making plays a very important role in daily life. Traditional GDM generally only involves a small number of decision-making experts, focusing on solving the problems of a few experts [42], [43], [44]. However, with the promotion of science and technology and social needs, many decision-making problems in reality require the participation of a large number of decision-making experts, such as commercial projects, electronic democracy, emergency decision-making, etc [45], [46], [47], [48]. In this situation, GDM that allows large-scale decision-makers to participate in the decision-making process has received increasing attention and has been widely applied [49], [50], [51], [52], [53]. Compared with decision-making, group decision-making can fully utilize various resources, fully leverage the advantages of different knowledge structures, and improve the comprehensiveness and objectivity of the decision-making process and results [54], [55], [56], [57], [58], [59]. The quality evaluation of large-scale multi-view 3D reconstruction is MAGDM. The IVIFSs [60] are employed as a technique for portraying uncertain information during the quality evaluation of large-scale multi-view 3D reconstruction. Furthermore, many decision techniques manage the traditional TODIM technique [61] and EDAS technique [62], [63] separately to manage the most optimal choice. Until now, no or few techniques have been implemented on Entropy technique [64] and TODIM technique based on EDAS technique [63], [65], [66], [67], [68] under IVIFSs. Therefore, an integrated interval-valued intuitionistic fuzzy TODIM-EDAS (IVIF-TODIM-EDAS) technique is implemented to manage MAGDM under IVIFSs. An illustrative example for quality evaluation of large-scale multi-view 3D reconstruction and some comparative analysis is implemented to demonstrate the validity and reliability of IVIF-TODIM-EDAS technique. The main aim and motivation of this paper is outlined: (1) the TODIM based on EDAS technique has been extended to IVIFSs based on information Entropy; (2) the Entropy technique is employed to manage the weight values based on score values under IVIFSs. (3) the IVIF-TODIM-EDAS technique is founded to manage the MAGDM under IVIFSs; (4) a numerical case study for quality evaluation of large-scale multi-view 3D reconstruction and some comparative analysis is supplied to verify the proposed technique.

The research structure of this paper is shown. In Sect. II, the IVIFSs is introduced in detail. In Sect. III, the IVIF-TODIM-EDAS technique is put forward under IVIFSs. Sect. IV gives the numerical example for quality evaluation of large-scale multi-view 3D reconstruction and several comparative analysis. Some remarks are managed in Sect. V.

II. PRELIMINARIES

Atanassov [60] implemented the IVIFSs.

Definition 1 ([60]): The interval-valued IFSs (IVIFSs) on the X is:

$$DI = \{\langle x, DM(x), DN(x)\rangle \mid x \in X\} \tag{1}$$

where $DM(x) \subset [0,1]$ is membership degree and $DN(x) \subset [0,1]$ is non-membership degree, and $DM(x), DN(x)$ meet condition: $0 \leq \sup DM(x) + \sup DN(x) \leq 1, \forall x \in X$. For convenience, we call $DI = ([DA, DB], [DC, DD])$ is an IVIFN.

Definition 2 ([69]): Let $DI_1 = ([DA_1, DB_1], [DC_1, DD_1])$ and $DI_2 = ([DA_2, DB_2], [DC_2, DD_2])$ be two IVIFNs, the operation laws are established:

$$DI_1 \oplus DI_2 = \begin{pmatrix} [DA_1 + DA_2 - DA_1DA_2, DB_1 + DB_2 - DB_1DB_2], \\ [DC_1DC_2, DD_1DD_2] \end{pmatrix} \tag{2}$$

$$DI_1 \otimes DI_2 = \begin{pmatrix} [DA_1DA_2, DB_1DB_2], \\ [DC_1 + DC_2 - DC_1DC_2, DD_1 + DD_2 - DD_1DD_2] \end{pmatrix} \tag{3}$$

$$\lambda DI_1 = \left(\left[1-(1-DA_1)^{\lambda}, 1-(1-DB_1)^{\lambda}\right], \left[(DC_1)^{\lambda}, (DD_1)^{\lambda}\right]\right), \lambda > 0 \tag{4}$$

$$DI_1^{\lambda} = \left(\left[(DA_1)^{\lambda}, (DB_1)^{\lambda}\right], \left[1-(1-DC_1)^{\lambda}, 1-(1-DD_1)^{\lambda}\right]\right), \lambda > 0 \tag{5}$$

From Definition 2, several properties are established.

(1) $DI_1 \oplus DI_2 = DI_2 \oplus DI_1, DI_1 \otimes DI_2 = DI_2 \otimes DI_1, \left((DI_1)^{\lambda_1}\right)^{\lambda_2} = (DI_1)^{\lambda_1\lambda_2}$;

(2) $\lambda(DI_1 \oplus DI_2) = \lambda DI_1 \oplus \lambda DI_2, \ (DI_1 \otimes DI_2)^{\lambda} = (DI_1)^{\lambda} \otimes (DI_2)^{\lambda}$;

(3) $\lambda_1 DI_1 \oplus \lambda_2 DI_1 = (\lambda_1 + \lambda_2) DI_1, \ (DI_1)^{\lambda_1} \otimes (DI_1)^{\lambda_2} = (DI_1)^{(\lambda_1+\lambda_2)}$.

Definition 3 ([70]): Let $DI_1 = ([DA_1, DB_1], [DC_1, DD_1])$ and $DI_2 = ([DA_2, DB_2], [DC_2, DD_2])$ be IVIFNs, the score assessed values (SAV) and accuracy assessed values (AAV) of DI_1 and DI_2 are established:

$$SAV(DI_1) = \frac{\begin{pmatrix} DA_1 + DA_1(1 - DA_1 - DC_1) \\ +DB_1 + DB_1(1 - DB_1 - DD_1) \end{pmatrix}}{2} \tag{6}$$

$$SAV(DI_2) = \frac{\begin{pmatrix} DA_2 + DA_2(1 - DA_2 - DC_2) \\ +DB_2 + DB_2(1 - DB_2 - DD_2) \end{pmatrix}}{2} \tag{7}$$

$$AAV(DI_1) = \frac{DA_1 + DC_1 + DB_1 + DD_1}{2}, \tag{8}$$

$$AAV(DI_2) = \frac{DA_2 + DC_2 + DB_2 + DD_2}{2} \tag{9}$$

For DI_1 and DI_2, in line with Definition 3, then

(1) *if* $SAV(DI_1) < SAV(DI_2), \ DI_1 < DI_2$;

(2) *if* $SAV(DI_1) > SAV(EI_2), DI_1 > DI_2$;

(3) *if* $SAV(DI_1) = SAV(DI_2), AAV(DI_1) < AAV(DI_2), DI_1 < DI_2$;

(4) *if* $SAV(DI_1) = SAV(DI_2), AAV(DI_1) = AAV(DI_2), DI_1 = DI_2$.

Definition 4 ([71]): Let $DI_1 = ([DA_1, DB_1], [DC_1, DD_1])$ and $DI_2 = ([DA_2, DB_2], [DC_2, DD_2])$, the IVIFN Euclidean distance (IVIFNED) is implemented in Eq. (8):

$$IVIFNED(DI_1, DI_2) = \sqrt{\frac{1}{4}\begin{bmatrix} (DA_1 - DA_2)^2 + (DB_1 - DB_2)^2 \\ +(DC_1 - DC_2)^2 + (DD_1 - DD_2)^2 \end{bmatrix}} \tag{10}$$

The IVIFWA and IVIFWG technique is implemented [72].

Definition 5 ([72]): Let $DI_j = ([DA_j, DB_j], [DC_j, DD_j])$ be a family of IVIFNs, the IVIFWA technique is implemented in Eq. (9):

$$IVIFWA_{d\omega}(DI_1, DI_2, \ldots, DI_n) = \mathop{\oplus}_{j=1}^{n} (d\omega_j DI_j) = \begin{pmatrix} \left[1 - \prod_{j=1}^{n}(1-DA_j)^{d\omega_j}, 1 - \prod_{j=1}^{n}(1-DB_j)^{d\omega_j}\right], \\ \left[\prod_{j=1}^{n}(DC_j)^{d\omega_j}, \prod_{j=1}^{n}(DD_j)^{d\omega_j}\right] \end{pmatrix} \tag{11}$$

where $d\omega = (d\omega_1, d\omega_2, \ldots, d\omega_n)^T$ be weight values of $DI_j = ([DA_j, DB_j], [DC_j, DD_j]), d\omega_j > 0, \sum_{j=1}^{n} d\omega_j = 1$.

Definition 6 ([73]): Let $DI_j = ([DA_j, DB_j], [DC_j, DD_j])$ $(j = 1, 2, \cdots, n)$ be a family of IVIFNs, the IVIFWG technique is implemented in Eq. (10):

$$IVIFWG_{d\omega}(DI_1, DI_2, \ldots, DI_n) = \overset{n}{\underset{j=1}{\otimes}} (DI_j)^{d\omega_j}$$
$$= \left(\begin{array}{l} \left[\prod_{j=1}^{n} (DA_j)^{d\omega_j}, \prod_{j=1}^{n} (DB_j)^{d\omega_j} \right], \\ \left[1 - \prod_{j=1}^{n} (1 - DC_j)^{d\omega_j}, 1 - \prod_{j=1}^{n} (1 - DD_j)^{d\omega_j} \right] \end{array} \right) \tag{12}$$

where $d\omega = (d\omega_1, d\omega_2, \ldots, d\omega_n)^T$ be weight values of $DI_j = ([DA_j, DB_j], [DC_j, DD_j])$, $d\omega_j > 0$, $\sum_{j=1}^{n} d\omega_j = 1$.

III. IVIF-TODIM-EDAS TECHNIQUE FOR MAGDM WITH ENTROPY

A. IVIF-MAGDM ISSUES

Then IVIF-TODIM-EDAS technique is implemented for MAGDM. Let $DA = \{DA_1, DA_2, \cdots, DA_m\}$ be alternatives, and the attributes set $DG = \{DG_1, DG_2, \cdots, DG_n\}$ with weight values $d\omega = \{d\omega_1, d\omega_2, \cdots, d\omega_n\}$, where $d\omega_j \in [0, 1]$, $\sum_{j=1}^{n} d\omega_j = 1$ and a family of experts $DE = \{DE_1, DE_2, \cdots, DE_q\}$ with weight values be $dw = \{dw_1, dw_2, \cdots, dw_q\}$. Then, IVIF-TODIM-EDAS technique is brought forward for MAGDM.

Step 1. Implement the IVIF-matrix $DR = \left[DR_{ij}^{t}\right]_{m\times n} = \left(\left[DA_{ij}^{(t)}, DB_{ij}^{(t)}\right], \left[DC_{ij}^{(t)}, DD_{ij}^{(t)}\right]\right)_{m\times n}$ and implement the average values matrix $DR = \left[DR_{ij}\right]_{m\times n}$ in Eq. (13)-(14):

$$DR = \left[DR_{ij}^{t}\right]_{m\times n} = \begin{array}{c} \\ DA_1 \\ DA_2 \\ \vdots \\ DA_m \end{array} \begin{array}{c} \begin{array}{cccc} DG_1 & DG_2 & \ldots & DG_n \end{array} \\ \begin{bmatrix} DR_{11}^{t} & DR_{12}^{t} & \ldots & DR_{1n}^{t} \\ DR_{21}^{t} & DR_{22}^{t} & \ldots & DR_{2n}^{t} \\ \vdots & \vdots & \vdots & \vdots \\ DR_{m1}^{t} & DR_{m2}^{t} & \ldots & DR_{mn}^{t} \end{bmatrix} \end{array} \tag{13}$$

$$DR = \left[DR_{ij}\right]_{m\times n} = \begin{array}{c} \\ DA_1 \\ DA_2 \\ \vdots \\ DA_m \end{array} \begin{array}{c} \begin{array}{cccc} DG_1 & DG_2 & \ldots & DG_n \end{array} \\ \begin{bmatrix} DR_{11} & DR_{12} & \ldots & DR_{1n} \\ DR_{21} & DR_{22} & \ldots & DR_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ DR_{m1} & DR_{m2} & \ldots & DR_{mn} \end{bmatrix} \end{array} \tag{14}$$

Based on IVIFWG technique, the $DR = \left[DR_{ij}\right]_{m\times n} = \left(\left[DA_{ij}, DB_{ij}\right], \left[DC_{ij}, DD_{ij}\right]\right)_{m\times n}$ is implemented in Eq. (15):

$$DR_{ij} = \left(DR_{ij}^{1}\right)^{dw_1} \otimes \left(DR_{ij}^{2}\right)^{dw_2} \otimes \cdots \otimes \left(DR_{ij}^{q}\right)^{dw_q}$$
$$= \left(\begin{array}{l} \left[\prod_{t=1}^{q} \left(DA_{ij}^{(t)}\right)^{dw_t}, \prod_{t=1}^{q} \left(DB_{ij}^{(t)}\right)^{dw_t} \right], \\ \left[1 - \prod_{t=1}^{q} (1 - DC_{ij}^{(t)})^{dw_t}, 1 - \prod_{t=1}^{q} (1 - DD_{ij}^{(t)})^{dw_t} \right] \end{array} \right) \tag{15}$$

Step 2. The $DR = [DR_{ij}]_{m\times n} = ([DA_{ij}, DB_{ij}], [DC_{ij}, DD_{ij}])_{m\times n}$ is normalized to $NDR = [NDR_{ij}]_{m\times n} = ([NDA_{ij}, NDB_{ij}], [NDC_{ij}, NDD_{ij}])_{m\times n}$ in Eq. (16)-(17).

For benefit attributes:

$$NDR_{ij} = \left(\left[NDA_{ij}, NDB_{ij}\right], \left[NDC_{ij}, NDD_{ij}\right]\right) = \left(\left[DA_{ij}, DB_{ij}\right], \left[DC_{ij}, DD_{ij}\right]\right) \tag{16}$$

For cost attributes:

$$NDR_{ij} = \left(\left[NDA_{ij}, NDB_{ij}\right], \left[NDC_{ij}, NDD_{ij}\right]\right) = \left(\left[DC_{ij}, DD_{ij}\right], \left[DA_{ij}, DB_{ij}\right]\right) \tag{17}$$

B. IMPLEMENT THE ATTRIBUTES WEIGHT THROUGH EMPLOYING ENTROPY TECHNIQUE

Step 3. The weight values are essential for MAGDM under different information settings [74], [75], [76], [77], [78]. Entropy technique [64] is the conventional technique to implement weight values. Then, the normalized IVIFN matrix is implemented based on the SAV and AAV in Eq. (18):

$$DIVIFNM_{ij} = \frac{\frac{1+AAV([NDA_{ij},NDB_{ij}],[NDC_{ij},NDD_{ij}])}{1+SAV([NDA_{ij},NDB_{ij}],[NDC_{ij},NDD_{ij}])}}{\sum_{i=1}^{m}\left(\frac{1+AAV([NDA_{ij},NDB_{ij}],[NDC_{ij},NDD_{ij}])}{1+SAV([NDA_{ij},NDB_{ij}],[NDC_{ij},NDD_{ij}])}\right)}, \tag{18}$$

Then, the IVIFN Shannon entropy $DIVIFNSE = (DIVIFNSE_1, DIVIFNSE_2, \cdots, DIVIFNSE_n)$ is produced based on the SAV and AAV in Eq. (19):

$$DIVIFNSE_j = -\frac{1}{\ln m}\sum_{i=1}^{m} DIVIFNM_{ij} \ln DIVIFNM_{ij} \tag{19}$$

and $DIVIFNM_{ij} \ln DIVIFNM_{ij} = 0$ if $DIVIFNM_{ij} = 0$.

Then, the weight values $d\omega = (d\omega_1, d\omega_2, \cdots, d\omega_n)$ is implemented through Eq. (20):

$$d\omega_j = \frac{1 - DIVIFNSE_j}{\sum_{j=1}^{n}(1 - DIVIFNSE_j)} \tag{20}$$

C. IVIF-TODIM-EDAS TECHNIQUE FOR MAGDM

Then, the IVIF-TODIM-EDAS technique is implemented for MAGDM.

Step 4. Implement relative weight information of DG_j through Eq. (21):

$$rd\omega_j = d\omega_j \Big/ \max_j d\omega_j, \tag{21}$$

Step 5. The IVIFN dominance degree values (IVIFNDDV) of DA_i over DA_t for DG_j is implemented in Eq. (22):

$$IVIFNDDV_j\left(DA_i, DA_t\right) = \begin{cases} \sqrt{\dfrac{rd\omega_j \times IVIFNED\left(NDR_{ij}, NDR_{tj}\right)}{\sum_{j=1}^{n} rd\omega_j}} \\ \quad \text{if } SAV\left(NDR_{ij}\right) > SAV\left(NDR_{tj}\right) \\ 0 \quad \text{if } SAV\left(NDR_{ij}\right) = SAV\left(NDR_{tj}\right) \\ -\dfrac{1}{\theta}\sqrt{\dfrac{\sum_{j=1}^{n} rd\omega_j \times IVIFNED\left(NDR_{ij}, NDR_{tj}\right)}{rd\omega_j}} \\ \quad \text{if } SAV\left(NDR_{ij}\right) < SAV\left(NDR_{tj}\right) \end{cases} \tag{22}$$

The IVIFNDDV under DG_j is implemented, as shown in the equation at the bottom of the page.

(3) Implement the IVIFNDDV of DA_i for other alternatives under DG_j in Eq. (23):

$$IVIFNDDV_j\left(DA_i\right) = \sum_{t=1}^{m} IVIFNDDV_j\left(DA_i, DA_t\right) \tag{23}$$

The IVIFNDDV is implemented, as shown in the equation at the bottom of the page.

Step 6. Implement the IVIFN average solution (IVIFNAS).

$$IVIFNAS = \left[IVPINAS_j\right]_{1\times n} = \left[\frac{\sum_{i=1}^{m} IVIFNDDV_{ij}}{m}\right]_{1\times n} \tag{24}$$

$$IVIFNDDV_{ij} = \frac{IVIFNDDV_{ij} - IVIFNNIS_j}{IVIFNPIS_j - IVIFNNIS_j}, \tag{25}$$

$$IVIFNPIS_j = \max_{j=1}^{n} IVIFNDDV_{ij}$$
$$IVIFNNIS_j = \min_{j=1}^{n} IVIFNDDV_{ij} \tag{26}$$

Step 7. Implement the IVIFN positive distance from IVIFNAS (IVPFNPDAS) and IVIFN negative distance from IVIFNAS (IVIFNNDAS):

$$IVIFNPDAS_{ij} = \left[IVIFNPDAS_{ij}\right]_{m\times n} = \frac{\max\left(0, \left(IVIFNDDV_{ij} - IVIFNAS_j\right)\right)}{IVIFNAS_j}, \tag{27}$$

$$IVIFNNDAS_{ij} = \left[IVIFNNDAS_{ij}\right]_{m\times n} = \frac{\max\left(0, \left(IVIFNAS_j - IVIFNDDV_{ij}\right)\right)}{IVIFNAS_j}, \tag{28}$$

Step 8. Implement the $IVIFNSP_i$ and $IVIFNSN_i$.

$$IVIFNSP_i = \sum_{j=1}^{n} d\omega_j \cdot IViFNPDAs_{ij},$$
$$IVIFNSN_i = \sum_{j=1}^{n} d\omega_j \cdot IViFNNDAs_{ij}, \tag{29}$$

Step 9. Normalized the $IVIFNSP_i$ and $IVIFNSN_i$:

$$IVIFNNSP_i = \frac{IVIFNSP_i}{\max_i\left(IVIFNSP_i\right)},$$
$$IVIFNNSN_i = 1 - \frac{IVIFNSN_i}{\max_i\left(IVIFNSN_i\right)}, \tag{30}$$

$$IVIFNDDV_j\left(DA_i\right) = \left[IVIFNDDV_j\left(DA_i, DA_t\right)\right]_{m\times m} = \begin{array}{c} \\ DA_1 \\ DA_2 \\ \vdots \\ DA_m \end{array} \begin{array}{c} \begin{array}{cccc} DA_1 & DA_2 & \cdots & DA_m \end{array} \\ \begin{bmatrix} 0 & IVIFNDDV_j\left(DA_1, DA_2\right) & \cdots & IVIFNDDV_j\left(DA_1, DA_m\right) \\ IVIFNDDV_j\left(DA_2, DA_1\right) & 0 & \cdots & IVIFNDDV_j\left(DA_2, DA_m\right) \\ \vdots & \vdots & \cdots & \vdots \\ IVIFNDDV_j\left(DA_m, DA_1\right) & IVIFNDDV_j\left(DA_m, DA_2\right) & \cdots & 0 \end{bmatrix} \end{array}$$

$$IVIFNDDV = \left(IVIFNDDV_{ij}\right)_{m\times n} = \begin{bmatrix} & DG_1 & DG_2 & \cdots & DG_n \\ DA_1 & \sum_{t=1}^{m} IVIFNDDV_1\left(DA_1, DA_t\right) & \sum_{t=1}^{m} IVIFNDDV_2\left(DA_1, DA_t\right) & \cdots & \sum_{t=1}^{m} IVIFNDDV_n\left(DA_1, DA_t\right) \\ DA_2 & \sum_{t=1}^{m} IVIFNDDV_1\left(DA_2, DA_t\right) & \sum_{t=1}^{m} IVIFNDDV_2\left(DA_2, DA_t\right) & \cdots & \sum_{t=1}^{m} IVIFNDDV_n\left(DA_2, DA_t\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ DA_m & \sum_{t=1}^{m} IVIFNDDV_1\left(DA_m, DA_t\right) & \sum_{t=1}^{m} IVIFNDDV_2\left(DA_m, DA_t\right) & \cdots & \sum_{t=1}^{m} IVIFNDDV_n\left(DA_m, DA_t\right) \end{bmatrix}$$

TABLE 1. Linguistic scale and IVIFNs.

Linguistic information scale	IVIFNs
Exceedingly Bad-DEB	$\langle[0.05,0.10],[0.85,0.90]\rangle$
Very Bad -DVB	$\langle[0.10,0.15],[0.75,0.85]\rangle$
Bad -DB	$\langle[0.15,0.20],[0.60,0.70]\rangle$
Medium-DM	$\langle[0.50,0.50],[0.50,0.50]\rangle$
Good-DG	$\langle[0.60,0.70],[0.15,0.20]\rangle$
Very Good -DVG	$\langle[0.75,0.85],[0.10,0.15]\rangle$
Exceedingly Good -DEG	$\langle[0.85,0.90],[0.05,0.10]\rangle$

TABLE 2. Evaluation information through DE_1.

	DG_1	DG_2	DG_3	DG_4
DA_1	DG	DM	DVB	DVG
DA_2	DM	DB	DVG	DG
DA_3	DG	DVG	DVB	DM
DA_4	DVB	DVG	DM	DVB
DA_5	DVG	DVB	DM	DB

Step 10. Implement the IVIFN appraisal ranking values (IVIFNARV) for decision alternatives.

$$IVIFNARV_i = \frac{1}{2}\left(IVIFNNSP_i + IVIFNNSN_i\right) \tag{31}$$

Step 11. In line with IVIFNARV, the higher IVIFNARV, the optimal choice is.

IV. NUMERICAL EXAMPLE AND COMPARATIVE ANALYSIS

A. NUMERICAL EXAMPLE FOR QUALITY EVALUATION OF LARGE-SCALE MULTI-VIEW 3D RECONSTRUCTION

In the past decades, multi view Iterative reconstruction methods have made great progress. The earliest reconstruction work was to calibrate the camera in advance, obtain internal parameters such as the focal length, as well as the spatial position and orientation of the camera, and then reconstruct the pairwise view. This method was quickly extended to video image sequences and multi view image sets, reducing the impact of noise by increasing the number of two-dimensional observations. Later, with the development of self-calibration technology, camera parameters can be solved according to images, so a large number of applications based on Internet images and closely related to multi view Iterative reconstruction have also been generated, such as photo based remote tour, 3D Wikipedia, automatic positioning of photos taken, etc. At the same time, the Triangle mesh of discrete point clouds and texture mapping technology based on multi view photos are also constantly developing and improving. By combining with camera self-calibration and stereo reconstruction technology, the basic process of multi view Iterative reconstruction is formed: after taking images from multiple views, the local correspondence between images is used to solve the sparse 3D points and camera parameters of the scene, that is, the structure from motion (SFM). Next, through the Multi View Stereo (MVS) technology, the dense 3D point cloud model of the scene is reimplemented. The Triangle mesh converts the point cloud model into a mesh representation. Texture mapping uses multi view images and camera parameters to calculate the true texture of the photo for the mesh model. For motion recovery structures, it can be further divided into three sub

TABLE 3. Evaluation information through DE_2.

	DG_1	DG_2	DG_3	DG_4
DA_1	DVG	DG	DM	DB
DA_2	DVG	DB	DVB	DM
DA_3	DM	DVG	DB	DG
DA_4	DVB	DM	DVG	DG
DA_5	DVB	DVG	DM	DG

TABLE 4. Evaluation information through DE_3.

	DG_1	DG_2	DG_3	DG_4
DA_1	DG	DVG	DB	DM
DA_2	DVB	DVB	DM	DG
DA_3	DM	DB	DVG	DG
DA_4	DG	DVG	DVB	DB
DA_5	DM	DG	DB	DM

TABLE 5. The $SR = \left[SR_{ij}\right]_{5\times4}$.

Alternatives	DG_1	DG_2
DA_1	([0.4454, 0.4657], [0.4501, 0.4765])	([0.3469, 0.4587], [0.2107, 0.4805])
DA_2	([0.5764, 0.5573], [0.4231, 0.4405])	([0.3473, 0.4526], [0.4571, 0.4783])
DA_3	([0.4723, 0.5121], [0.4431, 0.4726])	([0.4724, 0.4564], [0.1856, 0.2703])
DA_4	([0.2547, 0.2754], [0.6057, 0.6453])	([0.4367, 0.4523], [0.5253, 0.5406])
DA_5	([0.6354, 0.6415], [0.3301, 0.3521])	([0.5714, 0.6128], [0.3007, 0.4104])

Alternatives	DG_3	DG_5
DA_1	([0.4325,0.4587], [0.5472, 0.5712])	([0.4245, 0.4457], [0.5121, 0.5431])
DA_2	([0.5453, 0.5675], [0.4548,0.4106])	([0.4787, 0.4924], [0.4438, 0.4802])
DA_3	([0.4165, 0.4569], [0.5238, 0.5125])	([0.4928, 0.5364], [0.4317, 0.4506])
DA_4	([0.4378, 0.4426], [0.5051, 0.5231])	([0.4367, 0.4756], [0.4876, 0.5157])
DA_5	([0.5564, 0.5598], [0.4153, 0.4252)	([0.5324, 0.5425], [0.4207, 0.4528])

steps: local feature point extraction and matching, initial camera registration, and bundle adjustment (BA). The quality evaluation of large-scale multi-view 3D reconstruction is MAGDM. Therefore, the quality evaluation of large-scale multi-view 3D reconstruction is implemented to show the built technique. There are five potential large-scale multi-view 3D reconstruction schemes DA_i ($i = 1, 2, 3, 4, 5$) to choose. The decision experts select four attributes to assess these five large-scale multi-view 3D reconstruction schemes: ① DG_1 is reliability of large-scale multi-view

TABLE 6. The $NDR = \left[NDR_{ij}\right]_{5\times4}$.

Alternatives	DG1	DG2
DA1	([0.4454, 0.4657], [0.4501, 0.4765])	([0.2107, 0.4805], [0.3469, 0.4587])
DA2	([0.5764, 0.5573], [0.4231, 0.4405])	([0.4571, 0.4783], [0.3473, 0.4526])
DA3	([0.4723, 0.5121], [0.4431, 0.4726])	([0.1856, 0.2703], [0.4724, 0.4564])
DA4	([0.2547, 0.2754], [0.6057, 0.6453])	([0.5253, 0.5406], [0.4367, 0.4523])
DA5	([0.6354, 0.6415], [0.3301, 0.3521])	([0.3007, 0.4104], [0.5714, 0.6128])

Alternatives	DG3	DG5
DA1	([0.4325,0.4587], [0.5472, 0.5712])	([0.4245, 0.4457], [0.5121, 0.5431])
DA2	([0.5453, 0.5675], [0.4548,0.4106])	([0.4787, 0.4924], [0.4438, 0.4802])
DA3	([0.4165, 0.4569], [0.5238, 0.5125])	([0.4928, 0.5364], [0.4317, 0.4506])
DA4	([0.4378, 0.4426], [0.5051, 0.5231])	([0.4367, 0.4756], [0.4876, 0.5157])
DA5	([0.5564, 0.5598], [0.4153, 0.4252])	([0.5324, 0.5425], [0.4207, 0.4528])

TABLE 7. The weight values.

	DG1	DG2	DG3	DG4
weight values	0.1854	0.2875	0.2657	0.2614

TABLE 8. The relative weight.

	DG1	DG2	DG3	DG4
relative weight	0.6449	1.0000	0.9242	0.9092

3D reconstruction; ② DG_2 is interoperability the response time of large-scale multi-view 3D reconstruction; ③ DG_3 is scalability of large-scale multi-view 3D reconstruction; ④ DG_4 is algorithm effectiveness of large-scale multi-view 3D reconstruction. The DG_2 is cost attribute. The five potential large-scale multi-view 3D reconstruction schemes $DA_i\ (i = 1, 2, 3, 4, 5)$ are to be assessed with linguistic terms (See Table 1 [79]) with four attributes through three experts $DE_t\ (t = 1, 2, 3)$ with expert's weight values is $(0.3203, 0.3502, 0.3285)$ which is implemented through Analytic Hierarchy Process (AHP) technique.

The IVIF-TODIM-EDAS technique is employed to manage the quality evaluation of large-scale multi-view 3D reconstruction.

Step 1. Manage the IVIFN-matrix $DR = \left[DR^t_{ij}\right]_{5\times4}$ $(t = 1, 2, 3)$ (See Table 2-4).

Then in line with the IVIFWG technique, the $DR = \left[DR_{ij}\right]_{5\times4}$ is implemented (See Table 5).

Step 2. Normalize the $SR = \left[SR_{ij}\right]_{5\times4}$ to $NDR = \left[NDR_{ij}\right]_{5\times4}$ (See Table 6).

Step 3. Manage the weight values:

Step 4. Manage the relative weight values:

Step 5. Manage the $IVIFNDDV = \left(IVIFNDDV_{ij}\right)_{5\times4}$(See table 7):

Step 6. Manage the IVIFNAS (See table 10).

Step 7. Manage the IVIFNPDAS and IVIFNNDAS (See table 11-12):

Step 8. Manage the IVIFNSP and IVIFNSN (See Table 13).

Step 9. Manage the IVIFNNSP and IVIFNNSN is in Table 14.

Step 10. Manage the IVIFNARV (See Table 15).

Step 11. In line with the IVIFNARV, the order is: $DA_1 > DA_3 > DA_4 > DA_2 > DA_5$ and DA_1 is the best large-scale multi-view 3D reconstruction schemes.

B. COMPARATIVE ANALYSIS

Then, the IVIF-TODIM-EDAS technique is compared in detail with IVIFWA technique [72], IVIFWG

TABLE 9. The $IVIFNDDV = \left(IVIFNDDV_{ij}\right)_{5\times 4}$.

	DG_1	DG_2	DG_3	DG_4
DA_1	-0.2234	0.9092	0.2842	-1.2779
DA_2	0.2084	0.2959	-1.5745	0.9641
DA_3	-0.9899	-0.7499	0.6988	-2.7420
DA_4	0.6662	-0.4225	-0.4218	2.1602
DA_5	-0.8986	-1.1890	-0.5022	-0.1418

TABLE 10. The IVIFNAS.

	DG_1	DG_2	DG_3	DG_4
IVIFNAS	0.4483	0.4565	0.5593	0.5170

TABLE 11. The IVPFNPDAS.

	DG_1	DG_2	DG_3	DG_4
DA_1	0.0145	0.5435	0.2584	0.0000
DA_2	0.2752	0.2513	0.0000	0.2390
DA_3	0.0000	0.0000	0.4407	0.0000
DA_4	0.5517	0.0000	0.0000	0.4830
DA_5	0.0000	0.0000	0.0000	0.0134

TABLE 12. The IVPFNNDAS.

	DG_1	DG_2	DG_3	DG_4
DA_1	0.0000	0.0000	0.0000	0.2184
DA_2	0.0000	0.0000	0.5593	0.0000
DA_3	0.4483	0.2472	0.0000	0.5170
DA_4	0.0000	0.0911	0.0522	0.0000
DA_5	0.3932	0.4565	0.0876	0.0000

technique [73], interval-valued intuitionistic fuzzy power weighted average (IVIFPWA) technique [80], interval-valued intuitionistic fuzzy power weighted geometric (IVIFPWG) technique [80], IVIF-MABAC technique [81], IVIF-CODAS technique [82], IVIF-EDAS technique [83], IVIF-Taxonomy technique [84] and IVIF-TODIM technique [85]. The detailed comparative results are managed in Table 16.

TABLE 13. The IVIFNSP and IVIFNSN.

	IVIFNSP	IVIFNSN
DA_1	0.2276	0.0571
DA_2	0.1857	0.1486
DA_3	0.1171	0.2893
DA_4	0.2285	0.0401
DA_5	0.0035	0.2274

TABLE 14. The IVIFNNSP and IVIFNNSN.

	IVIFNNSP	IVIFNNSN
DA_1	0.9959	0.8027
DA_2	0.8127	0.4864
DA_3	0.5124	0.0000
DA_4	1.0000	0.8615
DA_5	0.0153	0.2141

TABLE 15. The IVIFNARV.

	IVIFNARV	Order
DA_1	0.7412	1
DA_2	0.4064	4
DA_3	0.6869	2
DA_4	0.6070	3
DA_5	0.0077	5

In accordance with RW coefficients [86], the RW coefficient between IVIFWA technique [72], IVIFWG technique [73], interval-valued intuitionistic fuzzy power weighted average (IVIFPWA) technique [80], interval-valued intuitionistic fuzzy power weighted geometric (IVIFPWG) technique [80], IVIF-MABAC technique [81], IVIF-CODAS technique [82], IVIF-EDAS technique [83], IVIF-Taxonomy technique [84], IVIF-TODIM technique [85] and the proposed IVIF-TODIM-EDAS technique is 1.0000, 0.7917, 1.0000, 0.7917, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, respectively. The RW coefficient shows the ranking results of the proposed IVIF-TODIM-EDAS are same to the ranking

TABLE 16. Order of different techniques.

Techniques	Order
IVIFWA technique [72]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIFWG technique [73]	$DA_1 > DA_3 > DA_2 > DA_4 > DA_5$
IVIFPWA technique [80]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIFPWG technique [80],	$DA_1 > DA_3 > DA_2 > DA_4 > DA_5$
IVIF-MABAC technique [81]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIF-CODAS technique [82]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIF-EDAS technique [83]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIF-Taxonomy technique [84]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$
IVIF-TODIM technique [85]	$DA_1 > DA_3 > DA_4 > DA_2 > DA_5$

results of IVIFWA technique [72], IVIFPWA technique [80], IVIF-MABAC technique [81], IVIF-CODAS technique [82], IVIF-EDAS technique [83], IVIF-Taxonomy technique [84], IVIF-TODIM technique [85]; the RW coefficient shows the ranking results of the proposed IVIF-TODIM-EDAS technique are slightly different to the ranking results of IVIFWG technique [73] and IVIFPWG technique [80]. Furthermore, the reason for this subtle difference is that IVIFWG technique [73] and IVIFPWG technique [80] emphasizes the individual's influence for entire decision result. This verifies the IVIF-TODIM-EDAS technique is effective. The main advantages of the IVIF-TODIM-EDAS technique are managed: (1) IVIF-TODIM-EDAS technique could consider the bounded rationality and manage the distance between each evaluation object and IVIFNAS and obtain the IVIFNARV information between each evaluation object and the IVIFNAS; (2) the proposed IVIF-TODIM-EDAS technique analyze the behavior of the TODIM technique and TOPSIS technique as MAGDM techniques when they are hybridized.

V. CONCLUSION

Iterative reconstruction is one of the core issues of computer vision research, which mainly includes the research direction of spatial 3D reconstruction based on different number of 2D images, such as single view, two view and multi view. In the field of computer vision, Iterative reconstruction technology based on multi views is also called Structure from Motion (SFM), which refers to the technology of Iterative reconstruction using images from different perspectives of the target object. It is widely used in various fields such as automatic navigation systems, target object detection, robots working in various dangerous situations, computer-aided surgery, and virtual reality, and has become a research focus in the academic community in recent years. For multi view reconstruction, since four or more image sequences do not add new constraints to feature points, often only the corresponding feature points in two or three images are discussed together, and it is assumed that the difference between adjacent images in the image sequence is not significant, that is, rotation, translation, and perspective changes are all small. For image acquisition of real objects, it is generally best to imitate a spherical coordinate measurement system, where the camera revolves around the camera at a certain angle to minimize the influence of shadows during shooting. In practical applications, the process of multi view reconstruction is prone to problems such as non-uniform projection depth, large spatial point errors in reconstruction, feature point degradation, occlusion, etc., which seriously affect the final reconstruction effect. The quality evaluation of large-scale multi-view 3D reconstruction is MAGDM. Recently, the TODIM-EDAS was employed to manage the MAGDM. The IVIFSs are employed as a useful tool for depicting uncertain decision information during the quality evaluation of large-scale multi-view 3D reconstruction. In this paper, we design the IVIF-TODIM-EDAS model to manage the MAGDM under IVIFSs. At last, a numerical example study for quality evaluation of large-scale multi-view 3D reconstruction is employed to show the IVIF-TODIM-EDAS technique. The main contribution of this paper is outlined: (1) the TODIM technique based on EDAS has been extended to IVIFSs based on information Entropy; (2) the information Entropy technique is employed to derive weight based on core values under IVIFSs. (3) the IVIF-TODIM-EDAS technique is founded to manage the MAGDM under IVIFSs; (4) a numerical case study for quality evaluation of large-scale multi-view 3D reconstruction and some comparative analysis is supplied to verify the proposed technique.

Through detailed research, this paper manages an IVIF-TODIM-EDAS technique for MAGDM under IVIFSs environment, and uses this novel technique to manage the problem of quality evaluation of large-scale multi-view 3D reconstruction, which has certain rationality and practical significance. However, there are still several shortcomings for quality evaluation of large-scale multi-view 3D reconstruction that need to be further explored in our future research: (1) When constructing the evaluation system for quality evaluation of large-scale multi-view 3D reconstruction, although some of the evaluation indicators were considered, in practical applications, more evaluation indicators may need to be considered to make the evaluation more scientific and ensure the rationality and accuracy of the performance evaluation results of IAOM in sports events. (2) In our future studies, we shall connect the TODIM technique and EDAS technique approach for quality evaluation of large-scale multi-view 3D reconstruction with RANCOM technique [87], CRITIC technique [88], [89], [90], [91], [92], COMET technique [93], [94], [95], [96], [97], [98], MAIRCA technique [99], [100], [101] and QUALIFLEX technique [102], [103], [104], [105], [106].

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