State-of-the-art review on asphalt mixture distribution uniformity based on digital image processing technology

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Abstract. Asphalt mixture uniformity has an important impact on the long-term performance of pavement. This paper introduces the asphalt mixture uniformity evaluation method based on digital image processing technology, lists a variety of evaluation indicators based on different evaluation ideas, and finally points out the advantages of this method compared with the traditional method and new detection technology, as well as the shortcomings of the current method.

1. Introduction
As a complex engineering material composed of aggregate, mineral powder, asphalt and voids, asphalt mixture is widely used in road engineering pavement. The asphalt pavement is prone to the segregation of asphalt mixture during the construction process, which leads to the increase of the voids between aggregates and water damage under the action of vehicles. The uniformity is directly related to the mechanical properties and service life of the pavement, which is an important guarantee for the long-term performance of the pavement. Therefore, it is particularly important to evaluate the homogeneity of asphalt mixture. At present, there are many methods for asphalt mixture uniformity evaluation, including traditional visual identification method, sand laying method, nuclear densitometer measurement, emerging thermal imaging technology, laser section technology and detection technology based on digital image processing. The traditional evaluation methods have some defects, such as strong subjectivity, long time-consuming and low accuracy; and the new non-destructive testing technology also has many limitations and lack of universality. The digital image processing technology (DIP) evaluation of asphalt mixture uniformity has the advantages of convenient use, good economy, large amount of available information and visualized storage, which has been widely valued and developed.

2. Digital image processing technology
Digital image processing technology is mainly divided into two parts, including image acquisition and processing of digital image and extraction of micro parameters. At present, there are mainly two kinds of image acquisition methods: CCD and CT. Digital camera recognition technology has been very mature and easy to operate. However, in the process of image acquisition, the operation is easy to be
affected by light which makes the image noisy. In addition, when using digital camera recognition technology to collect the internal structure image of mixture specimen or pavement core sample, it is necessary to cut the sample or core sample, and collect data destructively, which may cause damage to the subsequent extraction of meso parameters. Computer tomography technology uses X-ray to penetrate the object to scan, which can collect the internal image of the structure without damaging the test piece or core sample. However, the image collected by computer tomography often presents the situation that the brightness of the cross-section center is dim and the outer side is bright. Therefore, a special ring segmentation algorithm is needed to reduce the segmentation error[1, 2]. The processing flow of digital image is shown in Figure 1.

![Processing flow chart of digital image](image)

3. Uniformity evaluation index
There are many methods and indexes of asphalt mixture uniformity evaluation based on digital image processing technology, but it is found that the composition of uniformity index is usually based on the difference of aggregate quantity (aggregate area), aggregate position, aggregate cumulative area ratio, the difference of asphalt mixture composition in a certain area, the rotational inertia of aggregate to coordinate axis, the width and depth of the macro texture between the aggregates[3]. At the same time, fractal theory can be used to quantitatively evaluate the uniformity of asphalt mixture[4]. The advantages of these methods and the problems to be solved are described by listing several current mainstream uniformity evaluation methods based on digital image processing technology.

3.1 Uniformity evaluation based on static moment theory
There are many factors that affect the uniformity of asphalt mixtures, among which the area and distribution location of the aggregate are extremely important factors. Sha[5] analyzed the aggregate movement characteristics of the asphalt mixture during the rolling process and found that the fine aggregate has little effect on the uniformity, while the coarse aggregate has a great effect on the uniformity. Therefore, literature[6-9] filtered out finer aggregates according to the grade of aggregates, and concentrated on coarse aggregates for uniformity evaluation. The core idea is the static moment theory, which is the product of the aggregation area and the distance from the aggregation center to the coordinate axis, as shown in Figure 2.

![static moment diagram](image)

The method combines two micro parameters of aggregate area and aggregate location, which can effectively reflect the aggregate distribution in asphalt mixture. Table 1 lists a number of uniformity evaluation indexes derived from moment of static theory.
Table 1. Evaluation index of asphalt mixture uniformity based on static moment theory.

| Researchers            | Research content                                                                 | Research results                                                                                                                                 |
|------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Huang Zhifu, Zhao Yi[6]| Take AC-20 asphalt mixture 9.5~26.5mm aggregate as the main research object, and establish the uniformity evaluation index. | The static distance difference of each grade of aggregate to the X axis and Y axis, the static distance difference between the area and the original center, and Self-distance difference as a segregation index for judging asphalt mixture |
| Zeng Sheng, Liang Naixing[7], Wei Yu[9] | Taking the aggregate of AC-25 asphalt mixture over 9.5mm as the main research object, the uniformity evaluation index is established. | Based on the four-side static moment theory, the standard deviation of the four-side static moment is used as the uniformity evaluation parameter, and the most unfavorable moment standard is analyzed. |
| Zhao Yi, Liang Naixing[8] | Taking the coarse aggregates of AC-13 and AC-25 asphalt mixture as the main research object, the uniformity evaluation index is established | The digital image evaluation method and standard of asphalt concrete uniformity based on the variability of the four-sided static moments are established. Use the coefficient of variation of static moment as an index to evaluate the uniformity of digital images of asphalt concrete |

3.2 Evaluation of uniformity based on the number and location of regional aggregates

The number and location of aggregates are important parameters for evaluating the uniformity of asphalt mixtures, and are widely used as indicators for evaluating the uniformity of asphalt mixtures. Literature[10-14] established the overall uniformity evaluation index from a single horizontal section uniformity evaluation index to a mixed sample or core sample according to the depth of research. At the same time, influencing parameters such as gradation coefficient $\eta$ and aggregate area ratio $k$ are introduced to correct the uniformity index. Table 2 lists the uniformity evaluation indicators based on the number and location of regional aggregates.

Table 2. Uniformity evaluation indicators based on the number and location of regional aggregates.

| Researchers          | Research content                                                                 | Research results                                                                                                                                 |
|----------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Peng Yong, Sun Lijun, Yang Yuliang[10] | The uniformity of a single horizontal section of the asphalt mixture | The deviation rate $r$ between the centroid coordinate of aggregate at the same gear and the geometric center of cross-section and the relative standard deviation $\nu'$ of aggregate distribution quantity in 4 equal areas are established. |
| Peng Yong, Sun Lijun, Dong Ruikun[11] | Uniformity of Single Horizontal Section of Asphalt Mixture Specimen | The distribution quantity of aggregates of the same grade in 4 areas of equal area was studied, and the quantity distribution index $t$ was proposed to replace the relative standard deviation of the distribution quantity $\nu'$ |
| Peng, Y.,Sun, L. J.[13] | Overall uniformity of asphalt mixture specimens | On the basis of the above research, the overall uniformity evaluation index of the asphalt mixture in the horizontal section direction and the vertical section direction is established |
3.3 Evaluation of uniformity based on the moment of inertia method

This method is suitable for evaluating the uniformity of asphalt pavement core samples and asphalt mixture specimens. By rotating the specimen cross section, the moments of inertia of the aggregates of each gear relative to the coordinate axis are obtained, and the moments of inertia are compared. The difference is used to quantitatively analyze the homogeneity of the asphalt mixture, and the moment of inertia is shown in Figure 3.

![Figure 3. Schematic diagram of moment of inertia.](image)

Literature[16, 17] studied the uniformity of asphalt mixture distribution by the moment of inertia method. Table 3 lists the methods for evaluating the homogeneity of asphalt mixtures through the moment of inertia.

| Researchers               | Research content                                                                 | Research results                                                                 |
|---------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Chen Hua, Ying Hong[15]  | Establish the uniformity evaluation index of asphalt mixture based on the moment of inertia | Several uniformity evaluation parameters are proposed, such as the average value C and variance D of the moment of inertia, and the area A enclosed by the half-period curve of the moment of inertia and the coordinate axis. |
| Jiu peng Zhang, Huan jiao Liu[16] | Evaluate the horizontal and vertical uniformity of asphalt mixture specimens | Established a method for evaluating the uniformity in the horizontal direction by calculating the moment of inertia $I_x$ on the X axis and a method for evaluating the uniformity in the vertical direction by the centroid statistical index $S_a$. |

3.4 Evaluation of uniformity based on area method

The area method is also a commonly used method for evaluating the homogeneity of the mixture. This method divides the section of the asphalt mixture sample or the section of the asphalt pavement core sample into several equal areas. The difference in the cumulative sum or the difference in the cumulative area of the aggregate in the area of the area reflects the uniformity of the asphalt mixture. Li Zhi[17] et al. divided the cross-section of the specimen into 24 sectors with a scanning angle of 15°, as shown in Figure 4.
Calculate the proportion of aggregate cumulative area in 24 fan-shaped regions, evaluate the uniformity of the cross-section in the horizontal direction through the area ratio $S$ and the standard deviation of the horizontal area ratio $U$, and then use the standard deviation of the area ratio $V$ between the cross-sections to evaluate the vertical uniformity of the cross-section.

4. Conclusion

Through the introduction of the above-mentioned image processing technology and the list of uniformity indicators, it can be seen that the application of digital image processing technology to the uniformity detection and evaluation of asphalt mixtures can assist the artificial visual recognition method to quantify the uniformity of the mixture and reduce the subjective defect of manual evaluation. At the same time, it can directly rely on the composition of the mixture to evaluate the homogeneity, which is unmatched by traditional methods. Compared with the emerging detection technology, it also has the advantage of almost unlimited conditions. Based on these advantages, the use of digital image processing technology to detect and evaluate the uniformity of asphalt mixture has a good development prospect, but there are also the following shortcomings:

1) When the asphalt mixture is converted from a three-dimensional structure to a two-dimensional plane, its volume composition parameters cannot be completely reflected on the two-dimensional image, that is, a considerable part of the authenticity is lost.

2) The current research on uniformity is mainly concentrated on aggregates, and there are few studies involving the influence of other components of the mixture on uniformity.

3) There are few indicators for evaluating the overall uniformity of the asphalt pavement core sample. A single cross-section cannot represent the overall uniformity. Some of the overall uniformity indicators established cannot effectively and accurately reflect the overall uniformity of the mixture, which is more different from the actual uniformity.

4) There are many types of uniformity evaluation indexes, and the evaluation accuracy of different indexes also differ greatly. Image detection cannot completely replace traditional detection methods.

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