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Research on Morphology and Quality Inspection of *Panax Notoginseng* Main Roots Based on Machine Vision

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Abstract：As for the current sorting method of *Panax notoginseng* main root market, most of them use manual visual inspection for sorting, and this method has strong subjectivity, which consumes manpower and material resources, and the detection results are also unstable. This project uses MATLAB image processing technology to sort the shape and fullness of the main roots of *Panax notoginseng*. The orthogonal projection images of the main roots of *Panax notoginseng* are collected, and MATLAB image processing technology is used to preprocess the images, extracting parameters such as the horizontal axis, vertical axis, perimeter, and image area. An electronic scale is used to weigh the mass of individual *Panax notoginseng* roots, calculate their roundness, axial length ratio, and fullness, in order to determine whether the shape and quality of the main roots of *Panax notoginseng* are intact. The method adopted in this project can sort out higher quality *Panax notoginseng* main roots, improve sorting efficiency, eliminate subjective factors of manual sorting, and provide invaluable assistance towards the prospective deployment of an automated method for sorting Panax notoginseng primary roots, utilizing cutting-edge machine vision technology.

Keywords: Roundness; Axial Length Ratio; Shape; Fullness

1. Introduce

Panax notoginseng is a precious traditional Chinese medicinal herb that serves as a key constituent in several well-known medicines, including Yunnan Baiyao, Compound Danshen Tablets, and Zhangzhou Pien Tze Huang[1,2]. For this traditional herb, medicinal potency is highly dependent on the shape and turgidity of its taproot. As the market for Chinese medicinal materials expands and the demand for automated processing intensifies, developing an automated system for sorting *Panax notoginseng* taproots has become a research imperative.

The application of computer vision for agricultural product grading is well-established. Researchers have leveraged MATLAB-based techniques to develop robust grading models: for example, a BP neural network for defective chestnuts (91.67% accuracy) [3], an LSSVM for walnut quality (89.76% accuracy)[4], and a feature-based system for goji berry quality visualization[5]. Advanced methods, such as chromaticity analysis by D.J. Lee[6] and a 2D/3D RBF-SVM model for tomatoes by Innocent Nyalala (96.94% accuracy)[7], have further pushed the boundaries of accuracy and complexity. However, this body of work has not adequately addressed the grading of *Panax notoginseng* main roots. A critical limitation of existing MATLAB-based sorting strategies is their reductionist approach, which isolates shape as the primary classification criterion. This oversight neglects the intrinsic link between the root's geometric proportions (i.e., the ratio of transverse to longitudinal diameters) and its quality, and fails to account for fullness—a key indicator of medicinal value. The upgrading of fruit and vegetable sorting technology is essential for improving post-harvest processing efficiency and product quality. Liu Jun et al. provided a comprehensive review of the current status and development trends of sorting equipment, pointing out that the integration of artificial intelligence with machine vision, near-infrared spectroscopy analysis for internal quality, and flexible robotic arm gripping are the recent research hotspots, offering important references for technological upgrades [8]. To address the high costs of existing systems, Zhao Fangzhi et al. proposed a low-cost, edge-based fruit sorting system implemented on an FPGA platform. They innovatively defined a multi-feature recognition pattern (ZWM) and constructed a recognition system integrating multi-feature vectors such as color, shape, and damage degree, achieving synchronous fruit classification and grading [9]. Xu Hu et al. (2024) designed an automatic sorting system based on machine vision using apples as test samples; by combining color grading via HSV transformation and size measurement via Canny edge detection and the minimum circumferential circle method, they effectively improved sorting accuracy and automation levels [10]. Furthermore, Liu Xingwei et al. adopted a ResNet-18 deep residual network to address issues of low recognition accuracy and long processing times, validating the significant advantages and application value of deep learning in enhancing the intelligence and real-time performance of sorting systems [11]. In response to this limitation, the present work develops and validates a comprehensive sorting technology on the MATLAB platform. By jointly analyzing shape and fullness, this study aims to significantly augment the accuracy, effectiveness, and efficiency of automated sorting for premium *Panax notoginseng* main roots.

2. Materials and Methodology

2.1 Sample Acquisition

The dataset consisted of *Panax notoginseng* main roots obtained from the Yanshan County market in Wenshan, Yunnan. The samples were categorized into four groups: 16 standard fusiform roots, 16 standard nodular roots, 20 premium-quality roots, and 16 substandard-quality roots.

2.2 Methodology

2.2.1 Data acquisition protocol

A controlled acquisition environment was established to eliminate extraneous variables, featuring consistent illumination and a uniform backdrop. Image data was captured using a smartphone (4K/60 fps) set to 4K resolution to ensure high-fidelity visual information. Each root's mass was quantified using a precision electronic scale (±0.1 g). A dataset was then compiled, wherein each image was tagged with its respective ground-truth mass for later processing and model validation.

2.2.2 Image preprocessing pipeline

The raw image data was subjected to a preprocessing pipeline implemented in the MATLAB Image Processing Toolbox. The pipeline comprised the following sequential stages: grayscale conversion, image binarization, morphological filtering, subject isolation, and contour extraction. The objective of this pipeline was to mitigate artifacts and background noise, maximize the signal-to-noise ratio for feature extraction, and ultimately isolate the salient morphological attributes of the *Panax notoginseng* main roots. The complete workflow is depicted in Figure 1. Representative outputs of the subject isolation and contour extraction stages are illustrated in Figures 2 and 3.

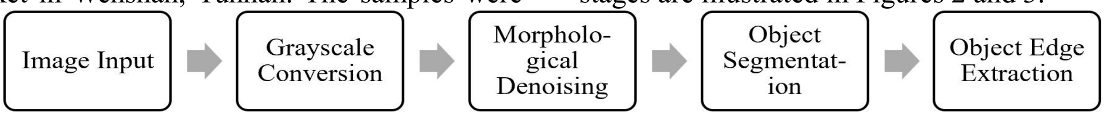

Figure 1. Image Preprocessing Flowchart

Figure 2. Object Segmentation Image

Figure 3. Object Edge Extraction

2.2.3 Feature extraction

To quantitatively characterize the *Panax notoginseng* main roots, a comprehensive set of features was extracted from their orthographic projections and physical measurements. These features include geometric properties (length, width, perimeter, projected area, circularity, and axis-length ratio) and physical mass. Two primary parameters were defined: circularity and axis-length ratio for morphological classification, and the mass-to-area ratio as an index of fullness.

2.3 Circularity Analysis

Circularity is utilized as a dimensionless shape index to quantify the proximity of the root's two-dimensional projection to an ideal circle. It is computed from the perimeter and area according to Equation (1):

$$C = 4\pi M/N^2 \quad (1)$$

Here, N represents the perimeter of the extracted contour, M is the area enclosed by that contour, and C is the calculated circularity. To standardize the interpretation, the circularity of a perfect circle is set as the reference value of 1 (Figure 4). Therefore, the deviation of a root's calculated circularity from 1 provides a direct measure of its non-circularity; values closer to 1 indicate a shape consistent with a root-tuber morphology.

Figure 4. Proximity of the *Panax Notoginseng* Main Root to a Circle

2.4 Axis-Length Ratio Analysis

The axis-length ratio is employed as a secondary morphological descriptor to classify the shape of the *Panax notoginseng* main root. This parameter is quantified by enclosing the root's image within its minimum bounding rectangle. In this framework, H denotes the length of the rectangle's major axis (horizontal dimension), D represents the length of its minor axis (vertical dimension), and L is the resulting axis-length ratio, as formulated in Equation (2):

$$L = H/D \quad (2)$$

The axis-length ratio for each individual root was computed by applying this formula to the dimensions of its respective bounding rectangle. As illustrated in Figure 5, a greater disparity between the lengths of the bounding rectangle's axes signifies a root morphology that is increasingly fusiform (spindle-shaped).

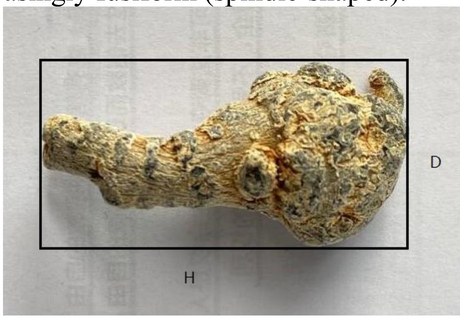

Figure 5. Rectangularity of the *Panax Notoginseng* Main Root

Based on the physical principle of constant material density for *Panax notoginseng*, the average thickness of the root serves as a direct indicator of its fullness. Consequently, the ratio of its mass to its projected image area is directly proportional to its average thickness. This study leverages the fullness metric to classify the quality of *Panax notoginseng* main roots, with the core task being to identify a critical threshold that demarcates high-quality from low-quality samples—a value to be determined experimentally. To empirically establish this critical threshold, an extensive experimental campaign was conducted. The protocol involved an initial manual classification of the samples into a high-quality cohort (n=20) and a low-quality cohort (n=16). Representative images from these two cohorts are presented in Figure 6 and Figure 7, respectively. Subsequently, the fullness index for each sample was calculated, and a rigorous data analysis was performed to pinpoint the optimal threshold value that effectively separates the two quality grades.

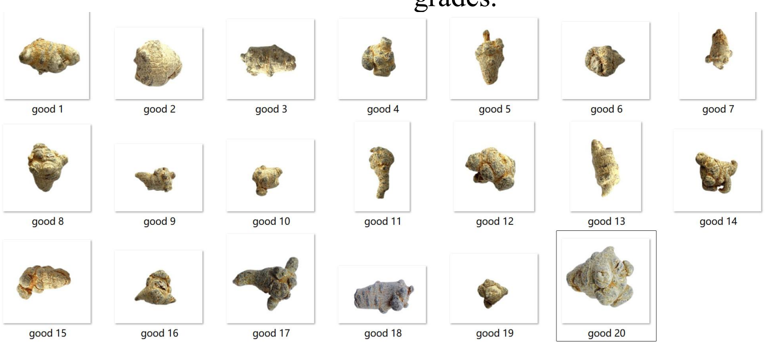

Figure 6. Image of a High-Quality *Panax notoginseng* Main Root

Figure 7. Image of a Low-Quality *Panax notoginseng* Main Root

The fullness of the *Panax notoginseng* main root is quantified by the ratio of its mass (m) to its projected image area (S). The experimental findings are tabulated in Tables 1 and 2, and the calculation is formulated as Equation (3):

$$P = m/S \quad (3)$$

As detailed in Table 1, analysis of the high-quality cohort (n=20) reveals that the measured fullness values ranged from a minimum of 5.57×10^{-5} to a maximum of 9.66×10^{-5}.

Table 1. Fullness of High-Quality *Panax Notoginseng* Main Roots

No	Mass(g)	Image Area(pixels^2)	Fullness Value
1	6.5	79277	8.20×10^{-5}
2	7.5	86865	8.63×10^{-5}
3	5.6	67084	8.35×10^{-5}
4	5.6	67471	8.30×10^{-5}
5	5.5	74569	7.37×10^{-5}
6	5.9	105149	5.61×10^{-5}
7	4.2	74426	5.57×10^{-5}
8	5.4	89717	6.02×10^{-5}
9	5.6	68147	8.22×10^{-5}
10	4.7	59187	7.94×10^{-5}
11	5.6	80909	6.92×10^{-5}
12	4.9	50713	9.66×10^{-5}
13	5.3	86256	6.14×10^{-5}
14	5.8	81029	7.16×10^{-5}
15	7.3	84943	8.59×10^{-5}
16	7.5	83696	8.96×10^{-5}
17	7.9	84563	9.34×10^{-5}
18	5.3	73501	7.21×10^{-5}
19	4.9	88246	5.57×10^{-5}
20	6.5	96530	6.73×10^{-5}

As detailed in Table 2, analysis of the low-quality cohort (n=16) reveals that the measured fullness values ranged from a minimum of 3.90×10^{-5} to a maximum of 5.50×10^{-5}. A comparative analysis of the data in Tables 1 and 2 indicates a distinct demarcation: the majority of high-quality samples exhibit fullness values exceeding 5.5×10^{-5}, whereas their low-quality counterparts predominantly cluster at or below this threshold. This empirical observation leads to the preliminary determination of a critical fullness threshold of 5.5×10^{-5}. Therefore, it is empirically validated that the calculated average thickness serves as a robust proxy for the fullness characteristic, enabling a subsequent classification of the root's overall quality.

Table 2. Fullness of Low-Quality *Panax Notoginseng* Main Roots

No	Mass(g)	Image Area(pixels^2)	Fullness Value
1	5.0	93761	5.33×10^{-5}
2	6.9	126765	5.44×10^{-5}
3	4.6	99397	4.63×10^{-5}
4	7.5	138908	5.40×10^{-5}
5	3.9	99953	3.90×10^{-5}
6	4.0	91327	4.38×10^{-5}
7	6.5	139220	4.69×10^{-5}
8	6.9	164779	4.19×10^{-5}
9	4.8	106305	4.52×10^{-5}
10	8.6	190137	4.52×10^{-5}
11	6.4	138911	4.60×10^{-5}
12	7.5	164218	4.57×10^{-5}
13	6.5	125870	5.16×10^{-5}
14	7.7	141423	5.44×10^{-5}
15	5.6	118676	4.72×10^{-5}
16	6.2	112559	5.50×10^{-5}

3. Analysis of Shape and Fullness Classification

3.1 Shape Classification

Shape classification is performed based on the circularity metric ©, which quantifies the root's proximity to a circular form. A value of C approaching 1 signifies a high degree of similarity to a circle; thus, the sample is classified as root-tuber-shaped. Conversely, a lower C value indicates a fusiform (spindle-shaped) morphology. The corresponding quantitative results summarized in Table 3.

The axis-length ratio is utilized to quantify the root's similarity to a fusiform shape. The classification logic dictates that a root is considered fusiform if its L value exceeds 1.2. Furthermore, the magnitude of L is directly proportional to the degree of fusiformity; a larger L value signifies a shape more closely resembling a spindle. Conversely, roots not meeting this criterion are categorized as root-tuber-shaped. The corresponding experimental results tabulated in Table 4.

Table 3. Experimental Classification Results for Root-Tuber-Shaped *Panax Notoginseng* Main Roots

No	Feature	Axis-Length Ration	Circularity	Method Judgment
1	Root-Tuber-Shaped	1.0278	0.7987	Root-Tuber-Shaped
2	Root-Tuber-Shaped	1.1611	0.7648	Root-Tuber-Shaped
3	Root-Tuber-Shaped	1.0763	0.8515	Root-Tuber-Shaped
4	Root-Tuber-Shaped	1.0156	0.8665	Root-Tuber-Shaped
5	Root-Tuber-Shaped	1.1853	0.8354	Root-Tuber-Shaped
6	Root-Tuber-Shaped	1.1308	0.7435	Root-Tuber-Shaped
7	Root-Tuber-Shaped	0.1527	0.7126	Root-Tuber-Shaped
8	Root-Tuber-Shaped	1.1808	0.7257	Root-Tuber-Shaped
9	Root-Tuber-Shaped	1.0617	0.7161	Root-Tuber-Shaped
10	Root-Tuber-Shaped	1.1362	0.7619	Root-Tuber-Shaped
11	Root-Tuber-Shaped	0.8965	0.9019	Root-Tuber-Shaped
12	Root-Tuber-Shaped	1.1593	0.8309	Root-Tuber-Shaped
13	Root-Tuber-Shaped	1.1199	0.7139	Root-Tuber-Shaped
14	Root-Tuber-Shaped	1.1679	0.7929	Root-Tuber-Shaped
15	Root-Tuber-Shaped	1.0046	0.7596	Root-Tuber-Shaped
16	Root-Tuber-Shaped	1.0162	0.7680	Root-Tuber-Shaped

Table 4. Experimental Classification Results for Fusiform *Panax Notoginseng* Main Roots

No	Feature	Horizontal Axis(pixels)	Vertical Axis (pixels)	Axis-Length Ratio	Method Judgment
1	Fusiform	548	355	1.5437	Fusiform
2	Fusiform	1322	589	2.2445	Fusiform
3	Fusiform	618	366	1.6885	Fusiform
4	Fusiform	587	300	1.9567	Fusiform
5	Fusiform	624	288	2.1667	Fusiform
6	Fusiform	658	282	2.3333	Fusiform
7	Fusiform	479	269	1.7807	Fusiform
8	Fusiform	504	334	1.5090	Fusiform
9	Fusiform	407	251	1.6212	Fusiform
10	Fusiform	384	235	1.6340	Fusiform
11	Fusiform	430	256	1.6797	Fusiform
12	Fusiform	399	289	1.3806	Fusiform
13	Fusiform	391	251	1.5578	Fusiform
14	Fusiform	476	256	1.8594	Fusiform
15	Fusiform	481	268	1.7948	Fusiform
16	Fusiform	447	286	1.5629	Fusiform

3.2 Morphological Analysis

A detailed morphological analysis of the *Panax notoginseng* main roots was conducted utilizing the MATLAB platform. The experimental protocol involved an initial dataset of 16 root-tuber-shaped and 16 fusiform main roots. To validate the robustness and accuracy of the classification model, an additional validation set comprising 16 randomly selected roots of varying morphologies was incorporated, with representative images presented in Figure 8. This validation set was first subjected to manual classification by human experts, which yielded a ground-truth distribution of 7 root-tuber-shaped and 9 fusiform samples. These samples were then pooled to form a composite test set for evaluation. The experimental results conclusively demonstrate that the proposed methodology, which relies on the extraction and analysis of key morphological features, can effectively discriminate between the different root shapes. In comparison to conventional manual sorting, the proposed algorithm not only substantially enhances operational efficiency but also yields a higher degree of classification accuracy. The comprehensive results for this validation experiment are summarized in Table 5.

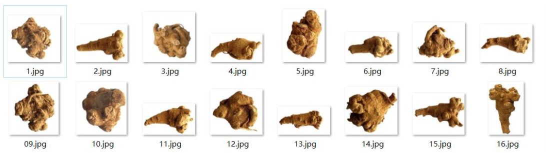

Figure 8. Randomly Selected Sample Images

Table 5. Experimental Shape Classification Results for Randomly Selected *Panax Notoginseng* Main Roots

No	Manual Judgment	Axis-Length Ratio	Circularity	Method Judgment
1	Root-Tuber-Shaped	1.0222	0.8057	Root-Tuber-Shaped
2	Fusiform	1.5559	0.5529	Fusiform
3	Root-Tuber-Shaped	1.0766	0.8483	Root-Tuber-Shaped
4	Fusiform	1.8369	0.2265	Fusiform
5	Fusiform	1.1823	0.6542	Root-Tuber-Shaped
6	Fusiform	1.7562	0.3516	Fusiform
7	Root-Tuber-Shaped	1.1456	0.6675	Root-Tuber-Shaped
8	Fusiform	1.8295	0.1474	Fusiform
9	Root-Tuber-Shaped	0.8956	0.9852	Root-Tuber-Shaped
10	Root-Tuber-Shaped	0.9653	0.9756	Root-Tuber-Shaped
11	Fusiform	1.7856	0.3412	Fusiform
12	Root-Tuber-Shaped	1.0265	0.7562	Root-Tuber-Shaped
13	Fusiform	1.7425	0.2653	Fusiform
14	Root-Tuber-Shaped	1.1167	1.7755	Root-Tuber-Shaped
15	Fusiform	1.8453	0.2589	Fusiform
16	Fusiform	1.7985	0.3115	Fusiform

3.3 Fullness Analysis

The quantitative analysis of fullness represents another pivotal aspect in realizing intelligent sorting. This is accomplished by computing the fullness metric for each root sample and subsequently comparing it against the predefined critical threshold. The classification logic dictates that a sample is designated as high-quality if its computed fullness exceeds this threshold, and is classified as low-quality if it falls below.

In summary, within the context of this research on MATLAB-based sorting technology for the shape and fullness of *Panax notoginseng* main roots, the precise analysis of fullness emerges as another pivotal component. Through the quantification of fullness and its incorporation as a key classification metric, the system facilitates a more precise and efficient intelligent sorting paradigm for *Panax notoginseng* main roots.

4. Performance Analysis

4.1 Method Evaluation

A validation experiment was conducted using a randomly selected subset of 16 orthographic projection images, comprising 8 standard root-tuber-shaped, 8 standard fusiform, 10 high-quality, and 6 low-quality samples. The experimental results indicate that the proposed method can accurately classify both the shape and quality of the roots. In contrast to conventional manual methods, this approach significantly reduces sorting time and enhances operational efficiency. Within this test set, the sorting accuracy of the proposed method markedly surpasses that of traditional manual sorting, thereby affirming its practical feasibility.

4.2 Accuracy Assessment

Experimental data reveals that within a defined operational scope, the conclusions drawn by the proposed method align with those of conventional approaches for assessing standard root morphology and quality, thus validating the feasibility of the proposed discriminative methodology. The empirical results further demonstrate that this method accurately identifies root shape and quality while offering a reduction in sorting time and an improvement in efficiency compared to traditional techniques. Through repeated trials and cross-validation experiments on this 16-sample set, the method achieved an accuracy exceeding 90%. Consequently, the screening precision of this method is demonstrably superior to that of traditional manual sorting, further corroborating its enhanced accuracy.

5. Conclusion

This study has demonstrated a method for evaluating the shape of *Panax notoginseng* main roots by analyzing the circularity and axis-length ratio of their orthographic projections. The results indicate that for samples with more regular morphologies, the method achieves precise shape classification. Furthermore, in the assessment of fullness, it effectively discriminates between premium and substandard quality. Extensive experimentation was performed to validate the efficacy and accuracy of the proposed sorting technology. The experimental results confirm that the sorting technology for shape and fullness, developed using MATLAB's image processing capabilities, is both reliable and highly efficient. It is fully capable of performing the required sorting tasks, providing a robust and accurate means of identifying both the shape and quality of *Panax notoginseng* main roots.

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