Terahertz Time Domain Hyperspectral Imaging for Rapid and Non-destructive Classification among Ginseng Species

Yang Research Group

Advisor: Prof. Shang-Hua Yang **Group: A499** **Group Member: Chih-Ling Kuo**

NATIONAL TSING HUA UNIVERSITY

Introduction

Panax ginseng (Asian ginseng) and Panax quinquefolius (American ginseng) are widely used in traditional Chinese medicine (TCM) .Despite taxonomic similarities, they differ in TCM classification—AsG is "warm" and AmG is "cool"—leading to distinct clinical applications [1].

Traditional [2]
- morphological inspection
- sensory evaluation

✗ lack reliability for processed form

Analytical techniques [3]
- gas chromatography-mass spectrometry
- high-performance liquid chromatography

✗ destructive sample preparation
✗ limit in laboratory settings

Optical spectroscopy [4]
- Raman and Fourier-transform infrared spectroscopy

✗ sensitivity to sample opacity
✗ the need for homogenized samples

Terahertz Imaging
- Terahertz Time Domain Hyperspectral Imaging

✓ reduce preprocessing time
✓ non-destructive

Result

A. Experimental Setup

- Terahertz Time Domain Hyperspectral Imaging (THz-HSI) measurements were conducted using an Asynchronous Optical Sampling (THz-TDS) system (Fig. 1).
- The system used two lasers to enable single-shot waveform acquisition and a ginseng slice could be scanned within 15–20 minutes.

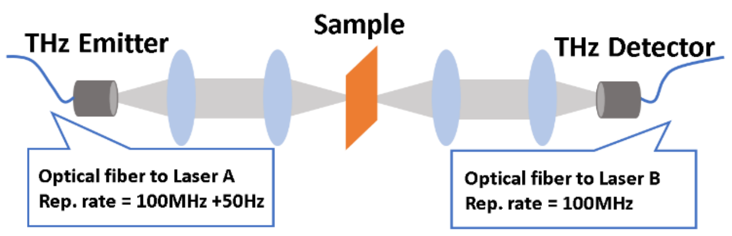

Fig. 1 An illustration of experimental setup of the THz-HIS experiment.

- Characteristic frequency can be selected for subsequent classification tasks, ensuring optimal contrast and feature extraction.

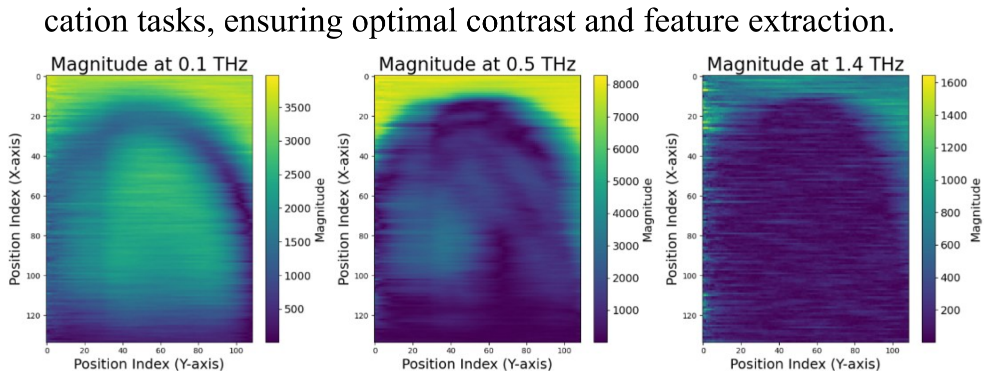

Fig. 2 the hyperspectral images of a ginseng slice at different frequencies.

B. Computation of Normalization

- The transmitted THz optical field is recorded as a time-domain wave-form$E(t)$; the spectral amplitude is $\bar{E}(\omega) = |F\{E(t)\}|$.
- Imaging data are structured into a 3D matrix, with spatial coordinates i, j and frequency dimension k.
- A normalization method (Eqn. 1) scales each pixel's spectrum to its maximum intensity.

$$\hat{E}^N = \left\{ \frac{\overline{E_{ij}}}{\max(\overline{E_{ij}})} \right\} \qquad \text{(Eqn. 1)}$$

- This normalization highlights relative spectral features rather than absolute amplitudes and compensates for sample inhomogeneities.
- Enhances visibility of intrinsic chemical signatures and suppresses physical artifacts, enabling more accurate discrimination [5].

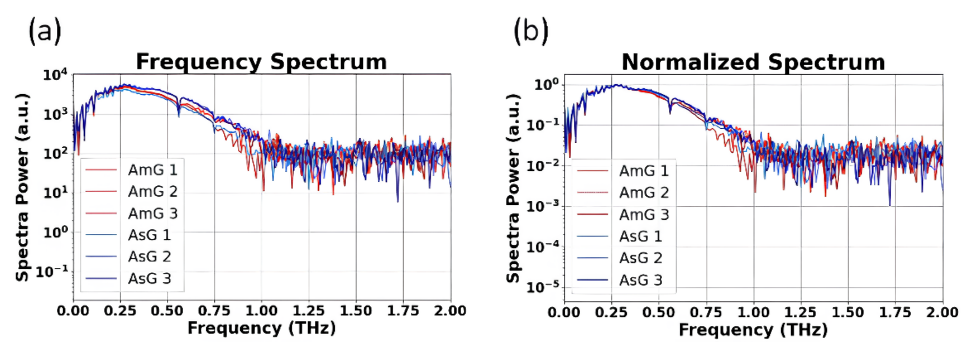

Fig. 3 Comparison and visualization of frequency spectra for multiple datasets (a) before and (b) after normalization.

C. Computation of Normalization

- An artificial neural network (ANN) is designed to classify two ginseng species (Fig. 4).
- Out of 12,250 total samples: 70% for training, 15% for vali-dation, 15% for testing.
- Training is optimized using back-propagation. Dropout regularization is applied to prevent overfitting.

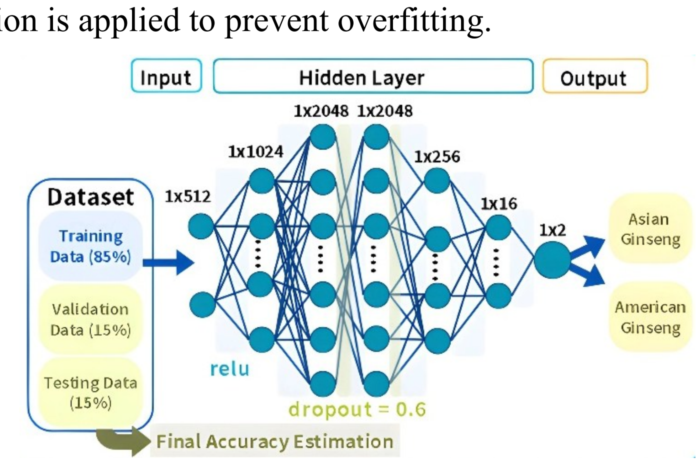

Fig. 4. An illustration of the ANN in this work for classification.

- Final classification performance is assessed on the test set.
- Results (Table 1) show the ANN accurately distinguishes between the two species.

Table1. Prediction accuracies of ANN

Prediction Scheme	Loss	Accuracy
0.2 ~ 1.2 THz	0.161	97.552%
0.2 ~ 3.0 THz	0.190	87.595%

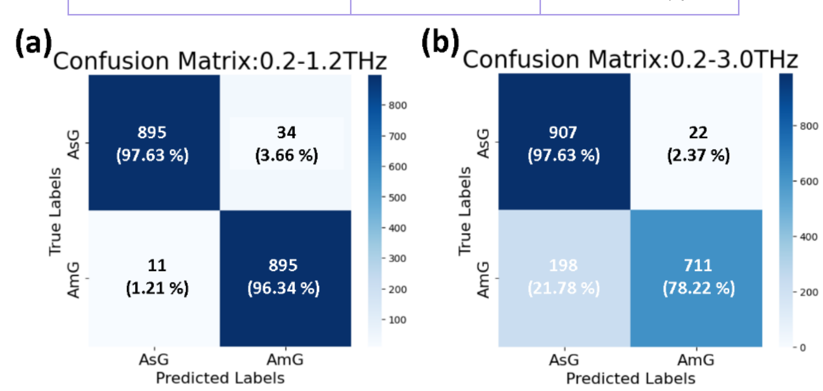

Fig. 5. Comparison and visualization of frequency spectra for multiple datasets (a) before and (b) after normalization

Conclusion

This study applies THz-SPI combined with deep learning to directly distinguish Panax ginseng and Panax quinquefolius from dried ginseng slices, bypassing destructive preprocessing. Innovations include a thickness-agnostic spectral normalization method to reduce sample inhomogeneity. A six-layer neural network trained on 12,250 spectral datapoints achieved 97.55% accuracy within the 0.2–1.2 THz range, with confusion matrices confirming robust classification. Compared to tablet-based methods, this approach significantly reduces preprocessing time, offering a scalable, non-destructive solution for rapid botanical authentication in pharmaceutical and food safety industries.

Yang Research Group

[1] C. F. Chen, W. F. Chiou, and J. T. Zhang, "Comparison of the pharmacological effects of *Panax ginseng* and *Panax quinquefolium*," *Acta Pharmacol. Sin.*, vol. 29, pp. 1103–1108, 2008.
[2] Z. Zhao et al., "Macroscopic identification of Chinese medicinal materials: Traditional experiences and modern understanding," *J. Ethnopharmacol.*, vol. 134, no. 2, pp. 556–564, 2011.
[3] S. H. Baek et al., "Recent methodology in ginseng analysis," *J. Ginseng Res.*, vol. 36, no. 2, pp. 119–134, 2012.
[4] Y. K. Kwon et al., "Discrimination of cultivation ages and cultivars of ginseng leaves using Fourier transform infrared spectroscopy combined with multivariate analysis," *J. Ginseng Res.*, vol. 38, no. 1, pp. 52–58, 2014.
[5] Martinez et al., "Chestnut quality classification by THz time-domain hyperspectral imaging combined with unsupervised learning analysis," Food Control, vol. 168, p. 110878, 2025.