Terahertz Spectroscopic Imaging and Unsupervised Analysis for Multidomain Non-Destructive Diagnostics

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Abstract: THz spectroscopic imaging combined with unsupervised learning was applied to food safety, environmental monitoring, protein identification and artistic stratigraphy, with planned extensions to pharmaceutical aging. The results demonstrate a unified, non-destructive framework capable of extracting structural, chemical and subsurface information with high sensitivity.

THz time-domain spectroscopy enables non-destructive access to structural and chemical features through its sensitivity to refractive index, absorption and layer interfaces. Its versatility spans heritage science, food inspection, environmental analysis and pharmaceuticals, with growing emphasis on coupling THz imaging with unsupervised machine learning to enhance the interpretation of complex datasets.

A multimodal THz framework combining spectroscopy, imaging and unsupervised learning was demonstrated across different application domains.

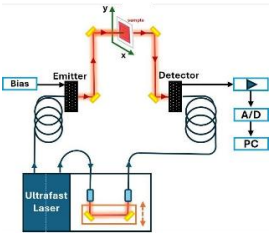

Fig.1 Experimental set up

- Fungal Infections in Chestnuts — Unsupervised machine learning applied to THz absorption features enabled the clustering of infected and healthy regions.
- Microplastics in Soil — Microplastics showed distinct THz spectral fingerprints, allowing correlation-based mapping of polymer distributions.
- Protein Identification — Ferritin, BSA, GFP and silica–protein composites exhibited characteristic signatures in the 0.2–0.5 THz band, separable via PCA and K-means.
- Underdrawings Detection — Graphite underdrawings beneath acrylic layers were revealed using complementary spectroscopic contrast and Pearson correlation.
- Pharmaceutical Aging — Planned analyses will monitor absorption-coefficient evolution to track binder degradation over time.

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