



A REVIEW OF POTENTIAL

HYPERSENSPECTRAL IMAGING (HSI) IN THE UV RANGE

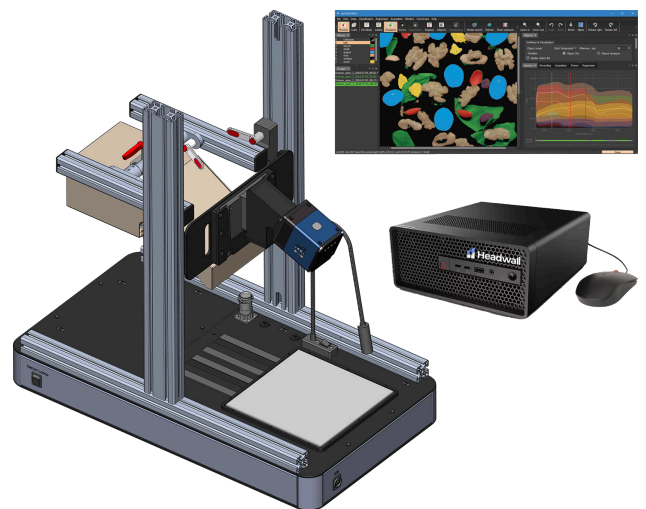
An Emerging Technique with Enormous Opportunities

ABSTRACT

Hyperspectral imaging (HSI) has evolved from a powerful tool in remote sensing to providing detailed spectral information about objects and surfaces for industrial use.

While traditional HSI systems primarily operate in the visible and near-infrared (VNIR) and shortwave infrared (SWIR) regions of the electromagnetic spectrum, recent advancements have enabled the development of HSI systems capable of capturing data in the ultraviolet (UV) range.

This review explores the potential applications of UV HSI across research, medical, and industrial fields, highlighting its unique capabilities, challenges, and future directions.



1. INTRODUCTION

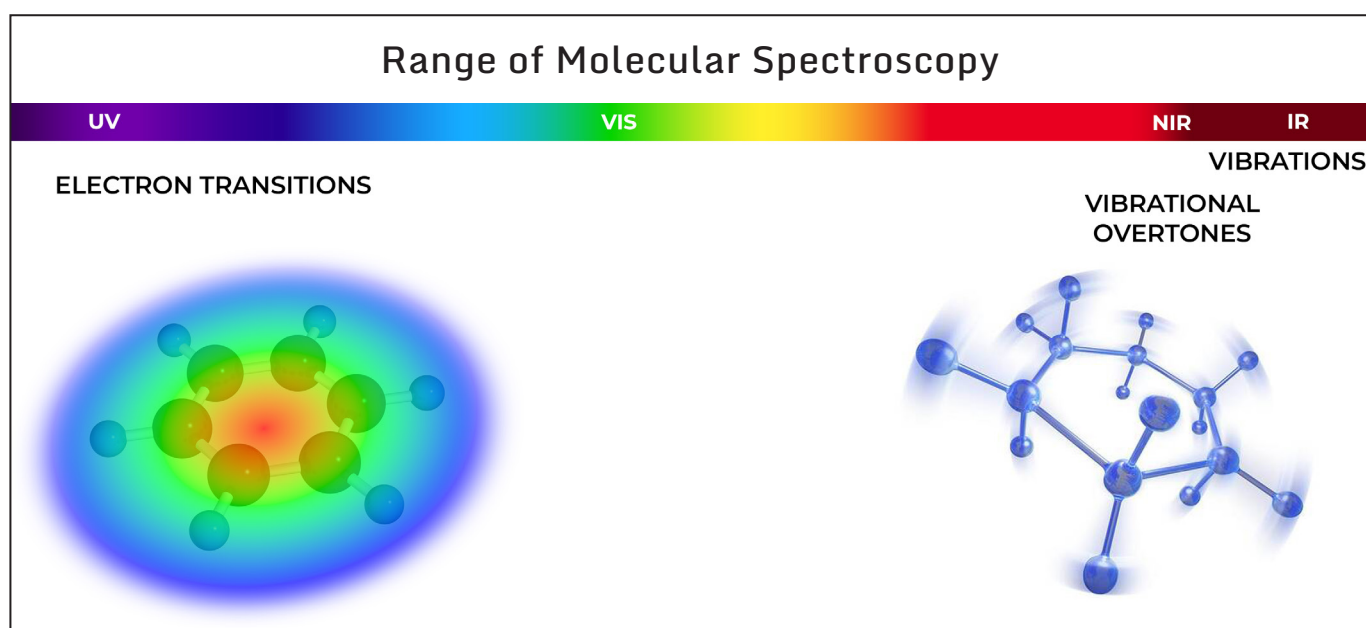
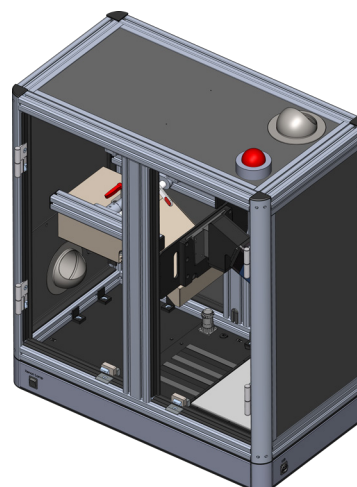
Hyperspectral imaging captures images at numerous contiguous spectral bands, providing detailed spectral information that allows for accurate identification and quantification of materials.

By analyzing spectral signatures, HSI systems have become invaluable tools in material analysis, process control, and pharmaceutical PAT.

Traditionally, HSI systems have been limited to the VNIR and SWIR regions. However, recent technological advancements have opened up the ultraviolet (UV) spectrum for HSI applications, particularly in fields that require high sensitivity to electron transitions.

The BlueEye UV HSI system, an **inno-spec GmbH** product featuring the BlueEye camera, safety enclosure and integrated illumination, sample stage, and ozone mitigation system, exemplifies these advancements by enabling researchers and industry professionals to explore previously inaccessible data in the UV range.

This paper provides an in-depth look at UV HSI applications, current technological challenges, and promising research areas for future exploration.



2. ADVANTAGES OF UV HYPERSPECTRAL IMAGING

UV hyperspectral imaging offers unique advantages due to its utilization of shorter wavelength and higher energy radiation compared to visible and infrared light:

- ▶ **Enhanced surface sensitivity:**
UV light penetrates less deeply than longer wavelengths, making it ideal for surface analysis and detecting surface contaminants or fine material details.
- ▶ **Sensitivity for electron transitions:**
While standard HSI technology at longer wavelengths mainly visualizes molecular vibrations, the UV range is particularly sensitive to electron transitions, making it highly valuable in studies of non-molecular substances such as minerals or semiconductors. In addition, materials containing certain molecular structures such as conjugated systems will show a unique spectral response in the UV range.

3. KEY FEATURES OF THE BLUEEYE UV HSI SYSTEM

The BlueEye UV HSI system is a groundbreaking development specifically designed for the UV range with unique applications. Extended tests have shown that it can be a valuable tool in the packaging industry by monitoring the curing process or composition of adhesives.

Moreover, UV hyperspectral imaging can be utilized in promising research areas, such as:

- Detecting coatings and contaminants on metal surfacesⁱ
- Analyzing active pharmaceutical ingredient (API) content in medicinesⁱⁱ
- Conducting tests on cultural heritage artifacts like archaeological finds or pigments in paintings, or natural science specimens such as insects and plants
- Identifying and grading cotton and other materials in the textile industryⁱⁱⁱ



Butterfly wings captured in the UV with BlueEye camera. © 2022 inno-spec GmbH.

According to customer reports following initial sales, it may even prove useful in environmental monitoring and industrial safety by detecting leakage of volatile compounds. These use cases underscore the versatility and high sensitivity of UV HSI, particularly for applications requiring precise surface or structural analysis.

4. CHALLENGES OVERCOME IN UV HSI TECHNOLOGY

Despite its promise, research lab and industrial UV hyperspectral imaging had faced several technical and practical challenges that have recently been addressed.

- The latest UV cameras have improved frame rates allowing a much more effective hyperspectral imaging system to be built.
- The broad-band line illumination suitable for a wide UV range used by the BlueEye UV HSI system by **inno-spec** focuses on the application at hand.
- UV light is hazardous and causes severe health implications, necessitating proper safety precautions against exposure to UV and ozone generated by the illumination. The **inno-spec** BlueEye UV HSI system features a safety enclosure that contains the UV radiation and also includes an ozone mitigation system.



Advances in UV camera technology have resulted in a next-generation BlueEye UV hyperspectral camera with faster frame rates suitable for integration into a research and commercial grade UV Hyperspectral Imaging System.

5. POTENTIAL APPLICATIONS OF UV HSI IN RESEARCH AND INDUSTRY

UV hyperspectral imaging is proving transformative across a variety of domains. The following sections highlight specific applications in research, medical fields, and industry.

5.1 Research Applications

UV HSI has high utility in research environments:

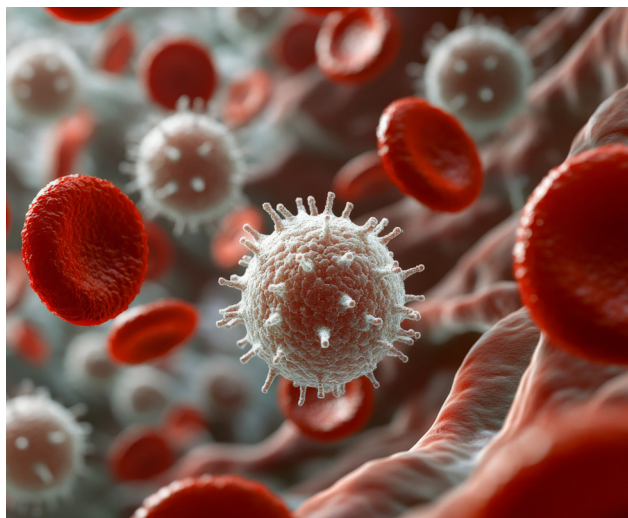
- ▶ **Protein analysis:**
Enabling monitoring of protein levels and detecting denaturation, important for biotechnology and pharmaceuticals.
- ▶ **Nanoparticle characterization:**
Assessing size, composition, and distribution, aiding applications in materials science and nanotechnology.
- ▶ **Enzyme activity or catalyst monitoring:**
Tracking kinetics, supporting research in biochemistry and engineering.
- ▶ **Photosynthesis research:**
Monitoring plant health and photosynthetic activity, informing agricultural and ecological studies.
- ▶ **Forensic analysis and cultural heritage:**
Non-invasive imaging for evidence preservation and artifact analysis.



Biochemistry and biotechnology research can benefit from UV HSI.

5.2 Medical Applications

In medical and clinical research, UV HSI offers significant potential due to its high sensitivity and ability to provide detailed biochemical information:



UV HSI can help with quality control in vaccine development.

- ▶ **Surgery monitoring:**
Assisting surgeons via biopsy to identify tissue types and boundaries with precision.
- ▶ **Drug screening:**
Aids in the drug development process by identifying molecular interactions, streamlining drug screening and discovery.
- ▶ **Vaccine development and quality control:**
Monitoring protein structures in vaccines, ensuring consistency and efficacy for public health safety.

5.3 Industrial Applications

UV HSI is widely applicable in various industrial settings, providing detailed insights that are crucial for quality control, contamination detection, and product evaluation:

- ▶ **Food composition analysis:**
Detecting key nutrient levels such as proteins, supporting quality control and nutritional analysis in the food industry.
- ▶ **Active pharmaceutical ingredient (API) monitoring:**
Tracking API distribution and level within pharmaceutical products, ensuring efficacy, quality control and consistency.
- ▶ **Metal surface analysis:**
Detecting oxides, contaminations or coatings in aerospace or automotive manufacturing with high-purity standards.
- ▶ **Material identification and grading:**
Applications in the textile industry, such as grading cotton and other materials.ⁱⁱⁱ



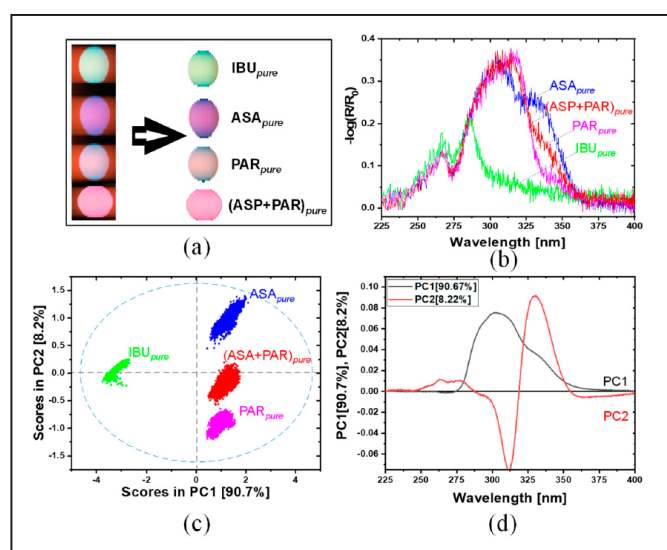
UV HSI can assist with API monitoring

6. CASE STUDY: ENSURING PHARMACEUTICAL QUALITY AND SAFETY

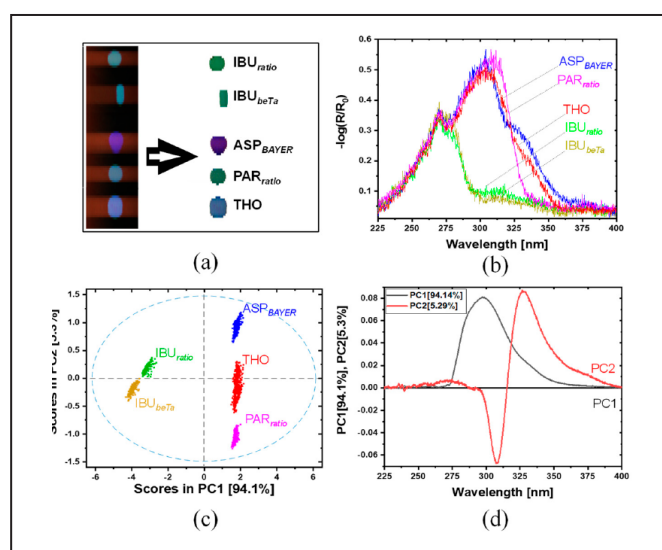
Hyperspectral UV imaging offers a powerful, non-destructive approach for rapid characterization of active pharmaceutical ingredients within pharmaceutical tablets. This method brings significant advantages for manufacturers, consumers, and regulatory bodies by ensuring that APIs are uniformly distributed, minimizing the risk of adverse effects and ensuring consistent drug efficacy.

In a recent study conducted by Reutlingen University in collaboration with the Institute of Physical and Theoretical Chemistry at Eberhard Karls University Tübingen, researchers utilized the **inno-spec** BlueEye camera for in-line API characterization in tablets. Their findings indicated that hyperspectral UV imaging “is a suitable technique for in-line measurements with the aim of a rapid real-time classification at a low cost.”

The study included two sample sets: one containing pure API (100%) and another comprising commercially available tablets. Results were cross-referenced with traditional liquid and solid phase analysis protocols, which are more labor-intensive and less suited for in-line monitoring.



The figures on the left show the results of hyperspectral UV imaging of the pure (100% API) drug samples.



The figures on the right show the results of hyperspectral UV imaging of the commercial tablets where the APIs have been identified.

Unlike traditional destructive testing methods, hyperspectral UV imaging preserves spatial information, enabling visualization of API distribution across the tablet surface.

7. FUTURE DIRECTIONS

To unlock the full potential of UV HSI for industry, ongoing research and development should focus on:

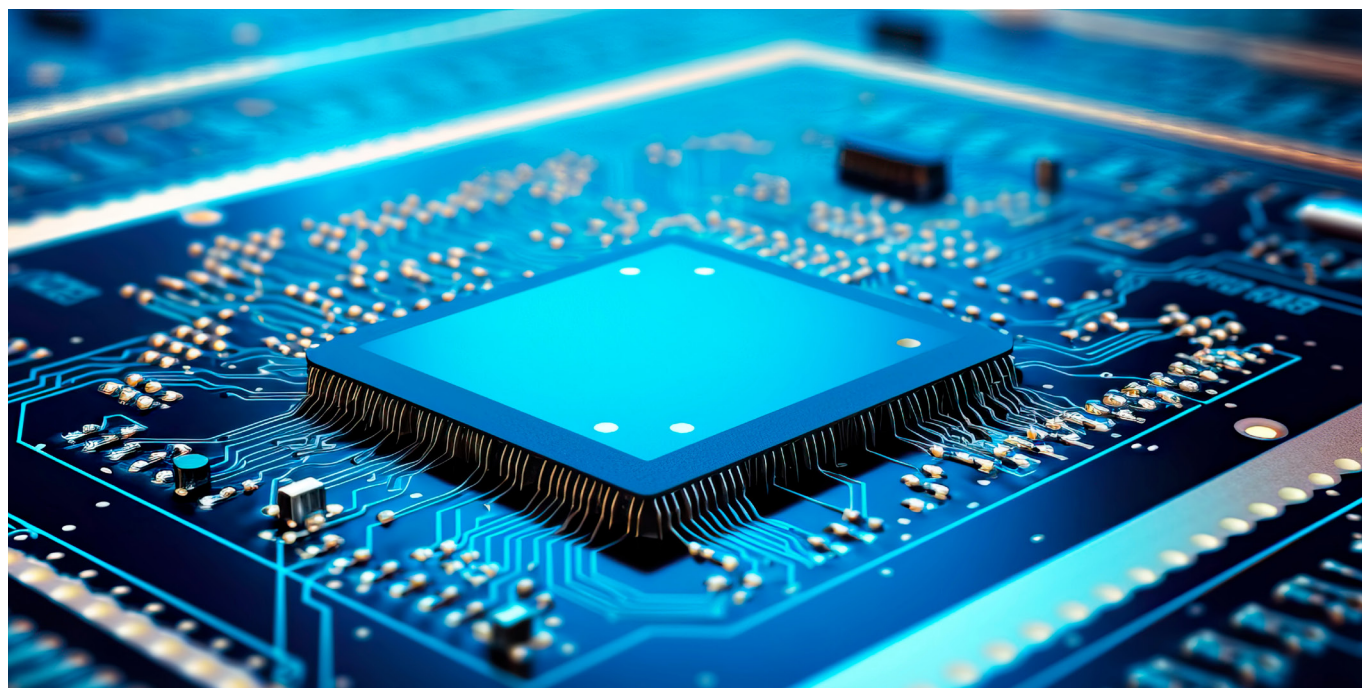
► **Sensor and detector development:**

Investments in developing high-sensitivity UV sensors have paid off with better spectral and spatial resolution to broaden the accessibility and applications of UV HSI. However, as mentioned in the Challenges section, investment in developing cameras with even higher frame rates would allow for process monitoring at even higher speeds.

► **Data processing algorithms:**

Algorithms need to be capable of counteracting various adverse process conditions including dust in the air that influences spectra, or changing light levels related to complex sample geometries, drifts, the presence of undesired contaminants, the chemical variability especially of natural products, varying surface morphologies and so on. This is a general challenge in HSI, not just in the UV range, and more advanced classification or regression algorithms will help increasing the predictive power of HSI systems in the future. The ever-increasing power of AI should also help in this regard. perClass Mira software for intuitive hyperspectral acquisition and analysis comes with the **inno-spec** benchtop UV HSI system, fulfilling multiple needs at once.

By addressing these challenges, researchers and developers can pave the way for more widespread adoption of UV HSI, opening even more avenues across scientific and industrial domains.



R&D into UV HSI is ongoing and should greatly expand its adoption across various applications.

8. CONCLUSION

UV hyperspectral imaging represents a promising frontier in research and industrial machine vision, offering unique capabilities by utilizing the UV spectrum. From surface contamination detection to analyzing material compositions beyond molecular analysis, UV HSI has applications across research, biomedical, and industrial fields.

Investment in UV HSI research and development will enable even broader applications and improve our understanding of material nuances, leading to innovations in material science, healthcare, environmental monitoring, and industrial quality assurance.

The BlueEye UV HSI system with the BlueEye hyperspectral camera offers a benchtop scanning system today for researchers who are investigating applications in the UV range.

ⁱ Al Ktash, M.; Stefanakis, M.; Englert, T.; Drechsel, M.S.L.; Stiedl, J.; Green, S.; Jacob, T.; Boldrini, B.; Ostertag, E.; Rebner, K.; et al., UV Hyperspectral Imaging as Process Analytical Tool for the Characterization of Oxide Layers and Copper States on Direct Bonded Copper, *Sensors* 2021, 21, 7332. <https://doi.org/10.3390/s21217332>

ⁱⁱ Characterization of Pharmaceutical Tablets Using UV Hyperspectral Imaging as a Rapid In-Line Analysis Tool, Al Ktash, M.; Stefanakis, M.; Boldrini, B.; Ostertag, E.; Brecht, M., *Sensors* 2021, 21, 4436. <https://doi.org/10.3390/s21134436>

ⁱⁱⁱ Ultraviolet-visible / near infrared spectroscopy and hyperspectral imaging to study the different types of raw cotton, M. Al Ktash, O. Hauler, E. Ostertag and M. Brecht, *J. Spectral Imaging* 9, a18 (2020). <https://doi.org/10.1255/jsi.2020.a18>

Interested in the BlueEye system for use in your projects?

Contact us here to discuss how we can help.

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