Survey On Hyperspectral Imaging Application

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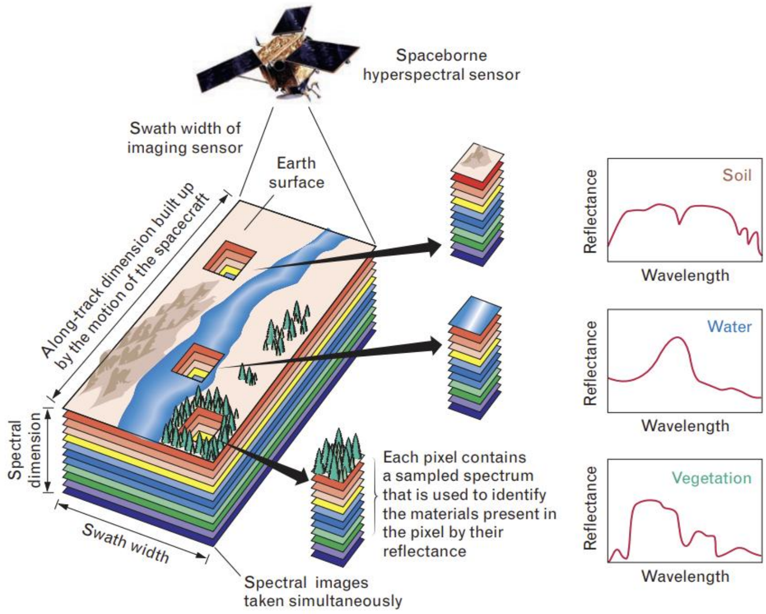
Abstract: ***Hyperspectral imaging (HSI) is a powerful technique that captures images across multiple narrow and contiguous wavelength bands, providing detailed spectral information for each pixel in an image. This rich spectral and spatial data enables precise analysis, opening new opportunities in a wide range of applications across various fields, from biology and environmental science to agriculture and beyond. The capability of HSI to capture unique spectral signatures allows for advanced material classification, chemical detection, and biological analysis, providing insights that are not achievable through traditional imaging methods. This paper presents a comprehensive survey of HSI applications, highlighting how this technology has transformed research and industry practices by enabling nuanced data interpretation, accurate diagnostics, and enhanced monitoring capabilities across diverse sectors.***

I. INTRODUCTION

Hyperspectral imaging (HSI) is a transformative technology that integrates digital imaging with the chemical specificity of spectroscopy, capturing light reflected from materials at hundreds of contiguous wavelengths across the electromagnetic spectrum, extending well beyond the visible range. As shown in Figure 1, HSI combines the spatial information of imaging with the spectral selectivity.



Hyperspectral imaging (HSI) is a transformative technology that integrates digital imaging with the chemical specificity of spectroscopy, capturing light reflected from materials at hundreds of contiguous wavelengths across the electromagnetic spectrum, extending well beyond the visible range. As shown in Figure 1, HSI combines the spatial information of imaging with the spectral selectivity of spectroscopy, offering an unparalleled measurement approach for diverse materials such as minerals, vegetation, and building materials, each of which interacts uniquely with light by reflecting or absorbing specific wavelengths.

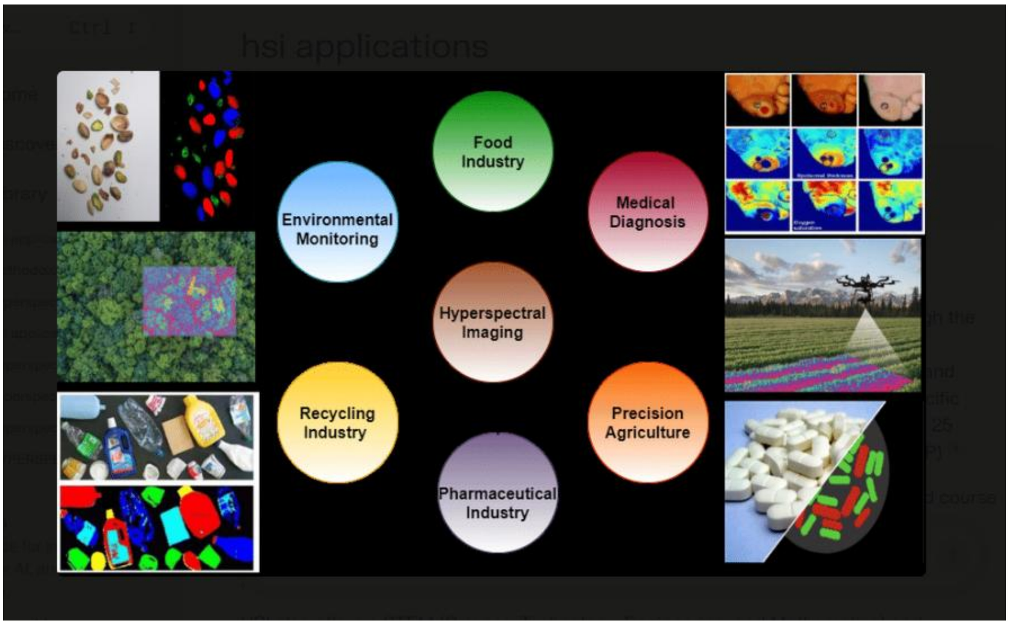
Current trends, including exponential growth in image processing capabilities, reductions in computational costs, and rapid miniaturization of hyperspectral sensors, are driving HSI's increasing relevance across scientific and industrial applications. HSI has the potential to redefine how we measure, analyze, and understand the physical world by capturing details beyond what conventional RGB imaging can achieve. Specialized sensors detect subtle spectral variations, allowing HSI to capture extremely fine spatial details, making it possible to observe distinctions that RGB imagery cannot resolve. The data acquired from HSI is stored in a "hypercube," essentially a stack of images of the same object or scene, each image corresponding to a specific wavelength. This data-rich hypercube provides dense and continuous spectral information for every pixel, enabling comprehensive material analysis. Effectively working with a hypercube requires advanced analytical software capable of handling and interpreting vast amounts of hyperspectral data to unlock its full potential. By capturing high-resolution spectral data at every point within a scene, HSI offers a complete, detailed, and multidimensional view of the world, paving the way for new insights and applications across numerous fields.

II. METHODOLOGY

Hyperspectral imaging (HSI) leverages the electromagnetic spectrum to analyze the unique spectral signatures of various materials and objects within a scene. Each material exhibits a distinct spectral response, much like a fingerprint, across hundreds of narrow and continuous wavelength bands that extend beyond the visible spectrum. HSI technology captures these responses by using specialized sensors to record data across multiple spectral bands or channels, producing a characteristic spectral profile for each material or object.

In practice, HSI operates by illuminating a scene and capturing how different materials reflect or absorb light across the entire range of measured wavelengths. This reflection and absorption pattern across spectral bands is unique to each material, allowing HSI to differentiate between them with high accuracy. Hyperspectral devices compile this data into a "hypercube," where each pixel contains a continuous spectrum of reflected wavelengths, representing the material's spectral signature. The hypercube thus provides a multidimensional dataset that enables precise identification and analysis of materials at a pixel level. In applications, HSI has proven to be a versatile tool in areas such as food quality inspection, where it can detect contamination or freshness; waste sorting, where it identifies recyclable materials; pharmaceutical manufacturing, where it ensures chemical consistency; chemical hazard detection, environmental monitoring, civil engineering, and even biomedical imaging, where it aids in diagnostic accuracy. Each application leverages the distinct spectral profiles of materials to classify, quantify, or monitor substances, making HSI an invaluable method for applications where fine discrimination of material composition is critical.Through this methodology, HSI advances our ability to analyze, monitor, and verify material composition with high specificity, enhancing quality control, safety, and precision across a wide array of industries.

Applications of Hyperspectral Imaging:
There are several applications were HSI were used in various field like mineral identification, crop health assessment, environmental monitoring, food quality, waste sorting and pharmaceutical production and so on. Some of the widely used applications were listed below.



Medical diagnosis:
Hyperspectral imaging in medical applications involves acquiring a three-dimensional dataset called a hypercube, which consists of two spatial dimensions and one spectral dimension. This technology provides diagnostic information about tissue physiology, morphology, and composition by capturing spatially resolved spectral imaging. In the medical field, hyperspectral imaging works by analysing the absorption, fluorescence, and scattering characteristics of tissue, which change during the progression of diseases. The reflected, fluorescent, and transmitted light from tissue, captured by hyperspectral imaging, carries quantitative diagnostic information about tissue pathology.

The proposed methodology involves an acquisition system for capturing in-vivo images during neurosurgery. After raw image acquisition, image pre-processing is performed, including HSI cube creation, calibration, spectral correction, and image normalization. A synthetic RGB image is created outside the operating room for labeling, and neurosurgeons use a labeling tool to create GT maps with five class labels: healthy tissue, tumor, venous vessel, arterial vessel, and dura mater. These GT maps are used to create datasets containing labeled pixel data and pixel labels for training SVM, RF, and CNN algorithms. Targeting HMSI-based systems for the classification and segmentation of skin lesions during gross pathology, such as melanoma, pigmented lesions, and bruising, a comprehensive study was carried out. The evaluation followed the Preferred Reporting Items for 2020 .Guidelines for Systematic Reviews and Meta-Analyses (PRISMA). Trends in HMSI acquisition, preprocessing, and analysis were found for reports that qualified and were published between 2010 and 2020. Skin tissue segmentation and classification using HMSI-based frameworks differ significantly. Because the majority of papers used tiny training datasets, simple image processing or machine learning was used. Most of the carefully curated datasets used to assess the methodologies focused on melanoma detection. The system's performance was impacted by the preprocessing scheme selection. Dimension reduction of some kind is frequently used to get around the redundancies that come with HMSI systems.

Food Science:
High-performance liquid chromatography, gas chromatography, polymerase chain reaction, and other conventional methods of testing for food safety and quality can be used to extract information about the composition, structure, physical and chemical properties, and sensory characteristics of food products by adjusting to the requirements in a laboratory setting Nevertheless, the majority of traditional detection methods are labor-intensive, subjective, damaging, non-real-time, unsuitable for online food analysis, and they also cause some delay in the flow of food information through the supply chain. For this reason, it is crucial to create quick, non-destructive, and effective detection methods for the food supply chain.One of the earliest methods for non-destructive testing (NDT) of food goods was machine learning based on the red, green, and blue (RGB) color model. This allowed for the quick identification of ripeness and mechanical damage.

Agriculture:
Extensive research on automatic weed detection has been spurred throughout the years by the rapid development of new technologies in smart agriculture based on RGB imaging , hyperspectral imaging , and non-imaging spectroscopy. There hasn't been a review on these methods of differentiating weeds from crops published as of yet. The need for weed management and the shortcomings of current commercial approaches are briefly discussed in this paper's introduction, which is followed by a summary of suggested weed control strategies. The subsequent section primarily outlines three methodologies, namely spectroscopy, RGB imaging, and hyperspectral imaging. In the third section, the sophisticated machine learning techniques for plant identification are presented. The research of various imaging and non-imaging sensing alternatives have been highlighted in the fourth section.

Pharmaceutical industry:
The capacity of conventional NIR spectroscopy to assess the homogeneity of medicinal products was constrained. This approach is deficient in the qualitative element related to mapping the spatial distribution. The statistical comparisons of NIR spectra from the same tablet and tablets in the same group were necessary to determine the homogeneity of the tablets. It is assumed that a measure of blend uniformity can be obtained by combining intra- and inter-tablet variability. Tablet heterogeneity led to an increase in both intra- and inter-tablet variability. With the exception of the Blend E tablets, each tablet

grade could be distinguished using the intra-tablet variability. For the Blend E tablets, the average percentage standard deviation linked to intra-tablet variability was less than anticipated. The ingredients were arranged side by side to create these unblended tablets.

Recycling industry:
Recycling demolition waste (DW) is an intriguing way to lessen the impact of the construction industry on the environment (CO2 emissions) and the exploitation of natural resources.1. In fact, implementing recycling solutions that lead to the creation of marketable clean aggregates is essential to improving the state of the environment. When contaminants (such brick, glass, paper, cardboard, plastic, wood, gypsum, and so forth) that are often found in a DW stream are either absent or below the standards set by the market, aggregates are deemed to be "clean."End-of-life (EOL) concrete identification is critical to facilitate DW conversion into valuable secondary raw materials and is a necessary step in the setup of an efficient sorting and/or quality control system.From this angle, the creation of methods for automatic

CONCLUSION

In Hyperspectral imaging each pixel in the image contains a complete spectrum. Therefore HSI is a very powerful technique for characterizing and analysing various applications. Its ability to capture detailed spectral information for each pixel in an image opens up opportunities for advanced analysis and interpretation. As the technology continues to evolve, we can expect further advancements and innovations in hyper spectral imaging leading to even more impactful application in the future.

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