advanced computational photography techniques such as high dynamic range and night mode. However, smartphone cameras tend to have lower image quality as they have smaller lenses, sensors, and image processors due to the size restrictions of the smartphones [7], [11].

Hyperspectral cameras employ imaging and spectroscopy techniques to generate multidimensional image data. Every pixel in an image is assigned to spectral data that span a broad range of individual wavelengths [12]. Hyperspectral cameras operate within 250–2500 nm, which covers ultraviolet (UV), visible, and near-infrared (NIR) spectrum [7]. The advantage of hyperspectral cameras is that they help to focus on a specific part of images or area of interest, which contains the anomalies (e.g., unhealthy/diseased parts of a plant leaf). This helps to establish special patterns or features to analyze the anomalies/diseases [10]. The multispectral camera operates differently than the hyperspectral cameras. Instead of using hundreds of individual wavelengths, the multispectral camera operates within ranges of wavelengths. Multispectral imaging uses a camera to create images in specific wavelength regions, while multispectral spectroscopy provides data about specific frequency bands. Multispectral cameras have the advantage of being more cost-effective compared to hyperspectral techniques. However, they capture less detailed information about the captured object (plant/leaf) because they use a wider frequency band [10]. Fluorescence cameras capture images of fluorescence. Fluorescence images have higher dimensions than other imaging techniques. It can easily isolate the area of interest from the area of noninterest. However, they are not suitable for detecting early-stage diseases as the images lack clear differences between healthy and diseased plant tissues [10]. Thermal cameras are devised to capture radiation within the infrared wavelength spectrum. The collected data are then translated into false-color images, where each image pixel indicates a temperature value. However, thermal images are often influenced by fluctuating environmental conditions [70]. This makes them more suitable to be used in controlled environment conditions [13].

Among all the abovementioned image acquisition techniques, hyperspectral imaging exhibits better prospects for early disease detection in plants by identifying minute changes in spectral reflectance caused by absorption or reflection. With hundreds of spectral bands, hyperspectral images can generate a comprehensive spectral profile, enabling the detection of slight variations in soil, canopies, or individual leaves. Hence, hyperspectral images can tackle a broader range of issues related to accurate and timely assessment of agricultural crops' physiological state [14].

This article extensively reviews the principles, types, and operational platforms of hyperspectral image sensors, specifically as they apply to plant disease detection, including disease identification, classification, severity analysis, and understanding of genetic resistance. While there have been other reviews focusing on the general use of hyperspectral imaging in agriculture [3], [15], [16], [17], this review uniquely concentrates on its application in plant disease detection. It not only covers the basics but also dives deeper into how this technology can be effectively applied to different aspects of disease detection, classification, severity analysis, and genetic resistance—a topic not extensively covered in other reviews. Furthermore, current challenges in this field and proposed potential solutions to advance the field are also highlighted. This review aims to aid the researchers in the field to know about the existing techniques already developed in the field at a glance. This review will serve as a baseline for researchers in the same field and aid in advancing the state of the art.

The rest of this article is organized as follows. Section II presents the fundamentals of hyperspectral image sensors. Section III discusses the common plant diseases for different types of plants. Section IV presents the application of hyperspectral imaging for plant disease detection. This section also highlights the current challenges and potential solutions for hyperspectral imaging. Finally, Section V concludes this article with some potential future studies.

II. FUNDAMENTALS OF HYPERSPECTRAL IMAGE SENSORS

Over the past few decades, hyperspectral imaging has been considered as a smart and beneficial tool for research analysis in various domains. The hyperspectral imaging system was mainly developed to merge the spectroscopic and image information so that the spatial distribution of different elements can be easily identified. The primary advantage of employing hyperspectral imaging over traditional RGB imaging is that hyperspectral imaging has the capability to capture detailed spectral information over multiple bands, which provides information for the spatial distribution of chemical components. Although hyperspectral and RGB imaging can be nondestructive, hyperspectral imaging provides the unique capability to visualize chemical compositions simultaneously. This section presents the principles of hyperspectral image sensors, types, and available platforms to conduct hyperspectral imaging for plant disease detection [14], [18].

A. Principle of Hyperspectral Image Sensors

Generally, hyperspectral imaging is the simultaneous acquisition of spatial images from several spectral bands measured from a remote platform. The spatial images and the spectroscopy in the hyperspectral image sensors aid in providing the physical, geometrical (size, shape, and color), and chemical composition. Apart from hyperspectral imaging, there are multispectral and ultraspectral spectral imaging techniques. All these spectral imaging techniques capture spectral images at different wavebands or within specific portions of the electromagnetic spectrum. The only difference is that each spectral imaging operates in different electromagnetic spectrums and bands. Ultraspectral imaging operates in fine spectral resolution. Multispectral imaging operates in smaller bands, typically around 10–15 spectral bands. Depending upon a multispectral camera's specifications, it can sometimes capture even more than 15 spectral bands [19]. On the other hand, hyperspectral imaging can operate in the UV at 250–400 nm, visible and near-infrared (VNIR) at 400–1300 nm, and short-wave infrared (SWIR) at 1300–2500 nm. However, it cannot operate on other ranges of the electromagnetic spectrum, such as X-rays or microwaves [7].