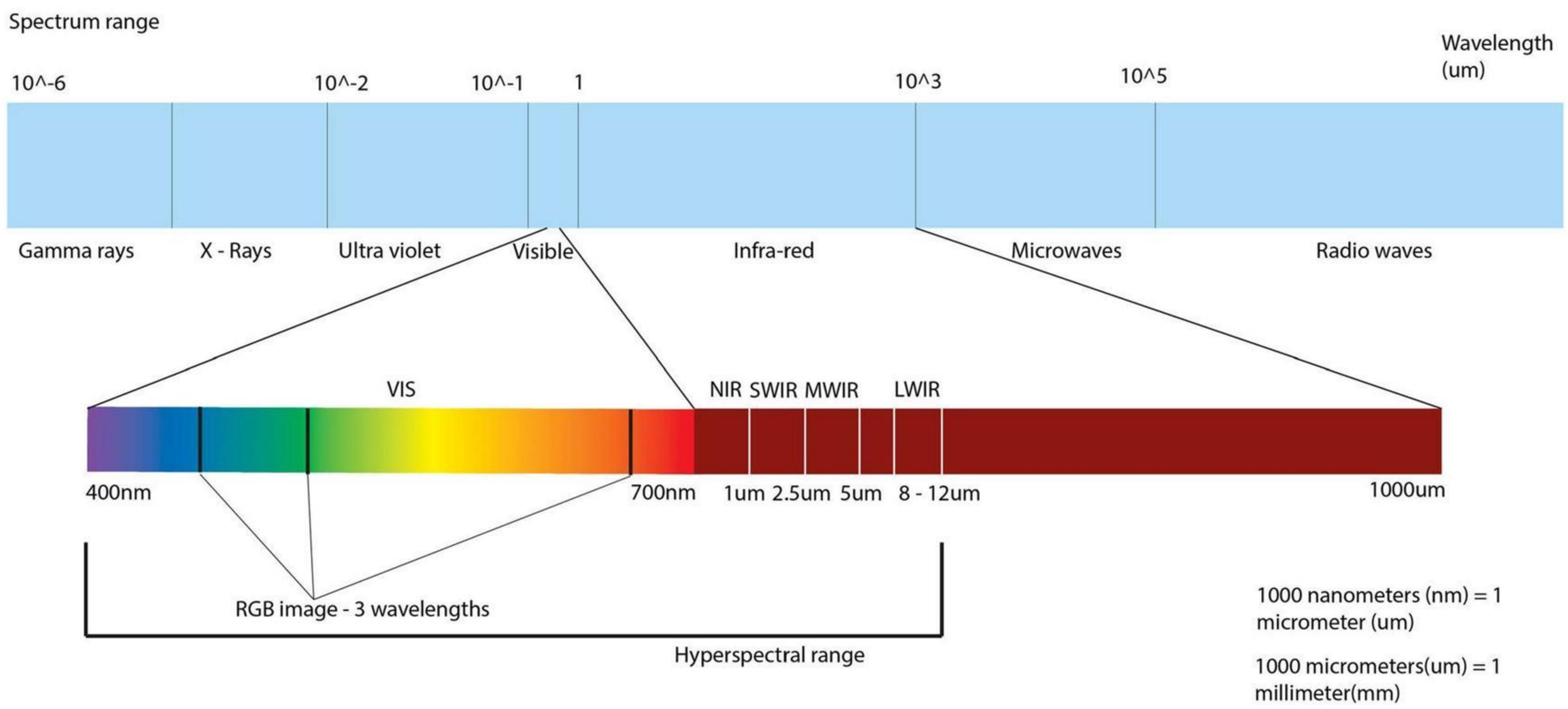

Fig. 2. Light spectrum [68].

4) *Multiplex PCR:* The multiplex PCR detects multiple pathogens simultaneously, is efficient and comprehensive, and ideal for complex or mixed infections.
5) *Nested PCR:* The nested PCR increases specificity and sensitivity through two rounds of amplification, excellent for detecting low-abundance or hard-to-detect pathogens. The use of nested PCR was explored in [6] to detect pathogens in soil infected with bacterial wilt.

B. Image Processing Techniques

Image processing involves analyzing visual data (images) to detect and diagnose diseases based on visual symptoms and asymptomatic conditions. Various imaging techniques have evolved over the years for the detection of disease in plants, such as red, green, and blue (RGB), thermal imaging, multispectral imaging, fluorescence imaging, and hyperspectral imaging (HSI) [10]. Image processing techniques play a crucial role in preprocessing and analyzing ginger plant images for disease toward obtaining the spectral signature of the disease and detection. The processing methods, such as segmentation, feature extraction, and texture analysis, help identify disease symptoms and distinguish healthy from infected plants. Segmentation involves dividing the image into distinct regions or objects, facilitating the isolation of areas affected by disease. Feature extraction, on the other hand, focuses on identifying and quantifying characteristics, such as color, shape, and texture, that indicate disease symptoms. Texture analysis specifically assesses surface patterns and irregularities, which can signal disease presence [37]. Together, these methods enhance the accuracy of disease detection by providing a comprehensive analysis of the visual data.

1) *RGB Image Processing:* RGB image processing techniques can be highly effective for detecting and diagnosing visible disease symptoms, which are direct indicators of disease in ginger plants. However, its application is more limited when it comes to detecting nonvisible symptoms. This method utilizes the RGB color channels in digital images to analyze and identify disease symptoms based on visual patterns and color changes in the leaves, stems, and other plant parts. The operations of the RGB are based on light wavelengths, as shown in Fig. 2 [68]. The RGB image processing has been largely explored for disease detection [69], [70], [71], [72]. The RGB images of ginger plants can be captured using digital cameras or smartphones or drones equipped with RGB cameras. The images are further preprocessed using noise reduction techniques, followed by image enhancement and separating the ginger plants from the background via segmentation techniques, such as thresholding, edge detection, and clustering algorithms. The application of RGB processing includes the detection of visible symptoms in ginger, such as leaf spots, mosaic viruses, and chlorosis. This has helped in monitoring and accessing ginger plant health. However, for a more improved diagnosis that includes nonvisible symptoms, integrating RGB with other imaging techniques can offer a more detailed and accurate assessment of plant health [71]. To address these limitations, RGB image processing is often complemented by other imaging techniques, such as thermal, multispectral, or HSI [72]. Fig. 2 shows the different ranges of the light spectrum and their respective wavelengths.
2) *Multispectral Imaging:* Multispectral imaging provides a more nuanced approach to detecting and diagnosing visible symptoms of disease in ginger plants compared with RGB image processing. The multispectral imaging ininvolves capturing data in a few discrete bands, such as RGB, near-infrared (NIR), and sometimes additional bands, such as short-wave infrared [73], [74], [75], [76]. This method can detect subtle physiological changes and internal conditions by analyzing reflectance in specific spectral bands that correlate with biochemical and physiological processes not apparent in the visible spectrum, thus enabling detailed analysis of plant health by capturing variations in reflected light across a broader range of wavelengths [74]. By integrating multispectral imaging

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