Trends in Technical & Scientific Research
ISSN: 2641-8355

Juniper Publishers
key to the Researchers

Review Article
Volume 7 Issue 2 - July 2024
DOI: 10.19080/TTSR.2024.07.555708

Trends Tech Sci Res

Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food

Kamaran Kheiralipour[1]*, Digvir S. Jayas[2,3]

[1]Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran

[2]University of Manitoba, Winnipeg, MB, Canada

[3]University of Lethbridge, Lethbridge. AB, Canada

Submission: June 29, 2024; **Published:** July 10, 2024

***Corresponding author:** Kamran Kheiralipour, Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran

Abstract

Applying imaging technology in different fields allowed accurate, reliable, repeatable, fast, nondestructive, and low-cost assessment of goals of the interest. Hyperspectral imaging as a near infrared imaging technique widely used for research and application purposes in different fields due to detection of nonvisible goals via recording materials' reflectance in the range of 400-2500 nm. It combined advantages of infrared wave analysis in spectroscopy and area assessment in imaging technology. These advantages allowed the assessment of both internal and external properties of materials. Different methods are applied to process the hyperspectral images to extract efficient wavelengths and image features and then analyze them to achieve useful results for decision making. Hyperspectral imaging has been used in biosystems engineering for improve different activities in agriculture, natural resources, and food sector. The hyperspectral imaging has been explained and different goals of applying the technique in agriculture, natural resources and food have been presented. The purpose of this literature review was to describe the applications of near-infrared hyperspectral imaging in biosystems engineering in Iran.

Keywords: Evaluation; Potential; Nigeria Trees; Extracts; Organic and Cosmetic Production

Abbreviations: HSI: Hyperspectral Imaging; PCA: Principal Component Analysis; ICA: Independent Component Analysis; ANN: Artificial Neural Artificial Neural Networks; PNN: Probabilistic Neural Network; SVM: Support Vector Machine; LS-SVM: Least Squares-Support Vector Machine; NB: Normal Bayes; PLS-DA: Partial Least Square Discriminant Analysis; KNN: K-Nearest Neighbor; LDA: Linear Discriminant Analysis; QDA: Quadratic Discriminant Analysis; SIMCA: Soft Independent Modeling of Class Analogy; ANN-CA: Artificial Neural Network-Cultural Algorithm; PPC: Psychotropic Plate Count; TVB-N: Total Volatile Basic Nitrogen; LDNN: Linear Deep Neural Network; PLSR: Partial Least-Squares Regression; MLR: Multiple-Linear Regression; BP-ANN: Back Propagation Artificial Neural Network

Introduction

Biosystems engineering is a field of applying engineering sciences and technologies in agriculture, natural resources, and food sectors to promote the required operations and activities to increase technical, social, and economic productivity and decrease environmental impacts. This means considering science and technology to work in the sustainable production path [1]. Biosystems engineering is important as well as agriculture, natural resources, and food sectors due to providing food and living medium for human [2]. Agriculture includes agronomy, horticulture, and livestock subsectors, natural resources include forest, pasture, and fishery subareas, and food includes processes of making final products from raw materials produced in agriculture and natural resources sectors. These sectors need the assists of agricultural economics and extension, plant protection, irrigation, biosystems, mechanization, and veterinary fields [3] to apply useful knowledge and technologies [4,5] to promote the operations, increase the productivity, solve the problems, and deal with various challenges [6]. Imaging technology is applied in different fields due to its advantages compared to human based duties and laboratory tests. These advantages are high accuracy, reliability, reputability, and speed, low cost, and non-destructivity [7]. Hyperspectral imaging (HSI), chemical imaging, or infrared imaging is a technique of imaging technology to acquire area information of objects from 400 to 2500 nm in electromagnetic spectrum, called hypercube. In fact, hypercubes include different image channels of the objects for each wavelength or a small range of wavelengths.

The wavelength range includes visible and nonvisible wavelengths. The HSI technique is widely used for research and application purposes in different fields due to detection of visible and nonvisible goals. It combines advantages of infrared wave analysis in spectroscopy and area assessment in imaging technology. These advantages allowed the assessment of both internal and external properties of materials [6,8]. The acquired hypercubes are processed using different methods to extract efficient wavelengths, calculate image features, and then analyze the extracted features to achieve beneficent results used in decision making processes. The technique has been applied for assessing agricultural and food products [6,8-11]. The technique has been used in indoor controlled imaging conditions for safety control [12] and quality assessment [13] of food products and assessment of agriculture products [14,15]. The method has been used in outdoor imaging conditions in agriculture [16] and natural resources [17,18]. Due to importance of biosystems engineering to assist agriculture, natural resources, and food sectors and advantages of hyperspectral imaging, the goal of the present paper is to review the applications of hyperspectral imaging in Iran as a powerful technique in these sectors.

Imaging technology

Imaging is defined as acquiring area information of objects. In this method, different wavelength bands of visible and nonvisible range of electromagnetic spectrum are acquired and changes them to visible images with color or gray scale type. Visible imaging systems acquire wavelengths in the visible band of the spectrum emitted from the objects' surface. Visible imaging systems have high speed, accuracy, reliability, and reputability and low cost. They are nondestructive systems and can be used for real time applications. According to wavelength range, other imaging methods have been developed such as thermal imaging, hyperspectral imaging, and X-ray [7,8,19].

Hyperspectral Imaging

Spectroscopy is a technique to receive the reflectance of the objects in near infrared wavelengths of the electromagnetic spectrum. It records different wavelengths of near infrared band emitted from single-points of objects. This approach has been used in hyperspectral imaging technique. Hyperspectral imaging technique acquires the area reflectance of objects in different wavelengths, separately. So, a hyperspectral image includes spatial (x and y direction of hypercube matrix) and spectral (z direction of hypercube matrix) information of the infrared reflectance from the objects' surface [7]. This ability allowed achieve both advantages of imaging and spectroscopy techniques. Also, the HSI technique includes both visible and infrared imaging because it acquires the reflectance from visible (400-750 nm) to near-infrared (750-2500 nm) wavelengths in the electromagnetic spectrum.

Different parts of hyperspectral imaging systems are detector or camera, lens, wavelength selection tool, illumination system, and personal computer. The duty of software parts of HIS systems are image acquisition and processing operations [8,20-22]. There are three types of hyperspectral imaging systems including point scanning, line scanning, and single-shot (area scanning) [23]. The systems are installed on different acquisition platforms to acquire hypercubes in various imaging conditions. So, the systems are divided to tabletop, handheld, UAV-mounted, aircraft-mounted, and satellite-mounted imagers [16]. Acquisition of hypercubes is a time-consuming task, compare to visible imaging, so that acquiring each hypercube may take up to 2 min [22]. This is due to acquiring many wavelengths separately. So, the HSI has limitation in real time applications and required developing multispectral imaging systems to acquire the object reflectance corresponded to efficient wavelengths. Hyperspectral imaging systems acquire the images of objects as a three-dimensional matrix including a two-dimensional spatial data of the imaged area and one-dimensional spectral data of the surface's reflectance [7,8]. This has a big data challenge and required data analysis more than visible image processing methods.

Image Processing

Hypercubes require big data analytical methods to decrease the volume of the spectral data of the hyperspectral image matrix [20]. This data reduction is essential to provide a hyperspectral image with lower wavelengths, called useful wavelengths. The useful wavelengths must be selected to be used for image processing step. In real applications, these wavelengths are used in multispectral imaging (Figure 1).

One of the widely-used methods to select the useful wavelengths of the hypercubes is principal component analysis (PCA). Independent component analysis (ICA), kernel PCA, local linear embedding, local tangent space analysis, diffusion maps, Laplacian eigen maps, multilayer autoencoders, isomap, local linear coordination, hessian local linear embedding, linear discriminant analysis wavelet transform (WT), (LDA), Fourier transform (FT), and multidimensional scaling (MDS) are other methods used for hyperspectral data reduction process [23-25]. The image corresponding to each wavelength is called image channel.

After wavelength selection, an image processing algorithm is required to extract features of the image channels. The extracted features are analyzed by artificial intelligence or statistical methods such as artificial neural network (ANN), probabilistic neural network (PNN), support vector machine (SVM), least squares-support vector machine (LS-SVM), Normal Bayes (NB), partial least square discriminant analysis (PLS-DA), K-nearest neighbor (KNN), Random Trees (DT), linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), and N-fold cross validation [25-28]. Recently, deep learning has been introduced as a strategy to analyze data. This strategy has been used to analysis the hyperspectral images [29-33]. The strategy conducts different image processing steps continuously; but it requires a large number of hypercubes [6].

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

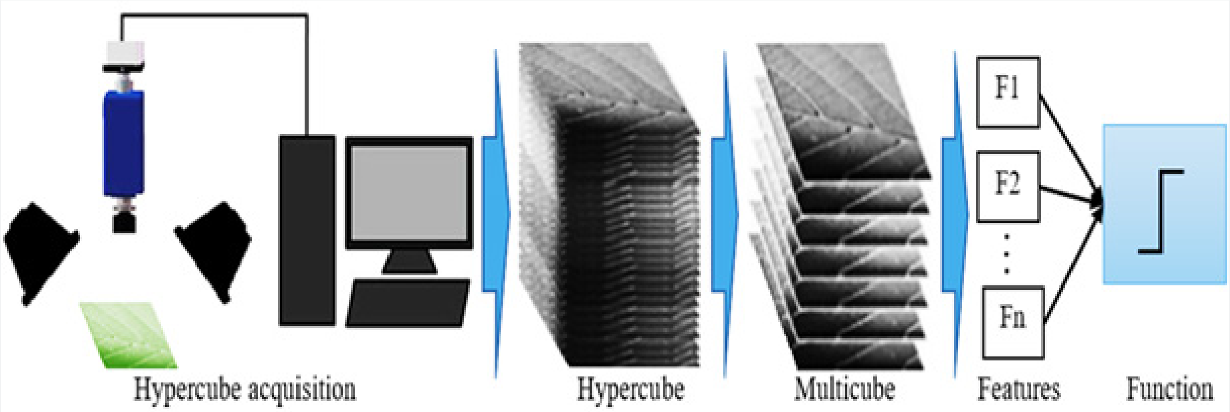

Figure 1: Different steps in hyperspectral imaging [2].

Applications of hyperspectral imaging

As HSI has high ability of both imaging and spectroscopy techniques together, the technique is widely used for assessing internal and external properties of materials. The external properties are assessed using visible reflectance and internal properties are evaluated using near infrared reflectance of the surface of the objects. The mentioned abilities provided successful applications of hyperspectral imaging in different fields including industry, medicine, agriculture, natural resources, and food. Hyperspectral imaging has been successfully used in indoor and outdoor applications in different areas of biosystems engineering [33-40]. In the next sections, the applications of hyperspectral imaging in biosystems engineering in Iran have been discussed.

Soil

Soli has high important in different studies because it is the base medium to produce agricultural products. Also, natural environment soil is studied in forest and pastures products. In the natural environment, hyperspectral imaging has been used for assessment of soil [38]. In soil studies, mainly hyperspectral imaging in remote sensing applications has been used whereas in wild animal assessment. Hosseiny et al. [41] combined hyperspectral imaging and machine learning based on convolutional neural network (CNN) to classify different land regions. The classification accuracies on their researchers were in the range of 92.35 to 98.14%.

Plant fields

Plant fields include farms to produce agronomic and horticultural products. The application of hyperspectral imaging in plant fields have been presented in (Table 1) [42-45]. Agronomy includes different steps from tillage, seed planting or transplanting, protecting, harvesting, and seed processing to produce different agronomical products including cereals, pseudo cereals, legumes, and oilseeds. Hyperspectral imaging technique has been applied in assessing different agronomic products [16,46]. In outdoor application of hyperspectral imaging, Imani [42] used the hyperspectral images of the Landsat 8 and analyzed them to detect land occupied by wheat cultivation farms. They reached to high accuracy as 96.09% using collaborative representation (AP-CR) method. Horticulture sector include different operations including orchard land preparation, seed and or seedlings planting, protecting, harvesting, and postharvest operations to produce fruits, vegetables, and medicinal, aromatic, and ornamental plants in the fields with smaller areas than those in agronomy. Hyperspectral imaging technology has been successfully used to assess different horticulture products [33,47-51]. Moghimi et al. [45] acquired hyperspectral images of healthy and diseased leaves of pistachio trees at the range of 400-1100 nm. They reported that the classification accuracy of the hypercube features using support vector machine method was 90.91%. In a research, nitrogen content in tomato leaves has been detected by hyperspectral imaging technology. Aslani [44] used the technique at the range of 400-1100 nm and machine learning based on artificial neural network. The correct classification rate of the research was 92.55%. In the similar research, nitrogen level in cucumber leaves has been studied. Sabzi et al. [43] analyzed hyperspectral image features using hybrid neural networks and the imperialist competitive algorithms. They obtained the highest accuracy as 96.11%.

Agronomic and horticultural products

Agronomic and horticultural products include final products harvested from farms such as fruits, leaves, and flowers of the plants and trees. Hyperspectral imaging technique has been used in this sector to assess different products [23,37,52-57]. Application of HSI in assessment of agronomic and horticultural products have been presented in Table 2 [58-71]. Darvishsefat

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

et al. [58] compared the canopy reflectance of different Iranian rice cultivars including Khazar, Hybrid, Nemat, Tarom plots, Fajr, Shiroudi, and Neda. The hyperspectral imaging system acquired the images at the range of 350-2500 nm. The researchers reported that the reflectance of the cultivars was significantly difference using analysis of variance and Tukey's paired test. Hyperspectral imaging technique has been used to detect contaminations in horticultural products. HSI technique has been used at range of 960 to 1700 nm to distinguish healthy form infected pistachio kernels by Aspergillus flavus fungus. Kheiralipour et al. [59] used linear and quadratic discriminant analysis methods to classify the hyperspectral images and reported 70-100% accuracy to distinguish different classes including healthy samples and unhealthy ones with different progress levels of infection. Kheiralipour et al. [5] developed different classifiers based on K-fold cross validation, support vector machine, and artificial neural network methods to classify the hyperspectral image features of healthy and fungal infected pistachio samples with and without considering infection progress levels. They reported that the classification accuracies of different methods were in the range of 69 to 99.71%.

Table 1: Applications of hyperspectral imaging in plant fields.

Product	Goal	Wavelength (nm)	Reference
Wheat	Detection of farm region	-	Imani [42]
Cucumber leave	Estimating nitrogen content	400-1100 nm	Sabzi et al. [43]
Tomato leave	Estimating nitrogen content	400-1100 nm	Aslani [44]
Pistachio leave	Detection of diseases	400-1100 nm	Moghimi et al. [45]

Table 2: Applications of hyperspectral imaging in assessment of agronomic and horticultural products.

Product	Goal	Wavelength (nm)	Reference
Rice	Cultivar classification	350-2500 nm	Darvishsefat et al. [58]
Pistachio	Detecting KK11 and R5 fungal infection	960-1700	Kheiralipour et al. [59]
Pear	Ripeness detection	425-1000	Khodabakhshian and Emadi [60]
Pomegran-ate	Estimating pH, titratable acidity, and total soluble solids	400-1700	Khodabakhshian et al. [61]
Orange	Detecting green mold	400-900	Ghanei Ghooshkhaneh et al. [62]
Pistachio	Detecting aflatoxin contamination	400-950	Zolfi et al. [63]
Cucumber	Estimating nitrogen content	400-1100	Pourdarbani and Sabzi [64]
Apple	Studying pH changes	400-1000	Golmohammadi et al. [65]
Apple	Estimating total phenol, titratable acid, soluble solids content, and pH	400-1100	Hasanzadeh et al. [66]
Apple	Studying peroxidase activity changes	400-1000	Golmohammadi et al. [67]
Saffron	Detection of adulteration	400-950	Hashemi-Nasab and Parastar [68]
Maize	Variety classification	400-1000 nm	Alimohammadi et al. [69]
Sugar beet	Estimating soluble solids, sugar content, moisture content, pH, and mechanical properties	400-1100	Molayi et al. [70]
Orange	Bruise's detection	400-1100	Pourdarbani and Sabzi [71]

Table 3: Applications of hyperspectral imaging in animal and fishery products.

Product	Goal	Wavelength (nm)	Reference
Beef and lamb	Recognizing meat types	400-950	Zolfi et al. [72]
Fish	Detecting spoilage	430-1010	Khoshnoudi-Nia and Moosavi-Nasab [73]
Fish	Estimating total volatile basic nitrogen	430-1010	MoosaviNasab et al. [74]

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

Zolfi et al. [63] used fluorescence hyperspectral imaging technique to distinguish healthy pistachio kernel and aflatoxin contaminated samples with low, medium, and high contamination levels. They used fluorescence light source at 360 nm to illuminate the pistachio samples. They obtained high correlations between the contamination and fluorescence reflectance of different samples. Applying hyperspectral imaging technique at range of 425-1000 nm, Khodabakhshian and Emadi [60] classified pear fruit based on ripeness level of unripe, ripe, and overripe. They classified the image features using soft independent modeling of class analogy (SIMCA), linear discriminant analysis (LDA), and partial least square-discriminant analysis (PLS-DA). The researchers reported that the classification accuracy of PLS-DA method (87.86%) had higher accuracy compared to other methods. Ghanei Ghooshkhaneh et al. [62] combined hyperspectral imaging and artificial neural network to detect green mold of orange. They acquired the hypercubes of healthy and infected orange samples at range of 400-900 nm. The researchers reported that 500, 800, and 900 nm were selected as the efficient wavelengths and acquired images using SCB-2000P Samsung camera and an infrared filter for the selected wavelengths. They achieved highest classification accuracy of 96.84%.

Hyperspectral imaging has been used to estimate chemical compositions of the products. Khodabakhshian et al. [61] predicted different chemical components of pomegranate fruit including the total soluble solids, and titratable acidity, and pH. They acquired hypercubes at the range of 400-1100 nm and analyzed them using partial least square method. Hasanzadeh et al. [66] estimated the soluble solids content, titratable acid, pH, and total phenol of apple fruit using hyperspectral imaging. They analyzed the hypercubes using partial least squares method and reported high prediction accuracies of 98.99 to 99.99%. Golmohammadi et al. [65] estimated peroxidase activity by acquiring hyperspectral images of apple fruits at the range of 400-1000 nm. They reported that an accuracy of 0.94% was achieved using partial least square method. in another research, Golmohammadi et al. [67] hyperspectral images of apple fruit at the same range were analyzed to estimate pH value of apple during storage. They reported that the partial least square method gave 98.0% accuracy for classification of the features extracted from the hyperspectral image data. Nitrogen content in cucumber fruit was estimated using hyperspectral imaging by Pourdarbani and Sabzi [64]. The researchers used hybrid neural network-cultural algorithm (ANN-CA), multilayer perceptron neural network (MLP), and support vector machine to find correlation between nitrogen content and image features. They reported higher accuracy of ANN-CA (92.00%) compared to SVM (89.51%) and MLP (78.97%).

The HSI technique has been used to detect adulteration in saffron. Hashemi-Nasab and Parastar [68] prepared saffron product adulterates by saffron style, safflower, turmeric, calendula, and rubia and acquired the hyperspectral images of the samples at the range of 400-950 nm. They used partial least squares-discriminant analysis (PLS-DA) for classification of the image features and reported that all samples were successfully classified by the model. Alimohammadi et al. [69] applied hyperspectral imaging at range of 400-1000 nm to classify different maize varieties. They used linear discriminant analysis and artificial neural network method and reported higher ability of the LDA (95% accuracy) to distinguish the varieties. The literature showed that HSI technique can be used to assess mechanical properties of fruits and vegetables. Pourdarbani and Sabzi [71] evaluated the ability of the HSI method in the range of 400-110 nm to detect orange bruises. In their research, the compare mean using Dunkan's multiple range test method showed significant difference between the reflectance of the sound and bruised orange samples. Molayi et al. [70] estimated soluble solids, sugar content, moisture content, pH, and mechanical properties of sugar beet using HSI technique. They used imaging system at the range of 400-1100 nm to acquire the hypercubes of the samples and least square regression method to analyze the image features and achieved 95-98% accuracy.

Animal and Fishery Products

HSI has been utilized in assessment of animal and fishery products. These applications for different goals have been listed in Table 3 [72,73]. Hyperspectral imaging has been used to estimate nitrogen content in fish. Moosavi-Nasab et al. [74] predicted the total volatile basic nitrogen (TVB-N) in rainbow trout fish fillet using HSI technique. They acquired the hyperspectral images at the range of 430-1010 nm. They applied linear deep neural network (LDNN) and support vector machine (SVM) to detect the nitrogen content based on the data extracted from the hyperspectral images. They stated that the accuracy of the classifier based on the SVM method (89.7%) was higher than ANN method. The shelf life of fish has been assessed using HSI method. Khoshnoudi-Nia and Moosavi-Nasab [73] acquired hypercubes of fish at the range of 430-1010 nm to assess the product spoilage. They measured sensory score, psychotropic plate count (PPC), and total-volatile basic nitrogen (TVB-N) of the fish. The researchers applied different data prediction methods including partial least-squares regression (PLSR), back-propagation multiple-linear regression (MLR), back propagation artificial neural network (BP-ANN), and least-squares support vector machine (LS-SVM) to analyze the date extracted from the hypercubes. The researchers obtained accuracies in the range of 85.3 to 92.1%. The HIS method has been applied to distinguish different meat types. Zolfi et al. [72] used HSI method to recognize the ground beef, lamb, and a combination of 70% beef and 30% lamb meat. the analyzed the image data using SVM and reported 11.56-19.66% error.

Future trends

Hyperspectral imaging technique has been used for different applications in biosystems engineering in Iran such as soil, agriculture, horticulture, and food. In future, the HSI technique

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

can be been utilized in livestock sector [75] to assess animal body [76] and welfare and feed quality [77]. The technique can been applied for in natural resources to study wild animals living the land and sea environment [17,78,79]. The method can be applied in precision agriculture considering remote sensing using satiate or other platforms with high spatial and spectral resolutions. A limitation in applying HSI technique is the time for acquisition of the hypercubes. Acquiring hypercubes is time-consuming because the images at different wavelengths are recorded. So, this technique is mainly used in laboratories and online and practical industrial applications are possible by applying the hyperspectral results to develop multispectral imaging systems. Multispectral systems use just efficient wavelengths and features that are faster in scanning and analyzing the images. Using these wavelengths in multispectral imaging systems cause to reach higher imaging speed compare to hyperspectral imaging.

Conclusions

Hyperspectral imaging is non-destructive technique to acquire infrared reflectance of objects in an imaging area. Applying different data analysis method for prediction and classification purposes, the technique gives high accuracy in assessing different materials so that they can be combined to reach vast research and application goals with high reliability. It has been used to assess internal and external properties of products. In the present study, applications of hyperspectral imaging and hypercube processing in biosystems engineering in Iran have been presented. In future, application of hyperspectral imaging can be more expanded, especially in animal and fishery sectors, animal body and feed, and the related food products. Hyperspectral imaging is more efficient than visible imaging because useful wavelengths in not only infrared domain, but also in visible range of the electromagnetic spectrum, can be find in the HSI. As acquiring hypercubes is time-consuming, the HSI technique is mainly used multispectral imaging systems can be developed to acquire the images in efficient wavelengths and to increase the imaging speed.

References

1. Kheiralipour K (2022) Sustainable Production: Definitions, Aspects, and Elements. (1st Editon.) Nova Science Publishers, New York, US.
2. Kheiralipour K, Jayas DS (2023) Applications of near infrared hyperspectral imaging in agriculture, natural resources, and food in Iran. 15th National Congress and the 1st International Congress of Biosystem Mechanical Engineering and Agricultural Mechanization. Karaj, Iran.
3. Kheiralipour K (2020) Environmental Life Cycle Assessment. (1st Edition). Ilam University Publication, Ilam, Iran.
4. Kheiralipour K (2021) Management of knowledge and technology in agriculture and natural resources. 13th National Congress on Biosystems Engineering and Agricultural Mechanization. Tehran.
5. Kheiralipour K, Ahmadi H, Rajabipour A, Rafiee S, Javan-Nikkhah M, et al. (2021) Processing the hyperspectral images for detecting infection of pistachio kernel by R5 and KK11 isolates of Aspergillus flavus fungus. Iran J Biosyst Engineer 52(1): 13-25.
6. Kheiralipour K, Jayas DS (2023) Image Processing for the Quality Assessment of Flour and Flour-Based Baked Products. In: Jayas, D.S. Image Processing: Advances in Applications and Research. Nova Science Publishers, New York, US.
7. Kheiralipour K, Ahmadi H, Rajabipour A, Rafiee S (2018) Thermal Imaging, Principles, Methods and Applications. (1st Edn.) Ilam University Publication.
8. Vadivambal R, Jayas DS (2016) Bio-Imaging: Principles, Techniques, and Applications. CRC Press, Taylor and Francis Group, New York, NY, US.
9. Sun DW (2010) Hyperspectral imaging for food quality analysis and control. (1st edition.) Elsevier, London, UK.
10. Park B, Lu R (2015) Hyperspectral imaging technology in food and agriculture. (1st edition). Springer, New York, USA.
11. Kheiralipour K, Singh CB, Jayas DS (2023b) Applications of Visible, Thermal, and Hyperspectral Imaging Techniques in the Assessment of Fruits and Vegetables. In: Jayas DS. Image Processing: Advances in Applications and Research. Nova Science Publishers, New York, US.
12. Gowen AA, O'Donnell CP, Cullen PJ, Downey G, Frias JM (2007) Hyperspectral imaging-an emerging process analytical tool for food quality and safety control. Trend Food Sci Technol 18(12): 590-598.
13. Basantia NC, Nollet MLL, Kamruzzaman M (2019) Hyperspectral imaging analysis and applications for food quality. (1st edition.) CRC Press. FL, USA.
14. Dale LM, Thewis A, Boudry C, Rotar I, Dardenne P, et al. (2013) Hyperspectral imaging applications in agriculture and agro-food product quality and safety control: A review. Appl Spectroscopy Rev 48: 142-159.
15. Mahesh S, Jayas DS, Paliwal J, White NDG (2015) Hyperspectral imaging to classify and monitor quality of agricultural materials. J Stored Products Res 61: 17-26.
16. Arias F, Zambrano M, Broce K, Medina C, Pacheco H, et al. (2021) Hyperspectral imaging for rice cultivation: Applications, methods and challenges. AIMS Agriculture and Food 6(1): 273-307.
17. Nevela NE, Baden T (2022) A low-cost hyperspectral scanner for natural imaging and the study of animal colour vision above and under water. Scientific Rep 9(1): 10799.
18. Pandey P, Srivastava PK, Balzter H, Bhattacharya B, Petropoulos G (2020) Hyperspectral Remote Sensing, Theory and Applications. (1st Edition). Elsevier, Amsterdam, The Netherlands.
19. Kheiralipour K, Chelladurai V, Jayas DS (2023a) Imaging Systems and Image Processing Techniques. In: Jayas, D.S. Image Processing: Advances in Applications and Research. Nova Science Publishers, New York, US.
20. Singh CB (2009) Detection of insect and fungal damage and incidence of sprouting in stored wheat using near-infrared hyperspectral and digital color imaging. Ph.D. dissertation. University of Manitoba, Winnipeg, Canada.
21. ElMasry G, Sun DW (2010) Principles of hyperspectral imaging technology. Chapter 1. Sun, DW. Hyperspectral Imaging Food Qual Anal Control. (1st edition.), Elsevier, Amsterdam, the Netherland.
22. Kheiralipour K (2012) Implementation and construction of a system for detecting fungal infection of pistachio kernel based on thermal imaging (TI) and image processing technology, Ph.D. Dissertation, University of Tehran, Iran.
23. Wu D, Sun DW (2013a) Advanced applications of hyperspectral imaging technology for food quality and safety analysis and assessment: A review - Part I: Fundamentals. Innovat Food Sci Emerg Technol 19: 1-14.

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

24. Wang W, Paliwal J (2006) Spectral data compression and analyses techniques to discriminate wheat classes. Transactions of the ASABE 49(5): 1607-1612.

25. Van der Maaten LJP (2007) An Introduction to Dimensionality Reduction Using Matlab. Report No., MICC 07-07. Maastricht University, Maastricht, the Netherlands.

26. Tamilarasi R, Prabu S (2020) Application of machine learning techniques for hyperspectral image dimensionality: A review. J Critical Rev 7(15): 3499.

27. Datta D, Mallick PK, Bhoi AK, Ijaz MF, Shafi J, et al. (2022) Hyperspectral Image Classification: Potentials, Challenges, and Future Directions. Comput Intelligen Neurosci 2022: 3854635.

28. Kheiralipour K, Ahmadi H, Rajabipour A, Rafiee S, Javan-NM, et al. (2014) Detection of healthy and fungal-infected pistachios based on hyperspectral image processing. 8th Iranian National Congress of Agricultural Machinery Engineering (Biosystems) and Mechanization. Mashahd, Iran.

29. Khan A, Vibhute AD, Mali S, Patil CH (2022) A Systematic review on hyperspectral imaging technology with a machine and deep learning methodology for agricultural applications. Ecolog Informat 69: 101678.

30. Ozdemir A, Polat K (2020) Deep Learning Applications for Hyperspectral Imaging: A Systematic Review. J Institute of Electronics and Comput 2: 39-56.

31. Paoletti ME, Haut JM, Plaza J, Plaza A (2019) Deep learning classifiers for hyperspectral imaging: A review. ISPRS J Photogrammet Remote Sensing 158: 279-317.

32. Ren C, Kim DK, Jeong D (2020) A survey of deep learning in agriculture: Techniques and their applications. J Inf Process Syst 16(5): 1015-1033.

33. Wang C, Liu B, Liu L, Zhu Y, Hou J, et al. (2021) A review of deep learning used in the hyperspectral image analysis for agriculture. Artif Intelligence Rev 54: 5205-5253.

34. Wan L, Li H, Li C, Wang A, Yang Y, et al. (2022) Hyperspectral sensing of plant diseases: principle and methods. Agronomy 12: 1451.

35. Shinde N, Singh G (2022) A Review of Plant Disease Prediction Methods for Agricultural Applications. International Journal of Engineer Adv Technol 12(1): 98-103.

36. Sethy PK, Pandey C, Sahu YK, Behera SK (2021) Hyperspectral imagery applications for precision agriculture- a systemic survey. Multimedia Tools and Applications 81(2): 3005-303.

37. Ravikanth L, Jayas DS, White NDG, Fields PG, Sun DW (2017) Extraction of spectral information from hyperspectral data and application of hyperspectral imaging for food and agricultural products. Food Bioprocess Technol 10: 1-33.

38. Pandey C, Kumar Sahu Y, Kumar Sethy P, Kumari Behera S (2022) Hyperspectral Imagery Applications for Precision Agriculture: A Systemic Survey. (1st Edition). CRC Press, Boca Raton, Florida, US.

39. Lu Y, Saeys W, Kim M, Peng Y, Lu R (2020) Hyperspectral imaging technology for quality and safety evaluation of horticultural products: A review and celebration of the past 20-year progress. Postharvest Biol Technol 170: 111318.

40. De Oliveira MRR, Ribeiro SG, Mas JF, Dos Santos Teixeira A (2020) Advances in hyperspectral sensing in agriculture: A Review. Revista Ciência Agronômica 51: e20207739.

41. Hosseiny B, Rastiveis H, Daneshtalab S (2019) Hyperspectral image classification by convolutional neural networks. GeoSpatial Conference, Karaj, Iran.

42. Imani M (2021) Target detection using multispectral images, a case study: wheat detection in Chenaran county in Iran. J. Electr. Comput. Eng. Innovat 9(1): 11-24.

43. Sabzi S, Pourdarbani R, Rohban MH, Garcia-MG, Paliwal J, et al. (2021) Early detection of excess nitrogen consumption in cucumber plants using hyperspectral imaging based on hybrid neural networks and the imperialist competitive algorithm. Agronomy 11: 575.

44. Aslani S (2022) Identification of healthy tomato plants from plants with nutritional abnormalities using hyperspectral imaging technique. M.Sc. Thesis. University of Mohaghegh Ardabili. Ardabil, Iran.

45. Moghimi A, Sazgarnia A, Aghkhani MH (2022) Spectral feature selection from the hyperspectral dataset to identify pistachio leaves infected by Psylla. J Agricultural Machin 12(2): 159-167.

46. Vaidya R, Nalavade D, Kale KV (2021) Hyperspectral imagery for crop yield estimation in precision agriculture using machine learning approaches: A review. Int J Creat Res Thought 9(9): 777-789.

47. Lu B, Dao PD, Liu J, He J, Shang J (2020) Recent advances of hyperspectral imaging technology and applications in agriculture. Remote Sens 12: 2659.

48. Lorente D, Aleixos N, Gomez-Sanchis J, Cubero S, Garcia-Navarrete OL, et al. (2012) Recent advances and applications of hyperspectral imaging for fruit and vegetable quality assessment. Food Bioprocess Technol 5: 1121-1142.

49. Kiani S, Van Ruth SM, Minaei S (2018) Hyperspectral imaging, a non-destructive technique in medicinal and aromatic plant products industry: Current status and potential future applications. Comput Electron Agric 152: 9-18.

50. Chandrasekaran I, Panigrahi SS, Ravikanth L, Singh CB (2019) Potential of near-infrared (NIR) spectroscopy and hyperspectral imaging for quality and safety assessment of fruits: an overview. Food Analytical Methods 12: 2438-58.

51. Lu R (2016) Quality Evaluation of Fruit by Hyperspectral Imaging. Chapter 14. Sun, D.-W. Computer Vision Technology for Food Quality Evaluation. (2nd edition.), Elsevier, Amsterdam, the Netherlands.

52. Lu Y, Huang Y, Lu R (2017) Innovative hyperspectral imaging-based techniques for quality evaluation of fruits and vegetables: A review. Appl Sci 7: 189.

53. Wu D, Sun DW (2013b) Advanced applications of hyperspectral imaging technology for food quality and safety analysis and assessment: A review - Part II: applications. Innovat Food Sci Emerg Technol 19: 15-28.

54. Taghinezhad E, Szumny A, Figiel A (2023) The Application of hyperspectral imaging technologies for the prediction and measurement of the moisture content of various agricultural crops during the drying process. Molecules 28(7): 2930.

55. Khan A, Munir MT, Yu W, Young BR (2020) A review towards hyperspectral imaging for real-time quality control of food products with an illustrative case study of milk powder production. Food Bioprocess Technol 13: 739-752.

56. Huang H, Liu L, Ngadi MO (2014) Recent Developments in Hyperspectral Imaging for Assessment of Food Quality and Safety. Sensors 14: 7248-7276.

57. Aviara AN, Liberty JT, Olatunbosun OS, Shoyombo HA, Oyeniyi SK (2022) Potential application of hyperspectral imaging in food grain quality inspection, evaluation and control during bulk storage. J Agric Food Res 8: 100288.

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

58. Darvishsefat AA, Abbasi M, Schaepman ME (2011) Evaluation of spectral reflectance of seven Iranian rice varieties canopies. J Agr Sci Tech 13: 1091-1104.

59. Kheiralipour K, Ahmadi H, Rajabipour A, Rafiee S, Javan-Nikkhah M, et al. (2015) Detection of fungal infection in pistachio kernel by long-wave near-infrared hyperspectral imaging technique. Quality Assurance and Safety of Crops & Foods 8(1): 129-135.

60. Khodabakhshian R, Emadi B (2017) Application of Vis/SNIR hyperspectral imaging in ripeness classification of pear. Int J Food Properties 20(S3): 149-163.

61. Khodabakhshian R, Emadi B, Khojastehpour M, Golzarian MR, Sazgarnia A (2017) Development of a multispectral imaging system for online quality assessment of pomegranate fruit. Int J Food Properties 20(1): 107-118.

62. Ghanei Ghooshkhaneh N, Golzarian MR, Mamarabadi M (2018) Investigation of perceptron artificial neural network ability to detect the healthy and contaminated area to orange green mold in visible and hyperspectral images. 11th Iranian National Congress on Mechanical Engineering of Biosystems and Mechanizasion. Hamadan, Iran.

63. Zolfi F, Soltani P, Panahi M, Darudi A (2021) Detection of aflatoxin in pistachio using fluorescence hyperspectral imaging. 28th Optics and Photonics Conference and the 14th Photonics Engineering and Technology Conference of Iran. Ahvaz, Iran.

64. Pourdarbani R, Sabzi S (2022) Detection of cucumber fruits with excessive consumption of nitrogen using hyperspectral imaging (with emphasis on sustainable agriculture). J Environ Sci Studies 7(4): 5485-5492.

65. Golmohammadi A, Tahmasebi M, Razavi MS (2022) Near infrared hyperspectral imaging for non-destructive determination of pH value in red delicious apple fruit during shelf life. Innovat Food Technol 9(2): 99-111.

66. Hasanzadeh B, Abbaspour-GY, Soltani-NA, Hernandez-HM, Gallardo-BI, et al. (2022) Non-destructive detection of fruit quality parameters using hyperspectral imaging, multiple regression analysis and artificial intelligence. Horticulturae 8: 598.

67. Golmohammadi A, Razavi MS, Tahmasebi M (2022) Prediction of peroxidase activity using near infrared hyperspectral imaging in red delicious apple fruit during storage time. Innovat Food Technol 9(3): 239-254.

68. Hashemi-Nasab FS, Parastar H (2022) Vis-NIR hyperspectral imaging coupled with independent component analysis for saffron authentication. Food Chem 393: 133450.

69. Alimohammadi F, Rasekh M, Afkari Sayyah AH, Abbaspour-GY, Karami H, et al. (2022) Hyperspectral imaging coupled with multivariate analysis and artificial intelligence to the classification of maize kernels. Int Agrophys 36: 83-91.

70. Molayi M, Golmohammadi A, Tahmasebi M (2024) Investigating the qualitative properties of sugar beet using hyperspectral imaging. J Environ Sci Studies 9(2): 8284-8298.

71. Pourdarbani R, Sabzi S (2024) Feasibility of using hyperspectral imaging to detect bruising in oranges. J Environ Sci Studies 9(1): 7938-7946.

72. Zolfi F, Daroudi A, Soltani P (2019) Determining the percentage of ground beef and lamb and fat percentage by hypercube analysis of hyperspectral camera data. 26th Iranian Optics and Photonics Conference and 12th Iranian Photonics Engineering and Technology Conference, Tehran, Iran.

73. Khoshnoudi-Nia S, Moosavi-Nasab M (2019) Prediction of various freshness indicators in fish fillets by one multispectral imaging system. Scientific Rep 9: 14704.

74. Moosavi-Nasab M, Khoshnoudi-Nia S, Azimifar Z, Kamyab S (2021) Evaluation of the total volatile basic nitrogen (TVB-N) content in fish fillets using hyperspectral imaging coupled with deep learning neural network and meta-analysis. Scient Rep 11(1): 5094.

75. Kumar A, Saxena S, Shrivastava S, Dhama K (2016) Hyperspectral imaging (HSI): Applications in animal and dairy sector. J Exp Biol Agri Sci 4(4): 448-461.

76. Coombs CEO, Allman BE, Morton EJ, Gimeno M, Horadagoda N, et al. (2022) Differentiation of livestock internal organs using visible and short-wave infrared hyperspectral imaging sensors. Sensors (Basel) 22(9): 3347.

77. Galaura Dantes PT (2020) NIR hyperspectral imaging for animal feed ingredient applications. PhD. Desertation, Iowa State University, Ames, Iowa, US.

78. Lu G, Wang D, Qin X, Halig L, Muller S (2015) Framework for hyperspectral image processing and quantification for cancer detection during animal tumor surgery. J Biomed Opt 20(12): 126012.

79. Chiao CC, Kenneth Wickiser J, Allen JJ, Hanlon RT (2011) Hyperspectral imaging of cuttlefish camouflage indicates good color match in the eyes of fish predators. Proc Natl Acad Sci US 108(22): 9148-9153.

How to cite this article: Kamran K. Current and Future Applications of Hyperspectral Imaging in Agriculture, Nature, and Food. Trends Tech Sci Res. 2024; 7(2): 555708. DOI:10.19080/TTSR.2024.07.555708

DOI: 10.19080/TTSR.2024.07.555708