Applications of Image Processing in Agriculture: A Survey

Anup Vibhute
Assistant Professor,
BMIT, Solapur(India)

S K Bodhe
Phd, Professor, College of
Engineering , Pandharpur

ABSTRACT

Image processing has been proved to be effective tool for analysis in various fields and applications. Agriculture sector where the parameters like canopy, yield, quality of product were the important measures from the farmers' point of view. Many times expert advice may not be affordable, majority times the availability of expert and their services may consume time. Image processing along with availability of communication network can change the situation of getting the expert advice well within time and at affordable cost since image processing was the effective tool for analysis of parameters. This paper intends to focus on the survey of application of image processing in agriculture field such as imaging techniques, weed detection and fruit grading. The analysis of the parameters has proved to be accurate and less time consuming as compared to traditional methods. Application of image processing can improve decision making for vegetation measurement, irrigation, fruit sorting, etc.

KEYWORDS- agronomy, Remote Sensing, hyper-spectral, fuzzy logic, neural network, Genetic algorithm, wavelet, PCA, fruit grading.

1. INTRODUCTION

In evolution towards sustainable agriculture system it was clear that important contributions can be made by using emerging technologies. Precision agriculture was new and developing technology which leads to incorporate the advance techniques to enhance farm output and also enrich the farm inputs in profitable and environmentally sensible manner. With these techniques/tools it was now possible to reduce errors, costs to achieve ecological and economically sustainable agriculture. Farm inputs were important parameters to be controlled and if not will result in adverse effects causing reduction in yield, deteriorating plant health, etc.

Irrigation/Water stress, Fertilizers, pesticides and quality of yield were the major factors of concern in agriculture. Most of the time the expertise were required to analyze the problems and which may be time consuming and costlier issue in developing countries. Image processing was one of the tools which can be applied to measure the parameters related to agronomy with accuracy and economy. Applications of image processing in agriculture can be broadly classified in two categories: first one depends upon the imaging techniques and second one based on applications. This survey mainly focuses on application of image processing in various domains of agriculture.

2. APPLICATIONS BASED ON IMAGING TECHNIQUES

In image processing source of radiation was important and the sources were Gamma ray imaging, X-ray imaging, imaging in UV band, imaging in visible band and IR band, imaging in Microwave band and imaging in Radio band. [1]

In agriculture, Remote Sensing (RS) technique was widely used for various applications. [2] Remote Sensing was the science of identification of earth surface features and estimation of geo-biophysical properties using electromagnetic radiation. Paper reviewed the Rs techniques and its applications with optical and microwave sensors. Author discussed about the satellites launched by different countries and their uses in various field along with spatial, spectral and temporal variations of data. Analytical techniques using digital image processing, multi-source data fusion and GIS were also discussed. Applications towards agriculture providing the earth observation data which supports increased area under agriculture, increased crop intensity and productivity, etc. RS data can provide the data related to groundwater helping in irrigation, flood management. Applications like environment assessment and monitoring, disaster monitoring and mitigation, weather climate, village resource center, etc. were also discussed.

RS data and pattern recognition technique was used to estimate direct and independent crop area in the study region [3]. In this review the authors reviewed the different techniques for crop inventory in Indian scenario. Optical and microwave data used to classify the crop. Chlorophyll and water were represented by optical data, crop geometry and dielectric properties were characterized by microwave. The crop discrimination was carried out using either by visual or digital interpretation techniques. Visual techniques based on FCC (False Color Composite) were generated at different bands and were assigned with blue, green and red colors where as the digital techniques applied to each pixel and use full dynamic range of observations were preferred for crop discrimination. For accurate discrimination a multi-temporal approach was used when single date data fails to do so. Spectral unmixing, direct estimation, crop area estimation, global estimation using confusion matrix and regression estimator were also reviewed.

RS used for mapping vegetation which provides information of manmade and natural environments. [4] The focus of review was on remote sensing sensors, image processing algorithms to extract vegetation information along with classification and limitations. Different remote sensing sensors like LANDSAT, TM, SPOI, MODIS, ASTER etc were covered along with features and mapping applications. Vegetation extraction using image processing was in two parts , first was image preprocessing for bad line replacement, radiometric and geometric corrections. Clouds which compose a big noise also require the preprocessing and need to be removed. Second part was image classification such as K-mean for unsupervised and MLC for supervised were reviewed. Spectral angle classifier-SAC used by Sohen and Rebello along with ANN and fuzzy was reviewed. Hyperspectral imagery for vegetation mapping was widely used as compared to multispectral as it was capable to discriminate complex mixed pixel community. Image fusion was another technique to improve the vegetation classification as individual sensor may be incomplete, inconsistent and imprecise. They concluded that the Remote sensing was advantageous over traditional methods of vegetation mapping and classification.

RS sensed images for extracting endmembers was the difficult problem in vegetation. [5] Endmember represents an idealized pure spectrum signature for given class. Vegetation mapping was the challenge because of plant canopy reflectance variation. Vegetation mapping was difficult in case for given vegetation species with relatively homogenous leaf spectral characteristics as it can exhibit marked spectral variance due to variability in background spectra. Endmember extraction algorithm (EEA) was used to extract the information from remotely sensed images. Its enhanced version support vector machine – based endmember extraction (SVM-BEE) provides highly accurate results. Complex image (AVIRIS) which comprise large number of classes in limited area was used to test the efficacy of SVM-BEE and N-FINDR endmember algorithms in linear mixing models. SVMBEE shows better performance as compared to N-FINDR and SMACC. The better performance of SVMBEE was because of the capability of support vector to convex hull was superb as well as robustly noise-tolerant and was able to accurately estimate endmembers.

Irrigation was also one of the important parameter in agriculture which was correlated with the canopy, its reflectance, nutrition etc. Satellite remote sensing has a lot of potential for routine monitoring of irrigation [6]. The benefits and drawbacks of remote sensing in crop location, productivity and irrigation setting were discussed. Authors defined Irrigated lands were the areas that receive full or partial application of water by artificial means to offset periods of precipitation shortfalls during the growing period. Spatial scales where the studies of local, regional and global areas were considered. Local area was related to command basin, regional to river basins and global to worldwide. Initially hard copies of satellite images were used to map the irrigated lands at lower costs. Archival image data from multiple years also proved useful as color changes were observed between newly and previously irrigated croplands. Digital image classification techniques for multiple image classification were accurate and useful as time required for analysis was shorter at lower costs. Commonly used image classification techniques were multi-stage classification, unsupervised clustering, density slicing with thresholds, and decision tree classifications. Normalized Difference Vegetation Index (NDVI) proved to be important for identifying irrigated areas in local scale studies as it was directly used as input to classification algorithm. Green index and Relative sensitivity index were calculated on the basis of reflectance and irrigation.

Thermal imaging and its applications in agriculture were discussed in [7]. Thermal imaging which was a passive technique (infrared range between 3 to 14 μm) focuses on Water. Water which affects the thermal properties of plant where leaf contains different amount of water per area can be utilized as an important parameter in pre harvesting operations. Applications of thermal imaging to Field nursery, irrigation scheduling, yield forecasting, green houses termite attack etc were reviewed. Post harvesting operations such as maturity evaluation, bruise detection, detection of foreign substances in food etc were also reviewed. Though the thermal imaging produces better results but cannot be accepted universally in agriculture applications as the plant physiology and climatic conditions varies from region to region.

X-ray imaging for luggage inspection of contraband food products, packaged food specifically bottle or can packed was highly suitable. Ronald P. Haff Æ Natsuko Toyofuku [39] presented technique of X-ray imaging in detection of defects and contamination in food. A packaged food (metal, plastic, glass, etc.) provides much higher contrast in X-ray images than the typical defects or contaminants of interest that were found in fresh produce (insect infestation, physiological defects, etc). Poultry inspection for bone fragments and thickness detection, grain inspection of wheat were few other fields where X-ray imaging can be utilized. Detection of disease on apple, insect detection in tree nuts and food grading were few more applications of X-ray imaging with limitation of high speed inspection. In food grading also X- ray imaging with classifiers were proved to be effective sorters[32].

2.1 Applications in Weed detection:

Weeds were the plants growing in wrong place in farm which compete with crop for water, light, nutrients and space, causing reduction in yield and effective use of machinery. Weed control was important from agriculture point of view, so many researchers developed various methods based on image processing. Weed detection techniques used algorithms based on edge detection, color detection, classification based on wavelets, fuzzy etc.

Real time weed recognition system for identifying outdoor plant using machine vision uses edge based classifier to identify broad and narrow weeds. [8] Images acquired in RGB were converted to gray scales and used to process as binary image. Bright pixels in dark background were identified as weed and classified as in broad and narrow using threshold values. The limitation that proposed model does not classify mixed weeds. In color detection method images were captured adjusting color gains and shutter time to gray plates. [9] Excessive green and thresholding was used for segmenting volunteer and non volunteer potato plant regions. Image was then transformed using EGRBI matrix to separate intensity information. EG and RB values help to separate potato pixels from sugar beet pixels. Pixel classification based on K-means clustering and Bayes classifier was used to measure the Euclidean distance. ART2 classifier was also tested for Euclidean distance based clustering. Objects classified on threshold value were identified as potato plants VP and sugar beet SB. Neural network based classification has proven better than K-mean Lookup table approach in classification of objects where as lookup table was four time faster than NN. For outdoor conditions plant growth and lighting conditions need to considered and adaptive methods required for classification in such conditions. Statistical methods such as mean and standard deviation were used for image classification of weeds into little, narrow and broad weeds. [11] But the limitation of method was that it cannot be applied for classification of mixed weed. Classification success rate of statistical method was less compared to color method with classifiers.

Feature extraction techniques using color image processing for weed detection with FFT and GLCM were discussed. [10] Excess color Ex-C filter was used to remove the color red and blue with green as an intensity value. Ex-C was implemented using formula 2*G-R-B. Gray level co occurrence matrix and FFT were used as feature extraction tools. GLCM represents the occurrence of gray levels in an image and its its relationship in co-occurrence matrix. EX-Color based approach was better than gray scale for better classification of weeds.

Wavelet based classification for weeds using Gabor wavelet (GW) and GFD for real time herbicide applications classifies weeds into broadleaf and narrow – grass categories.[12] Color images captured were preprocessed to remove red and blue using modified excess green MExG. This information was applied as input to GW and then followed by Gradient Field Transform.. Spatial locality, orientation selectivity and frequency characteristics made Gabor wavelet popular in image analysis. Convolution between MExG and GW provides the best contrast levels between plants and soil compared with R and B channels. Gradient field transform was applied for feature selection based on histogram or gradient bars and curve fitting on gradient bar which shows improved results over GW approach. ANN was used as classifier to classify weeds into grass and broadleaves. GW and GFD success rate was higher than GW used separately.

Weed infestation rate(WIR) in synthetic images using Gabor filtering and results of wavelets were compared in [13]. Daubechies, Symlet, Coiflet, Meyer, Biorthogonal, R-biorthogonal wavelets were used for image decomposition and reconstruction. Results of these and global confusion matrix were used to classify crop and weed into true and false categories. Daubechies 25 wavelet and the Meyer wavelets gives better result than Gabor filtering at the cost of average time in both synthetic and real images.

A genetic algorithm for weed extraction use combinational methods such as segmentation of vegetation and soil, crop row elimination and weed extraction. [14] For segmentation- S1 and S2 methods, for crop row elimination- E1, E2 and E3 methods and for weed extraction- F1 and F2 methods were proposed. S1 method combines RGB to gray conversion and Gray to BW using threshold values, where as S2 directly converts RGB to BW depending on pixel property. E1and E2 algorithms in which crop elimination was done by taking column pixels into considerations. F1 and F2 for weed extraction use the filtering and region extraction. Then the combinations of S, E and F were processed to find out the optimum value by genetic algorithm method. Results of the methods were compared with biomass and showed accuracy up to 96% with small computational complexity.

Uniform herbicide application was harmful to the crop. Case based reasoning (CBR) was problem solving technique using previous knowledge about problem and solution. [15] Images were categorized into light- sunny or cloudy, presence of sowing errors-true or false, crop growth stage-low, medium, high and infested field. Images were processed through segmentation methods -S1, S2, elimination- E1,E2,E3 and filtering- F1 and F2 were compared with decisive variables, advantages and drawbacks. Characteristic attributes were saved as Case indexing, then case representation and case base structure was followed. Case retrieval, case retention and learning were the steps where new cases were considered. Evaluation has been performed with different combinations of CBR methods proposed and compared. CBR technique shows high correlation coefficient as compared to non-CBR methods, Experts. They concluded with CBR can be used as a new expert system based on cases and solutions.

Fuzzy algorithm for site specific herbicide application was developed for reducing application of herbicides and protection of environment from pollution.[16] Greenness ratio calculated to identify the pixel as a part of image which indicates the weed coverage area in an image. Different illumination conditions and shadow makes it difficult to decide the threshold for greenness. Weed patchiness was calculated over neighborhood and map was developed. Fuzzy algorithm was applied in triangular and trapezoidal membership functions for input and output: low, normal and high functions for weed coverage thin, average, thick for weed patchiness and small, medium and large for herbicide applications. Weed coverage mapping was carried out between 1% o 5% and above which then related to herbicide applications. Application of image processing and fuzzy logic determines the weed coverage and useful for site specific herbicide application.

ANN can be used to develop model to classify crop and weeds effectively. [17] 8 bit BMP images captured by Kodak digital camera were converted to indexed based images on RGB color system. Pixel values represented as an integer in the range of 0 to 255 for black and white respectively. These assigned color index served as input to ANN. Two classifiers were used, one in which only one output and second in which two outputs were present. Output values discriminates the crop and weed. Classification was done in types named as Type 1-A, 1-B, 2-A, 2-B. These types were compared with each other for various PE's in hidden layers of ANN. Number of PE's were kept at 3% of input PE's. Success rate was between 60-80% and can be improved with higher number of PE's in hidden layers. Author concluded that ANN has potential for fast image recognition and classification.

Estimation of weed coverage using two techniques one with camera and second one with photodetectors for discrimination of weed from ground were proposed in [18]. In camera based method RGB luminance indicator, which was a RMS value and discrimination thresholds were utilized. Two thresholds Cr, Cg discriminate ground and weed. Second technique which uses photodetectors and flash lighting system was cheaper and faster, has limitation when sunny conditions were there. Camera based system proved to be better from uncertainty and accuracy point of view at the expense of complexity and cost.

Erosion and dilation segmentation algorithm was used to classify the weeds into broad and narrow leaves.[19] Image in RGB was decomposed to R, G, B components and converted to binary image which discriminates bright pixel as weed and dark as background. Erosion by structured element was used to eliminate the irrelevant details and then dilation was applied, storing the result in the form of tables. Success rate of classification was remarkable with less algorithm execution time.

For identification of the seeds of weeds and reorganization of the species using image processing, Principal component analysis (PCA), a common classical dimensionality reduction method and its modified versions were applied in [20]. PCA converts larger correlated data into uncorrelated ones which were known as principal components. Image matrix was converted to image vectors which help to reduce it to low dimensional space. 2DPCA based on Euclidian distance uses row and column direction of the image by computing eigenvalues and eigenvectors and $(2D)^2$ PCA which gives feature matrix from projection and proved to be better than original PCA. The four methods PCA, 2DPCA, e2DPCA, $(2D)^2$PCA were compared. Dimension Space requirement of $(2D)^2$PCA was much smaller and need less time than PCA for larger data sets. Weed recognition accuracy of $(2D)^2$PCA was also high.

2.2 Applications in fruit / food grading:

Need of accurate grading, sorting of fruits and foods or agriculture products arises because of increased expectations in quality food and safety standards. It causes increased processing and labor work. Computer vision and image processing were non destructive, accurate and reliable methods to achieve target of grading. Image processing in agriculture and food industries has been applied in the areas of sorting, grading of fresh products, detection of defects such as dark spots, cracks and bruises on fresh fruits and seeds, etc. Same kinds of concepts were explored by many researchers with different image processing approaches.

Image processing concepts for grading of bakery products, fruits, vegetables and grains were considered in [21]. Fruits characterized by color, size and shape, its condition in pre and post harvesting, damages were attributes for grading. Vegetables specially roots, tomatoes, mushrooms were also compared with its attributes for grading purpose. Socio economic Limitations were also discussed. Similar kinds of approaches for grading of Grains, fruits, vegetables were reviewed by other researchers [22-23]. The methods or techniques in image processing such as image segmentation, shape analysis and morphology, texture analysis, noise elimination, 3D vision, invariance, pattern recognition and image modality were applied for grading these categories. Automated system of sorting food and agriculture products provides rapid and hygienic inspection with computer vision.

For raisin grading specially designed hardware which captures the image was developed. [24] Image was processed with VB based algorithm for color and size of raisins. Pixel colors in RGB form were calculated and with position control, upper and lower pixels were determined. From these pixels middle position can be determined and features were extracted. Raisins with bad grade were identified as background and others in good category. From confusion matrix the classification rate obtained was higher as compared to human experts. This algorithm was also applicable to lentil and almond.

For detection of skin defects in citrus fruit PCA method was used for multivariate image analysis (MIA). [25] Images captured with 3CCD camera were applied to MIA algorithm which unfolds the images in RGB and spatial information. Reference eigenvector formed by training with defect free citrus was used to compute T^2 matrix. Threshold value decides the defect in fruit, if the value was greater, then it was considered as defect. This leads to preparation of defect map. Multi-resolution and post processing techniques were used to speed up the process with three different measures. In study of 9 defects detection average correct detection was 91.5% and classification into four damaged /sound classes was 94.2%. Author concluded with discussion of novelty detection and ability of model to identify new unpredictable defects.

K-mean clustering for strawberry grading into different categories on the basis of shape, size and color was proposed. [26] The hardware includes camera, photosensors with single chip microcomputer. Captured image was converted to G-R so that background can be separated after threshold. K-mean clustering was used to grade the strawberries. Shape was graded into long-taper, square, taper and rotundity using R-G channel and segmentation. This was used to find out contour helpful in indentifying the major axis of direction. Similarly horizontal line with threshold value was identified for size. Strawberry color feature was extracted by the dominant color method on a* channel in La*b* color space. System was also proposed for multi-feature gradation system. Size detection observed has average error of 3.55, color detection success rate was 88.8% and overall grading has 94%.

Fruits and vegetables classification using features and classifiers with fusion was proposed. [27] Images were the collected as a data over the period for distribution in supermarkets. 8bit color images were classified on the basis of statistical, structural and spectral basis. Image descriptors like global color histogram, Unser's descriptors, color coherence vector, border/interior, appearance descriptor, supervised learning techniques were considered. For background subtraction k-mean was utilized. Classification was done using diverse machine learning techniques such as Support Vector Machine (SVM), Linear Discriminant Analysis (LDA), Classification Trees, K-Nearest Neighbors (K-NN), and Ensembles of Trees and LDA and fusion. Multi-class classification provides custom-tailored solutions to problems and performed better. Model was helpful in classifying the species of produce and variety.

Morphological process based image analysis of shape in real time for inspecting and sorting processed mandarin segment was developed. [28] Images in RGB format illuminated with constant source were captured. These images were segmented in background and objects of interest. A morphological operation allows identifying the objects in complete, broken formats. The shape analysis was done by perimeter and area calculation. Once the contour was obtained, FFT was applied to discriminate low and high frequency details which were helpful in size determinations. Standard Bayesian discriminant analysis was used for classification. Mechanical system limits the speed of sorting. Model provided real time classification with enough accuracy.

Image processing- a noninvasive technique was used to evaluate the quality of the tomato on the basis of color, shape, size, firmness. [29] Many techniques such as invasive and noninvasive, destructive and nondestructive were reviewed. Image Processing techniques such as segmentation, Pattern recognition, Gray scale, Excess green, etc. were also reviewed with a conclusion that image processing is effective, fast measurement method and close to laboratory testing.

Hardware designed with a camera and with other hardware like feeder, hopper, etc. was used to sort red and white wheat. [30] Image analysis was carried out by separating R, G and B using Bayer filtering. Each plane was separated from blank image to identify the background and object. Three intensity histograms extracted as features were used for classification. Each histogram represents the scaled red, green, or blue pixel. Intensities from the wheat kernel image were computed. Parameters like mean and standard deviation of the red, green, and blue intensities were also computed. Linear Discriminant analysis was used as classifier. Classification accuracy was 97% compared to histogram feature method (88%). Average Accuracy of classification was greater than the commercial color sorters. Author concluded developed model was cost effective and accurate. Similar kind of hardware based grain classifier was developed with three CMOS sensor and FPGA combination for higher speed of inspection. [31] Red pixels were used to classify the red and white wheat grains. Parameter like variance was also utilized. The same hardware was used for popcorn classification of blue-eye damage. Classification accuracy rate was 91 % in wheat and corn cases.

The classification of vitreous and non-vitreous durum wheat kernels using imaging systems based on real time soft X-rays or transmitted light was proposed. [32] X-ray images were analyzed using histogram technique. Features like kernel area, total gray value, mean gray value, inverted gray value, and standard deviation of the gray levels were extracted and classified using statistical classifier. In case of Transmitted light images Densitometric and textural features like kernel area, skewness of gray level, kurtosis of gray level, standard deviation and mean gray values were extracted and classified using linear Bayes classifier. Classification accuracy was more in case non vitreous using Bayes classifier and also of transmitted light images compared to X-ray images.

Corn variety identification on the basis of the color, shape and geometric features using discrimination analysis and neural network was proposed in [33]. To avoid illumination and manmade disturbances images were captured with flat bed scanner. Features were extracted using morphological feature analysis and color feature. Morphological feature analysis of corn kernels was used to extract basic geometric features such as area, perimeter and derived shape features. Color analysis was used for classification. Mean and standard deviation of these color components were calculated to extract 28 color features for identification. To reduce computational burden and to enhance the performance of classification stepwise Discriminant analysis was used. Mahalanobis distance method with back propagation neural network was used to train and classify the corns with higher accuracies. Feature selection with discriminant analysis and two stage classifier identifies the variety at rate of average 90% .

Monochrome images with different illuminations like incandescent light (IL), fluorescent ring light (FRL), fluorescent tube light (FTL) were used to classify the wheat grains. [34] A linear discriminant function was used for the classification of wheat samples. 32 gray level textural features were extracted from the monochrome images. Mean gray value analysis used to identify wheat in two classes along with linear discriminant analysis. LDA analysis with FTL shows great results as compared to analysis with other sources in different moisture conditions.

Images in illumination of halogen lamps were captured using CCD camera for detection of defects in apple [36]. Apple was rotated and images were captured for multiscan image analysis. Different threshold segmentation methods were applied to detect the different defects. Success Rate claimed was high. Three camera systems were proposed to capture images of apple surface. [35] Preprocessing techniques like background segmentation, image de-noise, child image segmentation and sequential image processing were applied. The blemish detection procedure consisting initial segmentation and refinement were used to identify the defects in apple. Three color camera method reduced errors in classification effectively as compared to single camera. The main disadvantage noticed that method proposed could not distinguish different defect types.

Image processing technique was proposed for determining the volume of the fruit and sorting in [37]. In this method the standard water displacement method was compared with image processing technique. Image of cantaloupe was taken into RGB and converted to gray and then region of interest was found out by threshold technique. Major and minor axis pixels were counted. Mean difference confidence interval approach and Bland- Altman approach were used to calculate the volume of cantaloupe. This was comparable with water displacement method.

Quality of Jatropha curcas nuts in the biodiesel production depends upon skin color and fruit size, type and size of defects. [38] Color histogram technique like Mean Color Intensity (MCI) was used to analyze the red, green and blue (RGB) colors of Jatropha curcas. Grading technique for Jatropha was divided in three parts- image data collection, training and testing. Mean color intensity values were used to train the program and testing based on the standard mean was carried out. Jatropha curcas graded in three categories-raw, ripe and over ripe on the basis of mean values of RGB.

3. CONCLUSION

Image processing technique has been proved as effective machine vision system for agriculture domain. Imaging techniques with different spectrum such as Infrared, hyper spectral imaging, X-ray were useful in determining the vegetation indices, canopy measurement, irrigated land mapping etc with greater accuracies. Weed classification which affects the yield can be correctly classified with the image processing algorithms. The accuracy of classification varies from 85%- 96% depending on the algorithms and limitations of image acquisition. Thus with such great accurate classification farmers can apply herbicides in correct form. This approach helps to save the environment as well as the cost. In case of fruit grading systems the segmentation and classification can also be achieved with great accuracy as the case with weed detection. In this case also the classification accuracy can be obtained up to 96% with correct imaging techniques and algorithms.

Thus we can conclude that image processing was the non invasive and effective tool that can be applied for the agriculture domain with great accuracy for analysis of agronomic parameters.

4. REFERENCES

[1] Gonzalez Rafael C., Richard E woods, “Digital Image Processing”, 2nd Edition

[2] Ranganath R. Navalgund, V. Jayaraman and P. S. Roy, 2007, “Remote sensing applications: an overview”, current science, vol. 93, no. 12, 1747-1766.

[3] Dadhwal V.K., R.P. Singh, S.Dutta & J.S. Parihar 2002, “Remote sensing based crop inventory: A review of Indian experience”. International Society for Tropical Ecology,43(1): 107-122.

[4] Yichun Xie, Zongyao Sha and Mei Yu, 2008, “Remote sensing imagery in vegetation mapping: a review”, Journal of Plant Ecology, volume 1, number 1, 9–23

[5] Anthony M. Filippi, Rick Archibald, Budhendra L. Bhaduri, and Edward A. Bright, 2009, “Hyperspectral agricultural mapping using Support Vector Machine-Based Endmember extraction (SVM-BEE)” , Vol. 17, No. 26 / OPTICS EXPRESS 23823 .

[6] Mutlu Ozdogan , Yang Yang, George Allez and Chelsea Cervantes, 2010, “Remote Sensing of Irrigated Agriculture: Opportunities and Challenges”, *Remote Sensing*, *2*, 2274-2304.

[7] Annamalai Manickavasagan, Digvir S. Jayas, Noel D.G. White, Jitendra Paliwal, “Applications of Thermal Imaging in Agriculture – A Review”, The Canadian society for engineering in agriculture, food and biological systems, paper 05-002

[8] Imran Ahmed, Awais Adnan, Salim Gul, Md Islam, 2008, “ Edge based real time weed recognition system for selective herbicides”, Proceedings of IMECS, Vol-1.

[9]A.T. Nieuwenhuizen, L. Tang, J.W. Hofstee, J. Muller, 2007, “ Colour based detection of volunteer potatoes as

weeds in sugar beet fields using machine vision", Springer precision agric, pp 267-278.

[10] Kamarul Ghazali, Mohd Mustafa, Aini Hussain, 2007, "Color image processing of weed classification: A comparison of Two feature extraction technique", proceedings of ICEEI Institute technology Bangdung, Indonesia, pp 607-610

[11] Imran Ahmed, Syed shah, Md Islam, Awais Adnan, 2007, " A Real time specific weed recognition system using statistical methods" , World academy of science, engineering and technology, pp 143-145.

[12] Asnor J. Ishak, Aini Hussain, Mohd Marzuki Mustafa, 2007, " Weed image classification using Gabor wavelet and gradient field distribution" , Elsevier- computers and electronics in agriculture 66, pp 53-61.

[13] J. Bossua, Ch. Géea, G. Jones, F. Truchetetb, 2009, "Wavelet transform to discriminate between crop and weed in perspective agronomic images", Science Direct- computers and electronics in agriculture 6 5 (2009) 133–143

[14] Xavier P. Burgos- Artizzu, Angela Ribeiro, Gonzalo Pajares, 2010,"Analysis of natural images processing for extraction of agriculture elements", Elsevier- image and vision computing 28, pp 138-149.

[15] Xavier P. Burgos-Artizzua, Angela Ribeiroa, Alberto Tellaecheb, Gonzalo Pajaresc, Cesar Fernández-Quintanillad, 2009, " Improving weed pressure assessment using digital images from an experience-based reasoning approach", Science Direct computers and electronics in agriculture 6 5 (2009) 176–185

[16] Chun-chieh Yang, Shiv O Prasher, J Landry, H.S. Ramaswamy, 2003, " Development of an image processing system and fuzzy algorithm for site specific herbicide applications" Precision agriculture,4, pp 5-18.

[17] Chun-chieh Yang, Shiv O Prasher, J Landry, H.S. Ramaswamy and A. Ditommaso, 2000, " Application of artificial neural networks in image recognition and classification of crop and weeds", Canadian agricultural engineering, vol 42,no 3, pp 147-152.

[18] Marco Parvis, Marco Pirola, 1999, " A measurement of system for on-line estimation of weed coverage", IEEE transaction on instrumentation and measurement, vol 48, pp 990-994

[19] Muhammed H. Siddiqi, Irshad Ahmed, Suziah Sulaiman, 2009, " Weed recognition based erosion and dilation segmentation algorithm", IEEE International conference on education technology and computer, pp 224-228

[20] Mengbo You, Cheng Cai, 2009, " Weed seed classification based on PCA, 2DPCA, column –directional 2DPCA and $(2D)^2$PCA" , IEEE computer Society, IASIIAC, pp 187-190.

[21] Raji A. O and A. O Alamutu, 2005, "Prospects of computer vision automated sorting systems in agricultural process operations in Nigeria**",** Agricultural Engineering International: the CIGR Journal of Scientific Research and Development". Vol. VII. Invited Overview. February 2005.

[22] Narendra V G, Hareesh K S, 2010, " Prospects of computer vision automated grading and sorting systems in agricultural and food products for quality evaluation", International Journal of Computer Applications (0975 – 8887) Volume 1 – No. 4.

[23] E R Davies, 2009, "The application of machine vision to food and agriculture: a review", The Imaging Science Journal Vol 57.

[24] M. Omid, M. Abbasgolipour, A. Keyhani and S.S. Mohtasebi, 2010, "Implementation of an Efficient Image Processing Algorithm for Grading Raisins", International Journal of Signal and Image Processing (Vol.1-/Iss.1), pp. 31-34

[25] Fernando López-García, Gabriela Andreu-García, José Blasco, Nuria Aleixos, José-Miguel Valient, 2010, "Automatic detection of skin defects in citrus fruits using a multivariate image analysis approach", Science Direct Computers and Electronics in Agriculture 71 (2010) 189–197

[26] Xu Liming, Zhao Yanchao,2010, "Automated strawberry grading system based on image processing", Science Direct -Computers and Electronics in Agriculture 71, 2010 ,pp 32–39

[27] Anderson Rocha, Daniel C. Hauagge, Jacques Wainer, Siome Goldenstein, 2010, "Automatic fruit and vegetable classification from images", Science Direct -Computers and Electronics in Agriculture 70, pp96-104.

[28] J. Blasco, N. Aleixos, S. Cubero, J. Gómez-Sanchís, E. Moltó, 2009, "Automatic sorting of Satsuma (Citrus unshiu) segments using computer vision and morphological features", Science Direct -Computers and Electronics in Agriculture 66, pp 1-8.

[29] Abraham Gastélum-Barrios, Rafael A. Bórquez-López, Enrique Rico-García, Manuel Toledano-Ayala and Genaro M. Soto-Zarazúa, 2011, "Tomato quality evaluation with image processing: A review", African Journal of Agricultural Research Vol. 6(14), pp. 3333-3339,

[30] Tom Pearson, Dan Brabec, Scott Haley , 2008, "Color image based sorter for separating red and white wheat", Springer Sensor. & Instrumentation for Food Quality and safety, 00

[31] Tom Pearson, 2009, "Hardware-based image processing for high-speed inspection of grains", Science Direct, Computers and Electronics in Agriculture 69, pp 12–18

[32] S. Neethirajan, C. Karunakaran, S. Symons, D.S. Jayas, 2006, "Classification of vitreousness in durum wheat using soft X-rays and transmitted light images", Science Direct- Computers and Electronics in Agriculture 53, pp 71–78

[33] Xiao Chena, Yi Xunb, Wei Li a, Junxiong Zhang,2010, " Combining discriminant analysis and neural networks for corn variety identification", Science Direct - Computers and Electronics in Agriculture 71, pp 48–53

[34] A. Manickavasagan, G. Sathya, D.S. Jayas. 2008, "Comparison of illuminations to identify wheat classes using monochrome images", Science Direct -Computers and Electronics in Agriculture 6 3, pp 237–244

[35]Zou Xiao-bo, Zhao Jie-wen, Li Yanxiaoa, Mel Holmes, 2010, "In-line detection of apple defects using three color cameras system", Computers and Electronics in Agriculture 70 , pp 129–134

[36] Czesław Puchalski, Józef Gorzelany, Grzegorz Zaguła, Gerald Brusewitz, 2008, "Image analysis for apple defect detection", TEKA Kom. Mot. Energ. Roln. – OL PAN, 8, 197–205

[37] Majid Rashidi, Keyvan Seyfi, 2007, "Determination of cantaloupe volume by image processing", World applied sciences journal 6(2), 646-651.

[38] Zulham Effendi, Rizauddin Ramli, Jaharah Abdul Ghani, Zahira Yaakob, 2009, "Development of Jatropha Curcas Color Grading System for Ripeness Evaluation", European Journal of Scientific Research, vol 30 No. 4, pp.662-669

[39] Ronald P. Haff Æ Natsuko Toyofuku , ２００８, "X-ray detection of defects and contaminants in the food industry", Sens. & Instrumen. Food Qual. (2008) 2:262–273