Karaelmas Science and Engineering Journal
Journal home page: http://fbd.beun.edu.tr
DOI: 10.7212%2Fzkufbd.v8i1.1024

Review
Received / Geliş tarihi : 06.06.2017
Accepted / Kabul tarihi : 11.06.2017

Computer Vision Technology on Food Science

Gıda Biliminde Bilgisayarla Görü Teknolojisi

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Abstract

Computer vision is a science that extracts useful information about an object from an observed image or image sequence automatically by analyzing in theoretical and algorithmic bases. Computer vision systems are increasingly used for detection of the surface defects, contamination, and quality inspection of the foods in the food industry. Essentially, such systems take the place of human inspectors to assess the various quality characteristics of raw and ready-to-eat foods. Computer vision technology plays a key role by giving rapid, precise, and consistent results as well as having relatively low cost. Today, computer vision systems are considered as an indispensable part of food processing units for real-time quality assessment and control. Effective techniques will be developed to process image stream data in real time to meet increased production amounts and comply with quality requirements. Robot-controlled and fully automated production will be key technology about quality assurance for competitive food producers in near future. Also, consumers will be able to check the quality of their products by themselves in the near future thanks to developing mobile hardware and software technologies.

Keywords: Computer vision, Food quality assessment, Image analysis

Öz

Bilgisayarla görü; elde edilen görüntü veya görüntü sırasında bir nesne hakkında teorik ve algoritmik tabanda otomatik olarak yararlı bilgi çıkarmaya yarayan bir bilim dalıdır. Bilgisayarla görü sistemleri; gıda endüstrisinde gıda yüzeyinde kusurların belirlenmesinde, bozulmanın tespit edilmesinde ve gıdaların kalite muayenelerinde günden güne yaygınlaşarak kullanılmaktadır. Özellikle bu sistemler, ham ve işlenmiş gıdaların çeşitli kalite özelliklerini belirleyen insanların yerini almaktadır. Bilgisayarla görü teknolojisi; hızlı, kesin ve tutarlı sonuçlar vermesi ve diğerlerine oranla daha az maliyetli olması nedeniyle gıda endüstrisinde önemli rol oynar. Günümüzde bilgisayarla görü sistemleri; gerçek zamanlı kalite derecelendirilmesi ve kontolünde gıda işleme birimlerinin ayrılmaz bir parçası olarak görülmektedir. Kalite gereksinimlerine uyumlu kalmak ve artan üretim miktarlarına karşılık gerçek zamanlı olarak akan veriyi işleyebilmek üzere etkin ve yeni teknikler geliştirilmelidir. Yakın gelecekte tamamen otomatik ve robotlar tarafından kontrol edilen üretim, gıda üreticileri arasında anahtar bir teknoloji olacaktır. Ayrıca, gelişen mobil donanım ve yazılım teknolojileri sayesinde tüketiciler, gıdaların kalitelerini kendileri de kontrol edebileceklerdir.

Anahtar Kelimeler: Bilgisayarla görü, Gıda kalite değerlendirmesi, Görüntü analizi

1. Introduction

Control of the safety and quality of food and food products in modern food production facilities is an important and critical issue because the producers have to comply strictly with the rules and they have to fulfill the demands of the customers (Sun 2007).

Computer vision applications have become very common with the increasing computer processing power and image processing techniques. It is possible to find existing objects and to obtain properties belonging to objects from an image by using computer vision technologies. The main reasons for using this technology are objective, fast and cost-free results. It is used in areas such as quality control, classification, and evaluation (Vithu et al. 2016, Xiong et al. 2017).

Factors affecting the quality of food can be determined by visual inspection and image analysis. According to this inspection result, the price of the product can be

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determined or the last consumable date can be determined. These quality attributes are related to features that can be measured with non-destructive techniques. The quality of food can be evaluated by investigating the changes in their visual properties, such as size, color, shape, and texture (Wu et al. 2013, Valous et al. 2010).

These analyses were done by humans before computer vision systems were developed, and this method was costly and subjective. In addition, computer vision techniques can perform better than human operators and human perception in the spectral range of uncertain conditions for human operators.

2. Computer Vision Technologies

Great deals of inspection tasks are repetitive, boring, and extremely tedious so the effectiveness of the efficiency depends on the human inspectors. This inspection tasks can be automated using computer vision. Computer vision is a promising technology for food safety and quality assurance applications, because of having advantages such as much higher operating speed, consistency, reliability, objectivity and applicability to industrial environments (Park 2016).

Although computer vision systems are very easy to use, they have the ability to do quite complex tasks. The main tasks can be classified as image acquisition, processing or analysis, and recognition processes. The various properties of the objects are obtained from the acquired images during the analysis phase, and the final decisions are made in recognition process by using various image processing techniques and algorithms (Mery et al. 2013).

These images can be acquired in the visible spectrum or ultraviolet and infrared spectrum. Various image acquisition systems (multispectral, hyperspectral, ultrasound) may have to be used because of the response of products distinctly at different wavelengths (Daugaard et al. 2010, Kiani et al. 2016).

The first task in image processing is to capture the image. The image can be seen as a 2D matrix with integer values. Each element is called a pixel in this matrix. The information obtained from the image is the location of the pixels and intensity values of each pixel. Image preprocessing can be done to enrich the details before the image analysis phase. Image segmentation and feature extraction are the other important steps in image processing. Image segmentation can be defined as recognition of the object and separating it from the background of the image. Measurement of the characteristics (size, color, shape, appearance, texture) of the object takes part in feature extraction phase. The last step is object classification that is automation of human visual inspection and decision making process. Object can be identified and classified into one of the finite set of classes by simulating human thinking process artificially with algorithms such as artificial neural network (ANN), fuzzy logic, decision tree, statistical methods or support vector machine (SVM) (Jackman et al. 2013, Mery et al. 2010).

Image capture systems are not error-free and perfect, so this results in distortions and loss in the images. Image preprocessing techniques aim to remove noises, artifacts, and useless signals to correct these faults without cost (Dowlati et al. 2012).

2.1. Challenges

Lighting is one of the most important factors that most seriously affect the final result of any computer vision system. Improper lighting can cause unexpected or erroneous results in the system (Vithu and Moses 2016). However, providing sufficient image resolution is another challenge. High-resolution requirements are necessary to provide better performance in computer vision applications to improve accuracy (Zhang et al. 2014). Another challenge is to examine rounded objects by considering all their surfaces. Regular cameras capture images that represent only a portion of the surface, which is a projection of the object (Misimi et al. 2016).

3. Applications on Food Science

There are numerous and various computer vision based applications for food safety and control. In this study, applications are classified as Meat, Poultry, Seafood, Fruit, Vegetables, Grain, and Bakery products. Other studies that do not fall into this classification have been ignored (Sun 2007).

3.1. Meat

Meat quality can be evaluated by considering chemical, microbiological, and sensory attributes. The most important parameters are flavor of the meat, juiciness, and tenderness. Table 1 shows applications in the area of meat.

3.2. Poultry

Appearance and texture are two main attributes for prediction of quality. Skin color, appearance defects, and cooked meat pinkness parameters affect the final decision. Table 2 shows applications in the area of poultry.

3.3. Seafood

Fish and seafood are most vulnerable food products. Physical properties, microbial contamination, and appearance play an important role in assessing the quality of seafood. Table 3 shows applications in the area of seafood.

3.4. Fruit

The quality of fruits can be evaluated by considering physical and chemical attributes. Shape and texture also give information about the quality. Table 4 shows applications in the area of fruits.

3.5. Vegetables

The appearance of vegetables is one of the first quality determinants includes color, size, shape, and gloss. Table 5 shows applications in the area of vegetables.

3.6. Grain

Bulk density, moisture content, shape, diameter are important factors while classifying grain. Table 6 shows applications in the area of grain.

Table 1. Applications for Meat

Product	Application	Technique	Accuracy (%)	Reference
Porcine meats	Prediction of color and pH	NIR hyperspectral	72,6 and 86	Liu et al. (2014)
Pork muscles	Classification	IR hyperspectral	93.14	Pu (2015)
Pork	Detection of PSE (pale, soft, exudative	Image analysis	-	Chmiel et al. (2016)
Pork	Classification	Image analysis	89 – 100	Zapotoczny et al. (2016)
Beef	Measuring meat color	Image analysis	-	Girolami et al. (2013)
Meat and turkey	Assess quality parameters	Multi-spectral	95	Daugaard et al.(2010)
Lamb	Prediction of tenderness	Hyperspectral	84	Kamruzzaman et al. (2013)
Beef, lamb, and pork	Prediction of color	Hyperspectral	97, 84, and 82	Kamruzzaman et al. (2016)
Lamb	Predicting chemical constituents	Hyperspectral	95, 80, and 91	Pu et al. (2014)

Table 2. Applications for Poultry

Product	Application	Technique	Accuracy (%)	Reference
Broiler chickens	Weight prediction	3D camera	92,2	Mortensen et al. (2016)
Poultry	Classification	Image analysis	89 – 100	Zapotoczny et al.(2016)
Chicken	Measuring color	Image analysis	-	Girolami et al. (2013)
Chicken	Prediction of color	Image analysis	99, 74, and 88	Barbin et al. (2016)

Table 3. Applications for Seafood

Product	Application	Technique	Accuracy (%)	Reference
Salmon	Classification	Hyperspectral	98.2	Xu et al. (2017)
Grass Carp Fish	Microbial contamination	Hyperspectral	-	Cheng and Sun (2015)
Shrimp	Evaluating freshness	Image analysis	90	Ghasemi-Varnamkhasti et al. (2016)
Sea bream	Evaluating freshness	Image analysis	99	Dowlati et al. (2013)
Salmon fillets	Assessing tenderness	Hyperspectral and chemometric	90.5	He et al. (2014)
Shrimp	Assess quality	Multispectral	76, 100	Xiong et al. (2016)

3.7. Bakery Products

Most bakery products, such as cake, bread, crackers, and muffins have certain shape and size attributes that represent their quality. Standard deviation of change in thickness, diameter, and weight are important parameters to be considered. Table 7 shows applications in the area of bakery products.

4. Future Research Directions

Most challenging issues are developing effective image segmentation algorithms, system robustness, real-time

Table 4. Applications for Fruit

Product	Application	Technique	Accuracy (%)	Reference
Blueberries	Microbial contamination and assess quality parameters	Image analysis	-	Matiacevich et al.(2011)
Date fruits	Determining viscoelastic characteristics	Image analysis	-	Alirezaei et al. (2013)
Apple	Grading	Image analysis	92,5	Moallem et al. (2016)
Apple	Detection of bruise	Hyperspectral	98	Keresztes et al. (2016)
Grape	Prediction of quality	3D imaging	82, 83, and 71	Ivorra et al. (2015)
Mango	Prediction of maturity	NIR spectroscopy	74, 68	Jha et al. (2014)
Papaya	Prediction of shrinkage	Image analysis	85.2, 89.1	Udomkun et al. (2016)
Strawberry	Evaluation of ripeness	Hyperspectral	95, 83.3	Zhang et al. (2016)
Cherries	Classification	Image analysis	85	Wang et al. (2012)

Table 5. Applications for Vegetables

Product	Application	Technique	Accuracy (%)	Reference
Potato	Classification	Image analysis	94	Dutta et al. (2015)
Onion	Classification	Hyperspectral, 3D, and X-ray imaging	88.9	Wang et al. (2015)
Tomato	Evaluating the quality	Image analysis	96.47	Arakeri et al. (2016)
Potato	Detection of blackspot	Hyperspectral	94	López-Maestresalas et al. (2016)
Soybean	Prediction of color and moisture	Hyperspectral	86.2, 97.1	Huang et al. (2014)
Green peas	Evaluating the quality	Image analysis	-	Barzegar et al. (2015)
Carrot	Classification	Computed Tomography	87.9	Donis-González et al. (2016)

Table 6. Applications for Grain

Product	Application	Technique	Accuracy (%)	Reference
Rice	Classification texture, shape, and texture&shape	Image analysis	82.61, 88.00, and 87.27	Chaugule and Mali (2014)
Rice	Classification	Image analysis	98	Pazoki et al. (2014)
Rice kernels	Evaluation of implicit properties	Image analysis	92	Jinorose et al. (2014)
Wheat, cassava and corn flour	Analysis of flour adulteration	Hyperspectral	97	Su et al. (2017)
Wheat	Classification	Image analysis	85.72	Khoshroo et al. (2014)

Table 7. Applications for Bakery Products

Product	Application	Technique	Accuracy (%)	Reference
Corn tortillas	Classification	Image analysis	95	Domingo et al. (2010)
Biscuits	Detection of foreign bodies	Infrared thermography	-	Senni et al. (2014)
Potato chips	Identification of acrylamide	Image analysis	94	Dutta et al. (2015)

capability, and standardization. High quality data is not enough to obtain high accuracy without superior algorithms and developed system must be robust and comply with the standards (Cubero et al. 2011).

Hyperspectral imaging has recently begun to be used in food industry for food quality evaluation. The best opportunity to develop computer imaging solutions arises from hyperspectral imaging that can provide additional information about the captured image (Sun 2010). Cost-effective and efficient algorithms need to be developed to solve the problems of hyperspectral imaging and processing and to meet the requirements of food industry (Amigo et al. 2015).

More efforts should be made to develop fast, low cost systems to detect the internal defect of food, especially fruits by using thermal imaging, X-ray imaging and MR imaging. 2D computer vision systems will be converted to future 3D systems, because automatic inspection operations increasingly require 3D information such as height or depth of the object (Wang et al. 2015).

Robot-based automation can used in different phases such as evaluation, handling, and processing in the food industry and has advantage of potential to reuse in different applications easily by reprogramming. Robot-based automation will become more widespread because of enhanced capabilities, dropped costs, flexibility, and adaptability to the current industrial platforms. Cloud robotics is another promising concept to be exploited in the food industry with advantages of the cloud infrastructure and Big Data technologies. The robot can access to large scale datasets and use these to improve of learning capabilities for evaluation of quality by using high processing power provided by cloud services (Sun 2016).

5. Conclusion

Combined with effective digital image processing techniques, computer vision is a proven technology that can provide proper and convenient information on food quality and safety. Over the last two decades, computer vision techniques such as color, multispectral, hyperspectral, thermal, x-ray and MR imaging have been extensively researched and developed for fast, objective, consistent, reliable and non-destructive assessment and evaluation of food quality. It mostly uses reflectance mode to perceive and detect surface quality attributes such as shape, size, color, and texture.

Computer vision is an important technology that enables machines to localize raw materials and better characterize them before handling and processing. In recent years, it has shown great potential to perform such tasks by evaluating physical changes and their image properties. Computer vision will remain as a key research area for the food industry. Fast and reliable control systems are an important issue to ensure that food is safely produced during processing as the public demands better and safer food quality.

Impressive work has already been done on food characterization and quality control and safety, but more research can provides us to obtain more information from contactless methods. It has been proven that the non-destructive systems investigated in the quality evaluation and assessment has been successfully applied, so that objective measurements are provided. Digital imaging and spectroscopic technologies continue to advance rapidly, and developed techniques can be sophisticated in industrial applications.

6. References

Alirezaei, M., Zare, D., Nassiri, SM. 2013. Application of Computer Vision for Determining Viscoelastic Characteristics of Date Fruits. *J of Food Eng.,* 118(3):326-332.

Amigo, JM., Babamoradi, H., Elcoroaristizabal, S. 2015. Hyperspectral Image Analysis. A tutorial. *Analytica Chimica Acta.,* 896:34-51.

Arakeri, MP., Lakshmana, L. 2016. Computer Vision Based Fruit Grading System for Quality Evaluation of Tomato in Agriculture Industry. *Proc Comput Sci.,* 79:426-433.

Barbin, D.F., Mastelini, SM., Barbon, S., Campos, GFC., Barbon, APAC., Shimokomaki, M. 2016. Digital Image Analyses as An Alternative Tool for Chicken Quality Assessment. *Biosystems Eng.,* 144: 85-93.

Barzegar, M., Zare, D., Stroshine, R. L. 2015.An Integrated Energy and Quality Approach to Optimization of Green Peas Drying in a Hot Air Infrared-Assisted Vibratory Bed Dryer. *J of Food Eng.,* 166: 302-315.

Chaugule, A., Mali, SN. 2014. Evaluation of Texture and Shape Features for Classification of Four Paddy Varieties. *J. Eng.*, 2014: 1-8.

Cheng, JH., Sun, DW. 2015. Rapid Quantification Analysis and Visualization of *Escherichia coli* Loads in Grass Carp Fish Flesh by Hyperspectral Imaging Method. *Food and Bioprocess Technol.*, 8(5):951-959.

Chmiel, M., Słowiński, M., Dasiewicz, K., Florowski, T. 2016. Use of Computer Vision System (CVS) for Detection of PSE Pork Meat Obtained from M.semimembranosus. *LWT - Food Sci and Technol.*, 65: 532-536.

Cubero, S., Aleixos, N., Moltó, E., Gómez-Sanchis, J., Blasco, J. 2011. Advances in Machine Vision Applications for Automatic Inspection and Quality Evaluation of Fruits and Vegetables. *Food and Bioprocess Technol.*, 4(4): 487-504.

Daugaard, SB., Adler-Nissen, J., Carstensen, JM. 2010.New Vision Technology for Multidimensional Quality Monitoring of Continuous Frying of Meat. *Food Control.*, 21(5):626-632.

Donis-González, IR., Guyer, DE., Pease, A. 2016.ostharvest Noninvasive Assessment of Undesirable Fibrous Tissue in Fresh Processing Carrots Using Computer Tomography Images. *J. Food Eng.*, 190:154-166.

Dowlati, M., de la Guardia, M., Mohtasebi, SS. 2012. Application of Machine-Vision Techniques to Fish-Quality Assessment. *TrAC Trends in Analyt Chem.*, 40: 168-179.

Dowlati, M., Mohtasebi, SS., Omid, M., Razavi, SH., Jamzad, M., de la Guardia, M. 2013. Freshness Assessment of Gilthead Sea Bream *(Sparus aurata*) by Machine Vision Based on Gill and Eye Color Changes. *J. Food Eng.*, 119(2):277-287.

Dutta, M. K., Singh, A., Ghosal, S. 2015. A Computer Vision Based Technique for Identification of Acrylamide In Potato Chips. *Comput and Electron in Agric.*, 119:40-50.

Ghasemi-Varnamkhasti, M., Goli, R., Forina, M., Mohtasebi, SS., Shafiee, S., Naderi-Boldaji, M. 2016. Application of Image Analysis Combined With Computational Expert Approaches for Shrimp Freshness Evaluation. *Int. J. Food Properties,* 19(10): 2202-2222.

Girolami, A., Napolitano, F., Faraone, D., Braghieri, A. 2013. Measurement of Meat Color Using a Computer Vision System. *Meat Sci.*, 93(1):111-118.

He, HJ., Wu, D., Sun, DW. 2014. Potential of Hyperspectral Imaging Combined with Chemometric Analysis for Assessing and Visualising Tenderness Distribution in Raw Farmed Salmon Fillets. *J of Food Eng.*, 126:156-164.

Huang, M., Wang, Q., Zhang, M., Zhu, Q. 2014. Prediction of Color and Moisture Content for Vegetable Soybean During Drying Using Hyperspectral Imaging Technology. *J. Food Eng.*, 128:24-30.

Ivorra, E., Sánchez, A.J., Camarasa, JG., Diago, M.P., Tardaguila, J. 2015.Assessment of Grape Cluster Yield Components Based on 3D Descriptors Using Stereo Vision. *Food Control.*, 50: 273-282.

Jackman, P., Sun, DW. 2013. Recent Advances in Image Processing Using Image Texture Features for Food Quality Assessment. *Trends in Food Sci & Technol.*, 29(1)35-43.

Jha, SN., Narsaiah, K., Jaiswal, P., Bhardwaj, R., Gupta, M., Kumar, R., Sharma, R. 2014. Nondestructive Prediction of Maturity of Mango Using Near Infrared Spectroscopy. *J. Food Eng.*, 124:152-157.

Jinorose, M., Prachayawarakorn, S., Soponronnarit, S. 2014.A Novel Image-Analysis Based Approach to Evaluate Some Physicochemical and Cooking Properties of Rice Kernels. *J. Food Eng.*,124: 184-190.

Kamruzzaman, M., Makino, Y., Oshita, S. 2016. Online Monitoring of Red Meat Color Using Hyperspectral Imaging. *Meat Sci.*, 116: 110-117.

Kamruzzaman, M., ElMasry, G., Sun, DW., Allen, P. 2013. Non-Destructive Assessment of Instrumental and Sensory Tenderness of Lamb Meat Using NIR Hyperspectral Imaging. *Food Chem.*,141(1): 389-396.

Keresztes, JC., Goodarzi, M., Saeys, W. 2016. Real-Time Pixel Based Early Apple Bruise Detection Using Short Wave Infrared Hyperspectral Imaging in Combination with Calibration and Glare Correction Techniques. *Food Control.*, 66: 215-226.

Khoshroo, A., Arefi, A., Masoumiasl, A., Jowkar, GH. 2014. Classification of Wheat Cultivars Using Image Processing and Artificial Neural Networks. *Agric. Communications*, 2(1):17-22.

Kiani, S., Minaei, S., Ghasemi-Varnamkhasti, M. 2016.Fusion of Artificial Senses as A Robust Approach to Food Quality Assessment. *J. Food Eng.*, 171:230-239.

Liu, D., Ma, J., Sun, DW., Pu, H., Gao, W., Qu, J., Zeng,, XA. 2014.Prediction of Color and pH of Salted Porcine Meats Using Visible and Near-Infrared Hyperspectral Imaging. *Food Bioprocess Technol.*, 7(11):3100 - 3108.

López-Maestresalas, A., Keresztes, JC., Goodarzi, M., Arazuri, S., Jarén, C., Saeys, W. 2016.Non-Destructive Detection of Blackspot in Potatoes by Vis-NIR and SWIR Hyperspectral Imaging. *Food Control.*, 70:229-241.

Matiacevich, S., Silva, P., Enrione, J., Osorio, F. 2011.Quality Assessment of Blueberries by Computer Vision. *Proc. Food Sci.*, 1:421-425.

Mery, D., Chanona-Pérez, JJ., Soto, A., Aguilera, J.M., Cipriano, A., Veléz-Rivera, N., Arzate-Vázquez, I., Gutiérrez-López, GF. 2010.Quality Classification of Corn Tortillas Using Computer Vision. *J. Food Eng.*, 101(4): 357-364.

Mery, D., Pedreschi, F., Soto, A. 2013.Automated Design of a Computer Vision System for Visual Food Quality Evaluation. *Food Bioprocess Technol.*, 6(8): 2093-2108.

Misimi, E., Øye, ER., Eilertsen, A., Mathiassen, JR., Åsebø, OB., Gjerstad, T., Buljo, J., Skotheim, Ø. 2016. GRIBBOT– Robotic 3D vision-guided harvesting of chicken fillets. *Comput. Electron Agric.*, 121: 84-100.

Moallem, P., Serajoddin, A., Pourghassem, H. 2016. Computer Vision-Based Apple Grading for Golden Delicious Apples Based on Surface Features. *Info Pro Agric*, in press.

Mortensen, A.K., Lisouski, P., Ahrendt, P. 2016. Weight Prediction of Broiler Chickens Using 3D Computer Vision. *Comput and Electron Agric.*, 123: 319-326.

Park, B. 2016. Quality Evaluation of Poultry Carcasses. Computer Vision Technology for Food Quality Evaluation, Chapter, 9, pp. 213-218.

Pazoki, AR., Farokhi, F., Pazoki, Z. 2014. Classification of Rice Grain Varieties Using Two Artificial Neural Networks (MLP and Neuro-Fuzzy). *J. Anim. Plant Sci.*, 24(1): 336-343.

Pu, H., Sun, DW., Ma, J., Cheng, JH. 2015. Classification of Fresh and Frozen-Thawed Pork Muscles Using Visible and Near Infrared Hyperspectral Imaging and Textural Analysis. *Meat Sci.*, 99:81-88.

Pu,H., Sun, DW., Ma, J., Liu, D., Kamruzzaman, M. 2014. Hierarchical Variable Selection for Predicting Chemical Constituents in Lamb Meats Using Hyperspectral Imaging. *J. Food Eng.*, 143:44-52.

Senni, L., Ricci,M., Palazzi, A., Burrascano, P., Pennisi, P., Ghirelli, F. 2014. On-line Automatic Detection of Foreign Bodies in Biscuits by Infrared Thermography and Image Processing. *J. Food Eng.*,128:146-156.

Su, W. H., Sun, DW. 2016. Evaluation of Spectral Imaging for Inspection of Adulterants in Terms of Common Wheat Flour, Cassava Flour and Corn Flour in Organic Avatar Wheat (*Triticum spp.)* Flour. *J. Food Eng.*, 200:56-69.

Sun, DW. 2007. Computer Vision Technology for Food Quality Evaluation. Academic Press.

Sun, DW. 2010. Hyperspectral Imaging for Food Quality Analysis and Control. Academic Press.

Sun, D.W. 2016. Computer Vision Technology for Food Quality Evaluation. Academic Press.

Udomkun, P., Nagle, M., Argyropoulos, D., Mahayothee, B., Müller, J. 2016. Multi-Sensor Approach to Improve Optical Monitoring of Papaya Shrinkage During Drying. *J. Food Eng.*, 189: 82-89.

Valous, NA., Mendoza, F., Sun, DW. 2010. Emerging Non-Contact Imaging, Spectroscopic and Colorimetric Technologies for Quality Evaluation and Control of Hams: A review. *Trends Food Sci. Technol.*, 21(1): 26-43.

Vithu, P., Moses, JA. 2016. Machine Vision System for Food Grain Quality Evaluation: A review. *Trends Food Sci. Technol.*, 56:13-20.

Wang, Q., Wang, H., Xie, L., Zhang, Q. 2012. Outdoor Color Rating of Sweet Cherries Using Computer Vision. *Comput Electron Agric.*, 87: 113-120.

Wang, W., Li, C. 2015. A Multimodal Machine Vision System for Quality Inspection of Onions. *J. Food Eng.*, 166: 291-301.

Wu, D., Sun, DW. 2013.Colour Measurements by Computer Vision for Food Quality Control – A review. *Trends Food Sci. Technol.*, 29(1): 5-20.

Xiong, C., Liu, C., Liu, W., Pan, W., Ma, F., Chen, W., Zheng, L. 2016.Noninvasive Discrimination and Textural Properties of E-beam Irradiated Shrimp. *J. Food Eng.*, 175: 85-92.

Xiong, Z., Sun, D.W., Pu, H., Gao, W., Dai, Q. 2017. Applications of Emerging Imaging Techniques for Meat Quality and Safety Detection and Evaluation: A review. *Crit. Rev. Food Sci. Nutr*. 57(4): 755-768.

Xu, J.L., Riccioli, C., Sun, DW. 2017. Comparison of Hyperspectral Imaging and Computer Vision for Automatic Differentiation of Organically and Conventionally Farmed Salmon. *J Food Eng.*,196: 170-182.

Zapotoczny, P., Szczypiński, PM., Daszkiewicz, T. 2016. Evaluation of The Quality of Cold Meats by Computer-Assisted Image Analysis. *LWT - Food Sci. Technol.*, 67: 37-49.

Zhang, B., Huang, W., Li, J., Zhao, C., Fan, S., Wu, J., Liu, C. 2014.Principles, Developments and Applications of Computer Vision for External Quality Inspection of Fruits and Vegetables: A review. *Food Res Int*. 62: 326-343.

Zhang, C., Guo, C., Liu, F., Kong, W., He, Y., Lou, B. 2016. Hyperspectral maging Analysis for Ripeness Evaluation of Strawberry with Support Vector Machine. *J Food Eng.*, 179: 11-18.