Computer Science • 20(4) 2019 https://doi.org/10.7494/csci.2019.20.4.3163

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CURRENT RESEARCH OPPORTUNITIES FOR IMAGE PROCESSING AND COMPUTER VISION

Abstract *Image processing and computer vision is an important and essential area in today's world. Several problems can be solved through computer vision techniques. There are a large number of challenges and opportunities that require skills in the field of computer vision in order to address them. Computer vision applications cover each band of the electromagnetic spectrum, and there are numerous applications in every band. This article is targeted to research students, scholars, and researchers who are interested in solving problems in the field of image processing and computer vision. It addresses the opportunities and current trends of computer vision applications in all emerging domains. The research needs are identified through an available literature survey and classified in the corresponding domains. Possible exemplary images are collected from different repositories available for research and shown in this paper. The opportunities mentioned in this paper are explained through the images so that a naive researcher can understand it well before proceeding to solve the corresponding problems. The databases mentioned in this article could be useful for researchers who are interested in solving the problem further. The motivation of the article is to expose current opportunities in the field of image processing and computer vision along with the corresponding repositories. Interested researchers who are working in the field can choose a problem through this article and can obtain experimental images through the cited references for working further.*

Keywords computer vision, image processing, imaging applications, opportunities, challenges, application

Citation Computer Science 20(4) 2019: 387–410

1. Introduction

It is a perception that humans can visualize almost everything in this world; however, this is only true when we visualize through machines. We can see only a limited version through our eyes that falls under the visible spectrum band of the electromagnetic spectrum. The features observable in the visible spectrum are also limited for human eyes because of the various characteristics of an object; e.g., size (we are unable to see items at the nano and micro levels), distance (an object that is too far from us cannot be visualized), covered structure (human eye visibility cannot penetrate a body or real object), vision in the dark (human eyes cannot see without light), vision in fog (human eyes cannot see beyond fog), etc. However, imaging can help us visualize objects in all of the above-mentioned situations.

The electromagnetic spectrum defines many bands (i.e., radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma bands) that are used for imaging as well as other applications [95]. An imaging system is developed in each band of the electromagnetic spectrum, and highly specialized cameras/machines are available to acquire the same. These bands are listed in Table 1 along with types of imaging that concern applications of broad areas.

Table 1

Types of imaging as per electromagnetic band with corresponding applications

S. No.	Band of electromagnetic spectrum	Type of imaging	Broad Area	Applications
1.	Radio	MRI (Magnetic Resonance Imaging)	Computer-aided diagnosis	Diagnosis and Treatment planning [45]
2.	Microwave	Ultrasound imaging, Radar Tomography	Computer-aided diagnosis, Agriculture	Diagnosis and Treatment planning, Tumor ablation [102], Physical properties of food [53, 93], Assessment of moisture content [44], structural health monitoring [114], defect detection
3.	Infrared	Thermal imaging	Surveillance in the non-visible spectrum [16]	Surveillance through infrared camera [59], Monitoring of temperature pattern [4], 24/7 monitoring of human and vehicles [50], Structure health monitoring [28]
4.	Visible	Visible imaging	Surveillance, identification of humans and objects,	Face recognition [17], object detection [54], document handling [8], Motion tracking, Automatic character recognition, Texture Analysis [100]
5.	Ultraviolet	Fluorescence spectroscopy	Food and agriculture	Detecting anomalies in fruits and food [13, 97], fruit sorting [25, 74]
6.	X-ray	X-ray imaging, CT, CBCT	Computer-aided diagnosis, agriculture	Diagnosis and Treatment planning [99], seed analysis [90, 90]
7.	Gamma	Gamma Imaging	Computer-aided diagnosis	Diagnosis and Treatment planning, Cancer identification [92]

Each band is different based on its wavelength/energy range; consequently, the features/properties of the imaging are also changing. These properties help us acquire different types of information/data from the same environment/object that even humans cannot see. A computer system processes such images and extracts features followed by knowledge that is highly recommended input of a system to solve a particular problem.

2. Imaging techniques for image processing

There are a large number of applications for imaging in each electromagnetic band. MRI is a highly potential 3D imaging in the radio band for visualizing the internal structure of the human body without harmful radiation exposure. This type of imaging is used for patient diagnosis and treatment planning [45]. Similarly, the microwave band is used for ultrasound imaging, which is also used for patient diagnosis and treatment planning [20]. The imaging used in MRI is based on the spinning of the ions present in the body, while microwave imaging is based on the reflectance of the waves. In addition to medical diagnosis and treatment planning, microwave imaging is also useful for defect detection in agro applications [53] as well as civil applications [114]. Infrared imaging is used for surveillance by detecting the heat signature of any living/non-living body; therefore, infrared/thermal imaging is used in night-vision cameras. It is also useful for monitoring applications [4, 113].

Visible imaging is useful for surveillance in the visible band [54]. The monitoring of traffic, humans, and any object can be done by such imaging. Many other industrial applications like speed determination, face detection [17], object recognition [54], object identification, document handling, character recognition [8], handwriting recognition [68], texture analysis [100], etc. are based on imaging in the visible spectrum. The ultraviolet spectrum is useful for the acquisition of spectroscopic images of agro products, which are utilized for the detection of anomalies [13, 97] and grading the same [25, 74]. Ultraviolet light is absorbed on the surface of the object, which captures the surface topology without penetrating the surface. X-ray imaging has made a revolutionary change in health diagnosis and treatment planning. With the potential use of X-ray technology [41] and its derived imaging i.e. computed tomography (CT) [46], cone-beam computed tomography (CBCT), patient diagnosis and treatment planning has become easy and more appealing [99]. Imaging can acquires images of the internal structure of a living being's body has revolutionized medicine. Image processing helps us understand the acquired image data and assist the experts, saving both time and effort. With the introduction of image processing over X-ray [42, 107], CT [61], and CBCT [37, 39, 82] images, diagnosis and treatment planning becomes easy, and the efforts of experts/radiologists are reduced. Soft X-ray with comparatively less energy is also used for imaging in agro applications. The potentiality of a seed can be identified through soft X-ray imaging. Consequently, early prediction of crop growth can be estimated [52, 90]. Gamma rays are used with radioactive isotopes for image acquisition; this enables dynamic events to be studied [69]. It is also useful for the acquisition of images for the detection of cancerous nodules [92]. Therefore, it can be observed that imaging in each band is essential and dedicated for separate and critical useful applications. Many of these bands are jointly use for solving one application. Such hybrid approaches provide precise and significantly improved results.

3. Current trends in image processing

There are numerous applications that can be solved through the concept of image processing and computer vision. The rigorous research and development for every application have evolved based on certain parameters; i.e., improvement in imaging technique, improvement in principle, extension of computation power and space, and the use and requirement of applications in the current scenario. By keeping these parameters in mind, a number of applications are listed in Table 2 that are currently evolving and needed for research and development in these areas. These applications are classified based on the research areas; the corresponding opportunities are discussed in details.

Table 2
Various opportunities in field of image processing

S. No.	Research area	Opportunity	Modality
1.	Medical Diagnosis and Treatment Planning	Volumetric segmentation [18, 80]	3D
		Region of interest segmentation [64, 89]	2D
		Automatic detection of landmarks [37, 38]	2D, 3D
		Automatic registration and fusion [29]	2D, 3D
		3D surface reconstruction [58]	2D, 3D
		Tumor/cancer detection [64, 89]	2D, 3D
		Superimposition of facial structure [43]	3D
2.	Agricultural sector	Seed analysis and grading based on X-ray image [5, 90]	2D, 3D
		Automatic seed grading system based on visible spectrum [27]	2D, 3D
		Automatic fruit, pulse, rice grading system [12, 57, 73]	2D, 3D
		Categorization of plants [21]	2D
		Disease detection in plants [103]	2D
		Automatic monitoring of plants [96]	2D
3.	Monitoring applications	Surveillance through infrared imaging [50, 113]	2D
		Fault detection in machinery using thermal imaging [113]	2D
4.	Disaster Management application	Prediction of land sliding using image registration in sensitive areas [55]	2D
5.	Underwater Image Processing	Automatic classification of marine species in underwater imaging [101]	2D, 3D
6.	Others	Multiple image fusion [54, 87]	2D, 3D
		Exploration of hyperspectral images [85]	2D, 3D

3.1. Medical diagnosis and treatment planning

There are various applications in the dental and medical domain that can be solved through the concept of image processing and computer vision. Table 3 shows a few applications that are evolving based on the current requirement in a patient's diagnosis and treatment planning. Extensive work is required in these applications. To solve many of these problems, ground truth and data is also available publicly. Figures 1 and 2 demonstrate the exemplary images involved in solving the problems of diagnosis and treatment planning discussed in Table 3. Most of the links for publicly accessible data are also given along with the problem images in Figures 1 and 2.

Table 3

Current trends in automation for computer-assisted diagnosis and treatment planning

S. No.	Application	Objective
1.	Polyp detection	Automatic polyp detection in colonoscopy images/video [105]
2.	Melanoma detection	Automatic detection and classification of skin lesions based on dermoscopic images [66, 104]
3.	Left Ventricular Ejection Fraction (LVEF)	Automatic segmentation of left ventricle and estimation of LVEF based on cine-MRI images [70]
4.	Two-dimensional Cephalometric Analysis	Automatic detection of two-dimensional cephalometric landmarks [60, 63]
5.	Three-dimensional Cephalometric Analysis	Automatic detection of three-dimensional cephalometric landmarks [36–39, 83]
6.	Three-dimensional airway volume analysis	Automatic volumetric segmentation of upper human airway [37, 81]
7.	2D X-ray to 3D surface development	Development of three-dimensional surface image using two X-ray images [58]
8.	Detection of retinal diseases	Automatic detection and segmentation of different types of fluids on optical coherence tomography [94, 112]
9.	Classification of Breast Cancer	Automatic classification of breast cancer based on microscopy images [6]
10.	Liver segmentation	Automatic segmentation of liver from volumetric images CT/MRI [33, 48]
11.	Liver Tumor detection	Automatic segmentation of liver tumor from volumetric images MRI/CT [64]
12.	Lung segmentation	Automatic segmentation of lungs in lung CT images [111]
13.	Lung cancer detection	Automatic detection and segmentation of lung cancer in chest CT images [89]

Table 3 (cont.)

S. No.	Application	Objective
14.	Lung segmentation	Automatic segmentation of lungs in chest X-ray images
15.	Pulmonary blood vessel segmentation	Automatic segmentation of pulmonary blood vessel segmentation based on chest CT images [18]
16.	Cell Tracking	Automatic tracking of biological cell in microscopic sequencing [40]
17.	Nerve Segmentation	Automatic segmentation of nerve based on ultrasound images [32]
18.	Brain Segmentation	Automatic segmentation of brain based on MRI [26]
19.	Brain Tumor Segmentation	Automatic segmentation of brain tumor based on MRI [72, 105]
20.	Detection of Pediatric Bone Age	Automatic detection of skeletal age based on pediatric hand radiographs [24]
21.	Diabetic Retinopathy	Automatic detection and grading of diabetic retinopathy using retinal fundus images [56, 84]

In Figures 1 and 2, the exemplary image of each research problem is shown, and the possible output of the same problem is also included.

The problem discussed in Figures 1 and 2 is based on the patient's diagnosis and treatment planning. These problems may be referring to different applications; actually, these may be classified in a few areas such as volumetric segmentation [18], region-of-interest segmentation [64, 89], automatic detection of landmarks [36–38], automatic registration and fusion [29], 3D surface reconstruction [58], and tumor/cancer detection [64, 89]. These may be considered as opportunities with a large number of applications as discussed in Figures 1 and 2.

Figures 1 and 2 demonstrate example images from the image processing domains discussed above. These are the applications of the medical domain that are mostly based on the segmentation task. The mentioned problems require two-dimensional segmentation, three-dimensional segmentation, or classification. However, the area/volume of interest changes as per the section of the body. The mentioned application images are exemplary and listed to understand the problem. Similar types of other problems also exist but require a similar type of skills to solve them. There is a sensitivity of each problem with its result. The representation, comparison, and precision of the result are also important factors [35] that are not mentioned in this paper. However, this could also be reported along with the particular problem as well as its clinical significance. There is a certain different range for the precision of accuracy of each problem where it can be accepted clinically.

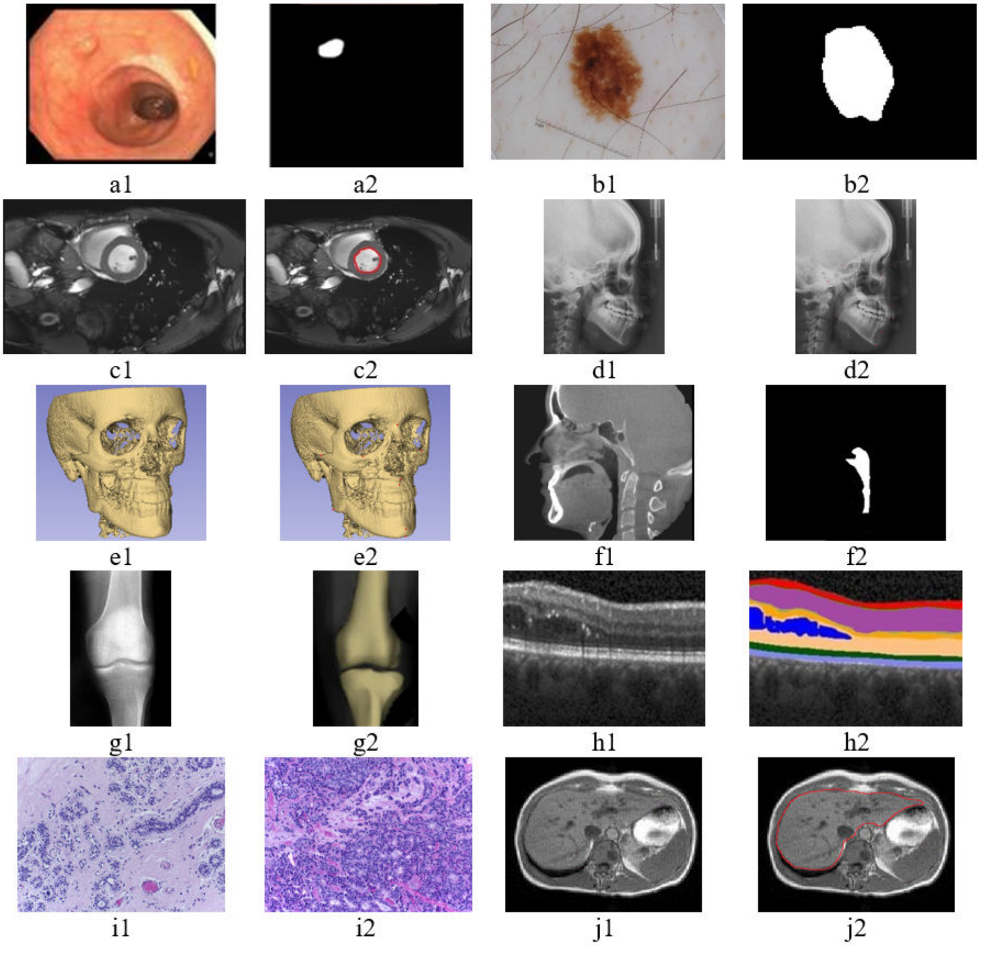

Figure 1. Colonoscopy image with polyp extracted from diagnostic video [9] (a1); detection of polyp in colonoscopy image [9] (a2); skin melanoma in dermoscopic images [19] (b1); automatic detection of melanoma (b2); cardiac cine-MRI image [23] (c1); segmentation of left ventricle (c2); lateral X-ray image for 2D cephalometric analysis [10] (d1); landmark plotted on lateral X-ray image for 2D cephalometric analysis (d2); volumetric image of 3D skull [1] (e1); volumetric image of 3D skull with cephalometric landmarks (e2); sagittal slice of cone beam-computed tomography data representing upper airway volume [1] (f1); slice representing segmentation of upper airway volume (similar multiple volumetric slices needed to segment for patient's upper airway volume) (f2); X-ray image of knee joints (g1); exemplary 3D surface image developed through one or two X-rays (this image is not a real development of 3D from Image g1) (g2); optical coherence tomography (OCT) image for detection of different types of fluids [14, 94] (h1); detection of fluids on OCT image (h2); microscopic breast image of normal patient [7] (i1); microscopic breast image with invasive carcinoma [7] (i2); slice of abdominal MRI image [76] (j1); exemplary segmentation of liver in abdominal MRI image (j2)

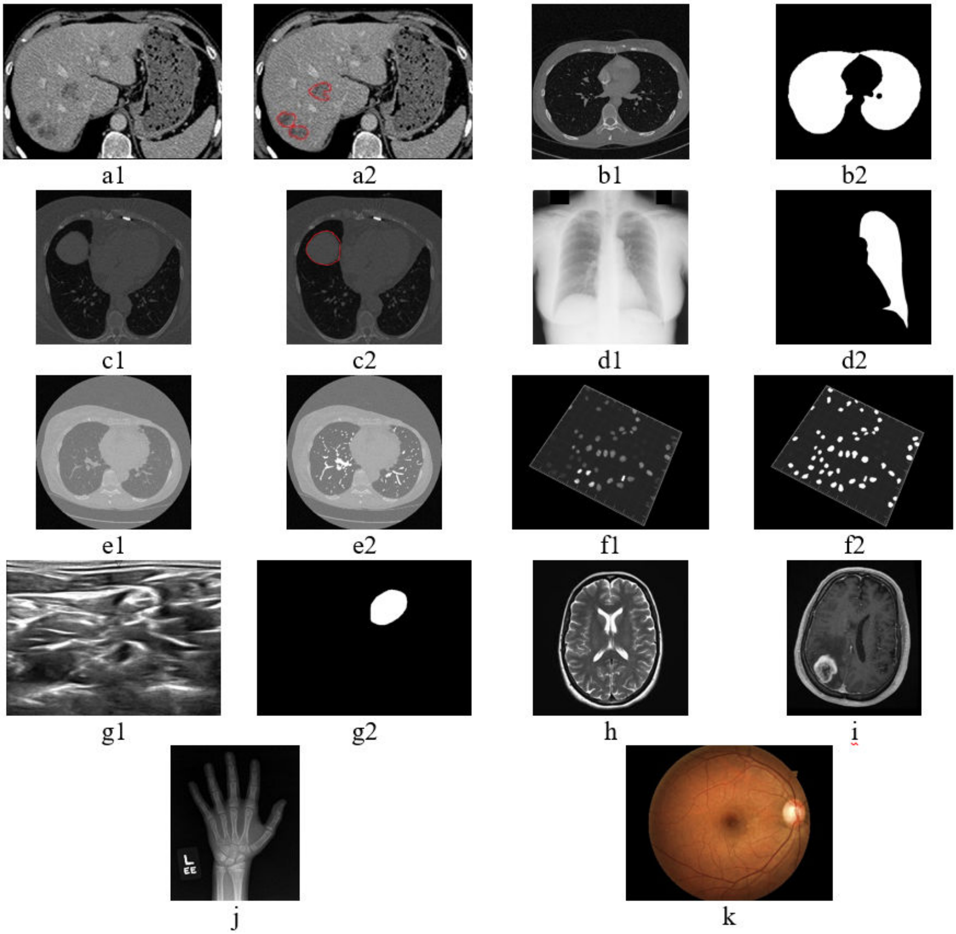

Figure 2. MRI slice of liver [65] (a1); detection of tumor in MRI slice of liver (a2); axial slice of a lung CT image [30] (b1); lung segmented from slice of CT image (b2); axial slice of lung CT image [30] (c1); segmented cancer nodule from slice of lung CT image (c2); chest X-ray image (d1); detection of left lung in chest X-ray image (d2); lung CT image slice [30] (e1); detection of pulmonary blood vessels in lung CT image (e2); microscopy image with some biological cells [67] (f1); detection of biological cells in microscopy images (f2); nerve structures in ultrasound image of neck [108] (g1); detection of nerve structure (g2); axial slice of brain MRI [15] (h); axial slice of brain MRI showing tumor [15] (i); pediatric hand radiograph for determining skeletal age [86] (j); retinal fundus image for detecting and grading diabetic retinopathy [88] (k)

3.2. Agricultural sector

The food and agricultural sector is very important for any national economy. It is always beneficial to be able to predict whether a particular seed will grow or not.

In this technological era, the X-ray and MRI imaging of seeds have made this possible. Not only is growth prediction possible, but the quality classification of a seed is also possible through such technologies. Table 4 lists a few applications using image processing techniques that are prominent in the agricultural sector. These techniques are emerging in this scenario due to the availability of resources.

Table 4
Current trends in automation for agricultural applications

S. No.	Application	Objective
1.	Non-destructive analysis of seeds	Quality assessment classifier for seeds based on X-ray [5, 90] and MRI scan [90]
2.	Leaf segmentation	Automatic segmentation of leaves for automatic monitoring of plant growth [95, 96]
3.	Fruit grading system	Computer-based apple grading system [73]
4.	Leaf disease detection in plants	Automatic detection of leaf disease and classification in plants [103]
5.	Rice quality grading	Classification and quality grading of rice grain based on imaging techniques [57]
6.	Pulse grading	Classification of pulses based on image [12]

An X-ray scanner is used for scanning a seed; this is a soft X-ray scanner and different from the one that is used for scanning living beings. MRI is also used to obtain a 3D image of a seed. Figure 3 demonstrates a few types of seeds where the good and poor seeds can be easily classified based on embryonic statistics. Similarly, a system can be designed to estimate the quality automatically, which is very helpful for the agricultural industry.

Figure 3 is an X-ray image of various types of seeds. X-ray and MRI images are helpful for visualizing the embryo of a seed (which is the major section of any seed). The early prediction of the growth of a plant based on its seed can be obtained by analyzing the statistical area of the seed's embryo. Classification algorithms and quality determination algorithms need to be evolved based on the X-ray and MRI images of a seed. Currently, these algorithms are lacking due to the non-availability of such scanners. As X-ray and MRI image scanners are limited and costly to establish, such image databases are not readily available.

Figure 4 demonstrates images involved in various applications of agriculture. Figures 4(a1) and 4(a2) are the images that are used for the automatic monitoring of plants. These are also important for the prediction of the growth and monitoring of a plant.

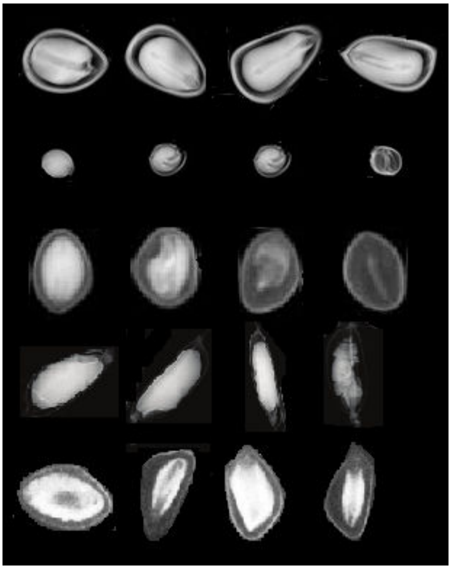

Figure 3. Soft X-ray image of different types of seeds for non-destructive quality analysis; five different types of seeds shown in X-ray image. Inner part of seed is called embryo (which is clearly visible for each image); quality of seed can be determined based on embryo

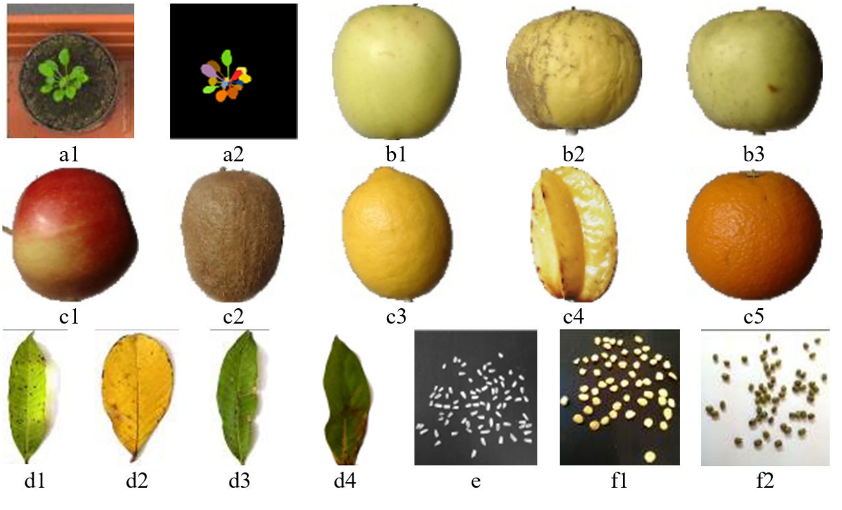

Figure 4. Image of a plant [98] (a1); segmentation of all leaves separately from plant and background [98] (a2); surface images of different golden apples at different orientations [77] (b1), (b2), (b3); red apple image (c1); kiwi image (c2); lemon image (c3); carambula image (c4); orange image [77] (c5); leaf images for detecting disease (d1), (d2), (d3), (d4); scanning of rice for the quality grading (e); images of pulses for quality grading (f1) and (f2)

Figures 4(b1), 4(b2), and 4(b3) show the surface images of golden apples, which are used for feature extraction; based on the statistical features, an apple can be graded to some class for quality assessment. Similarly, many other fruit images are also demonstrated in Figures 4(c1)–4(c5) for quality grading purposes. The images of fruits can be acquired on all surfaces at a 360-degree angle.

Figures 4(d1)–4(d4) demonstrate leaf images with some disease. A system may also be designed for the automatic detection of disease in plants based on a leaf image. Figure 4(e) demonstrates an image of rice grains, which may be used for automatic classification for quality assessment. Such a type of classification system is very helpful in the agricultural industry. Figures 4(f1) and 4(f2) demonstrate images of pulses, which are also used for quality classification. A high-resolution scanner can also be used for the scanning of fruits, seeds, and pulses. Based on a computerized analysis, it may be classified into many classes (such as excellent, good, poor, or very poor). Such types of work in the agricultural sector are emerging in the current scenario. The shown food items are not limited to computerized methods and X-ray analysis. There are many other food items (including fruits, pulses, seeds, etc.) that can be analyzed through computerized methods or X-ray imaging.

3.3. Monitoring applications

From a security perspective, imaging is essential in the current era. Everyone is aware of monitoring through surveillance cameras, which can work in the visible spectrum. However, a camera does not work without light in the visible spectrum. Therefore, thermal-imaging cameras are popular for surveillance – even in the dark. In hybrid camera surveillance, thermal cameras are also used alongside visible spectrum cameras, which provide 24/7 monitoring with a better appearance. Thermal cameras are also called infrared cameras, which identify the heat signature of anyone. Table 5 demonstrates the emerging applications of monitoring in the current scenario.

Table 5

Current trends in automation for monitoring applications

S. No.	Application	Objective
1.	Human monitoring	Automatic monitoring of humans using thermal imaging [50, 113]
2.	Hotspot monitoring	Automatic detection of faults in machinery using thermal imaging [113] Datacenter health monitoring using thermal imaging [51]

Figure 5 shows a human playing soccer while there is no visible light exposure during the acquisition of the image. An infrared camera captures the heat signature, and the pattern/shape represents the object. Such a type of work is emerging for tracking applications.

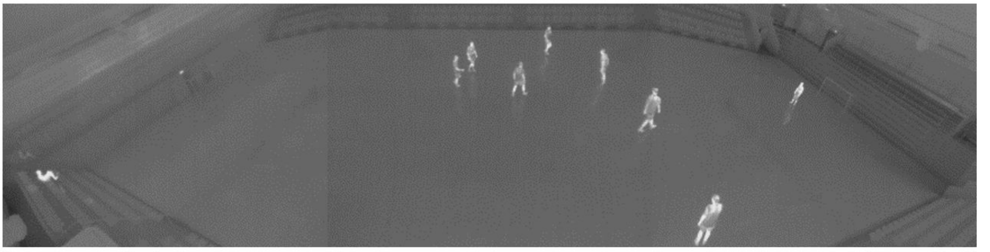

Figure 5. Image of human playing soccer using thermal camera [99]

3.4. Disaster management application

With the potential use of image processing and computer vision techniques, disaster may also be avoided. Satellite images of landslide-prone areas are taken during a certain interval. By using image registration techniques, these can be registered to each other, and the current movement can be recorded; this helps predict future landslides. This technique is very useful when satellite images of landslide-prone areas are available. Deviations in the positions of hills is estimated, which helps predict the amount of future landslides [55, 62].

Figure 6 demonstrates a Landsat 8 OLI/TIRS C1 level-2 image of the Indian Himalayan region. A thermal view and natural color view are also included of the same region. These views were taken during the year of 2018. Similarly, views can also be collected for previous years for comparison through the registration method. This area is important and emerging for disaster management applications.

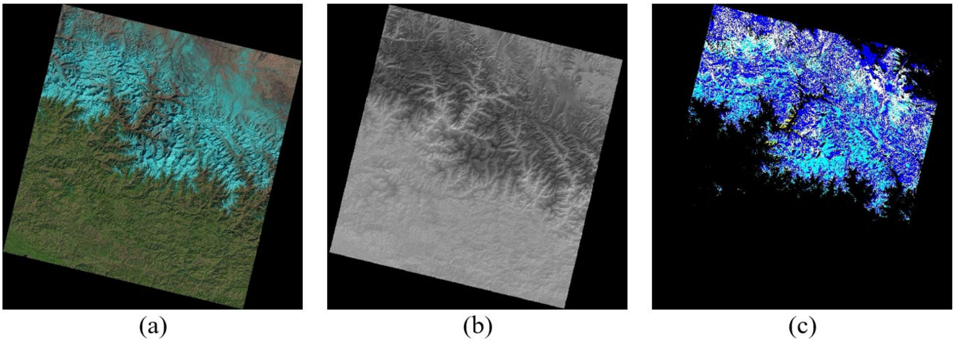

Figure 6. Landsat 8 OLI/TIRS C1 level-2 images of Indian Himalayan region: a) natural color image; b) thermal image of the same region in (a); c) quality region image of the same region in (a)

3.5. Underwater image processing

The research in underwater imaging is evolving and exposing undiscovered species in our oceans. Several continuous videos are recorded underwater; it is not possible to identify the species by visualizing all of the videos. Therefore, a computerized system that automatically detects/classifies species in underwater videos is required [71]. Hence, the development of an algorithm is required that can automatically determine the previously identified underwater species and can highlight newly detected objects. Figure 7 demonstrates underwater images in different video sequences. These images can be used for finding underwater species.

Figure 7. Underwater images demonstrating ocean's species: (a) and (b) are two different frames of different videos acquired from automatic identification of underwater species

3.6. Other applications

Beyond the classification of the applications demonstrated above, a few other types of image processing applications exist. Some of these are listed in Table 6. Multiple image fusion is the processing of images acquired through multiple sources. These image sources may exist in different bands so that multiple features can be captured for interpreting the acquired image.

With the availability of resources, cameras working in multiple bands can be coupled for a combined featured output. Infrared and vision band cameras can be coupled for surveillance with more features [54, 87]. Similarly, CT and MRI images of the same patients can be fused for better visibility in soft tissue as well as in hard tissue [91]. The features of both the modalities can be combined for assistance in diagnosis and treatment planning.

There is a recent advancement in the world of imaging science using hyperspectral cameras. There are number of applications that are emerging in the current scenario using hyperspectral cameras. A few such applications are listed in Table 6. Researchers are working on such applications and automating a few of them. Currently, these applications are in the development phase as per the availability of resources. In the future, research based on hyperspectral cameras will prevail.

Table 6
Current trends in automation for other image processing applications

S. No.	Application	Objective
1.	Multiple image fusion	Surveillance using coupled infrared and vision cameras [54, 87] The fusion of CT and MRI images [91]
2.	Exploration of hyperspectral images	Food fraud detection [85, 109] Object identification and feather extraction of Earth's surface in remote sensing [2] Viability prediction of seeds [78] Monitoring and tracking changes in environmental conditions [75] Target recognition and tracking [79] Identification of illegal/fake drugs [49] Evidence analysis in forensic investigation [47] Quality control of thin-film [34] Exploration of oil and gas [22] Creating vegetation index of agricultural data [2, 3, 106]

A hyperspectral camera can detect fake food where impurities are mixed with food items that have a similar color and texture. In the visible spectrum, such types of fake food items are not identifiable, while a hyperspectral camera catches them very easily due to the impurities showing different chemical properties. A hyperspectral camera provides an image with a large group of different wavelengths, which helps identify ground objects, vegetation, hills, water, etc. based on the features inherited at the corresponding location in the remote sensing images. Similar to seed analysis using infrared imaging, hyperspectral imaging is also helpful. Impurities in drugs can also be easily identified through hyperspectral images. At a crime scene, the chemical and physical properties of evidence can be identified, which is helpful for forensic investigation reports. Similarly, there are numerous opportunities that can be assisted by hyperspectral cameras.

4. Conclusion

A large number of existing and future opportunities in the field of image processing and computer vision are identified from the existing literature and listed in this article in their respective categories. The electromagnetic spectrum is covered based on emerging opportunities in the current scenario. Most of the problems are discussed through the example images, which is more appealing and motivating for readers.

Many data repositories are also mentioned along with their applications so that an interested researcher can find data for solving a corresponding research problem.

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Received: 14.01.2019
Revised: 14.08.2019
Accepted: 18.08.2019