Digital Image Processing
Lectures 1 & 2

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Introduction to DIP

The primary interest in transmitting and handling images in digital forms goes back to 1920's. However, due to lack of adequate computer systems and vast storage requirements the interest in this area was not fully explored until mid 1960's after the successful Apollo mission and other space programs. The serious work in the area of digital image processing (DIP) began at JPL when the need for processing lunar images was felt after the Apollo mission.

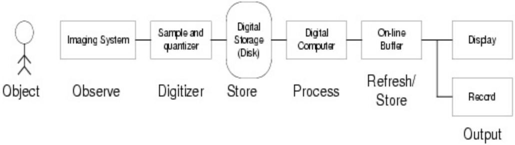
DIP, originally established to analyze and improve lunar images is rapidly growing into a wealth of new applications, due to the enormous progress made in both algorithm development and computer engineering. At present, there is no technical area that is not affected one way or another by DIP. The most important fields of growth appear to emerge in the areas of medical image processing (e.g. surgical simulators and tele-surgery), data communication and compression (e.g., 3D TV, mobile devices), remote sensing (e.g., meteorological, environmental and military), computer vision (e.g., robotics, autonomous systems and UAVs), etc.

Currently the emphasis is being shifted towards real-time intelligent DIP systems. For the years ahead, trends in computer engineering, especially in parallel/pipeline processing technologies, coupled with new emerging applications indicate no limitation for the horizon of the DIP area.

Applications:

1. Medical: Automatic detection/classification of tumors in medical images (e.g., X-ray, MRI, CT-scan, and ultrasound), chromosome identification, etc.
2. Computer Vision: Identification of parts in assembly lines, robotics, tele-operation, autonomous systems, etc.
3. Remote Sensing: Meteorology and climatology, tracking of earth resources, geographical mapping; prediction of agricultural crops, urban growth and weather, flood, fire control, etc.
4. Radar and Sonar: Detection and recognition of various targets, aircraft or missile guidance or maneuvering, etc.
5. Image Transmission: 3DTV and mobile systems, teleconferencing, communications over computer networks, sensor networks, space and satellite, etc.
6. Office Automation: Document (text and image) storage, retrieval and reproduction.
7. Identification Systems: Facial, Iris, finger-print-based ID systems, airport security systems, etc.

Digital Image: A sampled and quantized version of a 2-D function that has been acquired by optical or other means, sampled at equally spaced rectangular grid pattern, and quantized in equal intervals of amplitudes. A typical image processing system is:



DIP involves handling, transmitting, enhancing and analyzing digital images with the aid of digital computers. This calls for manipulation of 2-D signals. There are generally three types of processing applied to an image, namely *low-level*,*intermediate-level*, and *high-level* processing, which produce a modified version of the image.

Areas of DIP

1. Image Representation and Modeling: An image can be represented either in spatial or transform domains. An important consideration here is fidelity or intelligibility criterion for measuring quality of an image, e.g., contrast (gray level diversity), spatial frequencies, edge sharpness, etc.

Images represented in the spatial domain directly relate to the type and physical nature of imaging sensors; e.g., luminance of object in a scene for pictures taken by camera; absorption characteristics of body tissue for X-ray images; radar cross-section of a target for radar imaging; temperature profile of an object for infrared imaging; and gravitational field in geophysical imaging.

Linear models are also used to represent images in the spatial domain. These models allow development of algorithms useful for an ensemble set of images rather than a single image.

Alternatively, 2-D transforms or feature extraction methods are applied to extract such attributes as spectral content, power spectra, energy, texture, or any other salient features prior to filtering, data compression, and object recognition.

Areas of DIP-Cont

2. Image Enhancement (low-level): No imaging system generates images of perfect quality. In image enhancement the aim is to manipulate an image in order to improve its quality. This requires an expert human evaluator to recognize and extract useful information from an image. Since the human subjective judgement may either be wise or fickle, certain difficulties may arise. Thus, a careful study requires subjective testing of a group of human viewers. The psychophysical factors should always be considered in this evaluation process.

Examples of image enhancement are:

- Contrast & gray scale improvement
- Spatial frequency enhancement
- Pseudo-coloring
- Noise removal and filtering
- Edge sharpening
- Magnification and Zooming

Areas of DIP-Cont

3. Image Restoration (low-level): As in image enhancement, ultimate goal here is to improve the quality of an image in some sense. Image restoration involves recovering or estimating an image that has been degraded by some deterministic and/or stochastic phenomena. Blur is a deterministic phenomenon which is caused by such things as atmospheric turbulence (satellite imaging), relative motion between the camera and the object, defocusing, etc. Noise, on the other hand, is a stochastic phenomenon which corrupts the images additively or multiplicatively. Sources of additive noise are: imperfection of sensors, thermal noise, channel noise, etc. Examples of multiplicative noise are speckle in coherent imaging systems such as synthetic aperture radar/sonar (SAR/SAS), lasers, and ultrasound images and also film grain noise. Image restoration techniques aim at modeling the degradation and applying an appropriate process to recover (or estimate) the original image.

Areas of DIP-Cont

Among typical restoration methods are:

- Image estimation and noise smoothing
- Deblurring
- Inverse filtering
- 2-D Wiener and Kalman filters

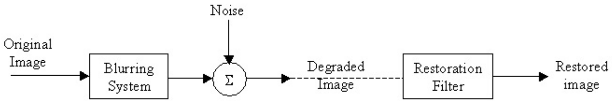


Image reconstruction can also be viewed as a special class of restoration where two or higher dimensional objects are reconstructed from several projections, e.g., medical CT-scan, astronomy, radar imaging and NDE. Typical methods are:

- Radon Transform
- Projection theorem
- Reconstruction algorithms

Areas of DIP-Cont

4. Image Transforms (Intermediate-Level): This process involves mapping digital images to the transform domain using unitary transforms such as 2-D DFT, 2-D Discrete Cosine transform (DCT), 2-D Discrete Wavelet Transform (DWT), and 2-D Karhunen-Loeve (KL) Transform or Principal Component Analysis (PCA). In the transform domain certain useful image characteristics, which cannot typically be ascertained in the spatial domain, are revealed. Image transformation performs both feature extraction and dimensionality reduction which are crucial for various applications e.g., data compression and pattern recognition.

5. Image Data Compression and Encoding: It is often required to significantly reduce the number of bits for representing images before transmission or storage images. For example, NOAA's Geostationary (GOES-15) satellite has five spectral channels (1 visible and 4 IR) each capturing 10-bit 3K$\times$3K pixel images every 20 minutes. Storage and/or transmission of such huge amount of data requires large capacity and/or bandwidth which could not be afforded.

Areas of DIP-Cont

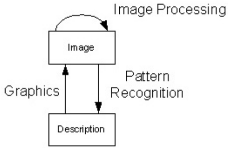
Straight digitalization using PCM requires e.g., 8 bits/pixel. Using predictive or frame encoding techniques (e.g., DPCM) or transform method one can reduce this to 1-2 bits/pixel while preserving the quality of images. For video, motion-compensated coding detects and estimates motion parameters from image sequences and motion-compensated frame differences are transmitted. An area of active research is stereo-video sequence compression and coding for wearable devices and mobile platforms.

Some of the typical schemes are:

- Pixel-by-pixel coding
- Predictive coding
- Transform coding
- Hybrid coding
- Frame-to-frame coding
- Vector quantization

Areas of DIP-Cont

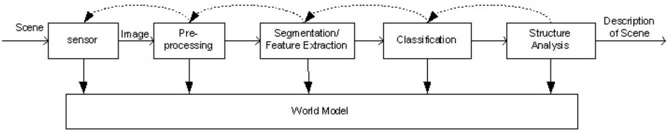
6. Image Analysis and Computer Vision (High-level): Involves: (a) segmentation, (b) feature extraction and (c) classification/recognition. Segmentation is used to isolate desired objects and facilitate feature extraction, e.g., separation of targets from background. A representative set of features is extracted from each segmented object. Quantitative evaluation of the features allow classification and description of the isolated objects.



Ultimate goal could be building an automatic recognition system that can derive *symbolic descriptions or semantics* from a scene. Pattern recognition can be regarded as the *inverse* of computer graphics. It starts with a picture and transforms it into an abstract description; a set of numbers, a string of symbols or a graph for the scene. See Fig. for relationship of different areas.

Areas of DIP-Cont

A complete image processing or computer vision system is shown below.



Sensor: Captures/aquires image data.

Preprocessor: Improves the contrast, removes noise, sharpen edges, etc.

Segmentation: Isolates objects of interest from the background and clutter.

Feature Extraction: Extracts a representative set of features from segmented objects.

Classifier: Categorizes each object or region and extracts high-level attributes from them.

Structural Analyzer: Determines relationships among classified primitives. The output is description of the original scene.

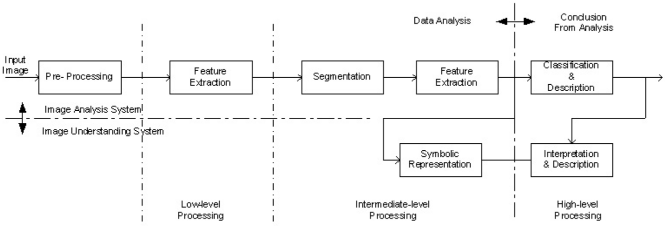
World Model: Guides each stage of the system the results of which can be used in turn to refine the world model. A world model is constructed incorporating sufficient *a priori* information about the scene before analyze the image.

Areas of DIP-Cont

Typical operations applied in image analysis are:

- Edge extraction
- Line extraction
- Texture discrimination
- Shape recognition
- Object recognition

A more complete image analysis system is shown below:



A computer vision System

Areas of DIP-Cont

The common questions underlying these areas are:

1. How do we describe or characterize images?
2. What mathematical methods do we want to use on an image?
3. How do we implement these algorithms?
4. How do we evaluate the quality of the processed images?

Goals of this course:

- Fundamental concepts
- Image processing mathematics
- Basic algorithms
- State-of-the-art
- Applications