Recent **Research Topics** related to **Image Processing**

1. Biomedical Imaging

   The current plethora of imaging technologies such as magnetic resonance imaging (MR), computed tomography (CT), position emission tomography (PET), optical coherence tomography (OCT), and ultrasound provide great insight into the different anatomical and functional processes of the human body. While such imaging technologies have improved significantly over the years to provide improved resolution and signal-to-noise ratio (SNR), as well as reduced acquisition speed, there are still many fundamental trade-offs between these three aspects due to operational, financial, and physical constraints. As such, the acquired data can be largely unusable in raw form due to factors such as noise, technology-related artifacts, poor resolution, and contrast. Furthermore, given the complexities of biomedical imaging data, it is often difficult for research scientists and clinicians to interpret and analyze the acquired data in a meaningful and efficient fashion.

   Related demos

   Skin Cancer Detection

   Bias Field Correction in Endorectal Diffusion Imaging

   Enhanced Low-dose Computed Tomography

   Correlated Diffusion Imaging

   Photoplethysmographic Imaging

   Multiplexed Optical High-coherence Interferometry

2. Computer Vision

Computer vision is the science and technology of teaching a computer to interpret images and video as well as a typical human. Technically, computer vision encompasses the fields of image/video processing, pattern recognition, biological vision, artificial intelligence, augmented reality, mathematical modeling, statistics, probability, optimization, 2D sensors, and photography. Applications range from easier tasks in highly constrained environments (e.g., industrial machine vision such as counting items on an assembly line) to more complicated tasks in more variable environments (e.g., an outdoor camera monitoring human actions - was that person running or walking?). Computer vision is useful for, as examples, controlling processes (e.g., robot navigation), tracking objects (e.g., tracking vehicles through an intersection - see Miovision), finding certain information (e.g., find all the 'cows' in a large digital image database), recognizing certain events (e.g., did someone leave a suitcase behind at the airport?), creating biological models (e.g.How does the human biological system work?).

Related demos

Action Recognition in Video
Disparate Scene Registration
Stereo Vision for Dimension Estimation
Enhanced Decoupled Active Contour Using Structural and Textural Variation Energy Functionals
Computer Vision for Autonomous Robots
Hybrid Structural and Texture Distinctiveness Vector Field Convolution for Region Segmentation
Grid Seams: A fast superpixel algorithm for real-time applications
VICS
VIP-Sal
VIP-LowLight
VIP RGB-D Scene Flow

3. Image Segmentation/Classification

Extracting information from a digital image often depends on first identifying desired objects or breaking down the image into homogenous regions (a process called 'segmentation') and then assigning these objects to particular classes (a process called 'classification'). This is a fundamental part of computer vision, combining image processing and pattern recognition techniques. Homogeneous may refer to the color of the object or region, but it also may use other features such as texture and shape. The methodology can be used to identify tumors in medical images, crops in satellite imagery, cells in biological tissue, or human faces in standard digital images or video. Each segmentation/classification implementation has the same fundamental approach; however, specific objects and imagery often require dedicated techniques for improved success.

Related demos

Action Recognition in Video
Decoupled Active Contours
Disparate Scene Registration
Image Denoising
3D Reconstruction of Underwater Scenes
Skin Cancer Detection
Statistical Textural Distinctiveness for Salient Region Detection in Natural Images
Enhanced Decoupled Active Contour Using Structural and Textural Variation Energy Functionals
Computer Vision for Autonomous Robots
Hybrid Structural and Texture Distinctiveness Vector Field Convolution for Region Segmentation
MAGIC System
Grid Seams: A fast superpixel algorithm for real-time applications
VIP-Sal

4. Multiresolution Techniques

Multiresolution Techniques span an exceptionally broad range of algorithms, models, methods, and concepts. Central to the multiresolution approach is to somehow express short-range, mid-range, and long-range relationships explicitly. The main reasons for a multiresolution approach is one of:

- improving performance, by capturing long-range phenomena that would otherwise not be utilized
- reducing computational complexity, by allowing algorithms to work on both fine and coarse scales, rather than waiting for local pixel-level operations to converge at large scales
- improving numerical robustness (reducing problem conditioning), whereby a multiresolution transformation is essentially an algebraic pre-conditioner
- simplifying the algorithm, by making accessible long-range features that might, in some problems, be much easier to work with than pixel-level features
- improving intuition, by modeling or analyzing the problem over multiple scales, getting deeper insights into the phenomenon at hand.

Although there are, for sure, many multiresolution approaches and algorithms which have been proposed, broadly these fall into a few groups:

Wavelet Methods

Problems in which a wavelet transform is used to decompose an image or video into multiple scales, very commonly for image/video denoising, or for feeding the coefficients at multiple scales into a classifier for image classification and segmentation.

Hierarchical Models

A model in which a pixelated, finest-scale random field is explicitly represented using a set of random fields over scales. In many cases the multi-scale model may be simpler, using principles of Markov decomposition to decouple the problem into pieces. A multi-scale model allows different models to be asserted at different scales, usually simpler or more meaningful than having a single-scale model which needs to assert all of the various scale-dependent behaviors simultaneously.

Hierarchical Algorithms

Even if there is no explicitly hierarchical model, it is possible for the processing algorithm to be hierarchical. Best known examples include multigrid methods, whereby a single-scale linear system is solved by casting the problem onto a hierarchy, and wavelet methods in image processing, whereby the image is transferred into a set of multiscale coefficients in the wavelet domain, in which certain operations (like image compression or image denoising) are relatively simple.

Related demos

Action Recognition in Video
Porous Media
Satellite SAR Sea Ice Classification

5. Remote Sensing

Remote sensing, or the science of capturing data of the earth from airplanes or satellites, enables regular monitoring of land, ocean, and atmosphere expanses, representing data that cannot be captured using any other means. A vast amount of information is generated by remote sensing platforms and there is an obvious need to analyze the data accurately and efficiently to improve throughput, reduce costs, and create new products. Whereas human operators can effectively interpret remotely sensed imagery, there is no known artificial algorithm able to perform such a task.

Related demos

Satellite SAR Sea Ice Classification
MAGIC System

6. Scientific Imaging

Image Processing and Computer Vision are very broad concepts, applicable to any number of contexts involving data acquisition from a camera of some sort. Most images studied in the context of denoising or compression are every-day, human-world images, photos of people, buildings, scenery etc. The human world has a complex structure, full of straight lines and edges, and is difficult to model, therefore many of the methods developed for such images are heuristic in nature.

In contrast, scientific imaging refers to working on two- or three-dimensional imagery taken for a scientific purpose, in most cases acquired either through a microscope or remotely-sensed images taken at a distance. In contrast to the complex structure of the human (meter) scale, at both the micron scale (crystals, grains of sand, groups of cells) and at the kilometer scale (forests, deserts) the natural world has a much more random, textured, or irregular structure which can often well be modeled mathematically as a random field.

The methods developed for scientific imaging tend to be less heuristic, and more model based, than those in photographic image processing. Markov random fields, Gibbs random fields, hidden Markov models, and wavelet models are some of the approaches which we use here.

Related demos

Porous Media
Multiplexed Optical High-coherence Interferometry

7. Stochastic Models

In many image processing, computer vision, and pattern recognition applications, there is often a large degree of uncertainty associated with factors such as the appearance of the underlying scene within the acquired data, the location and trajectory of the object of interest, the physical appearance (e.g., size, shape, color, etc.) of the objects being detected, etc. Given these uncertainties, there can be a wide range of possible outcomes for each of these factors that cannot be accounted for using deterministic approaches in an efficient or effective manner. Stochastic models, on the other hand, allow such uncertainties to be taken into account to provide a more complete picture and a robust representation of the problem at hand. Researchers in the VIP lab are investigating novel approaches for constructing robust, large-scale stochastic models to better tackle image processing and computer vision problems such as image denoising, segmentation, registration, and classification in an robust and efficient manner.

Related demos

[Porous Media]
[VIP-LowLight]

8. Video Analysis

   Video analysis is a field within computer vision that involves the automatic interpretation of digital video using computer algorithms. Although humans are readily able to interpret digital video, developing algorithms for the computer to perform the same task has been highly evasive and is now an active research field. Applications include tracking people who are walking; interpreting actions of moving objects and people; and using the technology to replace the array of screens used in monitoring high risk environments, such as airport security. Fundamental problems in video analysis include denoising, searching for events in video, object extraction (e.g., extract all the people in the scene), scale indifference (e.g. recognizing small trees or large trees, or trees close or far to the camera), reconstructing 3d scene information from video, removing vibration or jitter in the video, and spatially and temporally aligning video captured from multiple cameras.

   Related demos

   Action Recognition in Video

Different **Data Preprocessing** Approaches for **Image Data**

The choice of techniques depends on the nature of the image and the application. Here are a few techniques to improve image quality and suitability:

- **Noise Reduction**: Noise in an image can be caused by various factors such as low light, sensor noise, and compression artifacts. Noise reduction techniques aim to remove noise from the image while preserving its essential features. Some common noise reduction techniques include Gaussian smoothing, median filtering, and wavelet denoising.
- **Contrast Enhancement**: Contrast enhancement techniques aim to increase the contrast of an image, making it easier to distinguish between different image features. These techniques can be helpful in applications such as medical imaging and surveillance. Some standard contrast enhancement techniques include histogram equalization, adaptive histogram equalization, and contrast stretching.
- **Image Resizing**: Image resizing techniques are used to adjust the size of an image. Resizing can be done to make an image smaller or larger or to change its aspect ratio. Some typical image resizing techniques include nearest neighbor interpolation, bilinear interpolation, and bicubic interpolation.
- **Segmentation**: Segmentation techniques are used to divide an image into regions based on its content. Segmentation can be helpful in applications such as medical imaging, where specific structures or organs must be isolated from the image. Some standard segmentation techniques include thresholding, edge detection, and region growing.
- **Feature Extraction**: Feature extraction techniques are used to identify and extract relevant features from an image. These features can be used in object recognition and image classification applications. Some standard feature extraction techniques include edge detection, corner detection, and texture analysis.
- **Grayscale Conversion**: Grayscale is simply converting images from colored to black and white. It is normally used to reduce computation complexity in machine learning algorithms.Since most pictures don't need color to be recognized, it is wise to use grayscale, which reduces the number of pixels in an image, thus, reducing the computations required.
- **Data Augmentation**: *Data augmentation* is the process of making minor alterations to existing data to increase its diversity without collecting new data. It is a technique used for enlarging a dataset. Standard data augmentation techniques include *horizontal & vertical flipping*, *rotation*, *cropping*, *shearing*, etc. Performing data augmentation helps in preventing a neural network from learning irrelevant features. This results in better model performance. Standard data augmentation techniques include horizontal & vertical flipping, rotation, cropping, shearing, etc.
  There are two types of augmentation:
    - *Offline augmentation* - Used for small datasets. It is applied in the data preprocessing step.

        - Shifting: This is the process of shifting image pixels horizontally or vertically.
        - Flipping: This reverses the rows or columns of pixels in either vertical or horizontal cases, respectively.
        - Rotation: This process involves rotating an image by a specified degree.
        - Changing Brightness: This is the process of increasing or decreasing image contrast.
        - Cropping: This is the process of creating a random subset of an original image which is then resized to the size of the original image.
        - Scaling: An image can be scaled either inward or outward. When scaling an image outward, the image becomes more significant than the original and vice versa.
    - *Online augmentation*- Used for large datasets. It is normally applied in real-time.
- **Normalization**: It is also referred to as *data re-scaling*, it is the process of projecting image data pixels (intensity) to a predefined range (usually `(0,1)` or `(-1, 1)`). This is commonly used on different data formats, and you want to normalize all of them to apply the same algorithms over them. Normalization is usually applied to convert an image's pixel values to a typical or more familiar sense. Its benefits include:
    - Fairness across all images - For example, scaling all images to an equal range of [0,1] or [-1,1] allows all images to contribute equally to the total loss rather than when other images have high and low pixels ranges give strong and weak loss, respectively.
    - Provides a standard learning rate - Since high pixel images require a low learning rate and low pixel images high learning rate, re-scaling helps provide a standard learning rate for all images.
- **Standardization**: Standardization is a method that scales and preprocesses images to have similar heights and widths. It re-scales data to have a standard deviation of 1 (unit variance) and a mean of 0. Standardization helps to improve the quality and consistency of data.