Recommended Topics for
The Final Project

Image Acquisitions

The first stage of any image processing and vision system, which is the process of creation of images. The intended task on image may not be easily achievable if the image has not been acquired well.

- **Image Synthesis**: The process of creating new images from some sort of image description. In **Realistic Image Synthesis**, the goal is to create images that are accurate representations of real scenes.

Figure 1 Examples of realistic image synthesis. Images are created using a synthesis algorithm, and are not real.

Notable Papers:
- A Testbed for Realistic Image Synthesis (1983) [link]
- An Efficient Radiosity Approach for Realistic Image Synthesis (1986) [link]

Recent Studies:
- Combining Markov Random Fields and Convolutional Neural Networks for Image Synthesis (2016) [link]
- Generative Adversarial Text to Image Synthesis (2016) [link]
- Photographic Image Synthesis with Cascaded Refinement Networks (2017) [link]

Helpful Sources:
- *Book*: Radiosity and Realistic Image Synthesis (2012) [link]
- *Course*: Realistic Image Synthesis in University of California [link]
- *Course*: Realistic Image Synthesis in University of Tokyo [link]
- *Video*: Generative Adversarial Text to Image Synthesis [link]

- **Image Compression**: The process of reducing the cost for storage or transmission of digital images. The goal of the compression is to minimize the size of the image without degrading the quality of the image to an unacceptable level.

Figure 2 Applying an image compression technique on an image, which has greatly decreased its storage size while the visual differences aren't noticeable

Notable Papers:
- Image Compression using the 2-D Wavelet Transform (1992) [link]
- LOCO-I: A Low Complexity, Context-Based, Lossless Image Compression Algorithm (1996) [link]
- High Performance Scalable Image Compression with EBCOT (2000) [link]
- The JPEG 2000 Still Image Compression Standard (2001) [link]

Recent Studies:
- Lossy Image Compression using Singular Value Decomposition and Wavelet Difference Reduction (2014) [link]
- Image Compression and Encryption Scheme Based on 2D Compressive Sensing and Fractional Mellin Transform (2015) [link]
- Lossy Image Compression with Compressive Autoencoders (2017) [link]

Helpful Sources:
- *Video*: Courses of Image Compression (Prof. Guillermo Sapiro) [link]
- *Survey*: JPEG Image Compression using Discrete Cosine Transform: A Survey (2014) [link]
- *Book*: The Data Compression [link]

- **Image Retrieval**: The process of searching images in large databases based on their contents, using computer vision techniques.

  Notable Papers:
  - Using Discriminant Eigenfeatures for Image Retrieval (1996) [link]
  - Local Gray-Value Invariants for Image Retrieval (1997) [link]
  - Content-Based Image Retrieval at the End of the Early Years (2000) [link]
  - The Earth Mover's Distance as a Metric for Image Retrieval (2000) [link]

  Recent Studies:
  - Neural Codes For Image Retrieval (2014) [link]
  - Aggregating Local Deep Features for Image Retrieval (2015) [link]
  - Deep Semantic Ranking Based Hashing for Multi-Label Image Retrieval (2015) [link]
  - Deep Learning of Binary Hash Codes for Fast Image Retrieval (2015) [link]

  Helpful Sources:
  - *Survey*: Image Retrieval: Current Techniques, Promising Directions, and Open Issues (1999) [link]
  - *Survey*: Content-Based Multimedia Information Retrieval: State of the Art and Challenges (2006) [link]
  - *Survey*: Image Retrieval: Ideas, Influences, and Trends of the New Age (2008) [link]
  - *Survey*: Deep Learning for Content-Based Image Retrieval: A Comprehensive Study (2014) [link]
  - *Video*: Course of Prof. V.S. Rane on Image Retrieval [link]

- **Depth Maps**: An image which contains information of the distance of the objects in the scene from a viewpoint. Predicting depth plays an important role in understanding the geometry of a scene.

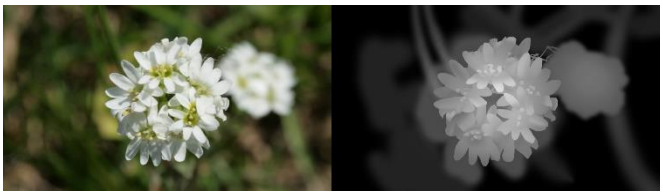

Figure 3 An image with its corresponding depth map image, where the closer parts appear brighter

- **Image Digitization**: Applying methods for storing images in an appropriate form for transmission, storage and processing.
- **Image Sampling and Quantization**: The process of digitizing of an image function both spatially and in amplitude. Sampling rate determines the spatial resolution, while the quantization level determines the number of grey levels in the digitized image.
- **Dynamic Imaging**: The creation of images by zooming, panning, colorize and performing other image processing methods on a copy of a digital master, which can be an image, PDF file, digital recording or another digital asset preserved as the “original” for the purpose of archival storage.
- **Stereo Image Processing**: The process of obtaining 3D information from digital images. These information may include depth, distance, shape and volume.

Image Transformation and Preprocessing

Transformation and preprocessing operations are intended to correct sensor and platform specific radiometric and geometric distortions of images.

- **Image Registration**: Aims to spatially align multiple images of the same scene into a single integrated image. The images are usually taken at different times and from different viewpoints. It plays an important role as a preprocessing step in many image enhancement purposes, like image super-resolution.

Figure 4 Registration of two satellite images of the same area, taken from different coordinates and angles. In the right image they are registered with respect to each other

Notable Papers:
- An Iterative Image Registration Technique with an Application to Stereo Vision (1981) [link]
- An FFT-Based Technique for Translation, Rotation, and Scale-Invariant Image Registration (1996) [link]
- Image Registration by Maximization of Combined Mutual Information and Gradient Information (2000) [link]
- A Fast Diffeomorphic Image Registration Algorithm (2007) [link]
- Parametric Image Alignment using Enhanced Correlation Coefficient Maximization (2008) [link]
- Accurate and Robust Brain Image Alignment using Boundary-Based Registration (2009) [link]
- Online Robust Image Alignment via Iterative Convex Optimization (2012) [link]

Recent Studies:
- Robust Feature Matching for Remote Sensing Image Registration via Locally Linear Transforming (2015) [link]
- A Novel Point-Matching Algorithm based on Fast Sample Consensus for Image Registration (2015) [link]
- Scalable High Performance Image Registration Framework by Unsupervised Deep Feature Representations Learning (2017) [link]

Helpful Sources:
- *Survey*: A Survey of Image Registration Techniques (1992) [link]
- *Survey*: Image Registration Methods: A Survey (2003) [link]
- *Video*: Introduction to Image Registration [link]
- *Video*: Image Registration Lecture of Prof. P.K. Biswas [link]
- *Tutorial*: Image Registration Tutorial from Harvard Medical School [link]
- *Tutorial*: Image Alignment and Stitching: A Tutorial [link]
- *Book*: Image Registration: Principles, Tools and Methods [link]

- **Image Segmentation**: Algorithms and methods which try to partition a digital image into several parts, in order to change it into a more meaningful and easier to analyse representation. It is used as a simple, yet effective, tool to analyse and classify image content.

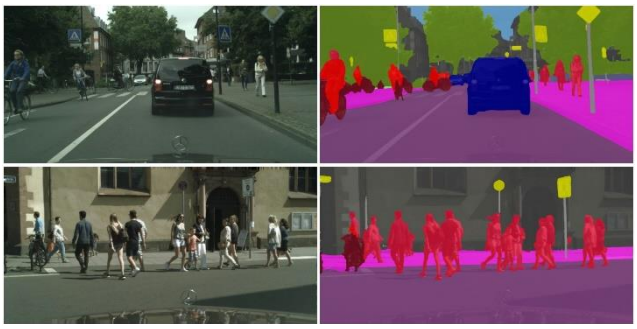

Figure 5 Image segmentation used in an autonomous vehicle to detect different objects in the road

Notable Papers:
- Robust Analysis of Feature Spaces: Color Image Segmentation (1997) [link]
- Normalized Cuts and Image Segmentation (2000) [link]
- Image Segmentation by Data-Driven Markov Chain Monte Carlo (2002) [link]
- Efficient Graph-Based Image Segmentation (2004) [link]
- Random Walks for Image Segmentation (2006) [link]
- Fuzzy C-Means Clustering with Spatial Information for Image Segmentation (2006) [link]
- Minimization of Region-Scalable Fitting Energy for Image Segmentation (2008) [link]
- Distance Regularized Level Set Evolution and Its Application to Image Segmentation (2010) [link]
- Contour Detection and Hierarchical Image Segmentation (2011) [link]

Recent Studies:
- U-Net: Convolutional Networks for Biomedical Image Segmentation (2015) [link]
- Image Segmentation by Generalized Hierarchical Fuzzy C-Means Algorithm (2015) [link]
- Semantic Image Segmentation via Deep Parsing Network (2015) [link]
- V-Net: Fully Convolutional Neural Networks for Volumetric Medical Image Segmentation (2016) [link]
- Segnet: A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation (2017) [link]
- Deeplab: Semantic Image Segmentation with Deep Convolutional Nets, Atrous Convolution, and Fully Connected CRFs (2018) [link]

Helpful Sources:
- *Survey*: A Review on Image Segmentation Techniques (1993) [link]
- *Survey*: Image Segmentation Evaluation: A Survey of Unsupervised Methods (2008) [link]
- *Survey*: Survey on Image Segmentation Techniques (2015) [link]
- *Video*: Detection and Segmentation Lecture in Stanford University [link]
- *Tutorial*: Image Segmentation [link]
- *Tutorial*: Image Segmentation [link]
- *Book*: Computer Vision on Image Segmentation [link]
- *Course Slides*: Basic Methods for Image Segmentation [link]

- **Image Interpolation**: The process of resizing an image from one pixel grid to another, by increasing the number of pixels comprising it.

Figure 6 Two different image interpolation method applied on a simple binary image

- **Image Mosaicing**: The process of merging separate images that are obtained from different angles of a scene, in order to produce a single and complete image of them all. It is widely used in document scanned papers (**Document Mosaicing**) and satellite images.

Figure 7 The result of image mosaicing using several images taken from a plane

- **Digital Watermarking:** Techniques which deal with hiding digital information in an image, where the hiding information usually contain a relation to the image content. It may be used to verify the authenticity or integrity of the image or to show the identity of its owners.

Figure 8 Two example of visible image watermarking. Note that image watermarking are not always visible

- **Image Morphology**: Applying a collection of non-linear operations on an image, which rely only on the relative ordering of the pixel values, and not to their numerical values.

Figure 9 Original (left) and Skeletonized (right) image of a fingerprint. As can be seen, applying morphological techniques on the input image has made it easire to analyse

- **Steganography**: The practice of hiding a message inside an image. It has a very close relationship with **Cryptography**, yet they are not exactly the same.

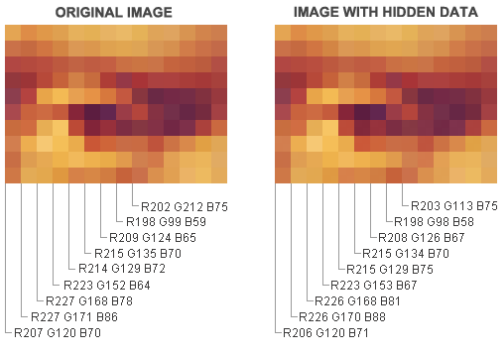

Figure 10 Original (left) and steganographed (right) image. As can be seen, both images are visually identical

- **Face Frontalization**: The process of synthesizing frontal facing views of faces in an image with variations in pose and illuminations. Because of its positive effect on face recognition, it recently has become a very popular research topic.

Figure 11 Applying a frontalization algorithm to different faces with considerable variations in pose

Image Enhancement

Image Enhancement is used to make digital images more suitable for display or further image analysis. It is different from Image Restoration in that it is designed to emphasize features of the image that make the image more pleasing to the observer, but not necessarily to produce realistic data from a scientific point of view.

- **Image Denoising**: The process of removing noise from an image. Two types of image denoising are linear and non-linear. The linear models, such as Gaussian and wiener filters work well in reducing noise in flat regions, but they are incapable of preserving image edge information. Non-linear models, on the other hand, have better edge preserving capability. Image denoising is also called **Noise Reduction**.

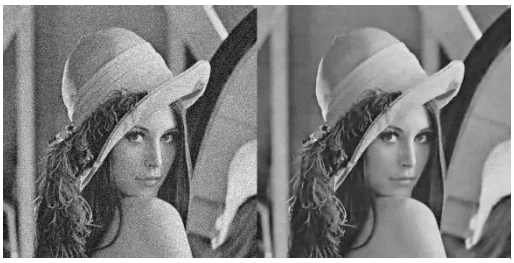

Figure 12 Usage of a denoising technique to reduce gaussian noise of the input image

Notable Papers:

- Adaptive Wavelet Thresholding for Image Denoising and Compression (2000) [link]
- Image Denoising using Scale Mixtures of Gaussians in the Wavelet Domain (2003) [link]
- Image Denoising via Sparse and Redundant Representations over Learned Dictionaries (2006) [link]
- Fast Gradient-Based Algorithms for Constrained Total Variation Image Denoising and Deblurring Problems (2009) [link]
- Two-Stage Image Denoising by Principal Component Analysis with Local Pixel Grouping (2010) [link]
- Sparsity-Based Image Denoising via Dictionary Learning and Structural Clustering (2011) [link]
- Global Image Denoising (2014) [link]

Recent Studies:

- Weighted Nuclear Norm Minimization with Application to Image Denoising (2014) [link]

- Hyperspectral Image Denoising via Sparse Representation and Low-Rank Constraint (2015) [link]
- Beyond a Gaussian Denoiser: Residual Learning of Deep CNN for Image Denoising (2017) [link]
- Denoising Prior Driven Deep Neural Network for Image Restoration (2018) [link]

Helpful Sources:
- *Survey*: Survey of Image Denoising Techniques (2004) [link]
- *Survey*: A Review of Image Denoising Algorithms, with a New One (2005) [link]
- *Survey*: From Heuristic Optimization to Dictionary Learning: A Review and Comprehensive Comparison of Image Denoising Algorithms (2014) [link]
- *Tutorial*: Image Denoising Tutorial [link]
- *Tutorial*: On Image Denoising Methods [link]
- *Video*: Image Denoising Lecture of Prof. Fred Hamprecht in the HCI / Heidelberg University [link]

- **Image Deblurring**: The process of removing blurring artifacts from an image, caused by out of focus aberration or motion. In order to deblur the image, a mathematical description of how it was blurred is needed. If that's not available, there are still algorithms to estimate the blur, called **Blind Deblurring** algorithms.

Figure 13 The result of a deblurring algorithm which hugely increases image details

Notable Papers:
- Iterative Methods for Image Deblurring (1990) [link]
- Image Deblurring with Blurred/Noisy Image Pairs (2007) [link]
- Adaptive Total Variation Image Deblurring: A Majorization–Minimization Approach (2009) [link]
- Single Image Deblurring using Motion Density Functions (2010) [link]
- Image Deblurring and Super-Resolution by Adaptive Sparse Domain Selection and Adaptive Regularization (2011) [link]
- Unnatural ℓ_0 Sparse Representation for Natural Image Deblurring (2013) [link]

Recent Studies:
- Image Deblurring with Coupled Dictionary Learning (2015) [link]
- Image Deblurring via Enhanced Low-Rank Prior (2016) [link]
- Scale-Recurrent Network for Deep Image Deblurring (2018) [link]
- A Concatenated Residual Network for Image Deblurring (2018) [link]

Helpful Sources:
- *Survey*: Linear and Nonlinear Image Deblurring: A Documented Study (1999) [link]
- *Survey*: Literature Survey on Image Deblurring Techniques (2013) [link]
- *Book*: The Image Deblurring Problem [link]
- *Book*: Deblurring Images: Matrices, Spectra and Filtering [link]

- **Image Super-resolution**: Aims to reconstruct a higher-resolution image from the observed low resolution image(s). The high resolution result offers a high pixel density and thereby more details about the original scene.

Figure 14 Applying image super-resolution techniques on the input (left) image made the text more easily readable (right)

Notable Papers:
- Example-Based Super-Resolution (2002) [link]
- Super-Resolution Through Neighbor Embedding (2004) [link]

- Image Super-Resolution using Gradient Profile Prior (2008) [link]
- Image Super-Resolution via Sparse Representation (2010) [link]

Recent Studies:
- Anchored Neighborhood Regression for Fast Example-Based Super-Resolution (2013) [link]
- Fast and Accurate Image Upscaling With Super-Resolution Forests (2015) [link]
- Image Super-Resolution using Deep Convolutional Networks (2016) [link]
- Accurate Image Super-Resolution using Very Deep Convolutional Networks (2016) [link]

Helpful Sources:
- *Survey*: Super-Resolution Image Reconstruction: A Technical Overview (2003) [link]
- *Survey*: Image Super Resolution: A Survey (2012) [link]
- *Survey*: Super-Resolution: A Comprehensive Survey (2014) [link]

- **Image Dehazing**: The process of removing "haze" – an atmospheric phenomenon like dust or smoke – from an image. It is also called **Image Defogging** or **Haze Removal**.

Figure 15 Haze effect is visible in the left image, and removed after a dehazing process in the right image

Notable Papers:
- Haze Detection and Removal in High Resolution Satellite Image with Wavelet Analysis (2002) [link]
- Single Image Dehazing (2008) [link]
- Single Image Haze Removal using Dark Channel Prior (2011) [link]
- Single Image Dehazing by Multi-Scale Fusion (2013) [link]
- Efficient Image Dehazing with Boundary Constraint and Contextual Regularization (2013) [link]
- Investigating Haze-Relevant Features in a Learning Framework for Image Dehazing (2014) [link]

Recent Studies:
- A Fast Single Image Haze Removal Algorithm using Color Attenuation Prior (2015) [link]
- Edge-Preserving Decomposition-Based Single Image Haze Removal (2015) [link]
- Dehazenet: An End-to-End System for Single Image Haze Removal (2016) [link]
- Non-Local Image Dehazing (2016) [link]
- Single Image Dehazing via Multi-Scale Convolutional Neural Networks (2016) [link]
- Fusion-Based Variational Image Dehazing (2017) [link]

Helpful Sources:
- *Survey*: A Review on Dark Channel Prior Based Image Dehazing Algorithms (2016) [link]
- *Survey*: Haze Visibility Enhancement: A Survey and Quantitative Benchmarking (2017) [link]
- *Survey*: Perceptual Evaluation of Single Image Dehazing Algorithms (2015) [link]
- *Video*: Single Image Dehazing: A Microsoft Research Presentation [link]

- **Blind Deconvolution**: An area which concerns recovery of the target scene from a single or set of blurred images, when the point spread function is poorly determined or even unknown.

Figure 16 Image blind deconvolution result (right), which has greatly removed blurring effect from the input image (left)

Notable Papers:
- Blind Image Deconvolution (1996) [link]
- Blind Deconvolution using a Variational Approach to Parameter, Image, and Blur Estimation (2006) [link]
- Understanding and Evaluating Blind Deconvolution Algorithms (2009) [link]

- Blind Deconvolution using a Normalized Sparsity Measure (2011) [link]
- Efficient Marginal Likelihood Optimization in Blind Deconvolution (2011) [link]
- Bayesian Blind Deconvolution with General Sparse Image Priors (2012) [link]

Recent Studies:
- Deep Convolutional Neural Network for Image Deconvolution (2014) [link]
- Blind Deblurring using Internal Patch Recurrence (2014) [link]
- Blind Image Blur Estimation via Deep Learning (2016) [link]
- Blind Image Deblurring using Dark Channel Prior (2016) [link]

Helpful Sources:
- *Book*: Blind Image Deconvolution: Theory and Applications [link]
- *Survey*: Blind and Semi-Blind Deblurring of Natural Images (2010) [link]
- *Survey*: A Comparative Study for Single Image Blind Deblurring (2016) [link]

- **Image Inpainting**: The application of algorithms to reconstruct lost or corrupted part of an image. It may come in handy in case of removing scratches which appear on images due to aging. The concept is close – yet not identical – to **Object Removal**.

Figure 17 Image inpainting technique used on a scanned image taken from a historical paper, which greatly removed the folding effects

Notable Papers:
- Simultaneous Structure and Texture Image Inpainting (2003) [link]
- Region Filling and Object Removal by Exemplar-Based Image Inpainting (2004) [link]
- An Image Inpainting Technique Based on the Fast Marching Method (2004) [link]
- Simultaneous Cartoon and Texture Image Inpainting using Morphological Component Analysis (MCA) (2005) [link]
- Image Inpainting by Patch Propagation using Patch Sparsity (2010) [link]
- A Variational Framework for Exemplar-Based Image Inpainting (2011) [link]
- Image Denoising and Inpainting with Deep Neural Networks (2012) [link]

Recent Studies:
- High-Resolution Image Inpainting using Multi-Scale Neural Patch Synthesis (2017) [link]
- Semantic Image Inpainting with Deep Generative Models (2017) [link]
- Depth Image Inpainting: Improving Low Rank Matrix Completion with Low Gradient Regularization (2017) [link]

Helpful Sources:
- *Survey*: Digital Inpainting-Survey and Multilayer Image Inpainting Algorithms (2005) [link]
- *Survey*: A survey on Variational Image Inpainting, Texture Synthesis and Image Completion (2008) [link]
- *Survey*: Review of Digital Image Inpainting Algorithms (2012) [link]
- *Survey*: Image Inpainting: Overview and Recent Advances (2014) [link]
- *Tutorial*: Image Inpainting [link]

- **Tone Mapping**: The process of mapping one set of colors to another. While it preserves the image details and color appearance of the original scene content, it tries to address the problem of strong contrast reduction from the scene radiance to a more displayable range.

Figure 18 The result of applying tone mapping on an image. It not only enhanced its visual appearance, but also increased the visible details inside the image

Image Classification and Analysis

Digital image classification uses the features extracted from an image and attempts to classify each pixel based on its feature. In other word, the objective is to assign all pixels in the image to particular classes or themes.

- **Face Recognition**: The process of identifying (**Face Identification**) or verifying (**Face Verification**) of a person using an image, based on a database of known faces. In recent years, **Uncontrolled Face Recognition** (or **Face Recognition in the Wild**) has attracted attentions, where the goal is to recognise faces in the presence of occlusion and variations in pose, illumination and facial expressions.

Figure 19 A facial recognition system which determines individual's identity by his/her name

Notable Papers:
- Face Recognition using Eigenfaces (1991) [link]
- Eigenfaces vs. Fisherfaces: Recognition using Class Specific Linear Projection (1997) [link]
- Face Description with Local Binary Patterns: Application to Face Recognition (2006) [link]
- Robust Face Recognition via Sparse Representation (2009) [link]
- Linear Regression for Face Recognition (2010) [link]
- Deep Face Recognition (2015) [link]

Recent Studies:
- DeepFace: Closing the Gap to Human-Level Performance in Face Verification (2014) [link]
- Deep Learning Face Representation by Joint Identification-Verification (2014) [link]
- Facenet: A Unified Embedding for Face Recognition and Clustering (2015) [link]
- Sphereface: Deep Hypersphere Embedding for Face Recognition (2017) [link]

Helpful Sources:
- *Survey*: Face Recognition: A Literature Survey (2003) [link]
- *Survey*: 2D and 3D Face Recognition: A Survey (2007) [link]
- *Survey*: A Survey of Face Recognition Techniques (2009) [link]
- *Video*: Face Recognition Course by Prof. Mubarak Shah (link)
- *Book*: Facial Recognition Technology A Survey of Policy and Implementation Issues [link]

- **Face Detection**: The technology used in applications that identifies human faces (position, size, etc.) in digital images. In recent years, Uncontrolled Face Detection has become a popular research topics, where there is no assumption on pose, illumination, facial expression of the faces, and images may also suffer from low-resolution and occlusions.

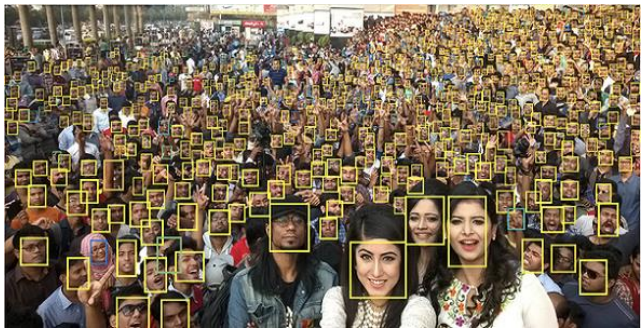

Figure 20 A face detection algorithm which has successfully detected nearly all visible faces in the image

Notable Papers:
- Training Support Vector Machines: An Application to Face Detection (1997) [link]
- Neural Network-Based Face Detection (1998) [link]
- Example-Based Learning for View-Based Human Face Detection (1998) [link]
- Robust Real-Time Face Detection (2004) [link]

Recent Studies:
- A Fast and Accurate Unconstrained Face Detector (2014) [link]
- A convolutional neural network cascade for face detection (2015) [link]
- Hyperface: A Deep Multi-Task Learning Framework for Face Detection, Landmark Localization, Pose Estimation, and Gender Recognition (2017) [link]

Helpful Sources:
- *Survey*: Face Detection: A survey (2001) [link]
- *Survey*: A Survey of Recent Advances in Face Detection (2010) [link]
- *Survey*: A Survey of Feature Base Methods for Human Face Detection (2015) [link]
- *Video*: Tom Neumark Facial Detection Course (link)

- **Object Recognition:** Trying to find specific object(s) in a digital image, by relying on matching, learning or pattern recognition algorithms using appearance-based or feature-based techniques. Sometimes it is called **Shape Matching**.

Figure 21 An object recognition algorithm result, which has determined what category every object in the scene belongs to

Notable Papers:
- Object Recognition from Local Scale-Invariant Features (1999) [link]
- Shape Matching and Object Recognition using Shape Contexts (2002) [link]
- Pictorial Structures for Object Recognition (2005) [link]
- Robust Object Recognition with Cortex-Like Mechanisms (2007) [link]
- Selective Search for Object Recognition (2013) [link]

Recent Studies:
- Decaf: A Deep Convolutional Activation Feature for Generic Visual Recognition (2014) [link]
- Multiple Object Recognition with Visual Attention (2014) [link]
- Recurrent Convolutional Neural Network for Object Recognition (2015) [link]
- Visual–Tactile Fusion for Object Recognition (2017) [link]

Helpful Sources:
- *Survey*: Survey of Appearance-Based Methods for Object Recognition (2008) [link]

- *Survey*: Analyzing the Performance of Multilayer Neural Networks for Object Recognition (2014) [link]
- *Book*: 2D Object Detection and Recognition (2002) [link]
- *Video*: Prof. Patrick Winston's Visual Object Recognition Course in MIT [link]

- **Object Tracking**: The act of locating one or multiple moving object(s) over time using digital images (or frames) of a camera.

Figure 22 An object tracking algorithm used to track players activities in the soccer field

Notable Papers:
- Object Tracking with Bayesian Estimation of Dynamic Layer Representations (2002) [link]
- Kernel-Based Object Tracking (2003) [link]
- Object Tracking using SIFT Features and Mean Shift (2009) [link]
- Robust Object Tracking with Online Multiple Instance Learning (2011) [link]
- Multiple Object Tracking using K-Shortest Paths Optimization (2011) [link]
- Robust Object Tracking via Sparsity-Based Collaborative Model (2012) [link]

Recent Studies:
- Multi-Store Tracker (Muster): A Cognitive Psychology Inspired Approach to Object Tracking (2015) [link]
- Learning to Track: Online Multi-Object Tracking by Decision Making (2015) [link]
- Fully-Convolutional Siamese Networks for Object Tracking (2016) [link]
- Tracking the Trackers: An Analysis of the State of the Art in Multiple Object Tracking (2017) [link]
- Robust Object Tracking via Key Patch Sparse Representation (2017) [link]

Helpful Sources:
- *Survey*: Object Tracking: A Survey (2006) [link]
- *Survey*: A Survey of Appearance Models in Visual Object Tracking (2013) [link]
- *Survey*: Online Object Tracking: A Benchmark (2013) [link]
- *Video*: Prof. Arnold W.M. Smeulders's Object Tracking Course in University of Amsterdam [link]

- **Object Detection:** Application a set of sophisticated algorithms to process images or video sequences in order to detect instances of semantic objects of a certain class, e.g. cars or traffic signs.

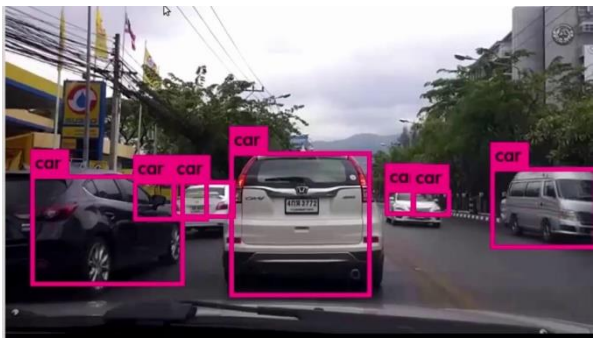

Figure 23 Object detection used to detect objects of the type "car" in an autonomous vehicle

Notable Papers:
- Rapid Object Detection using a Boosted Cascade of Simple Features (2001) [link]
- An Extended Set of Haar-Like Features for Rapid Object Detection (2002) [link]
- Object Detection with Discriminatively Trained Part-Based Models (2010) [link]
- Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation (2014) [link]

Recent Studies:
- Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks (2015) [link]
- You Only Look Once: Unified, Real-Time Object Detection (2016) [link]
- R-FCN: Object Detection via Region-Based Fully Convolutional Networks (2016) [link]

- Feature Pyramid Networks for Object Detection (2017) [link]

Helpful Sources:
- *Survey*: Object Tracking: A Survey (2006) [link]
- *Survey*: Salient Object Detection: A Survey (2014) [link]
- *Course*: Object Detection using Convolutional Neural Networks Course on Coursera [link]
- *Tutorial*: YOLO (You Only Look Once) Project Website [link]

- **Handwritten Digit Recognition**: A tool used to receive and interpret intelligible handwritten digits from a source like papers, photographs, touch-screens or other devices.

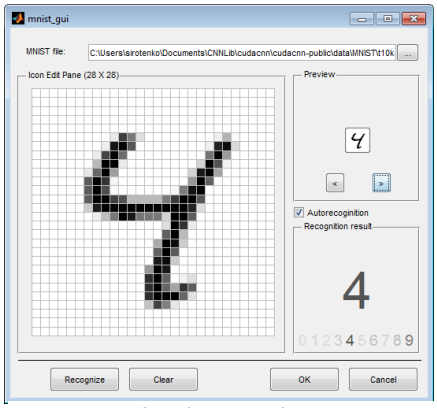

Figure 24 A handwritten digit recognition system

Notable Papers:
- Handwritten Digit Recognition with a Back-Propagation Network (1990) [link]
- Using Generative Models for Handwritten Digit Recognition (1996) [link]
- A Trainable Feature Extractor for Handwritten Digit Recognition (2007) [link]
- Deep, Big, Simple Neural Nets for Handwritten Digit Recognition (2010) [link]

Recent Studies:
- Efficient Handwritten Digit Recognition Based on HOGs and SVM (2014) [link]
- Novel Feature Extraction Technique for the Recognition of Handwritten digits (2017) [link]
- An Adaptive Deep Q-Learning Strategy for Handwritten Digit Recognition (2018) [link]

Helpful Sources:
- *Survey*: Learning Algorithms for Classification: A Comparison on Handwritten Digit Recognition (1995) [link]
- *Survey*: Comparison of Classifier Methods: A Case Study in Handwritten Digit Recognition (1994) [link]

- **Fingerprint Recognition**: Aims to identify or confirm the identity of a person based on the comparison of two fingerprints. It is considered as the most popular biometric solution used for authentication on computer systems.

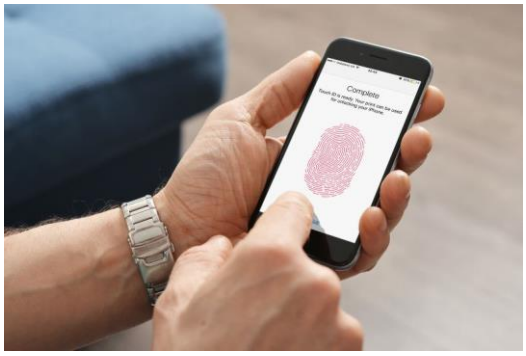
Figure 25 Fingerprint recognition system used in a smartphone as an identity verification

Notable Papers:
- Automated Fingerprint Recognition using Structural Matching (1990) [link]
- Novel Approach to Automated Fingerprint Recognition (1998) [link]
- Biometrical Fingerprint Recognition: Don't Get Your Fingers Burned (2000) [link]
- A Minutia-Based Partial Fingerprint Recognition System (2005) [link]
- Minutia Cylinder-Code: A New Representation and Matching Technique for Fingerprint Recognition (2010) [link]

Recent Studies:
- Giving Infants an Identity: Fingerprint Sensing and Recognition (2016) [link]
- Fingerprint Recognition of Young Children (2017) [link]
- Automated Latent Fingerprint Recognition (2018) [link]

Helpful Sources:
- *Book*: Fingerprint Recognition: Models and Applications [link]
- *Tutorial*: A Tutorial on Fingerprint Recognition [link]
- *Tutorial*: Fingerprint Recognition on IEEE Winter School on Biometrics [link]

- **CAPTCHA Recognition**: A vision system which tries to understand the contents inside a CAPTCHA image.

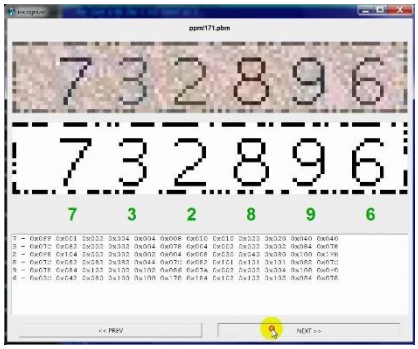

Figure 26 A CAPTCHA recognition system

Notable Papers:
- Recognizing Objects in Adversarial Clutter: Breaking a Visual CAPTCHA (2003) [link]
  Image Recognition Captchas (2004) [link]
- Breaking Visual Captchas with Naive Pattern Recognition Algorithms (2007) [link]
- reCAPTCHA: Human-Based Character Recognition via Web Security Measures (2008) [link]
- A Low-Cost Attack on a Microsoft CAPTCHA (2008) [link]

Recent Studies:
- CAPTCHA Recognition with Active Deep Learning (2015) [link]
- Breaking Text-Based CAPTCHAs with Variable Word and Character Orientation (2015) [link]
- Rotation Invariant Digit Recognition using Convolutional Neural Network (2018) [link]

Helpful Sources:
- *Survey*: A Study on CAPTCHA Recognition (2014) [link]
- *Survey*: Survey of Different Types of CAPTCHA (2014) [link]
- *Survey*: Captcha Security: A Case Study (2009) [link]
- *Survey*: A Survey on Breaking Technique of Text-Based CAPTCHA (2017) [link]

- **Gesture Recognition**: A research topic with the goal of interpreting human gestures using mathematical algorithms. Also it includes any bodily motion or state, it usually deals with face or hand.

Figure 27 Hand gesture recognition used in Microsoft Kinect One motion sensor

Notable Papers:
- Gesture Recognition using Recurrent Neural Networks (1991) [link]
- Orientation Histograms for Hand Gesture Recognition (1995) [link]
- An HMM-Based Threshold Model Approach for Gesture Recognition (1999) [link]
- Hand Gesture Recognition using a Real-Time Tracking Method and Hidden Markov Models (2003) [link]
- Hidden Conditional Random Fields for Gesture Recognition (2006) [link]
- Hand Gesture Recognition with Leap Motion and Kinect Devices (2014) [link]
- Gesture Recognition (2014) [link]

Recent Studies:
- Hand Gesture Recognition with 3D Convolutional Neural Networks (2015) [link]
- Moddrop: Adaptive Multi-Modal Gesture Recognition (2016) [link]
- Hand-Gesture Recognition Method (2017) [link]
- Challenges in Multi-Modal Gesture Recognition (2017) [link]
- A Unified Framework for Multi-Modal Isolated Gesture Recognition (2018) [link]

Helpful Sources:
- *Survey*: Vision-Based Gesture Recognition: A Review (1999) [link]

- *Survey*: Gesture Recognition: A Survey (2007) [link]
- *Survey*: Vision Based Hand Gesture Recognition for Human Computer Interaction: A Survey (2015) [link]

- **Gait Recognition**: The process of determining person's identity by the manner of his walking. It has been shown that the way a person walks – called gait – is a biometric identifier, i.e. a unique biological or behavioral identification characteristic such a fingerprint or a face.

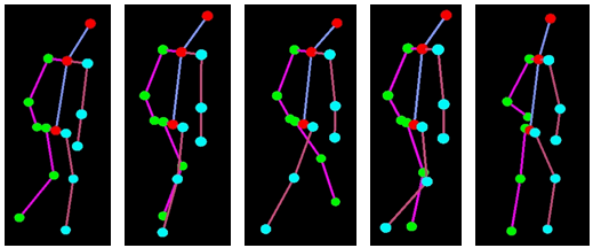

Figure 28 Detection and tracking key features extracted from an individual body

Notable Papers:
- Gait Analysis for Recognition and Classification (2002) [link]
- Automatic Gait Recognition Based on Statistical Shape Analysis (2003) [link]
- Individual Recognition using Gait Energy Image (2006) [link]
  Improved Gait Recognition by Gait Dynamics Normalization (2006) [link]
- General Tensor Discriminant Analysis and Gabor Features for Gait Recognition (2007) [link]
- Gait Recognition without Subject Cooperation (2010) [link]

Recent Studies:
- Human Gait Recognition via Sparse Discriminant Projection Learning (2014) [link]
- View Transformation Model Incorporating Quality Measures for Cross-View Gait Recognition (2016) [link]
- GEINet: View-Invariant Gait Recognition using a Convolutional Neural Network (2016) [link]

Helpful Sources:
- *Survey*: Gait Recognition: A Challenging Signal Processing Technology for Biometric Identification (2005) [link]
- *Survey*: A Review of Vision-Based Gait Recognition Methods for Human Identification (2010) [link]
- *Survey*: A Survey of Advances in Biometric Gait Recognition (2011) [link]
- *Survey*: Gait Recognition: Databases, Representations, and Applications (2015) [link]

- **Iris Recognition**: Refers to the usage of pattern recognition techniques on images or video sequences of one or both of the irises of a person's eye in order to identify or verify his/her identify.

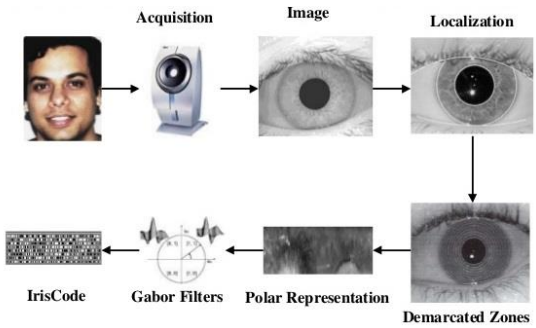

Figure 29 The procedure of an Iris recognition system

Notable Papers:
- Gait Analysis for Recognition and Classification (2002) [link]
- Automatic Gait Recognition Based on Statistical Shape Analysis (2003) [link]
- Individual Recognition using Gait Energy Image (2006) [link]
  Improved Gait Recognition by Gait Dynamics Normalization (2006) [link]
- General Tensor Discriminant Analysis and Gabor Features for Gait Recognition (2007) [link]
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- *Survey*: Gait Recognition: A Challenging Signal Processing Technology for Biometric Identification (2005) [link]
- *Survey*: A Review of Vision-Based Gait Recognition Methods for Human Identification (2010) [link]
- *Survey*: A Survey of Advances in Biometric Gait Recognition (2011) [link]
- *Survey*: Gait Recognition: Databases, Representations, and Applications (2015) [link]

- **Pedestrian detection**: Methods dealing with detecting (and sometimes tracking) pedestrians, mainly in a video sequence. It is used in many applications such as surveillance cameras and autonomous cars.

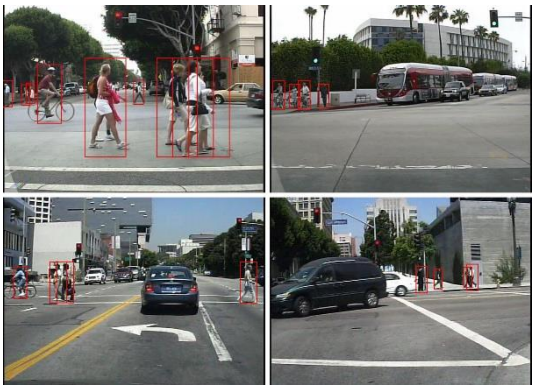

Figure 30 A pedestrian detection system used in an autonomous vehicle

Notable Papers:
- Pedestrian Detection using Wavelet Templates (1997) [link]
- Stereo-and Neural Network-Based Pedestrian Detection (2000) [link]
- Pedestrian Detection via Classification on Riemannian Manifolds (2008) [link]
- New Features and Insights for Pedestrian Detection (2010) [link]
- Pedestrian Detection with Unsupervised Multi-Stage Feature Learning (2013) [link]

Recent Studies:
- Joint Deep Learning for Pedestrian Detection (2013) [link]
- Deep Learning Strong Parts for Pedestrian Detection (2015) [link]
- Is Faster R-CNN Doing Well for Pedestrian Detection? (2016) [link]
- Fused DNN: A Deep Neural Network Fusion Approach to Fast and Robust Pedestrian Detection (2017) [link]
- Scale-Aware Fast R-CNN for Pedestrian Detection (2018) [link]

Helpful Sources:
- *Survey*: Monocular Pedestrian Detection: Survey and Experiments (2009) [link]
- *Survey*: Pedestrian Detection: An Evaluation of the State of the Art (2012) [link]
- *Survey*: Ten Years of Pedestrian Detection, What Have We Learned? (2014) [link]

- **Optical Character Recognition**: The process of identifying printed characters by converting the images of types, handwritten or printed text into machine-encoded texts.

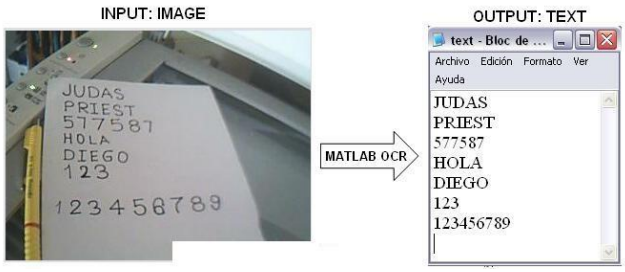

Figure 31 Optical Character Recognition used to read handwritten letters on a paper

Notable Papers:
- Optical Character Recognition by the Method of Moments (1987) [link]
- Optical Character Recognition: An Illustrated Guide to the Frontier (1999) [link]
- An Arabic Optical Character Recognition System using Recognition-Based Segmentation (2001) [link]
- Optical Character Recognition (OCR) for Printed Devnagari Script using Artificial Neural Network (2010) [link]

- Optical Character Recognition by Open Source OCR Tool Tesseract: A Case Study (2012) [link]

Recent Studies:
- Optical Character Recognition Implementation using Pattern Matching (2014) [link]
- Boosting Optical Character Recognition: A Super-Resolution Approach (2015) [link]
- Mass Digitization of Early Modern Texts with Optical Character Recognition (2017) [link]

Helpful Sources:
- *Survey*: Feature Extraction Methods for Character Recognition-A Survey (1996) [link]
- *Survey*: A Review on the Various Techniques used for Optical Character Recognition (2012) [link]
- *Survey*: A Survey of Modern Optical Character Recognition Techniques (2014) [link]
- *Survey*: A Survey on Arabic Character Recognition (2015) [link]
- *Video*: Optical Character Recognition using Machine Learning Algorithms [link]

- **Facial Expression Recognition**: Application of image processing and computer vision algorithms to locate faces in the image, extract facial features and classify them into some facial expression-interpretative categories such as "happiness" or "surprised". It is also called **Emotion Recognition**.

Figure 32 A facial expression recognition system, capable of determining four different emotion states

Notable Papers:
- Facial Expression Recognition using a Dynamic Model and Motion Energy (1995) [link]
- Facial Expression Recognition from Video Sequences: Temporal and Static Modelling (2003) [link]
- Facial Expression Recognition using Constructive Feedforward Neural Networks (2004) [link]
- Robust Facial Expression Recognition using Local Binary Patterns (2005) [link]
- Facial Expression Recognition in Image Sequences using Geometric Deformation Features and Support Vector Machines (2007) [link]
- Robust Facial Expression Recognition Based on Local Directional Pattern (2010) [link]

Recent Studies:
- Facial Expression Recognition via a Boosted Deep Belief Network (2014) [link]
- Automatic Facial Expression Recognition using Features of Salient Facial Patches (2015) [link]
- Image Based Static Facial Expression Recognition with Multiple Deep Network Learning (2015) [link]
- Going Deeper in Facial Expression Recognition using Deep Neural Networks (2016) [link]
- Facial Expression Recognition with Convolutional Neural Networks: Coping with Few Data and the Training Sample Order (2017) [link]

Helpful Sources:
- *Survey*: Automatic Facial Expression Analysis: A Survey (2003) [link]
- *Survey*: Facial Expression Recognition Based on Local Binary Patterns: A Comprehensive Study (2009) [link]
- *Tutorial*: Emotion from Facial Expression Recognition [link]
- *Tutorial*: Introduction to Emotion Recognition for Digital Images [link]

- **License Plate Recognition**: A technology which deals with reading car registration plates either in a still image or a video frames.

Figure 33 Applying license plate recognition algorithms to detect and read a vehicle plate number

  Notable Papers:
  - Car Plate Recognition by Neural Networks and Image Processing (1998) [link]
  - Automatic License Plate Recognition (2004) [link]
  - Application of Pattern Recognition for Farsi License Plate Recognition (2005) [link]
  - A License Plate-Recognition Algorithm for Intelligent Transportation System Applications (2006) [link]
  - An Algorithm for License Plate Recognition Applied to Intelligent Transportation System (2011) [link]

  Recent Studies:
  - An Iranian License Plate Recognition System Based on Color Features (2014) [link]
  - Vehicle License Plate Recognition Based on Extremal Regions and Restricted Boltzmann Machines (2016) [link]
  - License Plate Detection and Recognition Using Deeply Learned Convolutional Neural Networks (2017) [link]

  Helpful Sources:
  - *Survey*: License Plate Recognition from Still Images and Video Sequences: A Survey (2008) [link]
  - *Survey*: Automatic License Plate Recognition (ALPR): A State-of-the-Art Review (2013) [link]
  - *Survey*: A Survey on License Plate Recognition Systems (2013) [link]
  - *Tutorial*: License Plate Recognition: A Brief Tutorial [link]

- **Change Detection**: The process of determining areas of a scene which are different in two images or video frames of that scene.

Figure 34 Applying change detection algorithm on this satellite image shows the areas with more trees cut

  Notable Papers:
  - Bayesian Algorithms for Adaptive Change Detection in Image Sequences using Markov Random Fields (1995) [link]
  - Automatic Analysis of the Difference Image for Unsupervised Change Detection (2000) [link]
  - An Image Change Detection Algorithm Based on Markov Random Field Models (2002) [link]
  - Evaluation of Global Image Thresholding for Change Detection (2003) [link]
  - A Hopfield Neural Network for Image Change Detection (2006) [link]

  Recent Studies:
  - SAR Image Change Detection using Regularized Dictionary Learning and Fuzzy Clustering (2014) [link]
  - Using Combined Difference Image and -Means Clustering for SAR Image Change Detection (2014) [link]
  - Subsense: A Universal Change Detection Method with Local Adaptive Sensitivity (2015) [link]
  - A Theoretical Framework for Change Detection Based on a Compound Multiclass Statistical Model of the Difference Image (2018) [link]

Helpful Sources:

- *Survey*: Image Change Detection Algorithms: A Systematic Survey (2005) [link]
- *Video*: Change Detection Techniques in Remote Sensing Satellite Images [link]

- **Gender Recognition:** Aims to determine gender of individuals in an image. It may also contains a face detection step.

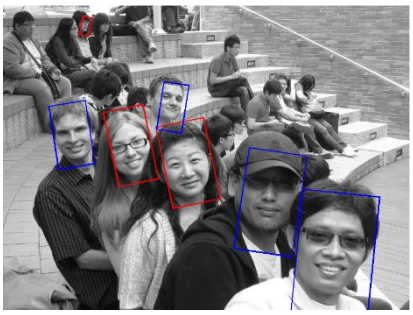

Figure 35 An example of a gender recognition algorithm, where the detected men and women are highlighted with the color blue and red respectively

- **Nudity Detection**: The process of determining whether an image or a video sequence contains nudity or not. It has a wide range of usage in censorship and filtering inappropriate contents in the internet. It is also called **Skin Detection** or **Abusive Content Classification**.

Figure 36 A nudity detection algorithm which has managed to detect skin areas

- **Traffic-sign recognition**: A technology which enables a vehicle to detect and recognize the traffic signs on the road, such as “speed limit” or “turn ahead”. It is widely used in autonomous vehicles.

Figure 37 An example of traffic-sign detection and recognition, which is used in an autonomous car

- **People Counting**: Methods used in applications like surveillance cameras to detect and count the number of individuals in an image or a video. It is usually applies similar techniques to **Pedestrian Detection**.

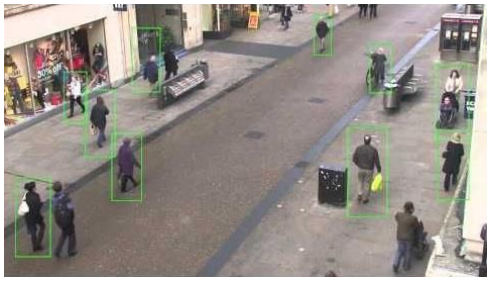

Figure 38 Detection and counting the number of people in the alley, using a people counting algorithm

Image Processing Applications

- **Medical Imaging**: The application of image processing techniques to analyse medical images, or improve their representation.

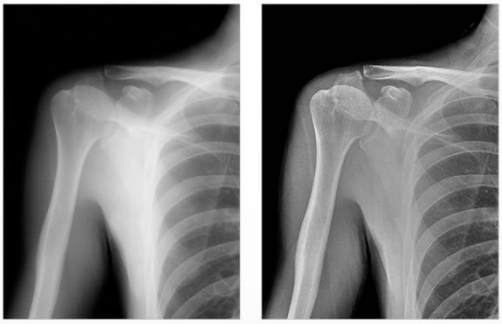

Figure 39 Enhancing visibility of an X-ray image taken from patient shoulder

- **Remote Sensing**: Using image processing methods to enhance or analyse images of the earth taken by a satellite.

Figure 40 Applying image segmentation on a satellite image, used in traffic analysis and creating maps

- **Microscopic Imaging**: The use of image processing methods and algorithms to process, analyse and present images taken from a microscope.

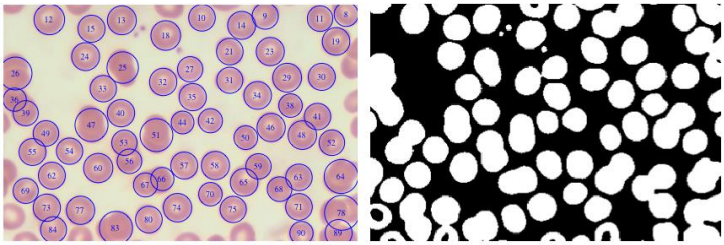

Figure 41 Counting the number of cells using two different image processing approaches; hough transform (left) and morphology (right)

- **Astronomical Image Processing**: Applying image processing algorithms in processing or enhancing images taken from radio telescopes.
- **Video Processing**: A particular case of image processing which deals with video files or video streams. As videos consist of several still frames, video and image processing techniques share many similar concepts.

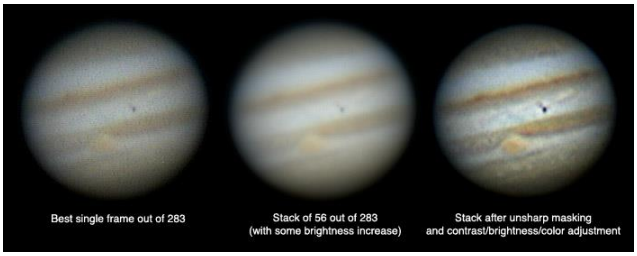

Figure 42 Enhancement of an image taken from a celestial object, using several images of it

- **Color Processing**: The usage of image processing algorithms on the input images which contain color information. It is motivated by the fact that humans can perceive thousands of shades of color as opposed to only about two dozen shades of gray. Color is also a powerful descriptor that greatly simplifies object segmentation and identification.
- **Robot Vision**: Applying image processing techniques to give robots the ability of understanding and analysing scenes they obtain from their sensors.