Set 1: Introduction & Digital Image Fundamentals

Lecturer Arto Kaarna

Lappeenranta University of Technology (LUT)
School of Engineering Science (LENS)
Machine Vision and Pattern Recognition (MVPR)

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http://www.lut.fi/web/en/school-of-engineering-science/research/machine-vision-and-pattern-recognition

Course arrangements

- Check the course pages in Moodle, and follow them for announcements (material, schedules, etc.)
- Lectures: 3h/week, 6+5 weeks
- Excercises: 2h/week, 5+6 weeks (starting NEXT week)
  - Tasks should be done *before* the exercise as homework
- Practical assignment, second period
  - PA seminars during the last lecture week (but some can perhaps be held during the lecture time)
- Office hour: on Weds. 15.00-16, room 2412

Seminars

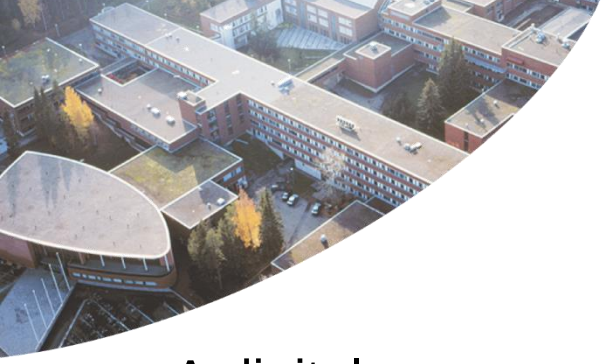
- Seminars will be done in groups of 2 students (presentation, opponent)
- Possible topics will be related to
  - Image coding and compression
  - Image filtering, image restoration and reconstruction
  - Edge detectors, Corner detectors
  - LBP (Local Binary Pattern)
  - Segmentaion methods
  - Etc.
- Consider the group and topic (presentations in period 4.)
- If there is a particular topic related to the course that you are an expert in or interested in, you may *suggest* to make a seminar on that instead of the possible topics.

Content

- Introduction
  - Fundamentals of image processing
  - Digital image processing systems
  - Applications of Machine Vision
- Digital image fundamentals (wrt. DIIP)
  - Elements of visual perception
  - A simple image model
  - Sampling and quantization
  - Basic relationships between pixels
  - Imaging geometry

Introduction

- Digital image processing and analysis
- Machine vision system
  - Recognition, guidance, inspection
- Machine vision in LUT
- Applications
  - Quality control, robot vision, process automation
  - Other applications
- Conclusions



Machine Vision Sensor

- A digital camera = a new type of sensor
- A camera does not produce ”simple” unambiguous data
- Image data are converted to be suitable to a problem (image processing logic)
- Cameras and hardware inexpensive, but general purpose machine vision software not yet available

+

image processing and analysis logic

=

machine vision sensor

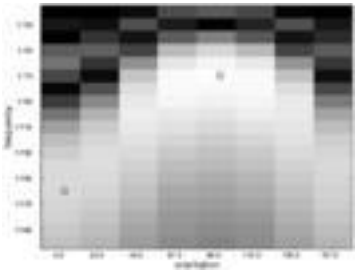
Automatic Cheese Production (MAG, Ltd.)

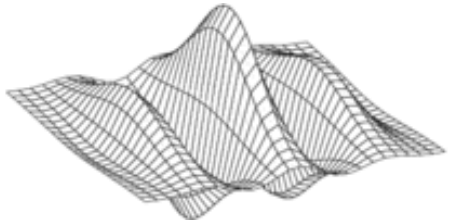
- Get rid of human interaction (vision and hands)
- Check also the quality of a product

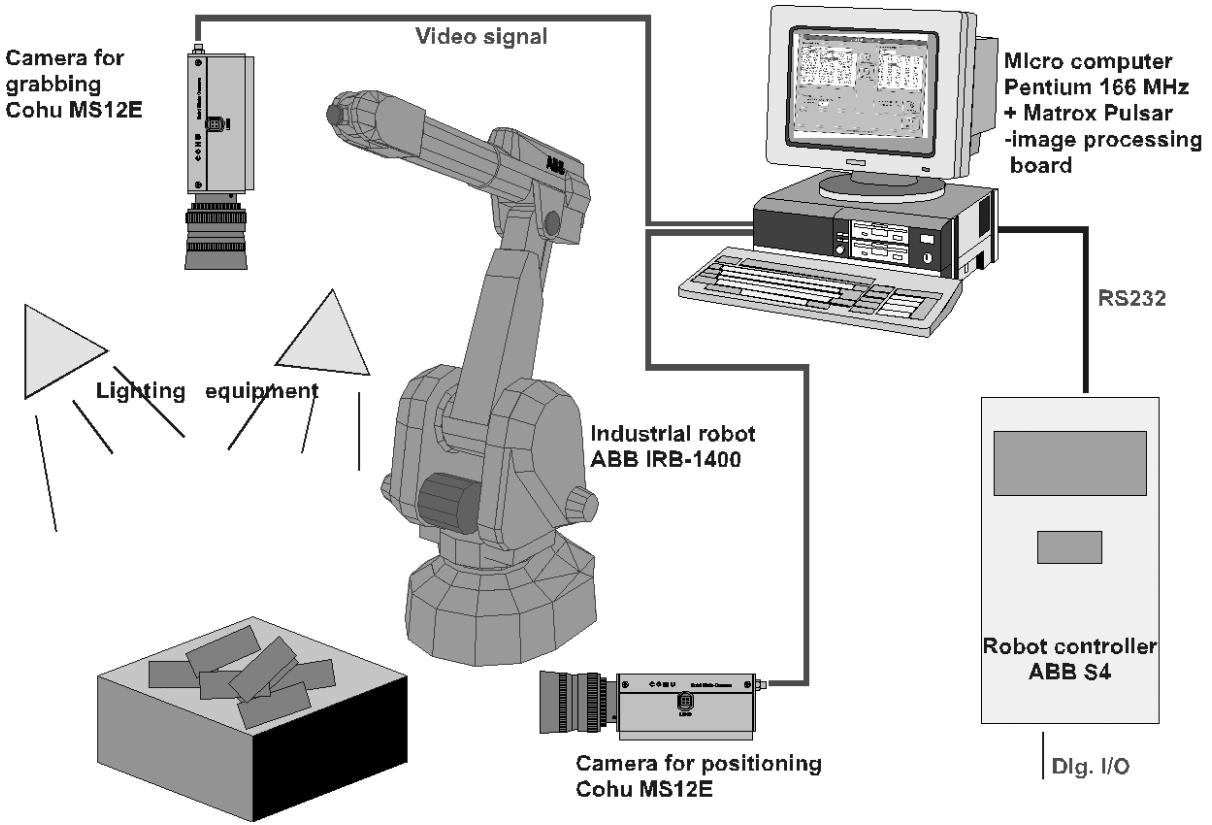
Human Vision vs. Machine Vision

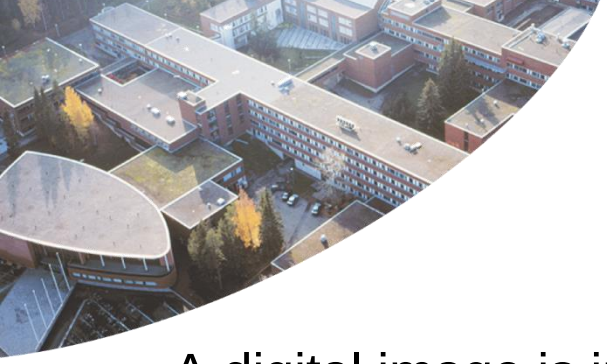
- Disadvantages of human evaluation (monotonous or even dangerous tasks):
  - Deviation in performance
    - Who makes the evaluation and when
  - Low accuracy of evaluation
  - Limited working speed
  - High cost of manpower
- The artificial vision system could
  - assist human vision
  - replace human vision
  - perform tasks that are impossible to human vision

Machine Vision System









Pattern Recognition and Machine Vision

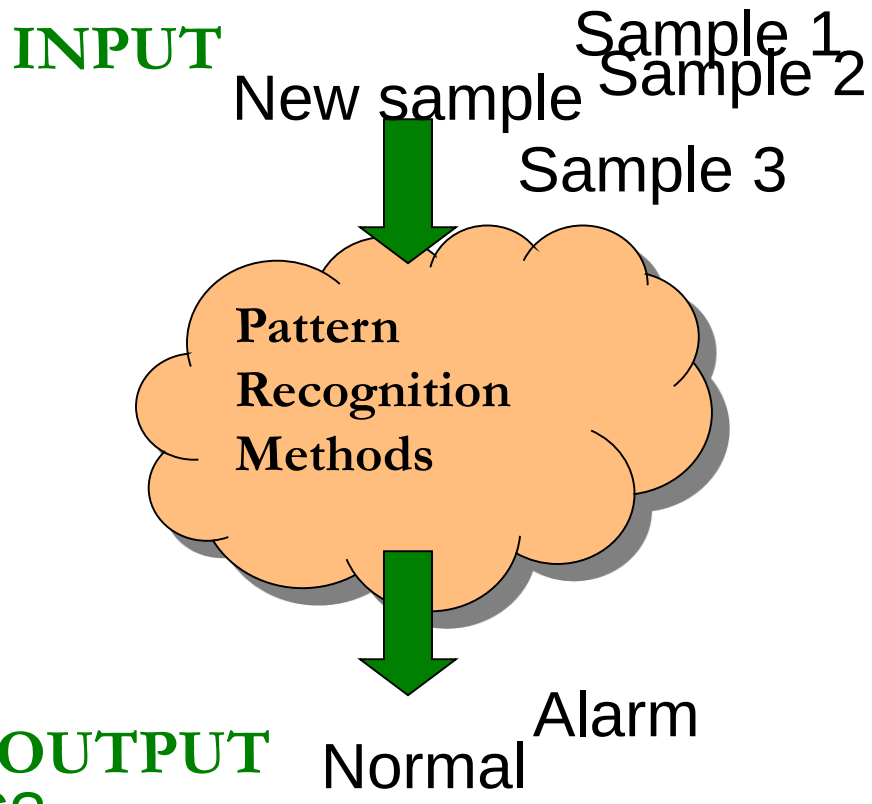
- A digital image is just a set of pixels ?
  - Image f(x,y): (intensity) value f, spatial coordinates x and y, resolution of pixels
  - Black&white, gray-level, color, spectral images
  - Neighborhood of pixels
- **Pattern recognition** (hahmontunnistus) = measurements and observations from natural scenes and their automatic analysis and recognition
- **Computer vision** (tietokonenäkö, konenäkö) = **image analysis** (kuva-analyysi) using pattern recognition techniques
- **Machine vision** (soveltava konenäkö) = application oriented image analysis

Related courses at LUT

- Introduction to Intelligent Computing
- Digital Imaging and Image Preprocessing
- Computer Vision
  - Main difference to MVDIA: 3D scenes and moving objects (here 2D images)
- Pattern Recognition
  - Make classification based on *features* extracted with methods learned here
    - ”feature” = number that describes the object, e.g. mean gray-value of the object area

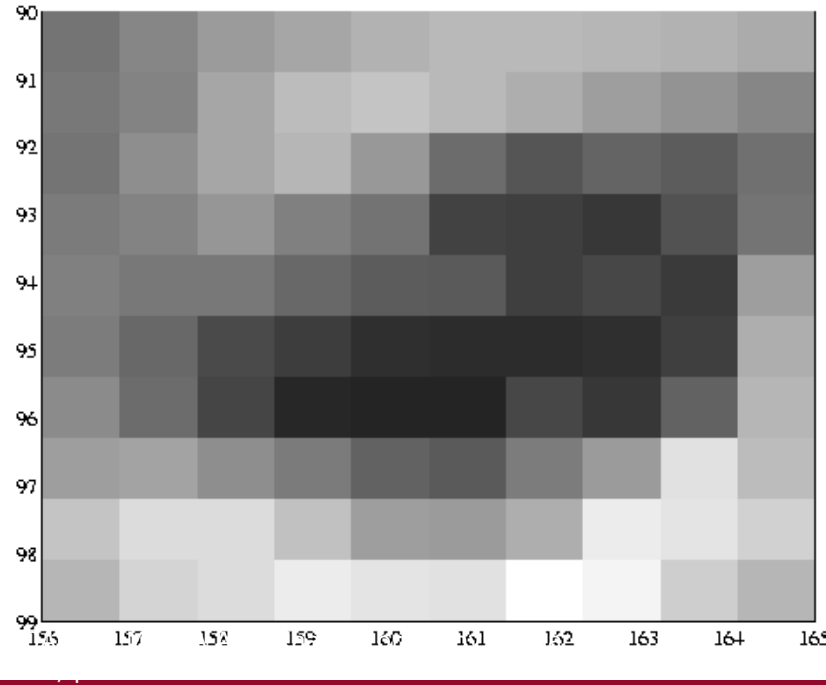
Pattern Recognition

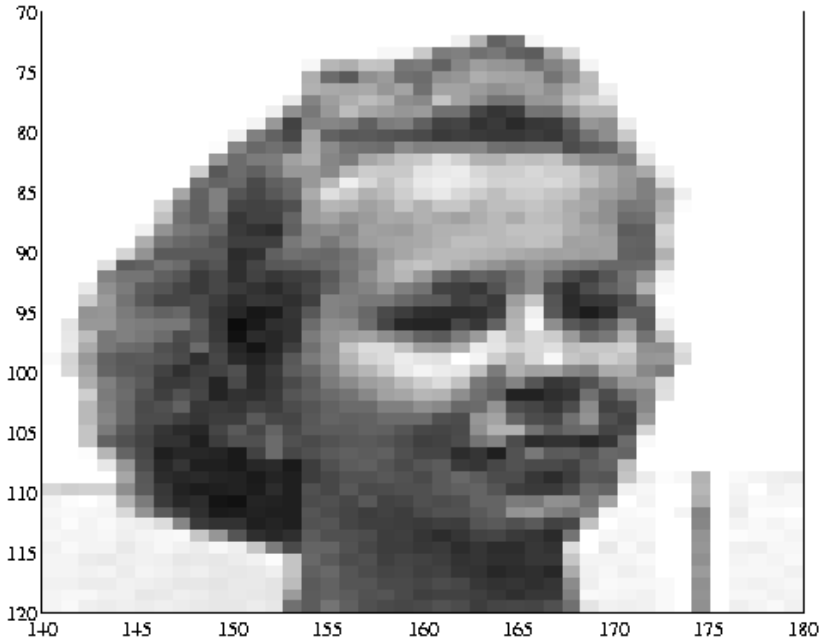
- Pattern recognition methods learn from samples
- Useful when a problem is difficult to understand and/or model
- Pattern recognition experts may produce preliminary results fast



TEACH THE SAMPLES

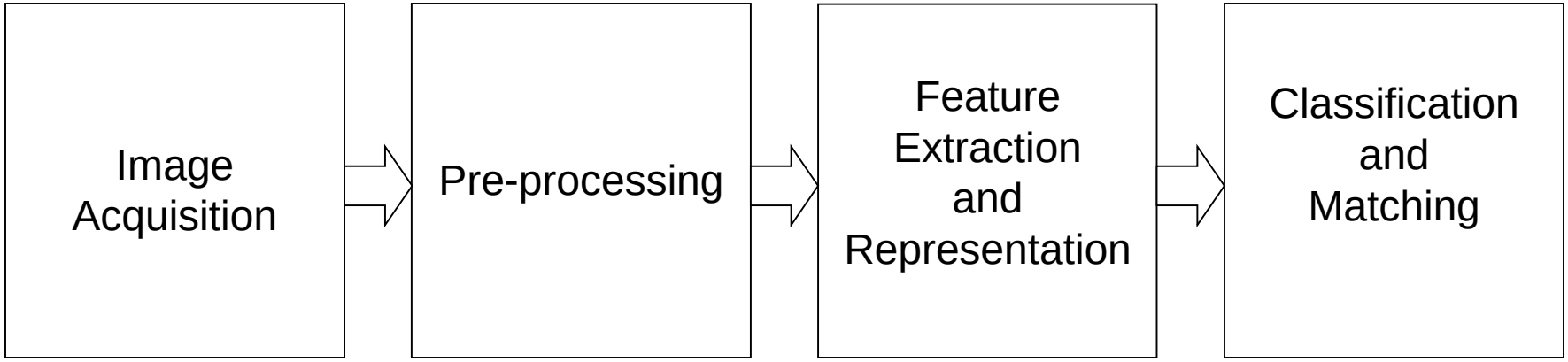
TEST WHETHER IT LEARNS?



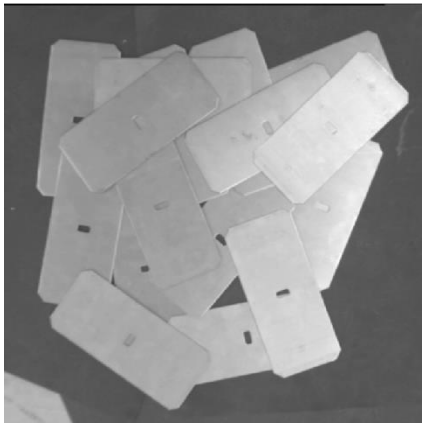


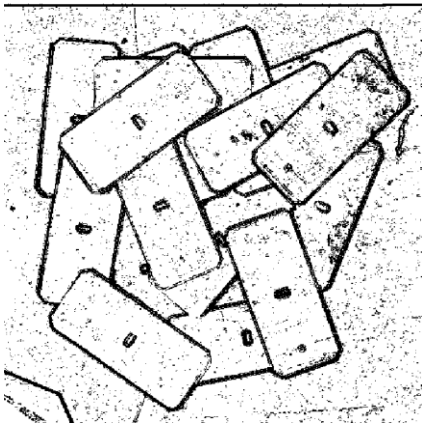
- Pattern recognition at many different resolutions
  - from large scale to small details
  - Building ”big picture” from the small recognized features

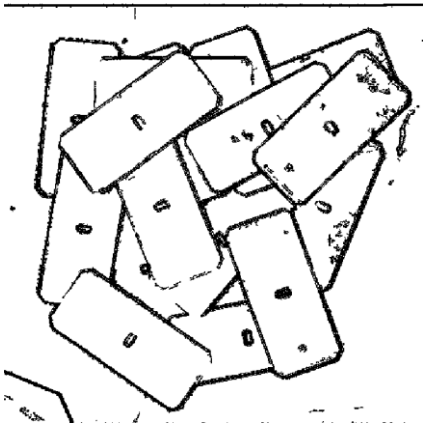
Steps in a Machine Vision System

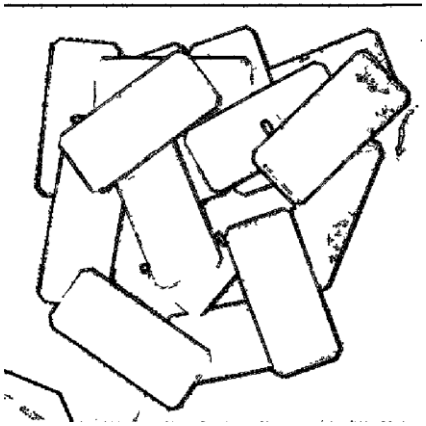


Robotized Manipulation









Requirements for Successful Applications

- Fast
  - No delays. **The** bottleneck: Real-time!
- Accurate/Reliable
  - Assist/replace human vision
- Not too expensive
  - Return of investment
- Easy to implement and use
  - End users are experts in their own field only!

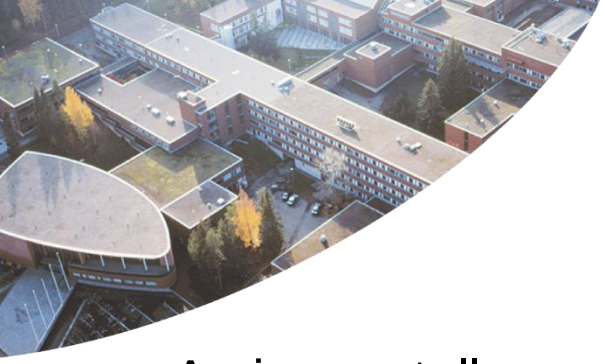
Think who is your expected end user!

Industrial Application Fields

- Applications of
  - recognition, guidance, and inspection

  for
  - quality control, robotics, process automation

  in
  - electronics, metal, wood processing and paper making, food production, etc. industry.

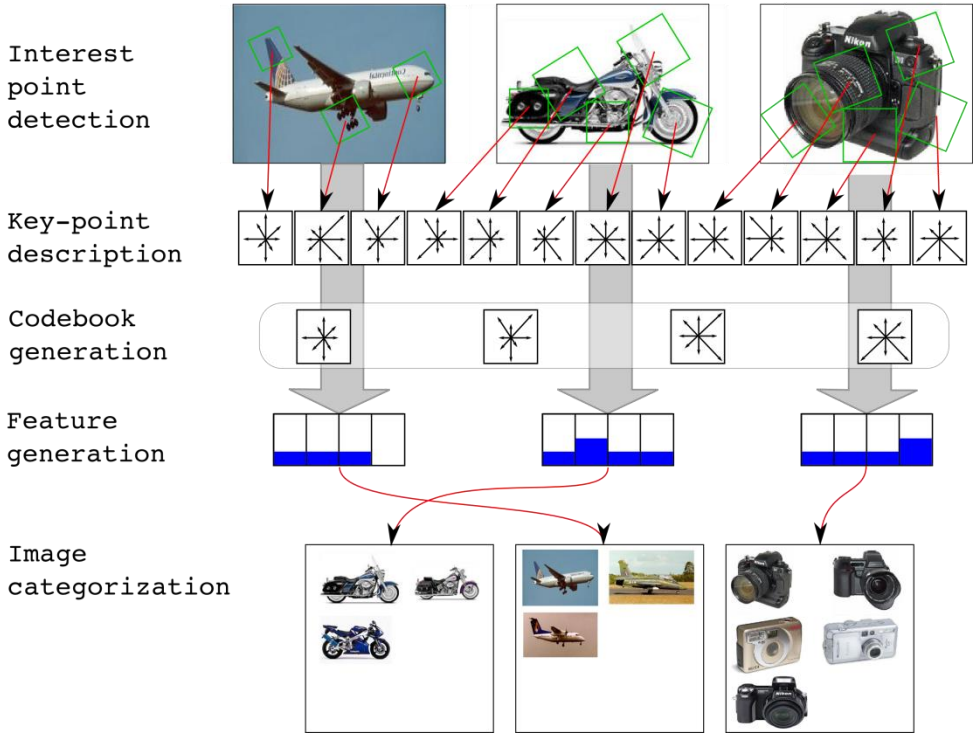


Is it clear or unclear what is in an image?

- An image tells more than 1000 words!
- Are those “1000 words” same to all the people?
- Visual Object Categorization:

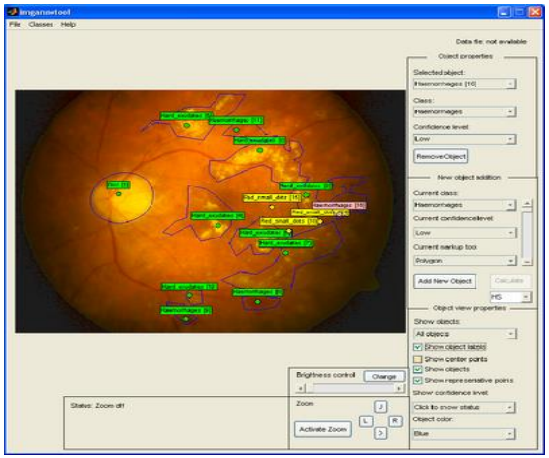
  Find the most important “words” automatically (VisiQ).

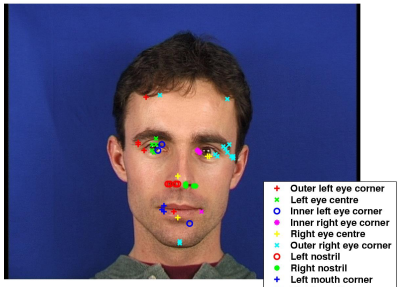
  http://www2.it.lut.fi/project/visiq/
- PicSOM information browsing and retrieval:
  - Find the overall similar images.
  - http://www.cis.hut.fi/picsom/

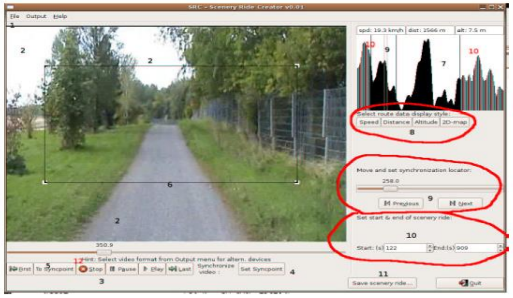


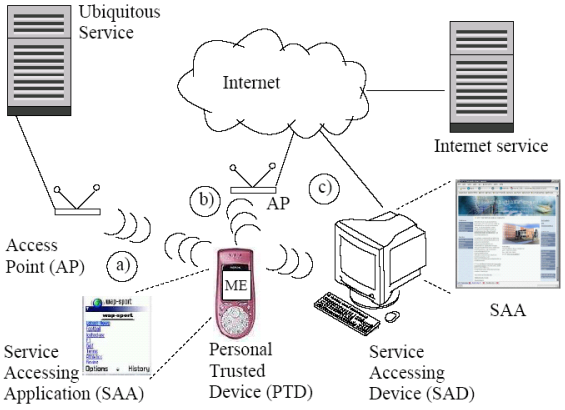
Machine Vision and Pattern Recognition at LUT: Research Profile

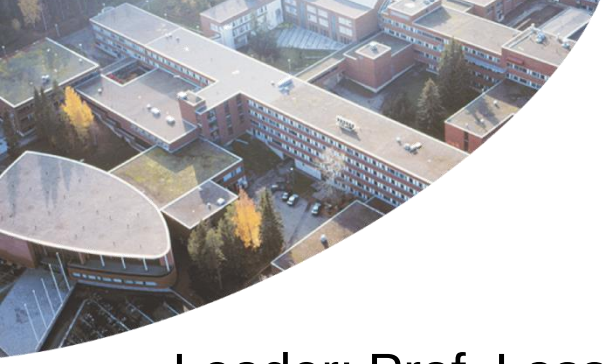
- Machine Vision and Pattern Recognition
  - Former Center of Excellence in Research
  - Cooperation with Mathematics and Physics











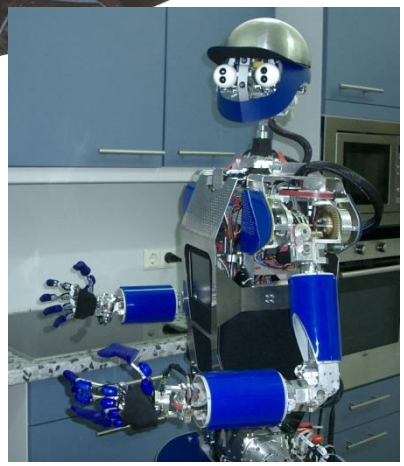
MVPR Laboratory

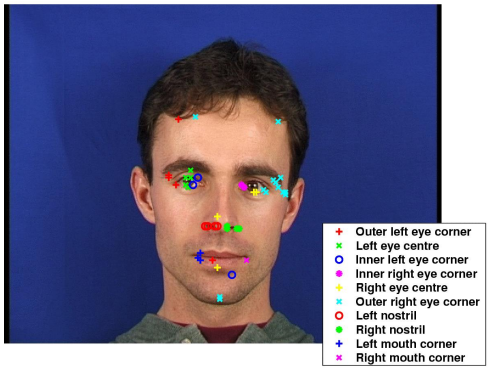
- Leader: Prof. Lasse Lensu
- Prof. Heikki Kälviäinen
- Post docs, PhD students, other researchers/teachers…

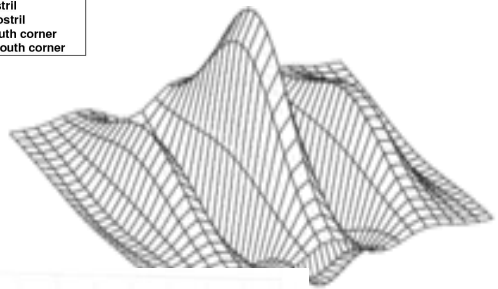
- Specialization in Intelligent Computing
- Machine Vision and Pattern Recognition Solutions
  - Applications for industry, medical imaging etc.
- Limited robotics, feature extraction, face recognition

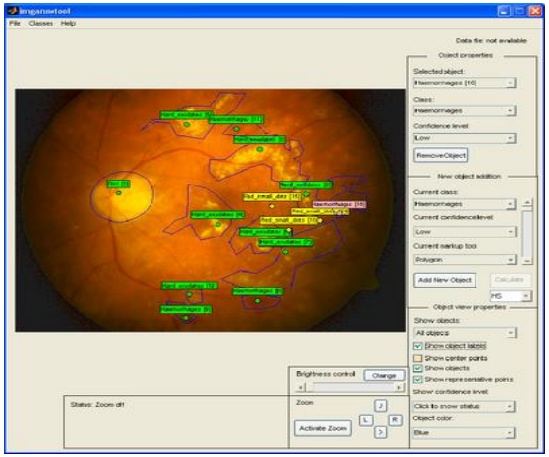
http://www.lut.fi/web/en/school-of-engineering-science/research/machine-vision-and-pattern-recognition

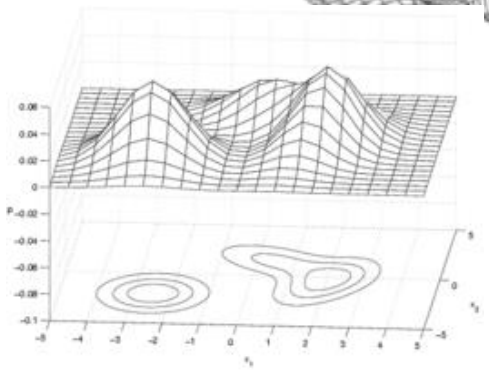
MVPR: Overview of Academic Research Activities











Research Profile

Academic topics

- Inverse Imaging
- Data analytics
- Biomolecular computing

Applied topics

- Forest and printing industry
- Medical image processing
- Security and surveillance
- Visual control systems

MVPR Research Projects

- Biometric identification: face recognition (FACEDETECT)
- Paper Printability Inspection using Machine Vision (PAPVISION)
- Paper Surface Roughness Measurement using Machine Vision (PAPSURFACE)
- Fusion of digital and visual print quality (DIGIQ)
- Fusion of Computational and Visual Salience Based Printed Image Quality Assessment (VISIQ)
- Image-based measurement methods for quality in pulping and papermaking (QVISION)
- Optimal detection and decision-support diagnosis of diabetic retinopathy (IMAGERET)
- Biomolecular computing (BIOCOMP)
- Real-time mosaicing and 3-D reconstruction (RTMOSAIC)
- Multisensor tracking and mapping (MULTIMAP)
- Emergence of cognitive grasping through emulation, introspection, and surprise (GRASP)
- Integration of visual and tactile sensing for robots (TACVISION)
- Learning real-time analysis and control system for turning (FEEDCHIP)

Object (Category) Detection, Localisation and Recognition

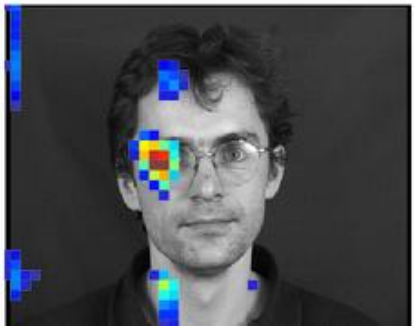
Main objective: To develop new and to improve state of the art methods for 2D, 3D-to-2D and 3D object localisation and recognition.

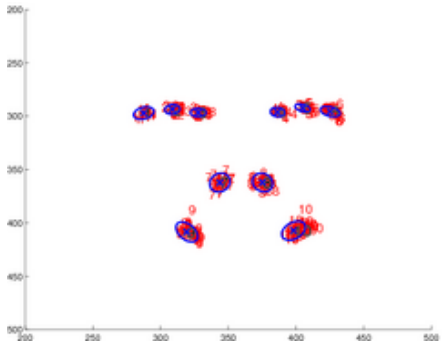
Collaboration: Centre for Vision, Speech and Signal Processing (CVSSP), University of Surrey, UK.

Main results: State of the art results in accurate 2D face localisation. Fully automatic 3D assisted 2D face recognition system.

Object Detection and Localisation

Spatial constellation search over locally extracted image features (2D).



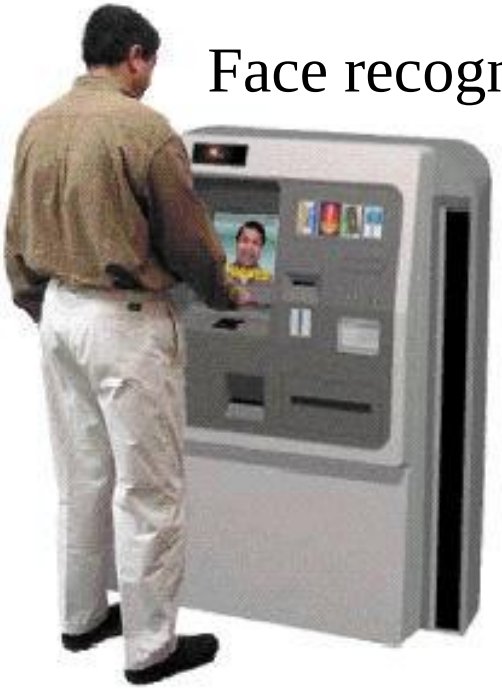


Biometric Person Authentication

Hand geometry

Iris

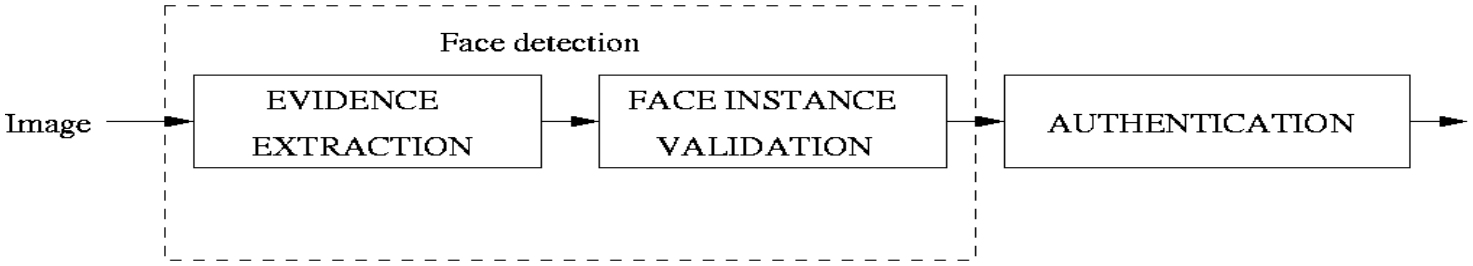
Face recognition

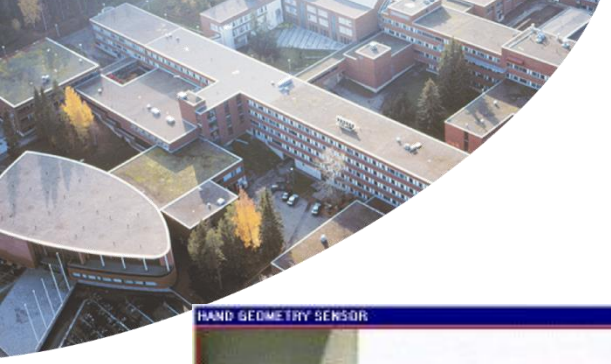


Fingerprints

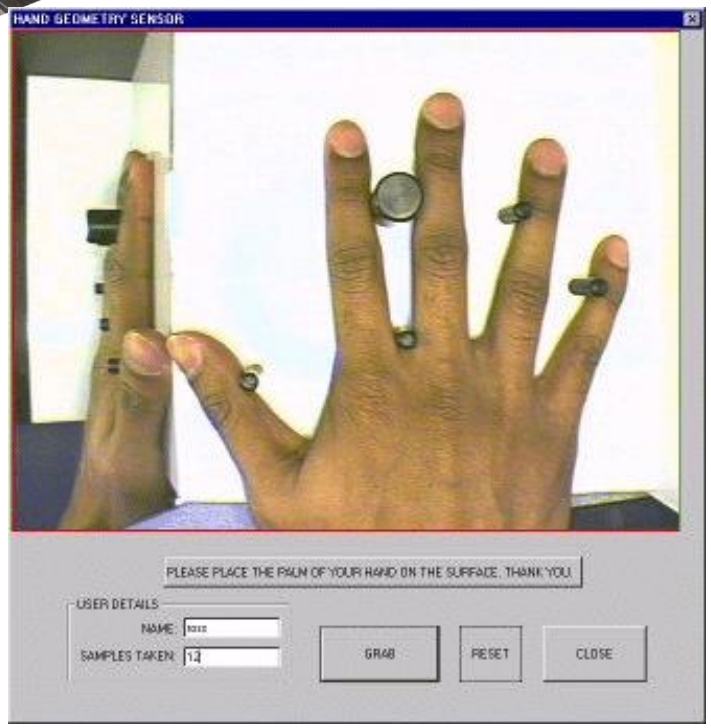
Biometric Identification

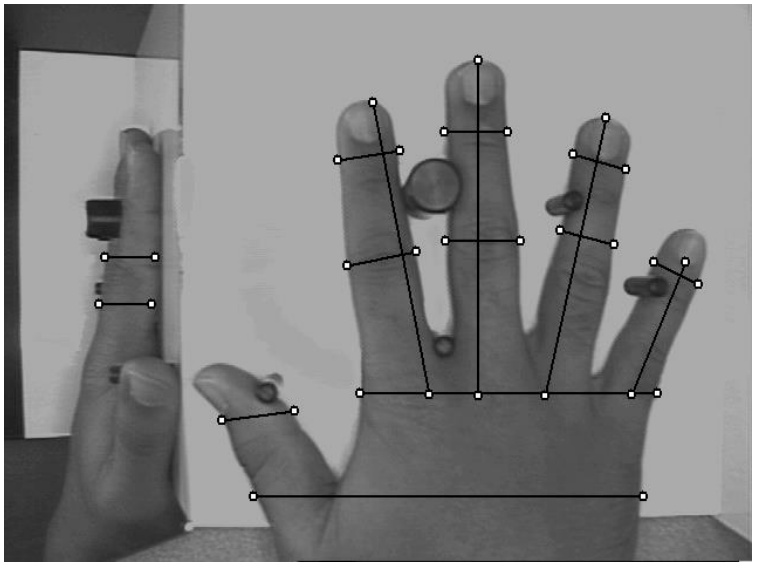
- Face, fingerprints, voice, iris, keyboard dynamics, gait recognition etc.:
  - Authentication: Are you Mr. X?
  - Identification: Who are you?
- Monitoring, surveillance, security in industry, airports, cash dispensers, etc.
- Image databases.
- LUT & CVSSP, University of Surrey, UK





Biometric Identification/Authentication example: Hand geometry

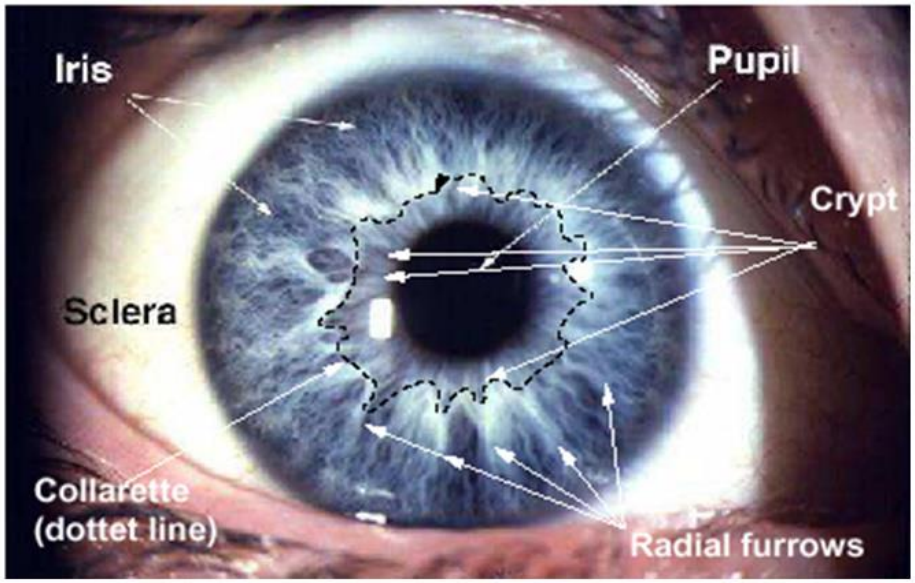




Typical features:

- Finger lengths, widths, heights
- Palm widths

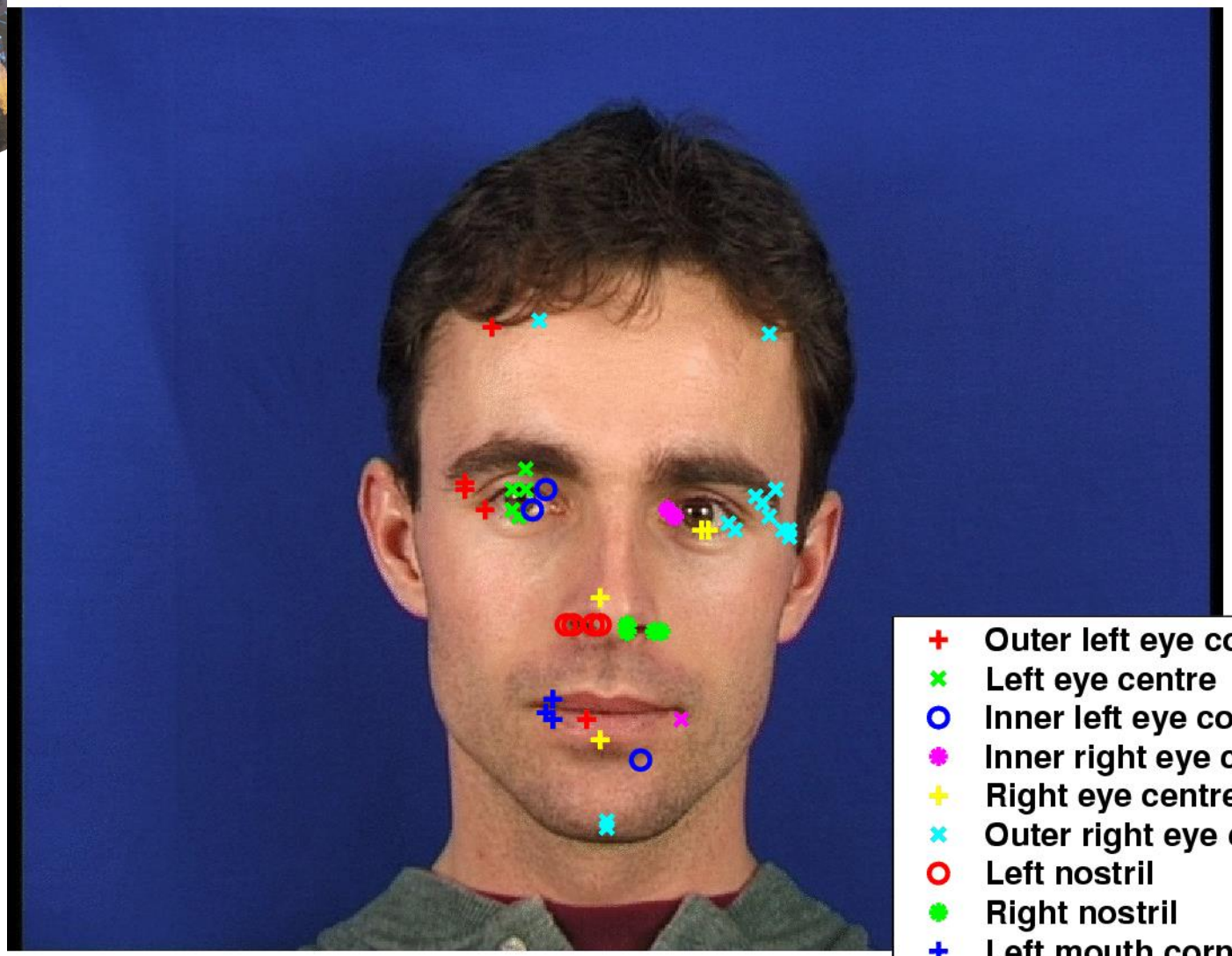
Biometric Identification/Authentication example: Retina / Iris

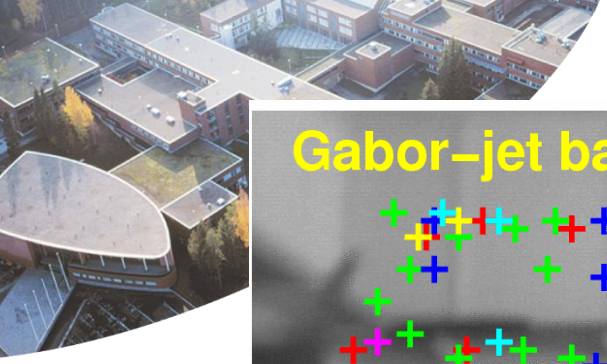


- Compare (accuracy, usability…)
- Retinal images used also in medical applications (e.g. diabetes diagnosis)

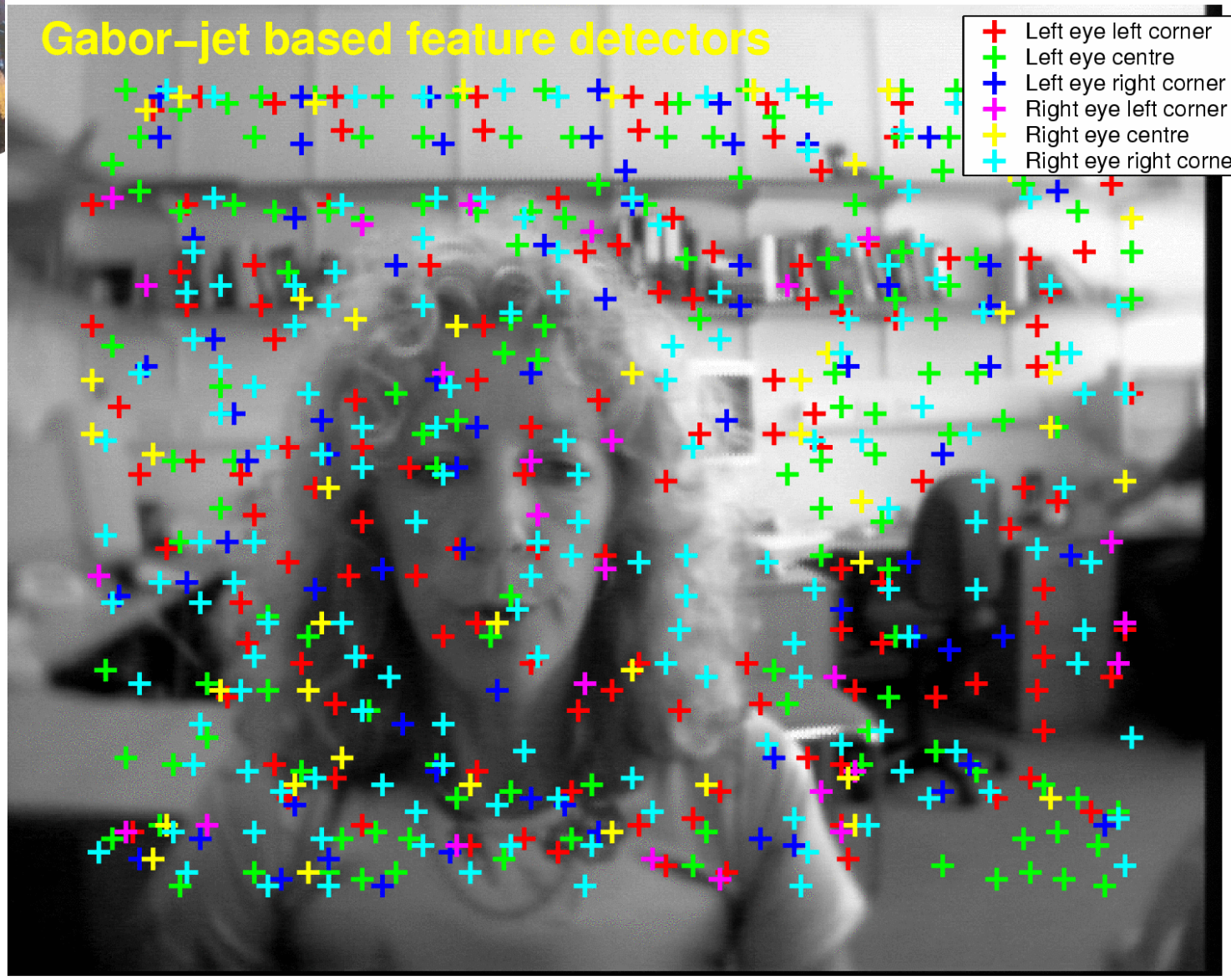
Biometric Identification/Authentication more examples

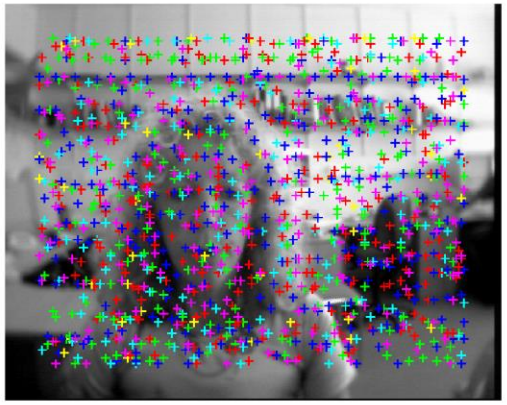
- Gait (how you walk and move)
- Keystroke dynamics (how you type)
- Author recognition (what kind of words and language structures you use)
- Signature / handwriting recognition
- Ear shape
- Odor
- Infrared…

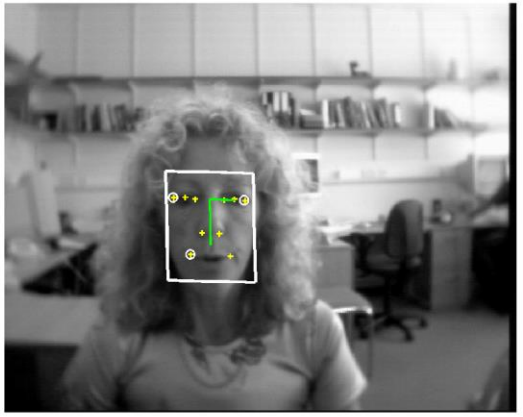

Outer left eye corner
Left eye centre
Inner left eye corner
Inner right eye corner
Right eye centre
Outer right eye corner
Left nostril
Right nostril
Left mouth corner
Right mouth corner



Gabor–jet based feature detectors







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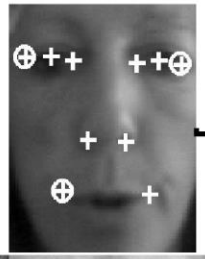
FACE SPACE

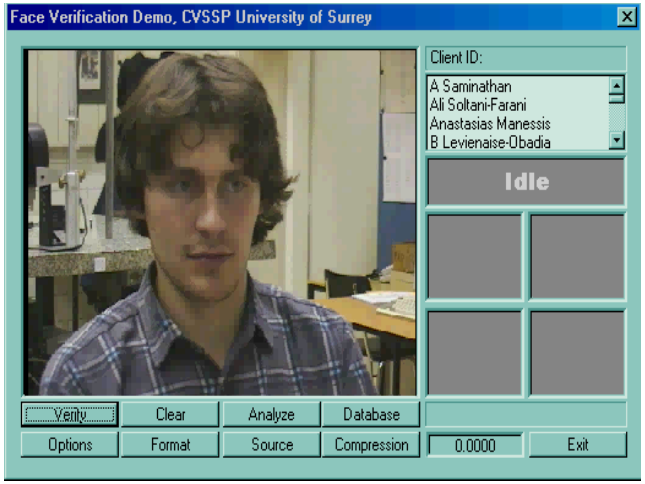


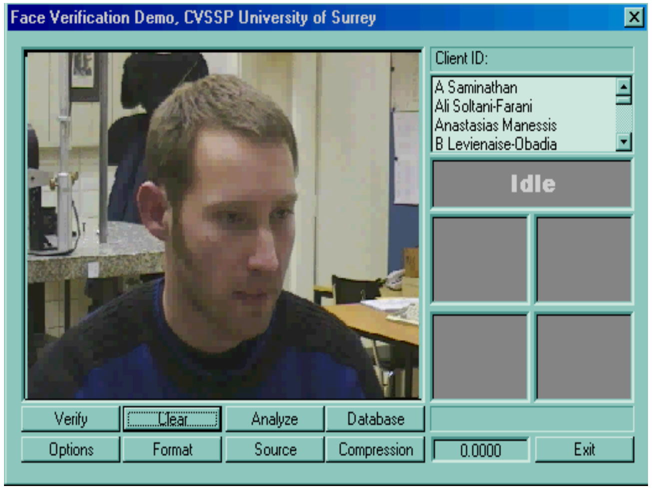
TRANSFORMATION MODEL

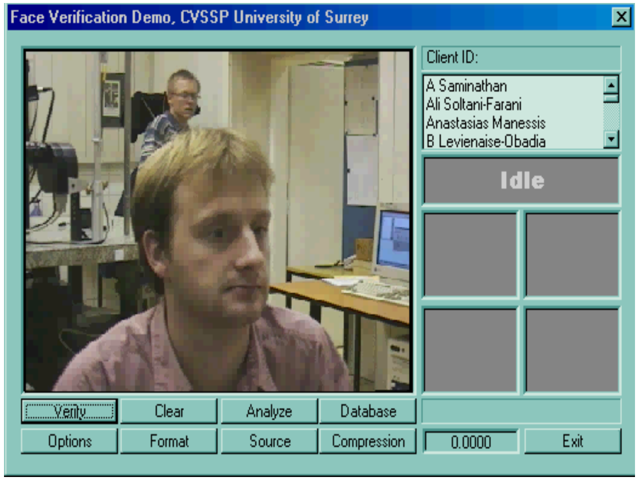
APPEARANCE MODEL

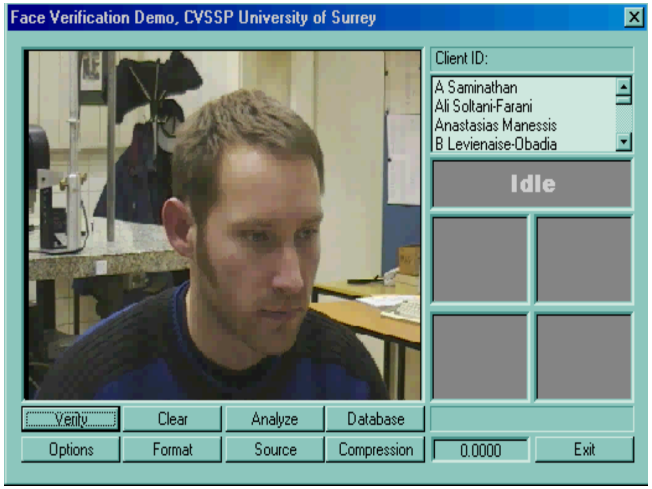
FACE DETECTED

Recognition System

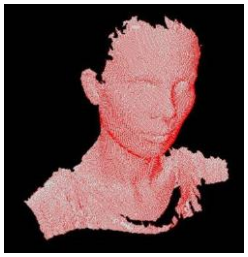


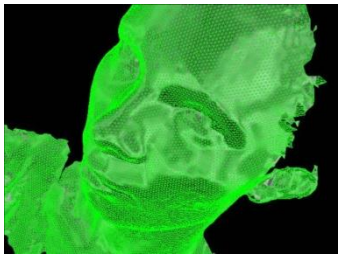






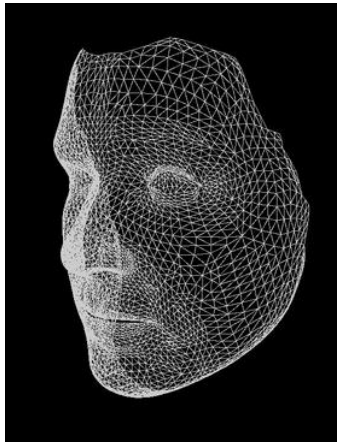
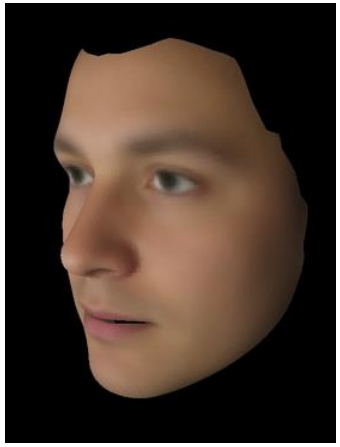
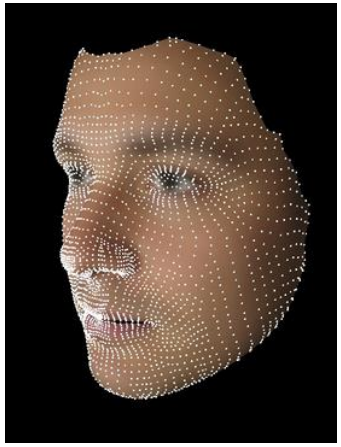
3-Dimensional Face Recognition





3D and 2D Face Recognition

- Based on the “average” 3D model
- Fast 3D capturing required
- 3D structure preserving
- 2D mapping
- A 3D model is morphed to an 2D input image.
- Illumination and pose are normalised.


Active and robot vision

Main objective: Robust (i.e., they really work in practice) real-time methods for 3D tracking and SLAM (Simultaneous Localization And Mapping), visual servoing, integration of visual and tactile control, and robot localisation.

Collaboration: Center for Autonomous Systems (CAS), Royal Institute of Technology (KTH), Sweden. Mechatronics Group, Department of Mechanical Engineering, LUT.

Main results: Novel multisensor and 3D tracking methods.

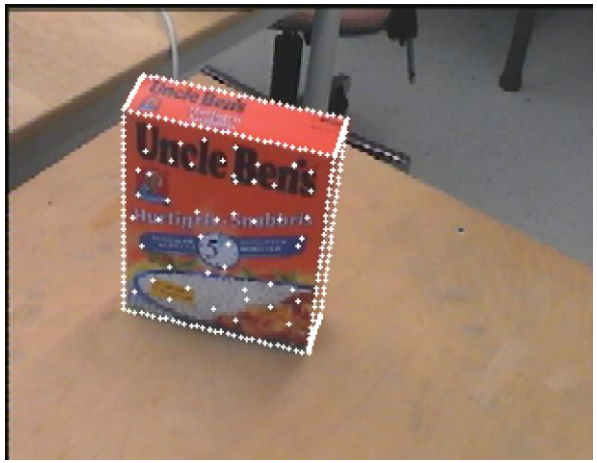
Visual 3D Tracking and SLAM
Localisation in mobile robotics

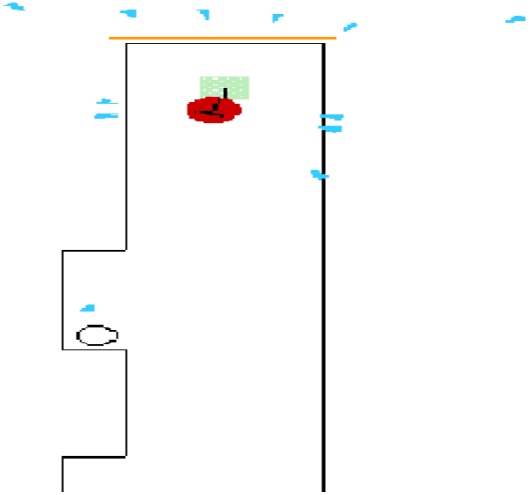
Tracking:

Integration of model-based and model-free cues (multiple cues).

Localisation:

Increase of robustness using multiple weak sensors.

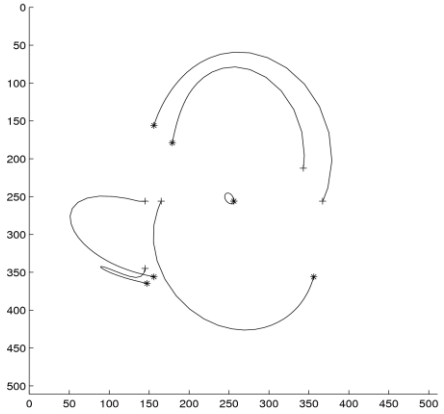


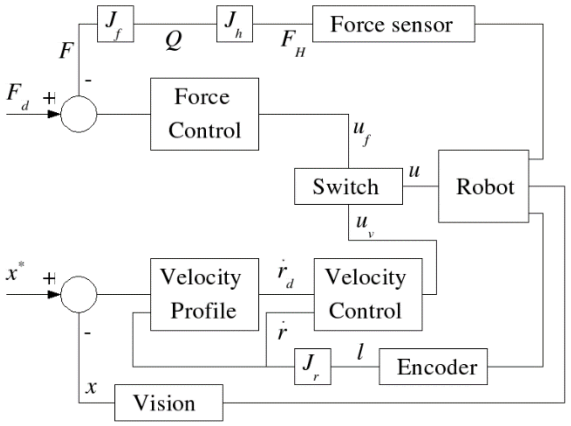


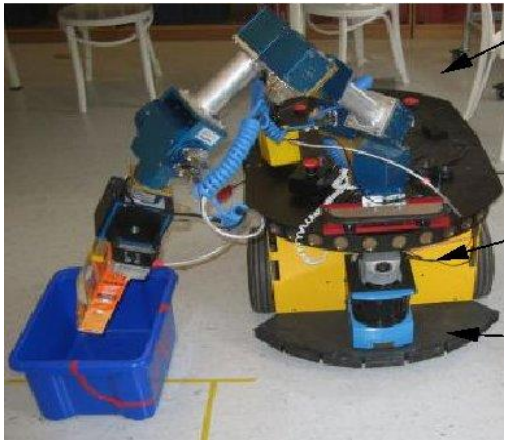
Visual servoing
Integration of visual and tactile control

Increase of robustness of visual servoing (feedback control with visual feedback) by modelling uncertainties.

Increase of the robustness and efficiency of robot control using the integration of vision and other sensors







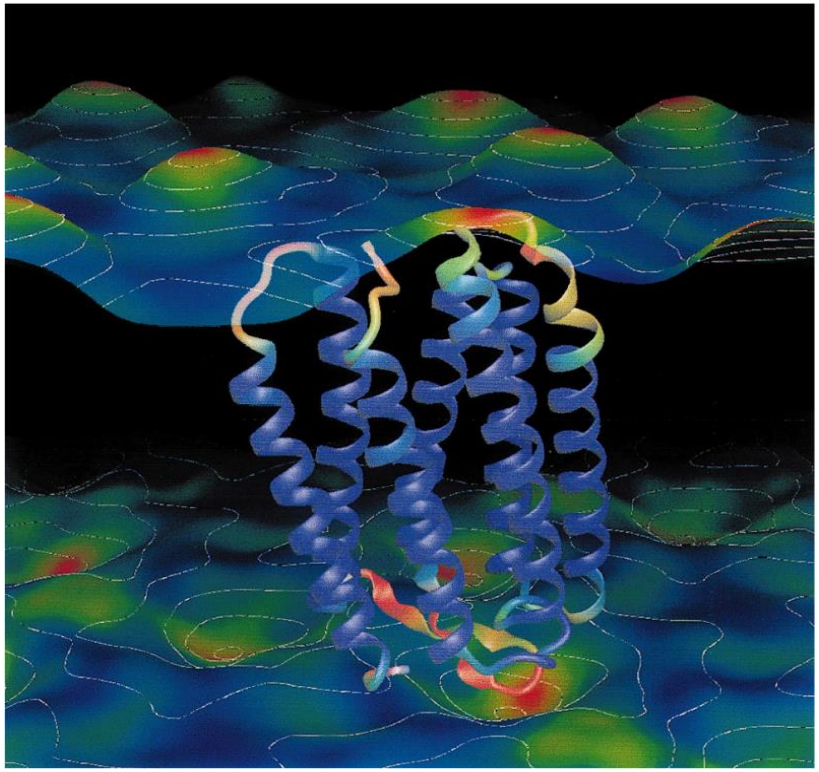
Biomolecular Computing

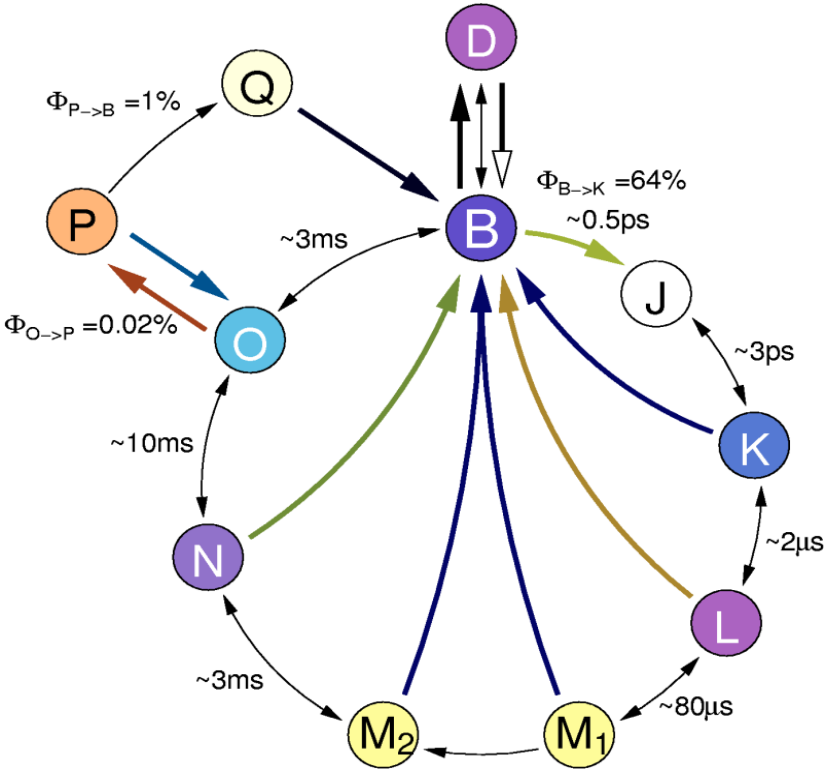
Main Objective: To utilise biomolecular reactions in information processing. To model natural and to develop novel artificial (colour) vision systems.

Collaboration: Color Research Group, University of Joensuu, Finland.

Main results: Models for certain biomolecules and vision systems. Colour-sensitive camera based on biomolecule**.**

Model for Biomolecular Information Processing

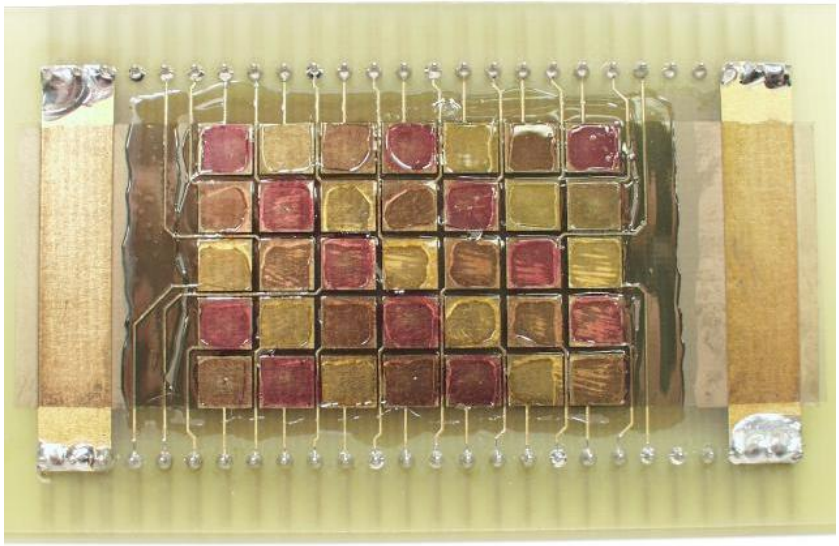


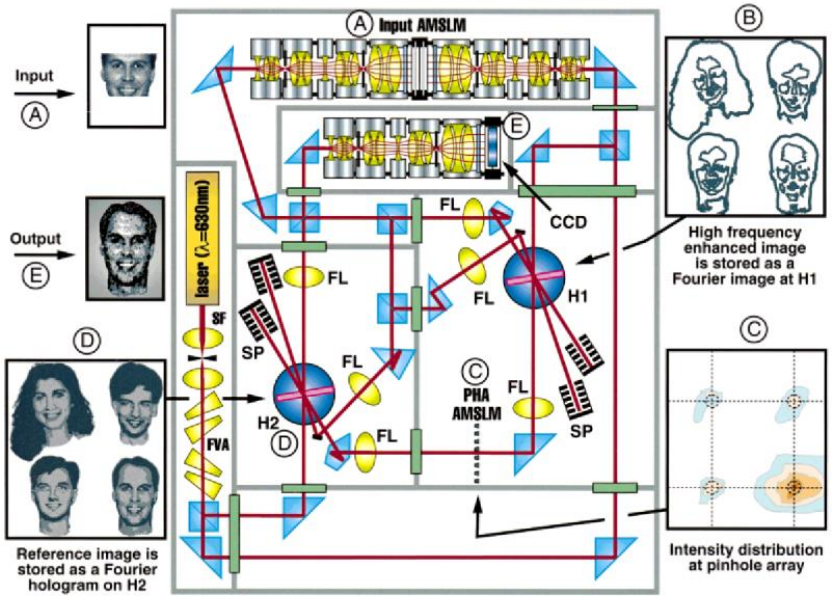


Bacteriorhodopsin molecule [1] and its photocycle

[1] Müller, et al., Atomic force microscopy of native purple membrane. BBA, 1460:27-38, 2000.

Biomolecular Camera and Memory





Applications – colour camera and associative memory [1]

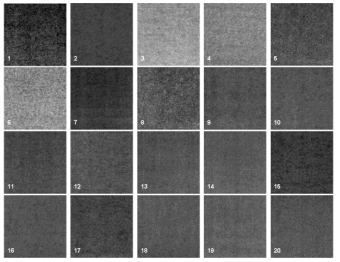
[1] Birge, et al., Biomolecular electronics: protein-based associative processors and volumetric memories. Journal of Physical Chemistry B, 103:10746-10766, 1999.

Forest and Printing Industry

Main objective: To develop methods for estimating print quality based on measurable physical and visual characteristics

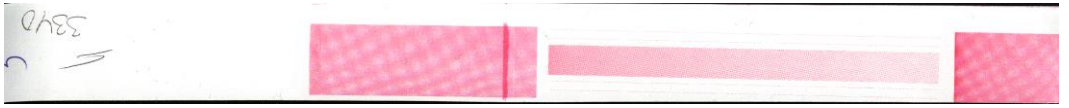
Collaboration: All main national and several international players in the paper industry. All main national research laboratories in the field

Main results: Novel methods and hardware for evaluation of visual print quality. Top national knowledge on applying computer vision in paper and printing industry



PAPVISION & DIGIQ PROJECTS: Making better paper

← distance →



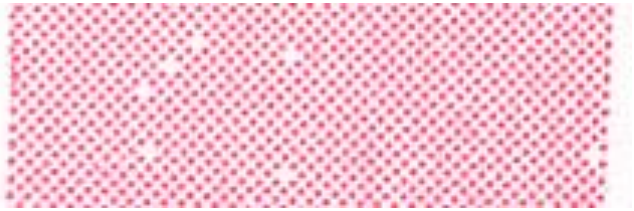
PAPVISION

(http://www.it.lut.fi/project/papvision)

Paper and Board Printability Testing Using Machine Vision

Q: Can printability tests of paper and board be automated by machine vision?

Where is the 20th missing dot from the beginning?

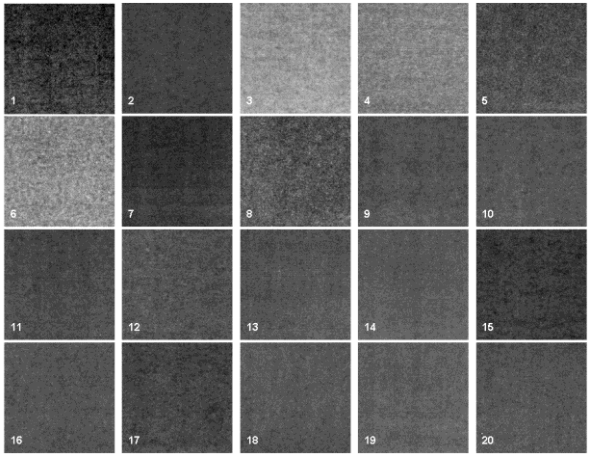


DIGIQ

(http://www.media.hut.fi/digiq/)

Fusion of Digital and Visual Print Quality

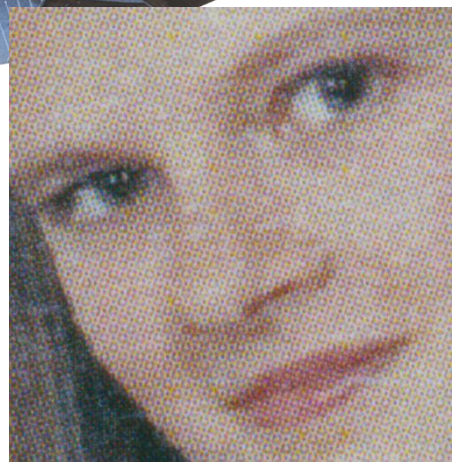
Q: Can Visual Quality Index (VQI) be estimated?

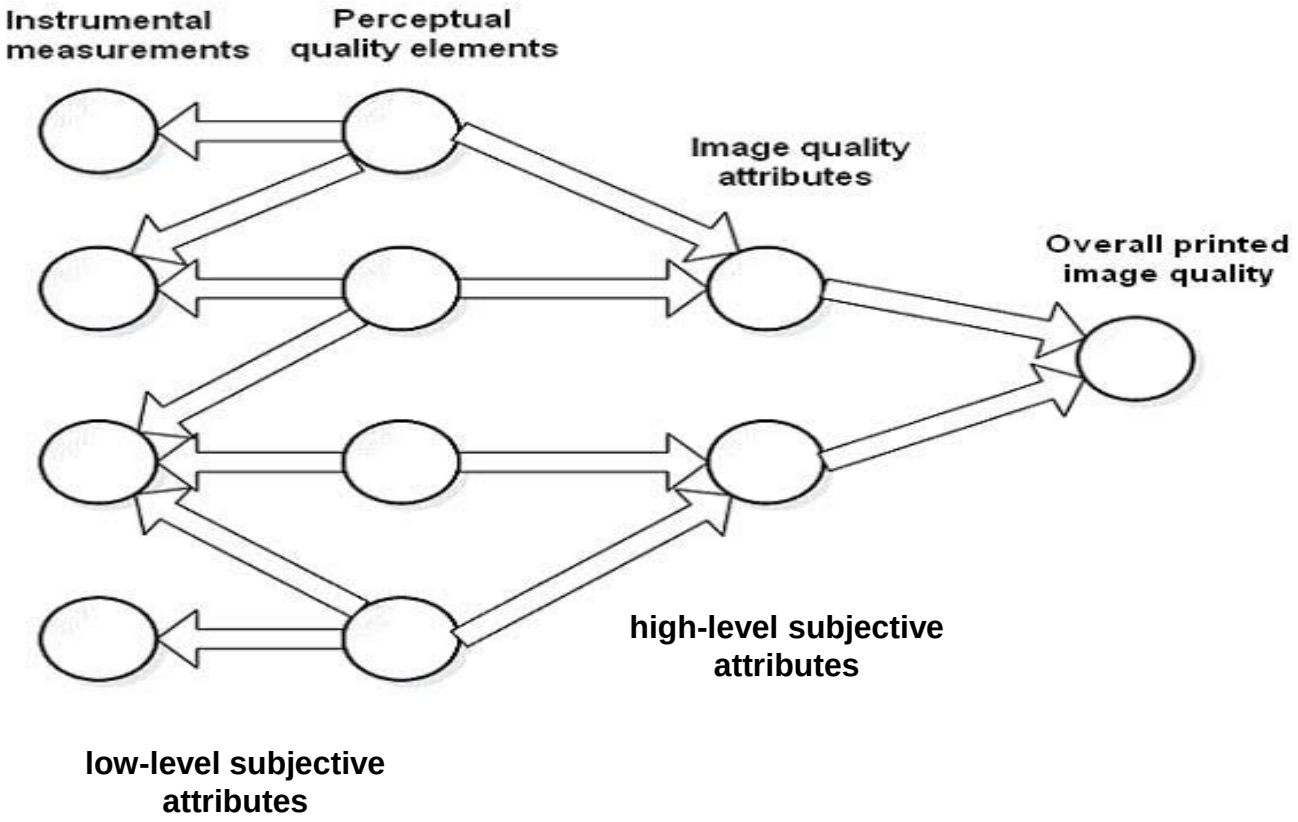


Local startups – Systems for Measurement

- Machine vision systems for the paper and printing industry
- PapVision System – perfecting print quality:
  - Machine vision based measurement modules
- Development of measurements and methods to become standards
- Current focus: topography measurement using photometric stereo (based on results from the PAPSURFACE project)

DIGIQ: Which one looks better to a human and can we measure it?





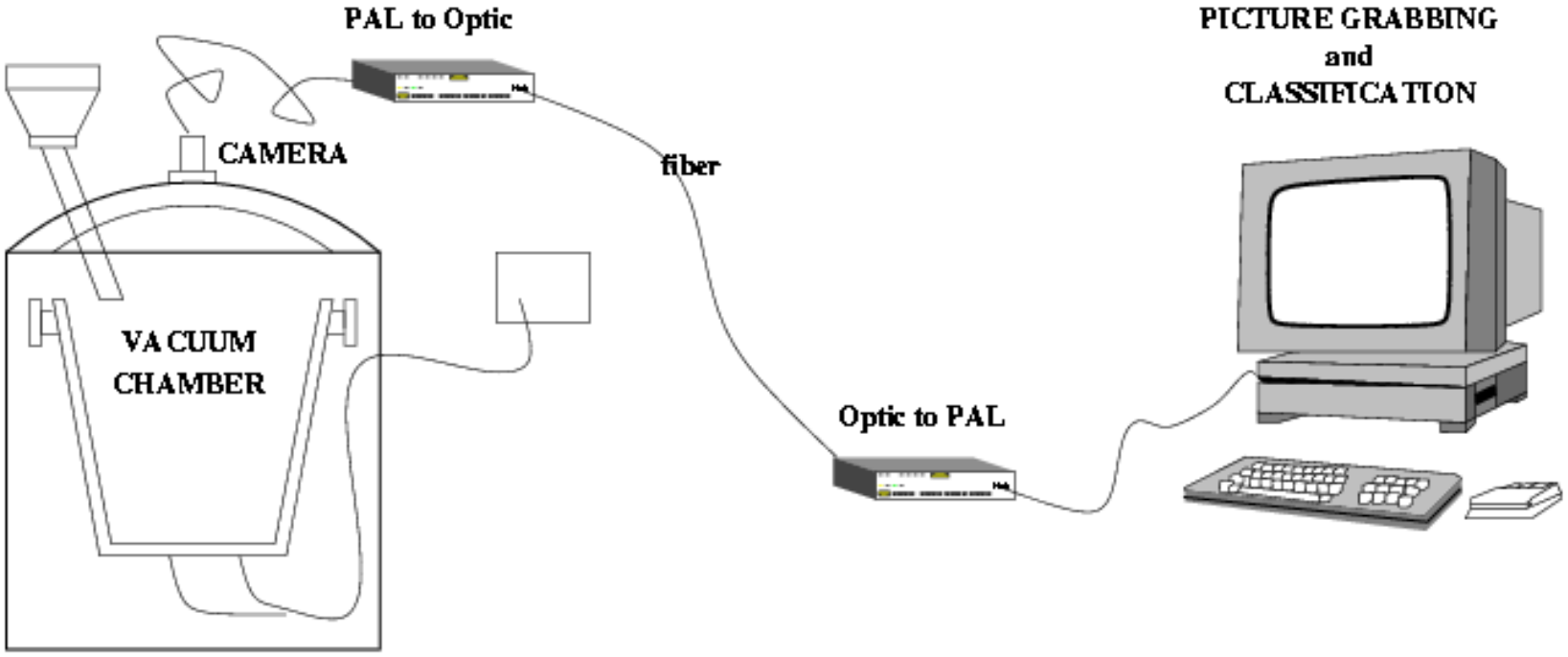
Visual Control Systems

Main objective: To develop methods for integrating visual and tactile information to the control loop of robot vision systems and mechanical tool wear systems

Collaboration: Companies and Mechatronics Group, Department of Mechanical Engineering, LUT

Main results: Novel methods to real-time machine vision based control and to integrate visual and tactile control

Visual Quality Control in Steel Manufacturing (Finx, Ltd.)

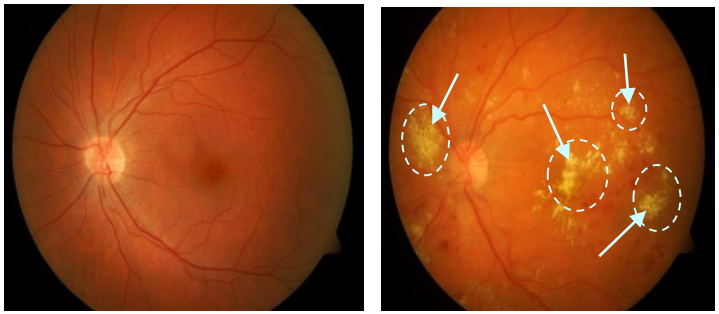


Medical Image Processing

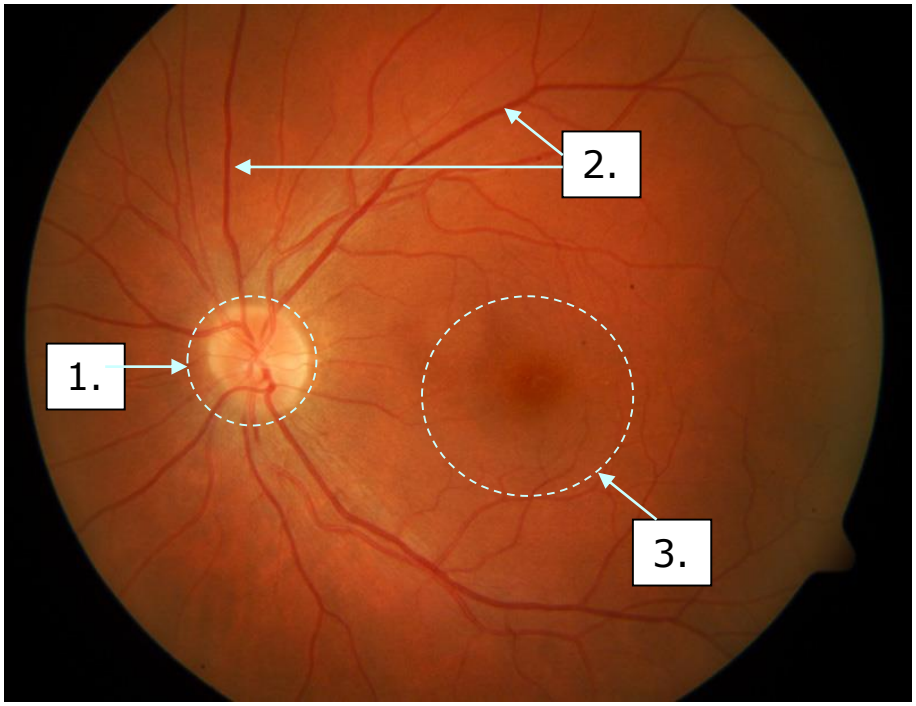
Main objective: To develop methods for detecting diabetic retinopathy from fundus images.

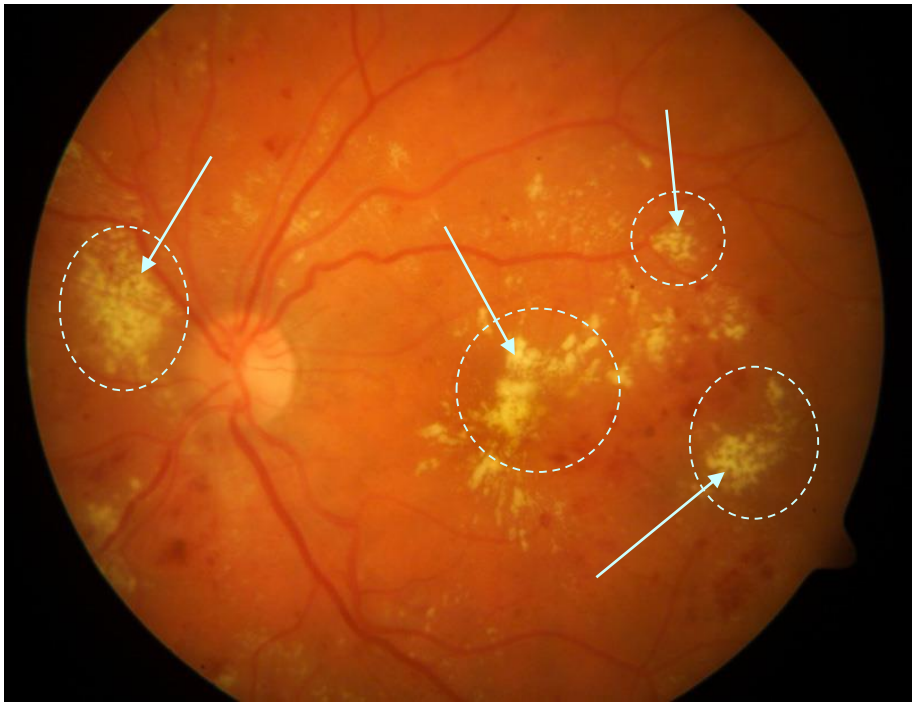
Collaboration: Main national companies in eye disease diagnosis. London Imperial College, UK. University of Bristol, UK. Koblenz-Landau University, Germany. Color Vision Group, University of Joensuu, Department of Ophthalmology University of Kuopio, University of Tampere, Finland.

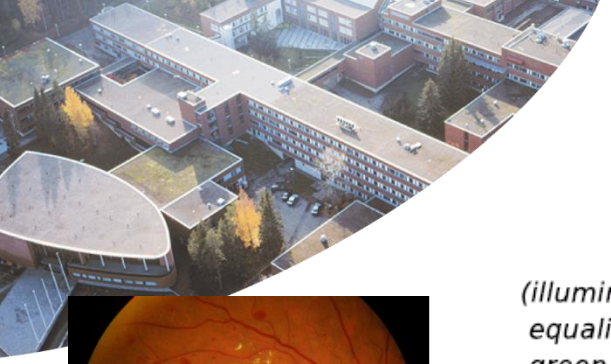
Main results: First public database and protocol for evaluating diabetic retinopathy detection methods.



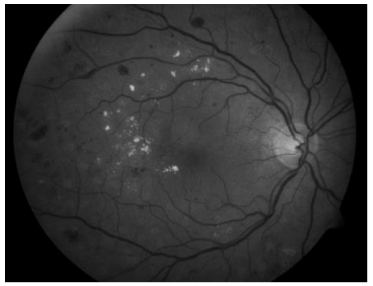
Normal Fundus Image and Hard Exudate







Abnormality Detection: Phases



(illumination-equalized green channel)

(binary fundus mask)

Dark: hemorrhages and microaneurysms
Bright: exudates

abnormality detection part

Segmentation of dark and bright regions

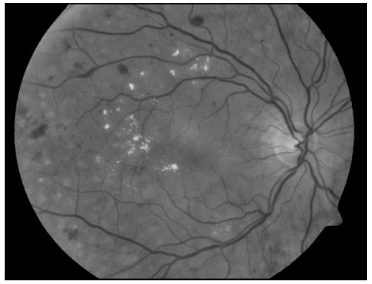
(dark and bright areas in binary masks)

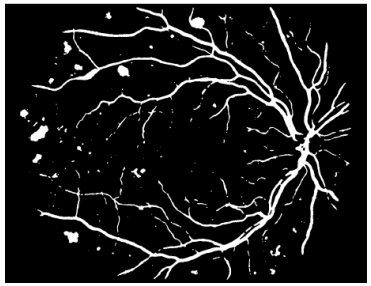
Candidate lesion searching

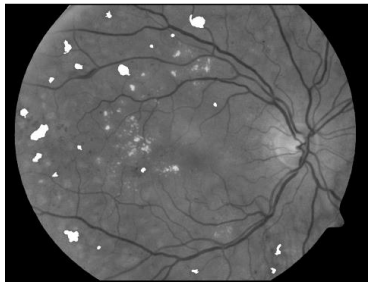
(candidate lesions in separate binary masks)

Candidate lesion classification

(objects classified as lesions in separate binary masks)

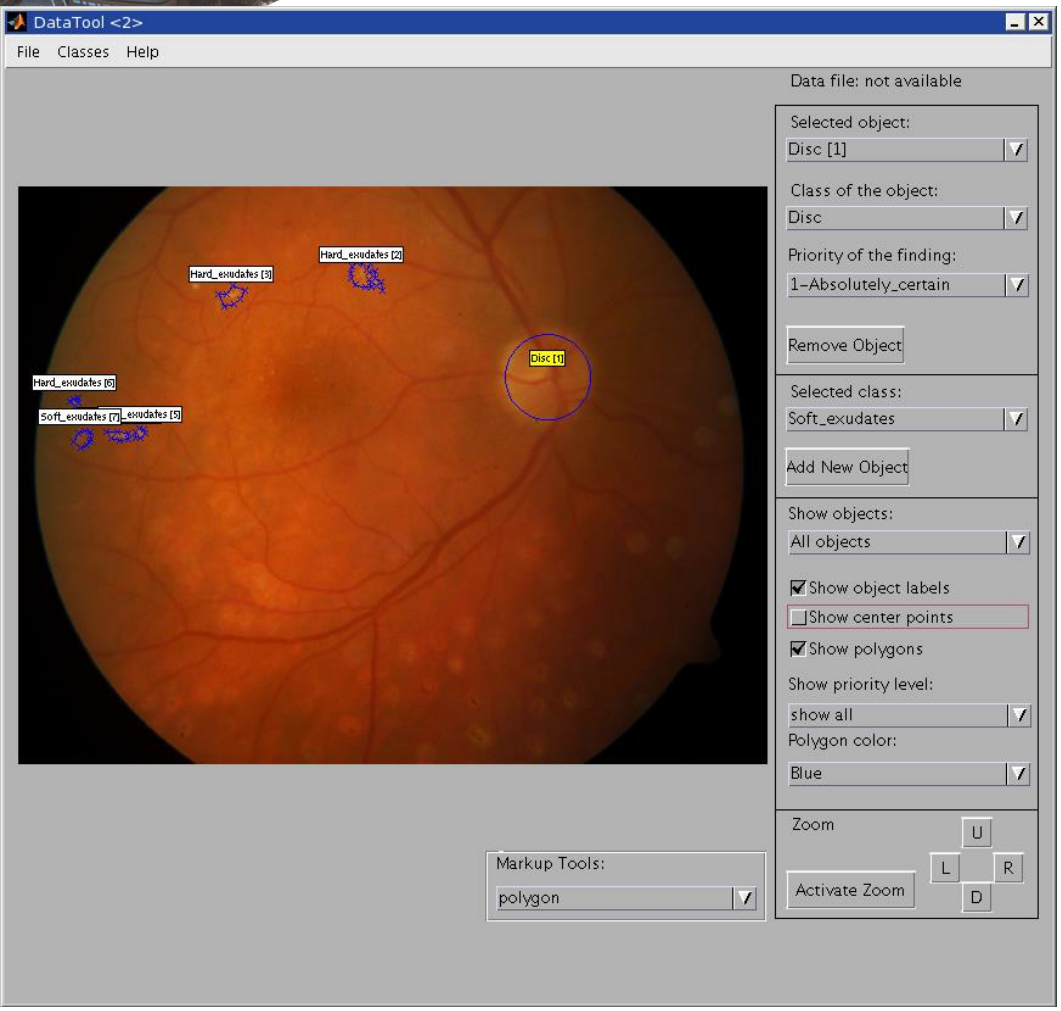




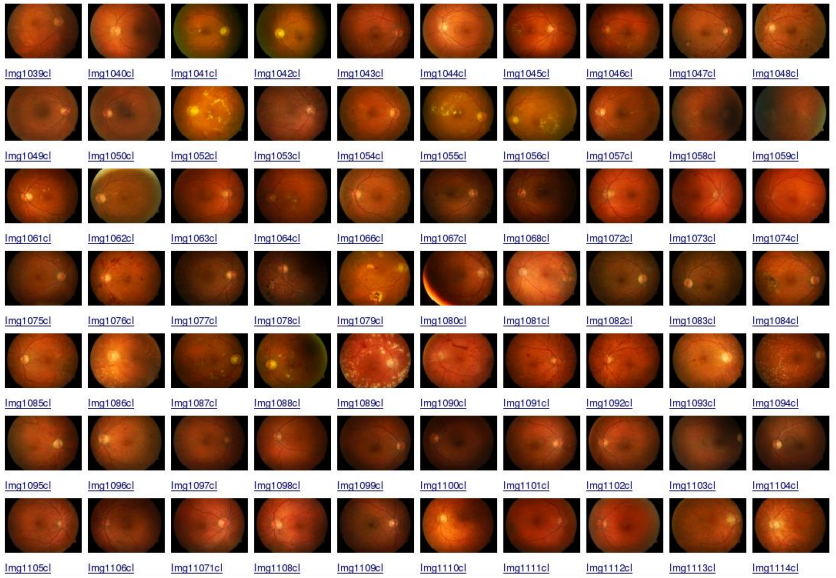


=> Hemorrhages

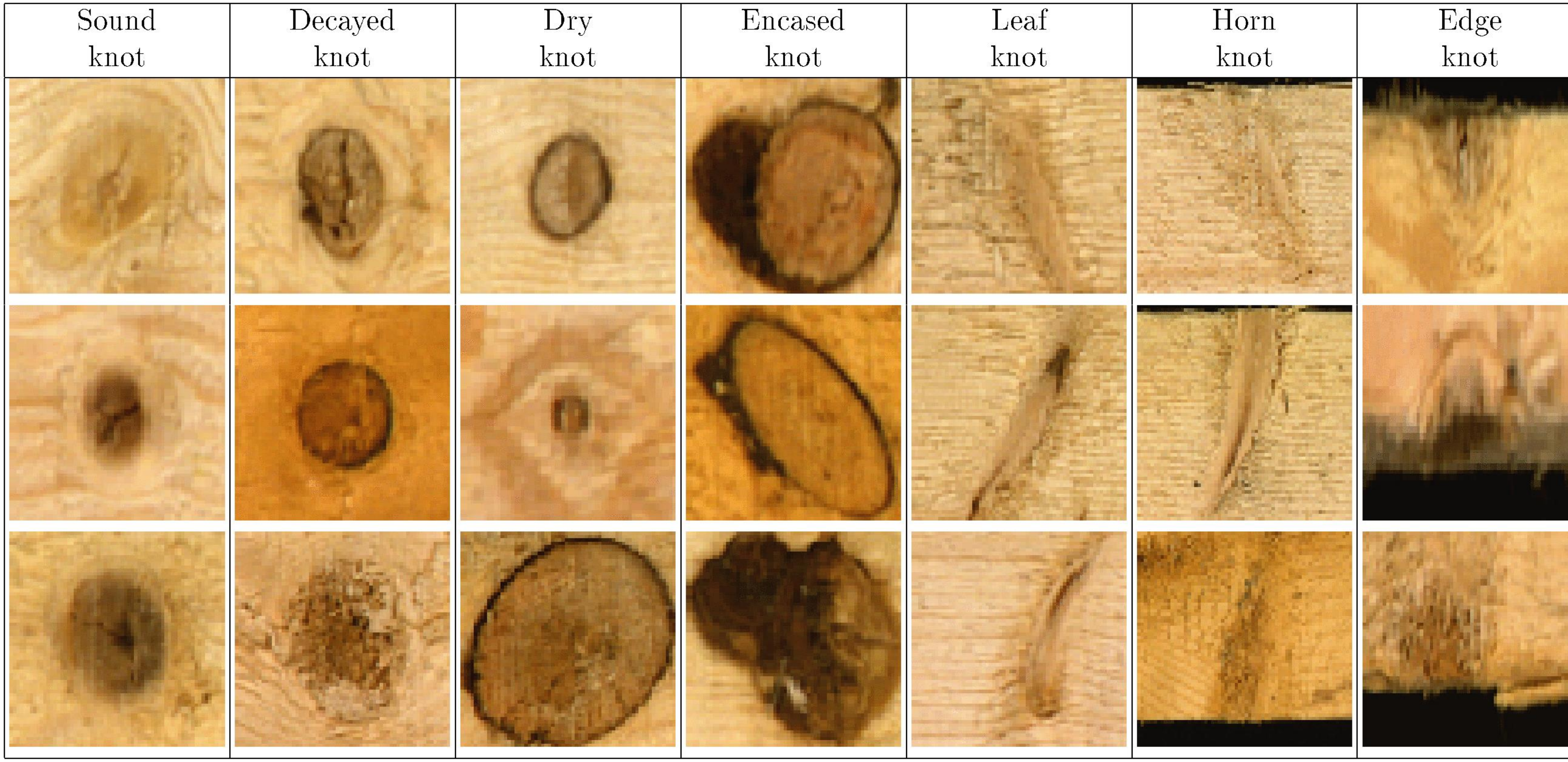
Fundus Image Database and Expert System



Diabetic retinopathy image database



Classification of Knots

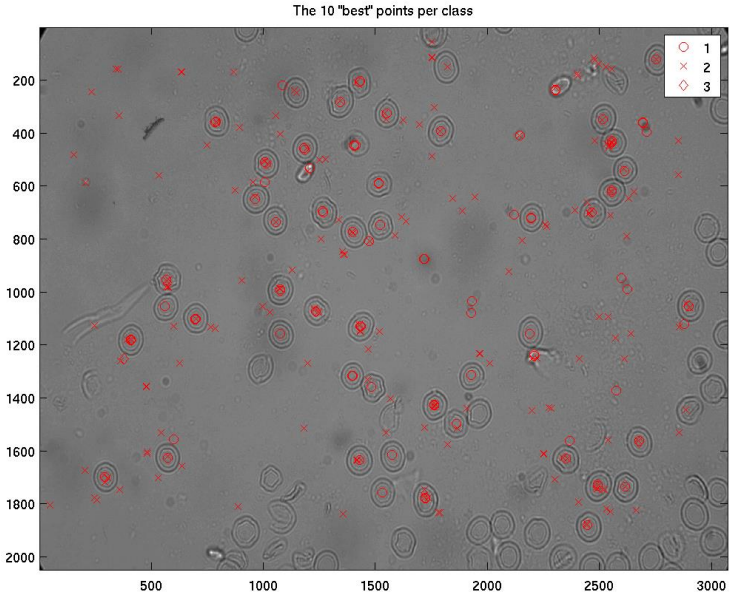


Analysis of Pollen Images

Microscope images of pollen samples: Analysis either

- manually or
- by automated image analysis.

In co-operation with LUT & Universidade de Vigo, Spain.



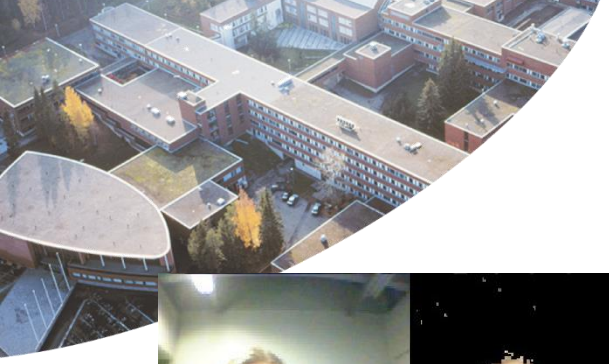
Environmental Monitoring Using Image Analysis

- Vegetation changes in Lake Saimaa (a sound, Soinilansalmi).
- In co-operation with, Saimaa Water Protection Association, Kymijoki Protection Association, UPM-Kymmene, NORDI, European Union.

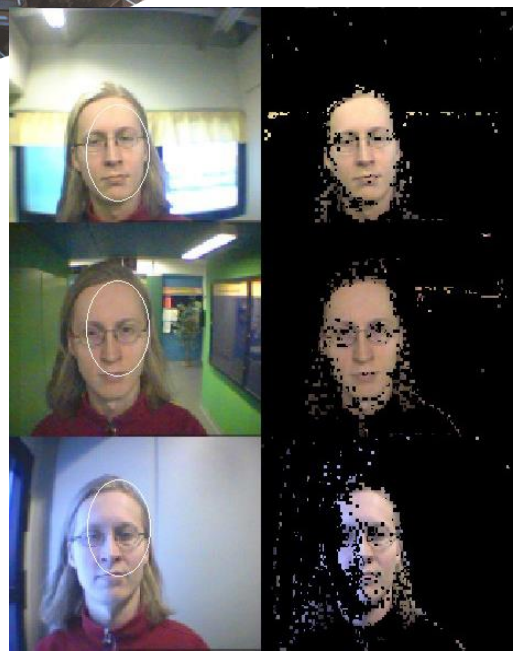
• ENVISION – Cross-border environmental monitoring using image analysis.

1996

1999

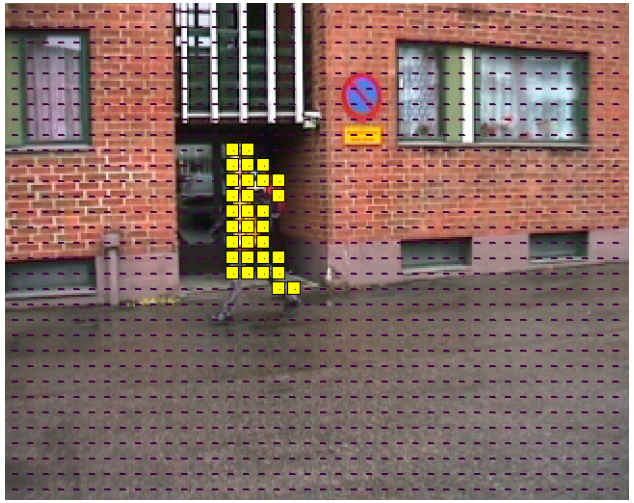


Understanding of Human Actions from Video (Oulu)

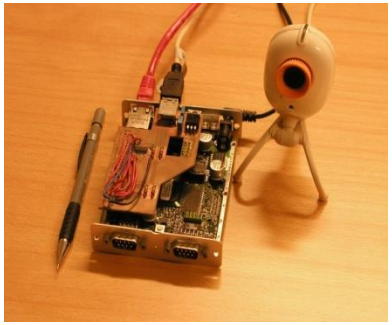


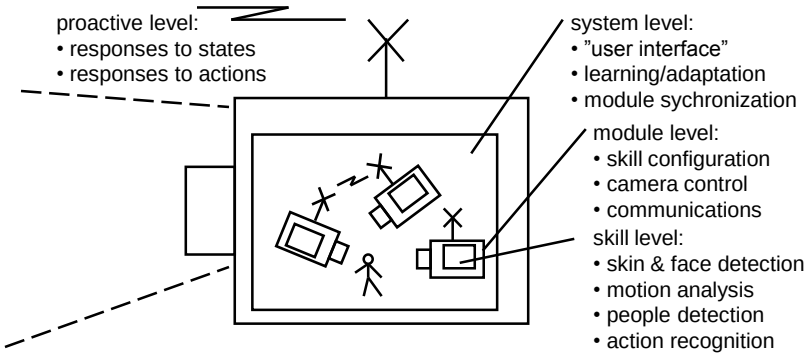
Skin and face recognition, person identification

Detection and tracking

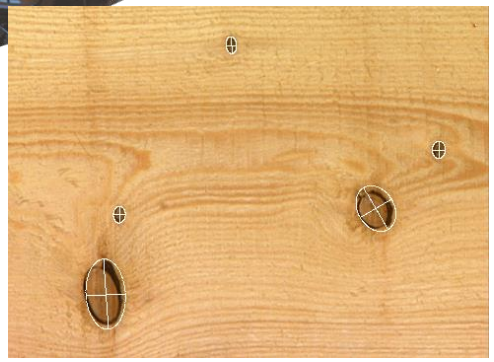


Multi-camera system implementation

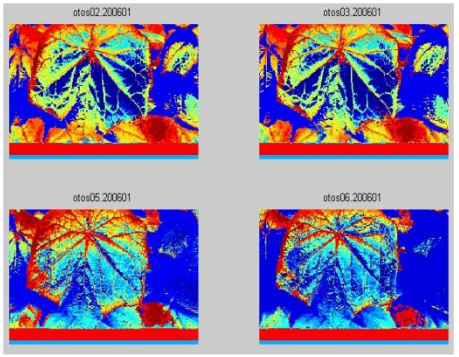




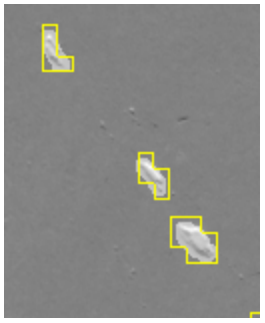
Examples of Visual Inspection Projects



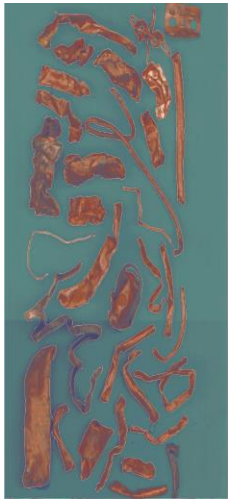
Wood surfaces



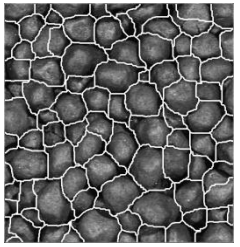
Vitality of greenhouse plants



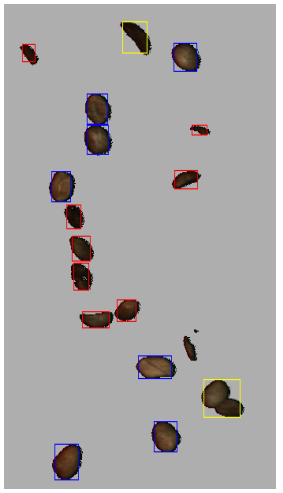
Metal surfaces



Scrap metal

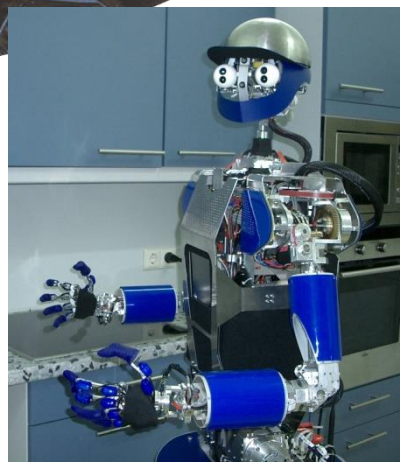


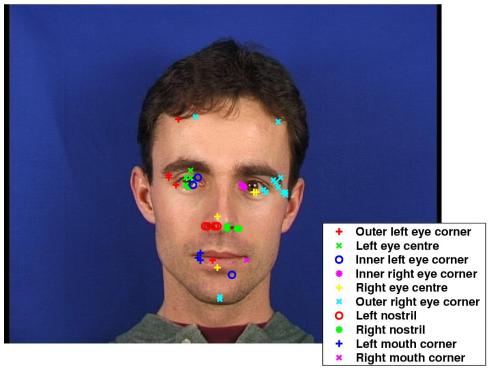
Granulometry

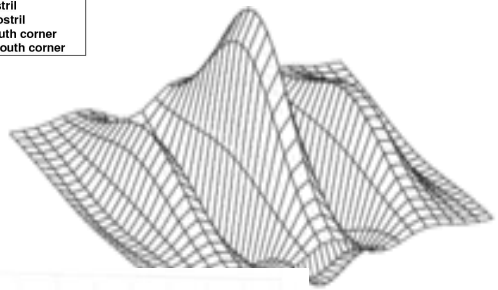


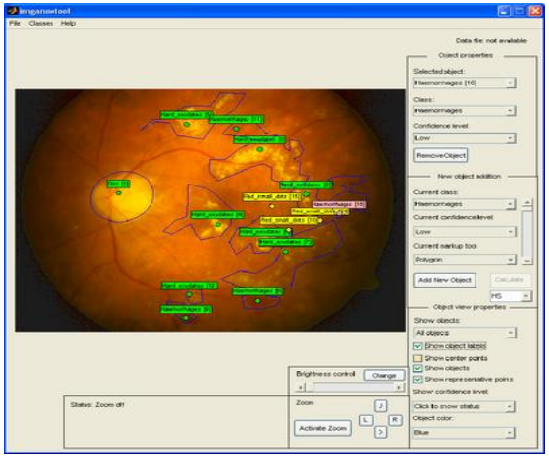
Food particles

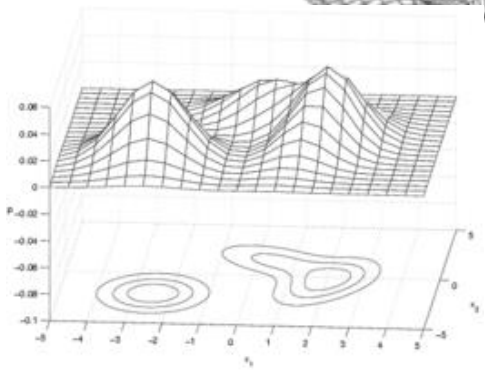
MVPR: Overview of Academic Research











Levels of Vision

- Low-Level Vision
  - Intensity, color
  - Frequencies (spatial, temporal)
- Intermediate-Level Vision
  - Textures, lighting
  - Surfaces, depth, motion
- High-level vision
  - Objects, pattern recognition
  - Automated Inspection, Surveillance

Conclusions

Research challenges:

- Real-time detection and tracking
- Recognition
- General purpose systems
- Sensor fudion and multimodal systems

Growing application areas:

- Industrial machine vision (e.g., forest and metal industry, food production, medical industry)
- Medical image processing (micro and macro level images)
- Security and surveillance applications (biometrics, law enforcement, digital watermarking, etc.)
- Applications in home entertainment and electronics (service robots, smart clothes & rooms, computers & networks, mobile devices, etc.)