Imperial College London

Lecture 1

Introduction to Design of Visual Systems

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This module explores the various knowledge, skills, algorithms, methods, technologies and insights useful for the design of visual systems. This is an elective module for 4th year MEng and MSc students in the Dyson School of Design Engineering.

This lecture set out the syllabus, assessment and context for this module.

Why this module?

- Many devices and systems nowadays involve visual information, e.g self-drive, CCTV, face recognition etc.
- Visual systems is not covered by any other modules (except maybe slightly in robotics?)
- Visual systems are really interesting – instant feedback and gratification.
- Extension of signal processing in DE2 Electronics 2.

A large proportion of devices, systems and services rely on acquiring and processing visual information. Examples are transport systems (traffic violation detection, access control such as congestion charging, driver assistant systems), health-care system (imaging and diagnosis) and robotics. This module provides students with a broad understanding in image and video acquisition, processing, transmission, and storage, and how people perceive and interpret such information. Students completing this course will understand the constraints imposed by the latest technology on vision processing, the important factors that must be considered in design a system that involve visual data, the software and hardware toolkits available for deployment in vision-related designs and the underpinning mathematics and algorithms.

What will be covered?

- Physiology and anatomy of human visual system
- Physics of human visual system
- Technology of visual systems
- Algorithms in visual system design
- Understanding and machine interpretation of visual information

- **Physiology and anatomy of human visual system**

  Basic physiology of the human eye (relevant to design engineers); pathway from photons to brain; fovea vs peripheral vision; super-resolution vision due to microcasade(?); human sensing and perception of colour; dynamic behaviour of human vision; how human visual system process visual information.

- **Physics of human visual system**

  Optical pathway of the human eye; emitted light vs reflected light; visible light as electromagnetic wave; principle of night vision; colour matching principle; monochrome vs RGB vs XYZ vs YUV; understanding aperture and focal length; improve what human sees through optics.

- **Technology of visual systems**

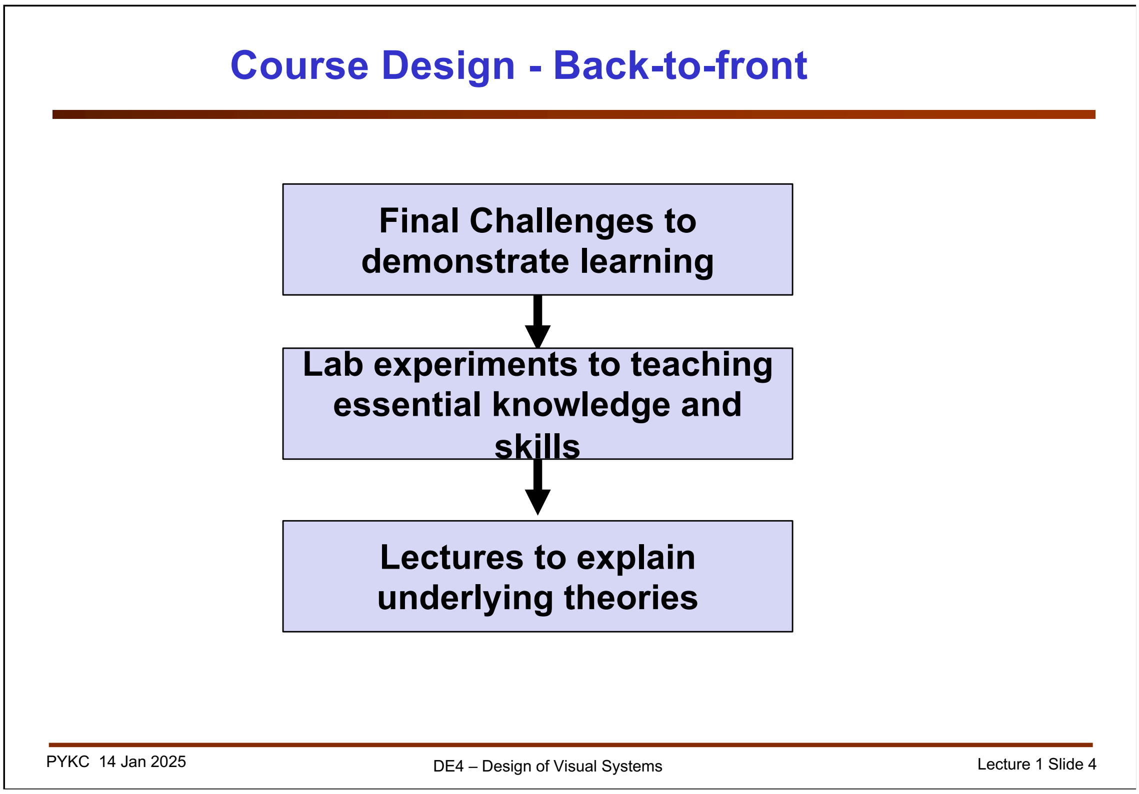
  Image sensor technology; non-visual sensors (e.g. lidar); image data representations and standards; video data representations and standards; challenges with data bandwidth limitations; vision system stabilization methods (optic vs digital); resource requirement in a visual system; vision processor technology.

- **Algorithms in visual system design**

  Algorithms to perform edge detection; motion estimation; segmentation; motion prediction; colour mapping; compression and coding.

- **Understanding and machine interpretation of visual information**

  Application of machine learning in visual systems.



As with Electronics 2, I designed this module back to front.

I first came up with the final project (the pinnacle of the challenges), then work out what Lab Experiments are needed for you to acquire the knowledge and skills to do the project. I then design the Lab Experiments are designed to be self-contained.

I then plan the lectures around the Lab Experiments to ensure that you understand the underlying theories.

Assessment & Textbook

- DRAW week mini-project (15%)
- Final Project (25%)
- Examination on week 1 of Summer Term (60%)

- Textbook:

"Digital Image Processing", Gonzalez & Woods (4th edition)

Electronics copy of this book is available on:
https://imperial.alma.exlibrisgroup.com/leganto/public/44IMP_INST/lists/44618090290001591?auth=SAML

Note that I will be using the book by Gonzalez and Woods, which is available for you to read electronically via the URL shown. You need to log in with your Imperial College account to access this book.

Course schedule (2025)

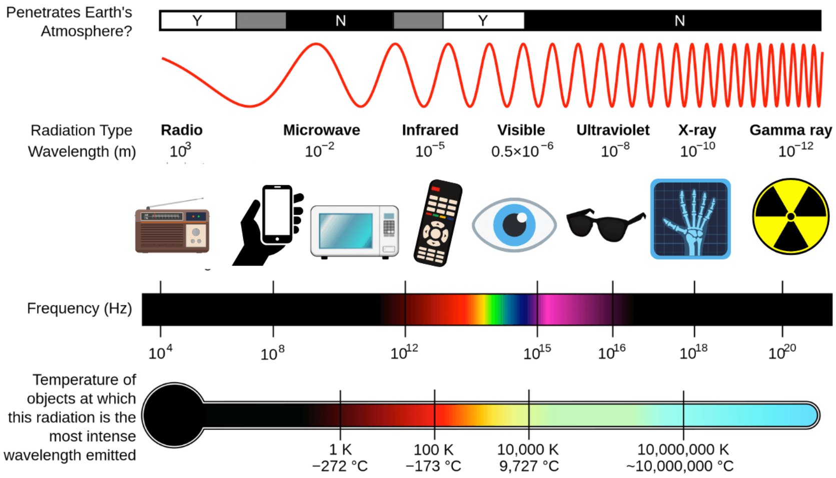
This schedule is subject to change

Week starting	Lectures (Tuesday 14.00 – 16.00)	Lab (Thursday 13.00 – 16.00)
wk1 – 13 Jan	The Anatomy & Physiology of Human Visual System	Lab 1: Intro to MATLAB
wk2 – 20 Jan	How we see colours?	Lab 2: Vision test & Colours
wk3 – 27 Jan	Intensity transformations and spatial filtering	Lab 3: image enhancement & filtering
wk4 – 3 Feb	Morphological processing	Lab 4: Morphological Operations
wk5 – 10 Feb	DRAW WEEK (no lectures)	Mini-Challenges & Logbook – 15% of module
wk6 – 17 Feb	Image Segmentations and Feature Extraction	Lab 5: Segmentation and Extraction
wk7 – 24 Feb	Image Classification	Peter is away – no lab
wk8 – 3 Mar	Physics of visual systems (by Freddie Page)	Final Challenges explained + Lab 6: Image Classification
wk9 – 10 Mar	Technologies for visual systems	Final Project
wk10 – 17 Mar	FINAL WEEK (no lectures)	Final Challenges submission via GitHub on Friday 21 March (25%)

Here is a preliminary schedule for the lectures and the labs. Note the following:

- This is the first year I deliver this module. Therefore, the schedule is subject to change depending on how the module progresses during the term.
- There will be FIVE lab experiments all based around MATLAB. I chose MATLAB because it is widely used in industry and it is very quick to prototype a solution.
- I will be away between 26 Feb and 4 March inclusive (conference trip). The lecture on Tuesday 4th of March will be delivered by Freddie Page.

Electromagnetic (EM) Spectrum



- Visible light is only a small fraction of the entire electromagnetic spectrum
- It lies between infrared and ultraviolet frequencies
- Emitted light from an object helps to identify the temperature of that object

Source: sciencenote.org

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Christiaan Huygens and Thomas Young discovered in late 18th and 19th centuries the wave theory of light and that it is part of the electromagnetic spectrum. Isaac Newton further demonstrated that when sunlight passes through a glass prism, a continuous spectrum of visible light from violet to red is produced. He further proposed that light could be made up of tiny particles, which he called corpuscles, but now we call photons.

The entire electromagnetic spectrum goes from low frequency range of radio waves (around 10^4 Hz) to very high frequency range of Gamma rays (> 10^{20} Hz). These waves are normally characterized but their wavelength, frequency or energy with the following relationships:

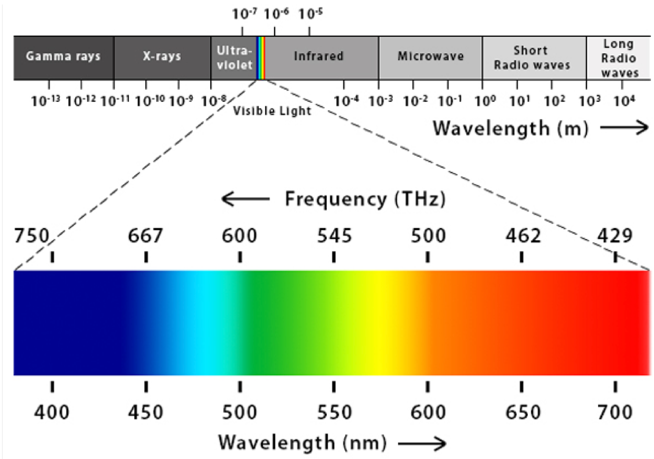
$\lambda = \frac{c}{\nu}$ where λ = wavelength, c = speed of light (~ 300 m/µs), and ν = frequency;

$\mathrm{E} = h\nu$ where E= Energy in electron-volt or eV, h = Planck's constant (~ 4.136 eV/Hz).

This implies that the higher the frequency of an electromagnetic wave, the higher its energy.

Note also that only radio waves and visible light can propagate effectively in Earth's atmosphere. Others such as ultraviolet, X-ray and Gamma radiations are absorbed by our atmosphere. This provides us with protection from the damaging components from sunlight.

The Visible Light Spectrum



- Visible light has a wavelength between 380nm (blue) and 740nm (red)
- The frequency range is between 4 x10^{14} Hz (red) and 8 x 10^{14} Hz (violet)
- Visible light is the energy source of human vision
- Non-visible light such as infrared, X-rays and Gamma rays can also be used

Source: sciencefact.net

Although this module is mostly about design of visual systems for human where only the visible spectrum from 380nm (violet) to 700nm (red) can be perceived, images can also be formed in other spectral ranges. This includes X-ray and Gamma ray.

Further, non-electromagnetic wave such as ultrasound can also produce useful images for medical diagnosis or infra-red for night vision systems.

It is important to understand that light carries energy. For example, solar panels transduces the light energy into electrical charges to charge batteries and thus provides electricity. In a similar manner, the energy from visible light is turned into electrical signals in our human visual system through a process called **transduction**.

In the remainder of this session (next Lecture), we will examine the process through which such light energy (in the form of photons) are turned into electrical impulses that allows human (and indeed animals) to see.

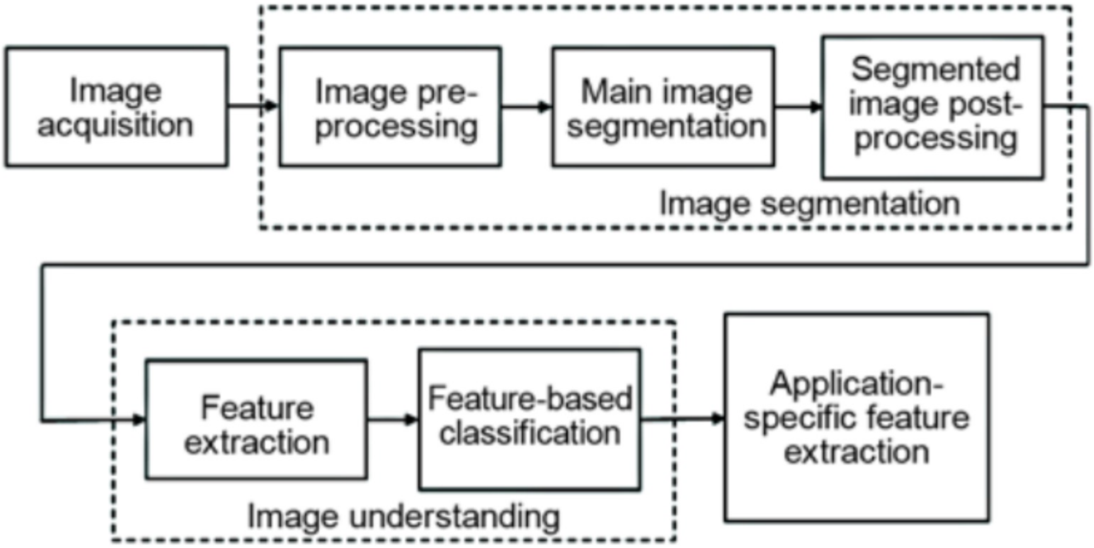
Visible Light Wave – a NASA video

Source: NASA series on EMS

Here is an excellent short video on visible light wave from NASA.

https://www.youtube.com/watch?v=PMtC34pzKGc

A typical visual system



Here is a block diagram showing a typical visual system. In this module, will be examining a number of these blocks in the diagram in details. You will also have a chance to apply what you learn in lectures during the laboratory experiments and the two projects.