Imperial College London

DE2 Electronics 2

Signals, Systems and Control

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Welcome back after the Christmas and New Year break.

Electronics 2 is COMPLETELY DIFFERENT from Electronics 1 and Gizmo. This is NOT an easy module – be prepare to learn many new things. It will not be a walk-over. However, if you persist, you will hopefully find this module not only educationally beneficial, but you may even have fun alone the way.

www.ee.ic.ac.uk/pcheung/teaching/DE2_EE/

Organization and Schedule (may change)

SCHEDULE (SPRING TERM 2025)

Week (starting)	Lectures	Lab	Comments
1 (6 Jan)	-	-	Exam week
2 (13 Jan)	1, 2, 3	Lab 1 – Sig Proc & Matlab	
3 (20 Jan)	4, 5, 6	Lab 2 – Sig Proc & Pybench	
4 (27 Jan)	7, 8	Lab 3 – Systems	
5 (3 Feb)	9, 10	Lab 4 – IMU & OLED	
6 (10 Feb)	-	LAB Oral	DRAW week
7 (17 Feb)	11, 12	Lab 5 – real-time systems	
8 (24 Feb)	13, 14	Lab 6 – Motor Control	
9 (3 Mar)	15, 16	Lab 7 – Challenges	
10 (10 Mar)	17	Lab 8 – Challenges	
11 (17Mar)	-	FINAL LAB Oral	Final week

- Textbooks (not compulsory)
  - BP Lathi, Linear Systems and Signals (International ed, ????)
  - Schaum's Outline of Feedback and Control Systems (~£29 Amazon)
- DRAW week Lab Oral (20%), Final week Lab Oral (20%)
- Examination on first week of Summer Term, 1.5 hour paper (60%)

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I will organise my course module with supporting Laboratory sessions, which are compulsory, formal lectures where I will provide the theorectical underpinning, tutorial problems to help you learn the subject, interactive tutorial for us to discuss any issues that the class find difficult or confusing, and a final group project to bring everything together.

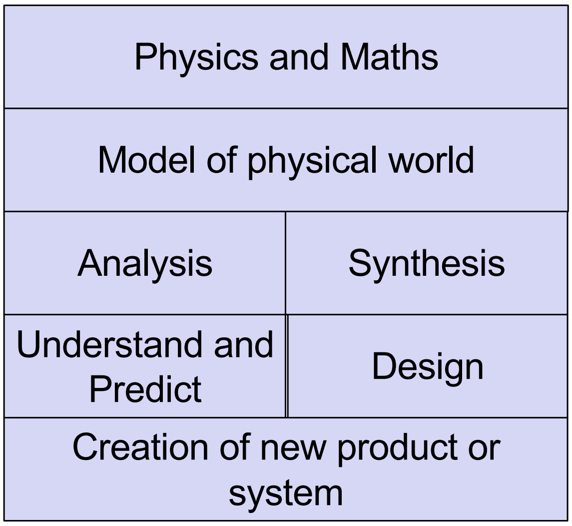
Although I am not using the "flip classroom" model for my module, I have faithfully follow the principle that:

1. I first designed the final group project;
2. I then designed all the laboratory experiments which are necessary for you to learn what's needed in order to do the project;
3. I finally constructed the lectures in a way that you will understand what you do in the laboratory sessions.

In other words, although I am not strictly doing "problem-based" learning, I am not too far from that model. Having said that, I am still a strong believer of the strict mathematical approach to signals, systems and control. I will not be "dumbing down" anything, except that what I teaching will be focused.

Remember, I want you to acquire CONFIDENCE in the subject, and know both what you know, as well as what you don't know.

Why is this module important to Design Engineering?



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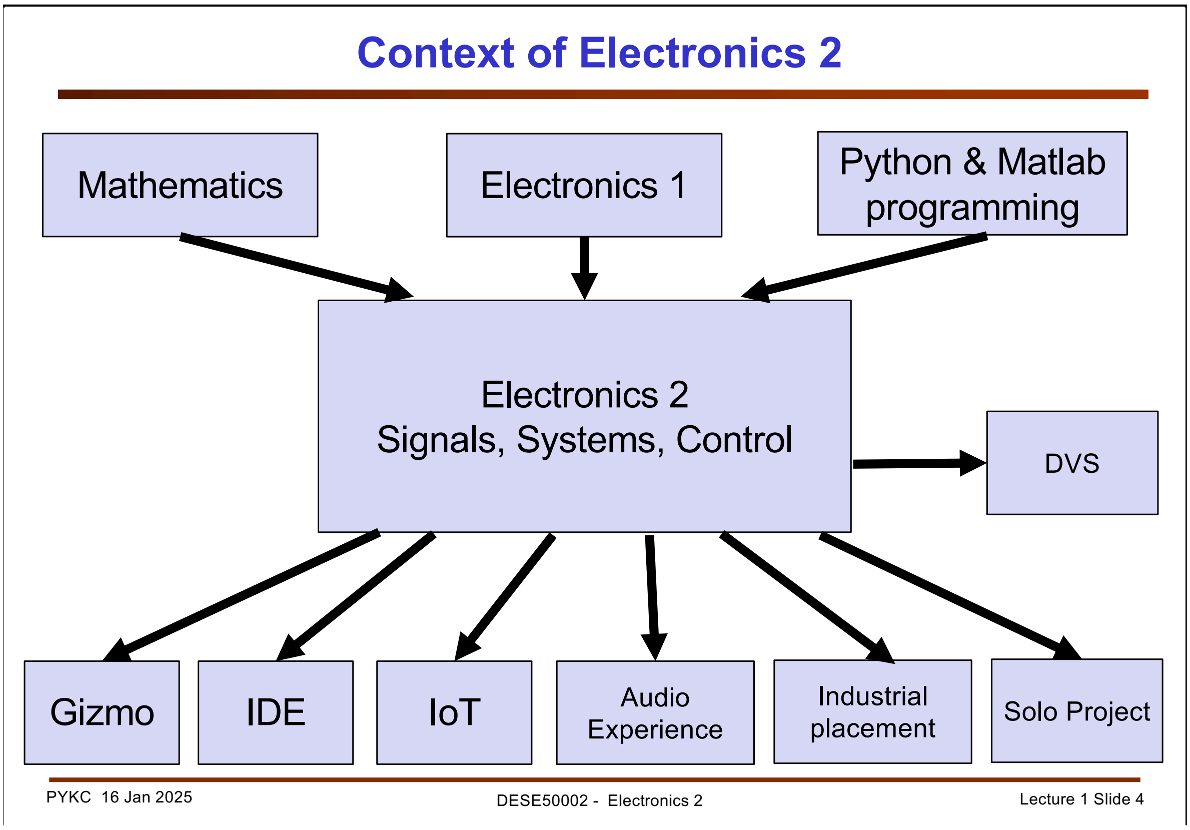
If you want to create a well-designed product or system, which is founded on solid engineering principles, you need acquire the knowledge and skills provided by this module.

We start with the underpinning disciplines of physics and mathematics. Unlike many areas of design, this module generally has answers that are either right or wrong, or at least better or worse solutions. This is because the foundation of this subject is on science.

Based on the underlying physically principle and mathematical formulation, we create model of the physical object or environment. This model usually is a simplified version of reality where some assumptions are made. The quality and accuracy of the model will vastly influence the results. Bad model leads to poor design.

Once we have the model, we can perform analysis, which allows us to do prediction and answer the “what-if” question. Furthermore, we can also perform synthesis, which is the design of a program, an electronic circuit and/or the entire collection of bits to form the final product or system.

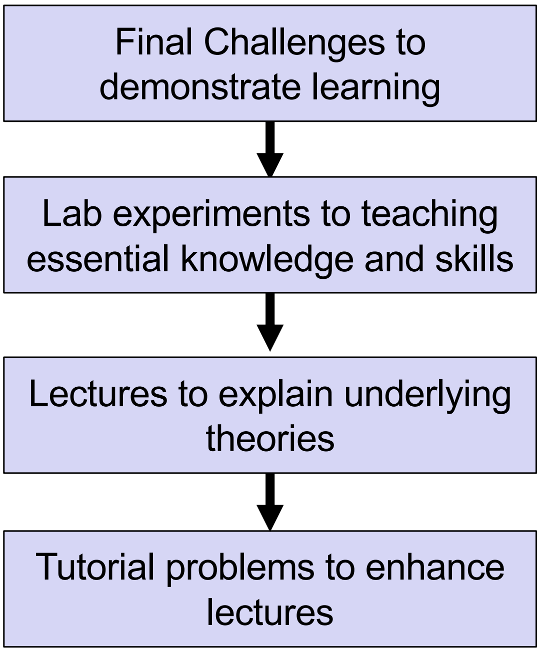
Without these steps as shown in the slide, you can make design and pray that your design works. With the ability to model, analyse, predict and then synthesis, you know that your design is much more likely to work (or close to working).



This model is built upon what you learned in Year 1 from Mathematics, Electronics 1 and the two Computer Programming modules.

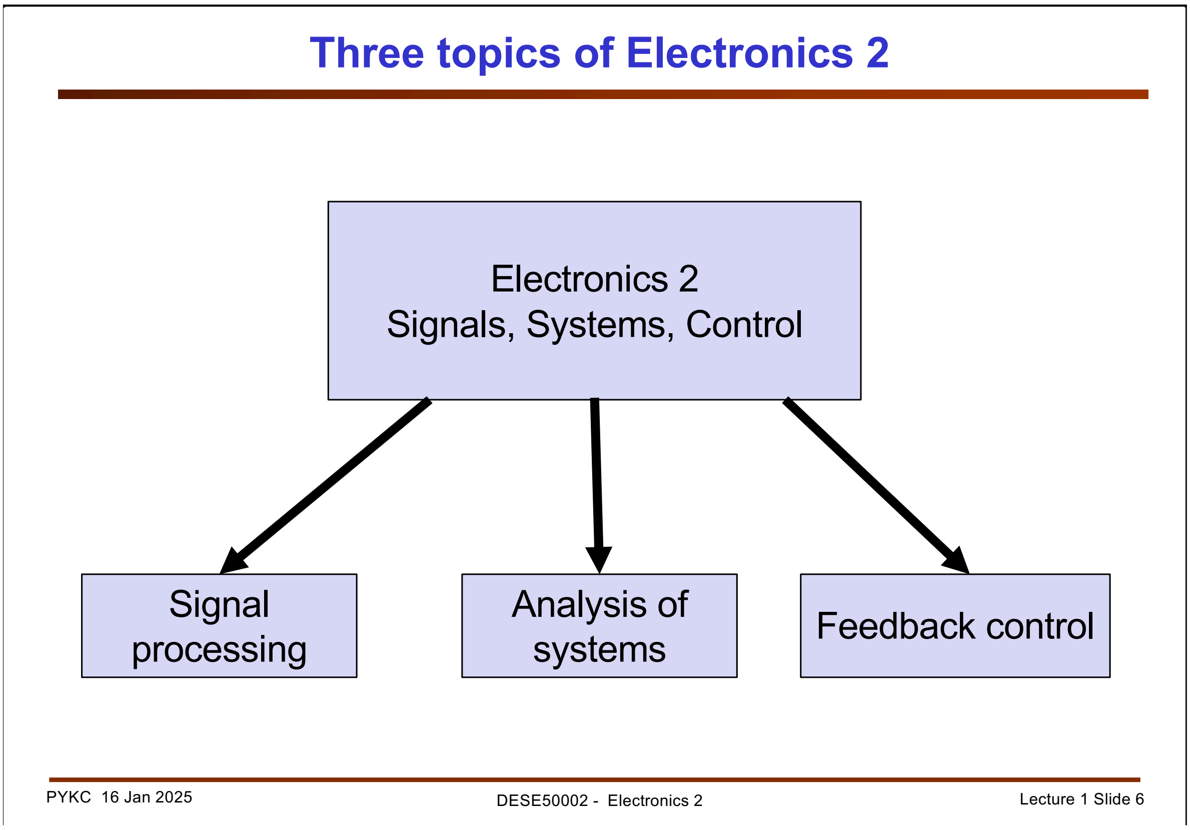
Once completed, this module will help you with Year 2's Gizmo, Engineering Product Design, Year 3's IoT, Audio Experience and Industrial Placement, and Year 4 Master degree project (at least for some students).

Course Design - Back-to-front



As discussed earlier, 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 which should be fairly self-contained.

I then plan the lectures around the Lab Experiments to ensure that you understand the underlying theories. Finally I created the problem sheets to help you learn the theories.



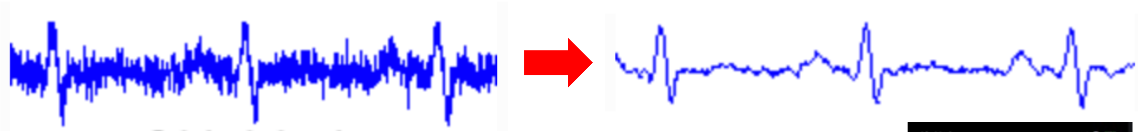
This year's electronics module is not just about electronics. Instead, I will be covering THREE fundamental aspects of electrical engineering that ALL EEE UG students would learn by the end of their second year. These are:

1. **Signals** – this is about how to process electrical signals in order to extract useful information from them, to eliminate noise, to compress information, and to transform them into a form that is more useful;
2. **Systems** – this is about the behaviour of electronic (or other non-electronic) systems as black-boxes, or as mathematical models, so that one can either predict its behaviour, or design circuits around such a system in order to obtain desirable behaviour;
3. **Control** – this is about using feedback as a technique to modify the overall behaviour of the system.

We will next consider why each of these topics are important for a Design Engineers to learn.

Why is signal processing important?

1. To reduce noise in an electrical signals – e.g. clean up ECG signal



2. To make correction or desired changes to the signal – e.g. blur surrounding while keep part of the camera photo in focus

3. Derive useful information from the signal – e.g. derive health condition of an individual on a phone

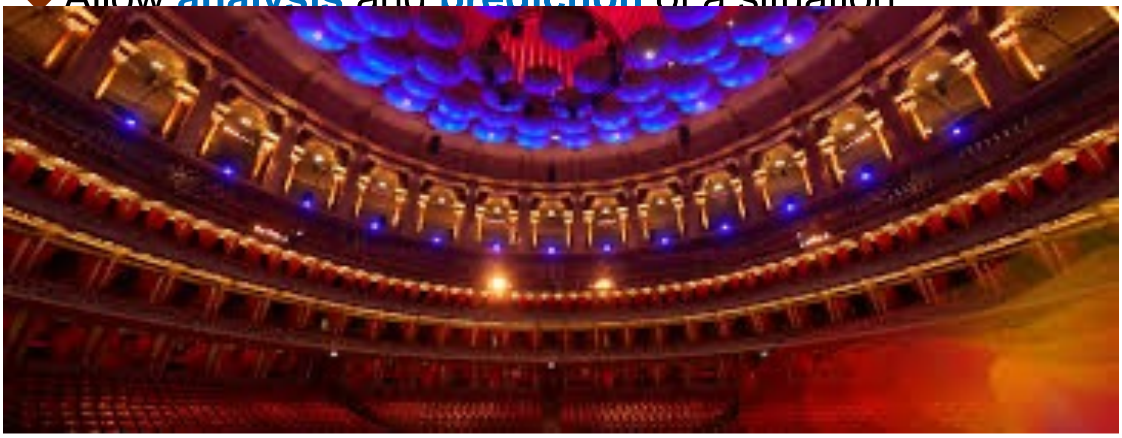
To put everything in context, learning signal processing is fundamental to electrical engineering as a discipline. Electronic circuits, including transducers, are all to do with producing signals. What then do we do with these signals? We make use of them to do useful things or derive useful information.

There are three broad use of signal processing:

1. **Mitigate against unwanted components of the signal, which we often call noise.** Every signal contains unwanted components. Signal processing can eliminate, or at least reduce, these unwanted elements of the signal. As shown above, a ECG signal may contain lots of unwanted noise. Signal processing can clean up this signal as shown on the right.
2. **Make adjustment to the original signal.** Signal may be distorted by some external factors. An example of this is that images taken by a telescope may be distorted by the imperfection (or even errors) of its mirror (e.g. Hubble Telescope). If we know the distortion function, signal processing techniques can restore the original image by compensating for the distortion. The example here is the iPhone using a signal processing algorithm to deliberately blurring the background of the photo (taken by me at Kew Garden, London last Summer).
3. **Derive other information from the signal.** Here is the health monitoring screen from a phone showing various metric of exercises one had accumulated in the day. These are derived information for the signal acquired.

Why is system analysis important?

◆ Allow **analysis** and **prediction** of a situation



INPUT x(t)		H(s) or h(t)		OUTPUT y(t)
Sound from orchestra	→	System Behaviour	→	What audiences hear

The second topic is system analysis. We are limiting ourselves to analysis of LINEAR systems only. Non-linear system is too complicated for us to handle.

The purpose of system analysis is to create a mathematical model of a problem in hand (which could be an electronic circuit, a robotic arm with mechanical and electrical parts, an ecosystem etc.), and predict what behaviour of this system under different scenario.

For example, the system could be the Royal Albert Hall. The problem in hand could be to solve the poor acoustic property of the Hall to modern classical music performed by the orchestra. The goal is that the audiences would have a nice experience attending a concert. To help designing the sound absorbing installations for it, we would need to create a model for the acoustic property of the Hall, then analyse this to predict how putting up absorption materials would give us the desired effect. The end results can be seen – there are mushroom-like installations at the ceiling of the Albert Hall which make it a world-class venue for concerts.

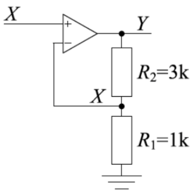
The Hall is model by some system equation as h(t) in the time domain, or as H(s) in something called the frequency domain.

The orchestrial sound are the input signal x(t). Knowing h(t) or H(s) allows us to predict what the output y(t) would be.

Why is feedback control important?

- Automatic correction of behaviour – e.g. robotic arm under load

- Achieve desired performance – e.g. keep Segway upright



- … and achieve the impossible – e.g. fly this flighter jet which is impossible for a human to fly

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The third topic is feedback control. Feedback is something we have already covered in the context of operational amplifier. You have already seen how in op-amp circuits, we used feedback to fix the gain of the amplifier so that the overall gain of the circuit depends only on the ratio of resistors. In this context, we use feedback to achieve some desirable performance in our system.

Another use of feedback control is to automatically make corrections to the behaviour of a system. An example is the use of a robotic arm to move heavy load. Without feedback control, movement of the arm is likely to have oscillation and the amount of oscillation will be load dependent. Feedback control helps to make the correction so that the robotic arm will move with little or not oscillations.

Finally feedback control can make something impossible possible. A good example are flying of a modern flighter jet airplane. These are designed to be agile and able to make very tight turns. It makes the plane impossible for a human pilot to fly without the help of clever electronics. Planes like this are equipped with carefully design feedback controllers to make sure that the plane does not fall out of the sky. Another similar example are drones and helicopters. Without feedback control, they will be impossible to fly by a human operator!

You will acquire these KNOWLEDGE

- Handling of discrete time, quantised signals
- Application of Fourier transform (time vs frequency domain)
- Application of Laplace transform
- Characterisation of dynamic systems
- Difference between steady state and transient response of a system
- Idea of convolution
- Basic digital filtering (and simple z-transform)
- Use of a simple feedback control method called PID control

This module will teach you many different knowledge. These are list above. You may not appreciate the significance of some of them at this stage. Suffice to say that there are ”hard core” engineering here that, if you do not study it as part of this degree, you may never learn it, or even know that such knowledge exists!

You will acquire these SKILLS

- Enhance your Python skills – particularly in Classes and object-oriented programming
- Learn embedded and real-time programming of a microcontroller
- Enchance your Matlab skills used for signal processing and GUI
- Apply mathematics to model and analyse physical systems

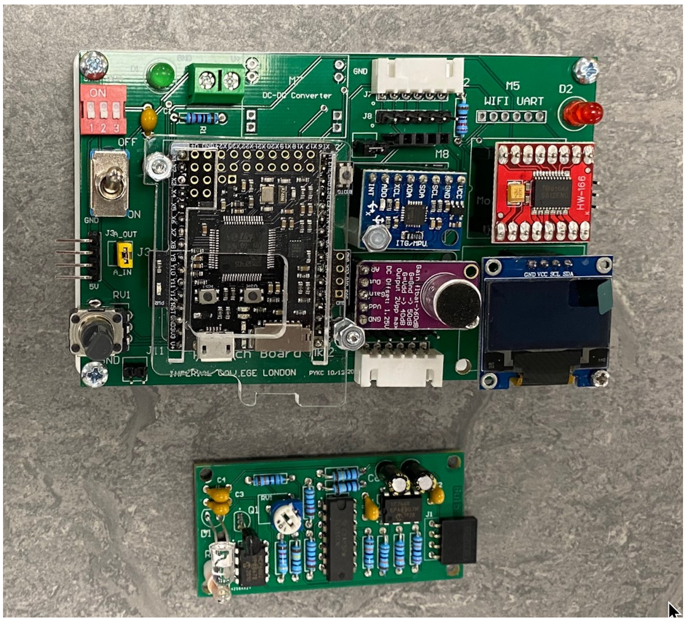
In addition to knowledge, this module also help you to acquire transferrable skills. Most of all, it helps you to be a better Python programmer because like last year, you will be controlling the electronics with MicroPython.

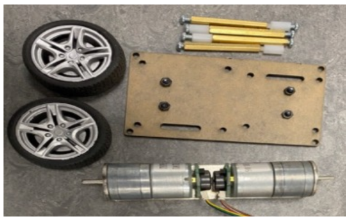
You will also learn how to design and program a stand-alone system using the ARM-based microcontroller. The processor board is called a Pyboard (not Pi), and it uses the same processor found in Raspberry Pi, but it is NOT a Raspberry Pi! Instead, like the ESP32, it runs MicroPython. You will learn how to write programs that do multiple things simultenously and react to real-time events.

You will also learn more about Matlab, something that you touched on in your Maths class last year. You will be using Matlab to process signals, and even write some Graphic User Interface (GUI) codes.

Finally, you will be apply what you learned in Maths last year. This module is highly mathematics – there is no way round it! All three topics are strongly underpinned by mathematics. Nothing will be dumb down. Instead I will attempt to maintain a high degree of rigour.

Lab-in-a-Box Kit





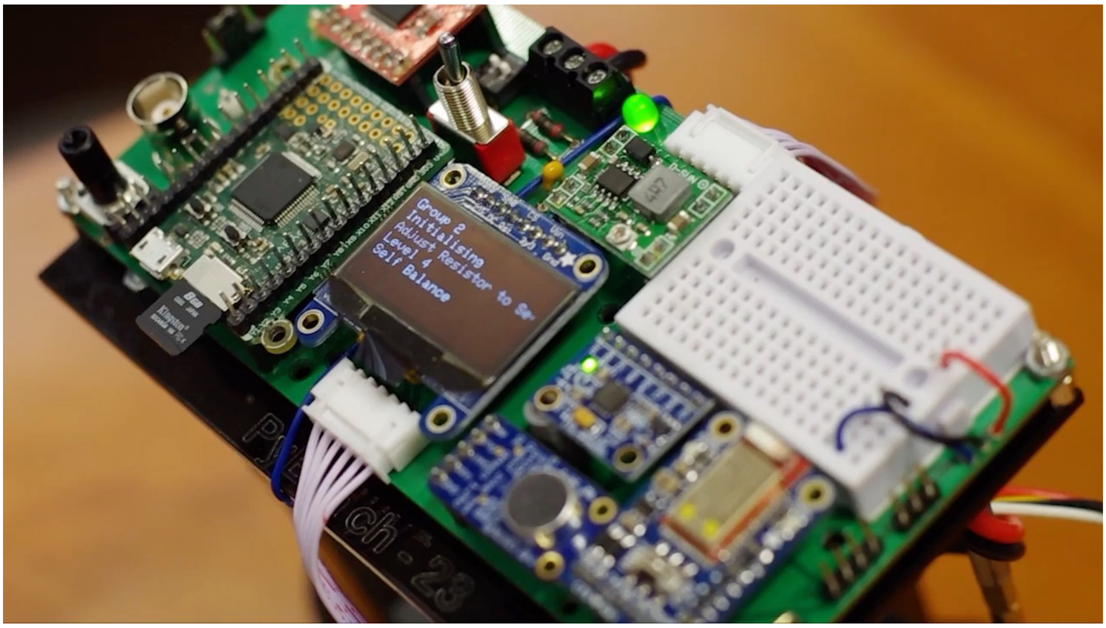
The Lab-in-a-Box Kit for this module consist for two bespoke (i.e. purpose built) boards. The main board is known as the PyBench unit. It consists of the main processor board (Pyboard), motor driver, display, microphone with automatic gain amplifier and an IMU. Unlike last year or Gizmo, you DO NOT need to build any circuits. These are modules are all connected together with a PCB.

There is also a bespoke small board known as the Bulb Board. This will be to support one of the Lab Experiments.

You are also provided with a dual motor unit with mounting components and wheels, a wifi unit for remote control and a neopixel strip that you already come across last year.

You will be required to share one set of this equipment per pair. You must also return the kit to me at the end of the module so that they can be used by students next year.

What your senior did before you



The capstone project for this module is to design a self-balance miniature two-wheel Segway that dances to music. There are other less difficult challenges that you may choose to attempt instead of this ultimate goal.

Here is a video made by students in an earlier year showing what can be achieved.

What next?

- Return Electronics 1 Kit if not already done so.
- Find yourself a lab partner.
- Complete survey form by noon 17 Jan 2025:
  https://forms.office.com/e/fRDHAm1vy8

- Lab-in-a-Box will be issued to you on Friday 17 Jan., during the afternoon Session.

This slide shows what you need to do next.

You must complete a survey form here: **https://forms.office.com/e/fRDHAm1vy8**

Enjoy the module!