Challenge 2
CS-EEE

Connected Bioreactor Design Specification

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Hello everyone. This is Ryan speaking. Over the next slides, we will look at the specification and the elements of the small-scale bioreactor control system you are asked to design, implement and test.

Objectives for this task

- Given the connected bioreactor design specification, identify:
  - The different components that make up the small-scale bioreactor system.
  - The subsystems into which the bioreactor system can be broken down.
  - The functionalities associated with each subsystem, as well as the overall system.
- You will need to produce:
  - Requirements, block diagrams, structure charts, flowcharts, wireframes to describe the architecture and explain the functionality of the bioreactor system and its subsystems.

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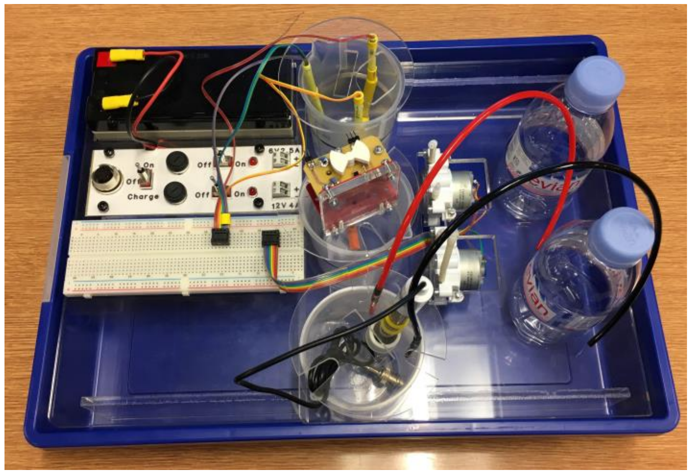
By the time you complete this task, you should be able to identify:

The different components that make up the small-scale bioreactor system.
The subsystems into which the bioreactor system can be broken down.
The functionalities associated with each subsystem, as well as the overall system.

Having understood the bioreactor design specification, you are then called to use different modelling tools to describe the architecture and explain the functionality of the bioreactor system and its subsystems.

Small-scale bioreactor testbed



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Here is a picture of the small-scale bioreactor testbed. There are three core elements to this bioreactor testbed, namely, the heating subsystem, the stirring subsystem and the pH subsystem.

Bioreactor design specification

- The inlet water temperature is assumed to be in the range of 10-20°C.
- The temperature control system must be able to maintain the temperature at a set point in the range 25-35°C to within ±0.5°C of the set point.
- The stirring subsystem must be able to maintain the stirring speed at a set point in the range 500-1500 RPM within ±20 RPM of the set point.
- The pH subsystem must be able to maintain the pH value at a setpoint in the sensing range 3-7.
- **Instructions**: You should do some research to find the optimal values for the above parameters. Provide justification for your choice.

- **ATTENTION**: All subsystems should:
  - Log data.
  - Provide a user interface for monitoring the parameters and allowing the set point values to be adjusted.

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Here is the design specification pertaining to this bioreactor system. To start off, it is assumed that the inlet water temperature is in the range of 10-20 degrees Celsius. Subsequently:

The temperature control system must be able to maintain the temperature at a set point in the range 25-35°C to within ±0.5°C of the set point.

The stirring subsystem must be able to maintain the stirring speed at a set point in the range 500-1500 RPM within ±20 RPM of the set point.

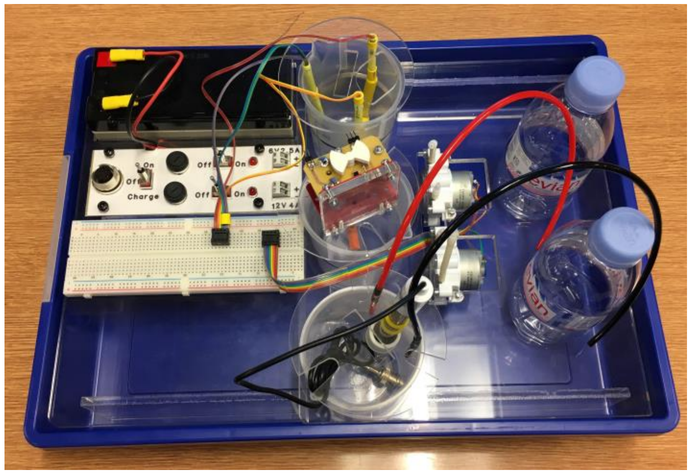
The pH subsystem must be able to maintain the pH value at a setpoint in the sensing range 3-7. By default, this subsystem should maintain the pH at an optimum 5.

Note also that all subsystems should:

Log data.

Provide a user interface for monitoring the parameters and allowing the set point values to be adjusted.

Let’s visualise each subsystem



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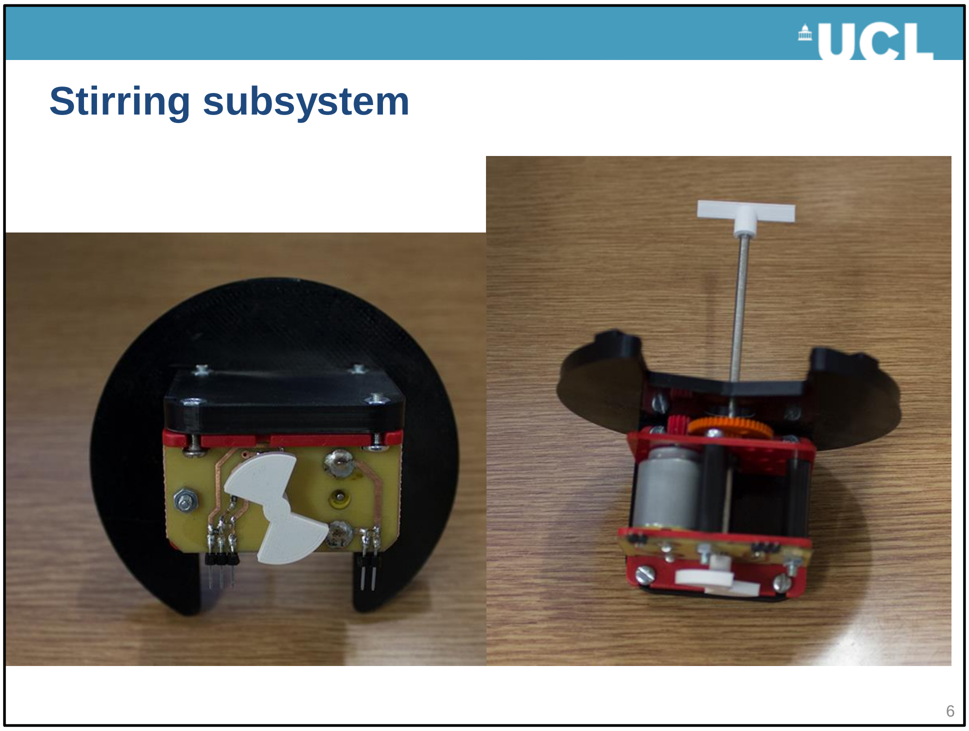
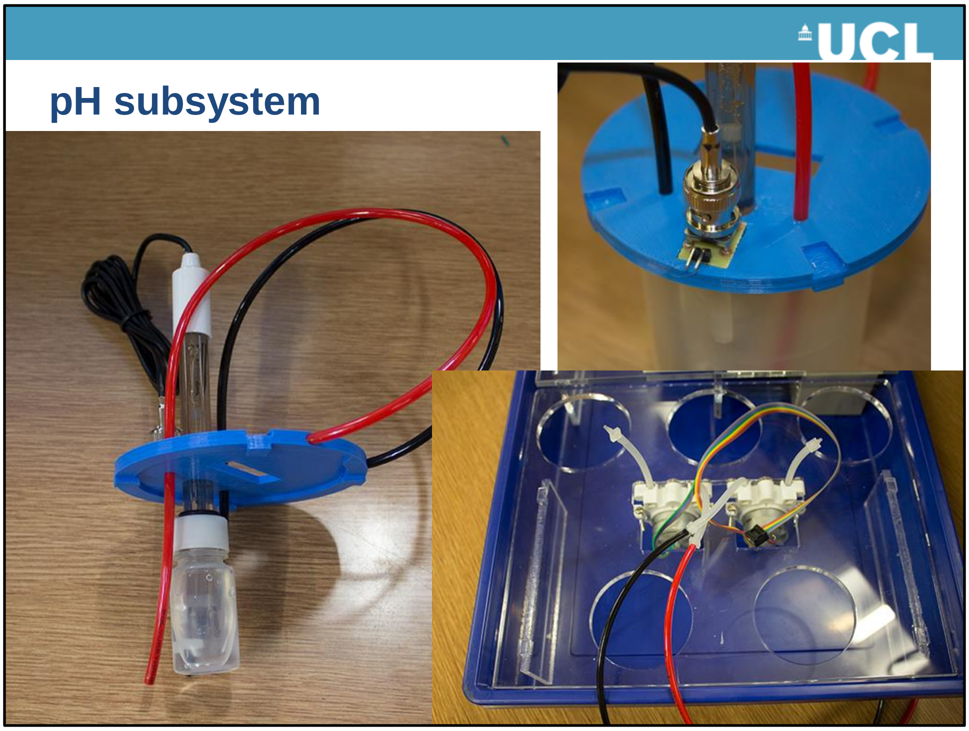
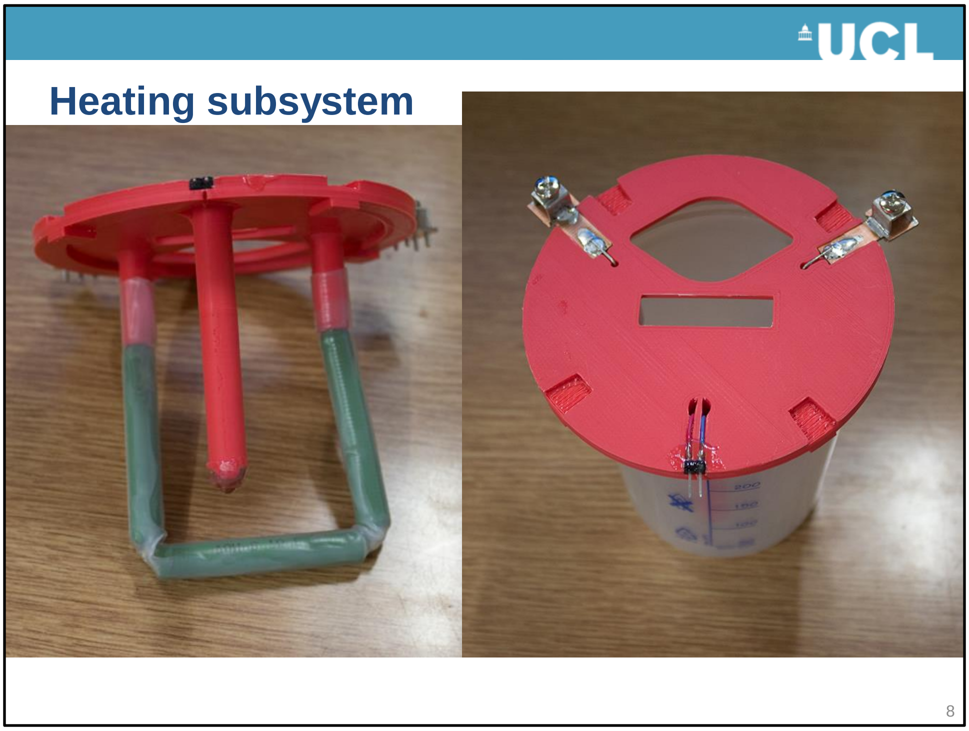
Let us now visualise each element of the bioreactor testbed in more detail. As shown in the slide, the power supply is provided by a rechargeable lead acid battery, which gives a 12V and a 6V output.
The two motors shown to the right are 6V, 1A peristaltic pumps, which are part of the pH subsystem and are used to pump alkali or acid into the pH solution.



The stirring subsystem consists of a propeller, that stirs the liquid in our system, a motor and some gearing. Behind the board, there is an IR LED and phototransistor, which are arranged as a reflective sensor looking at the gear wheel on the output shaft. The gear wheel reflects the light in such a way that it results in two pulses per revolution.

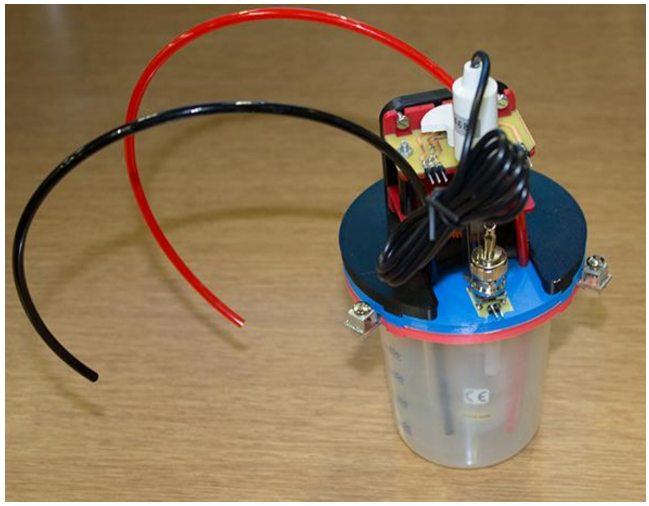


The pH subsystem consists of a pH probe being the glass tube shown in the slide, and which acts as the pH sensor. Here we can also see the pH pumps used to pump alkali or acid into the solution.



Finally, the heating subsystem of a 3 Ohm, 30W heating element, represented by the green part, as well as a 10 kOhm thermistor, which monitors the temperature of the solution.

All together now…



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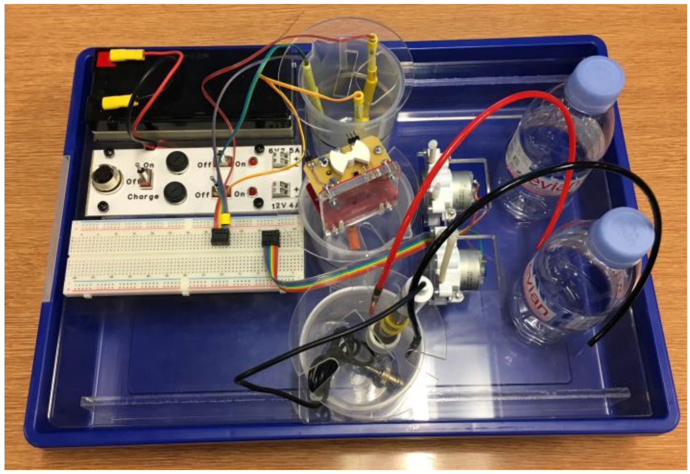
In this slide, we can see how the three separate subsystems can be stacked on top of each other to form the complete bioreactor system, which monitors and controls the temperature, stirring and pH of the liquid in the pot.

Bioreactor testbed – What is missing?



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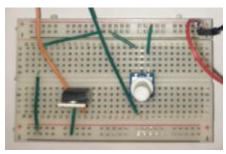
It should be evident that this testbed on its own is incomplete. While the peripherals are there, the components required to monitor and control the peripherals are missing.

UCL

What is missing? - Circuits and software

Part 1 - Circuits and software

- The microcontroller development board, which acts as the ‘brains’ of the system.
  - Needs to be programmed in software to provide processing and control.
- Electronic circuits for interfacing the bioreactor elements between them, as well as with the microcontroller development board.

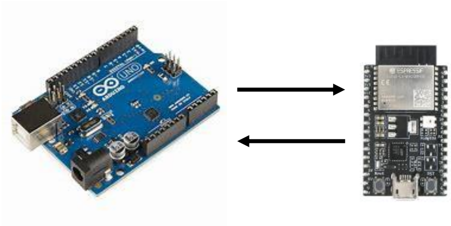


Herein, is were you, as an inter-disciplinary team of CS and EEE students come in. Your task is to develop the circuits and program the boards required to interface the bioreactor to its peripherals, as well as to monitor and to control them.

What is missing? – Connectivity

Part 2 - Connectivity

- An ESP32, (microcontroller development board),
  - Needs to be programmed in software to provide connectivity with the outside world.
- Two-way communication between the Arduino Uno and the ESP



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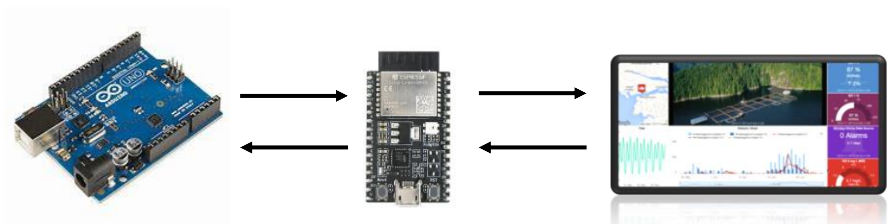
The Arduino Uno has no network capabilities. You will establish connectivity between the Arduino Uno and the ESP32 so that data, from the Arduino can be transferred to server on the internet for subsequent processing.

What is missing? - Connectivity

Part 2 - Connectivity

- Two-way communication between the ESP32 and a server where the data can be stored, processed and displayed to a user.
- Communication is 2-way. The operator may need to send commands back to the bioreactor



Dashboard image: Stephanie Malhomme, wikimedia

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The Arduino Uno has no network capabilities. You will establish connectivity between the Arduino Uno and the ESP32 so that data, from the Arduino can be transferred to server on the internet for subsequent processing.

So is connecting it all together sufficient?

- No! Simply connecting all the elements together and demonstrating basic functionality is not sufficient.
  - That is to say, simply say that the motor spins or the heater heats the liquid is not sufficient.
  - You need to demonstrate that your system can meet the given specification.
    - That is to say, that your system can operate in such a way that the system parameters (temperature, stirring speed, pH) can be maintained within the specified range.

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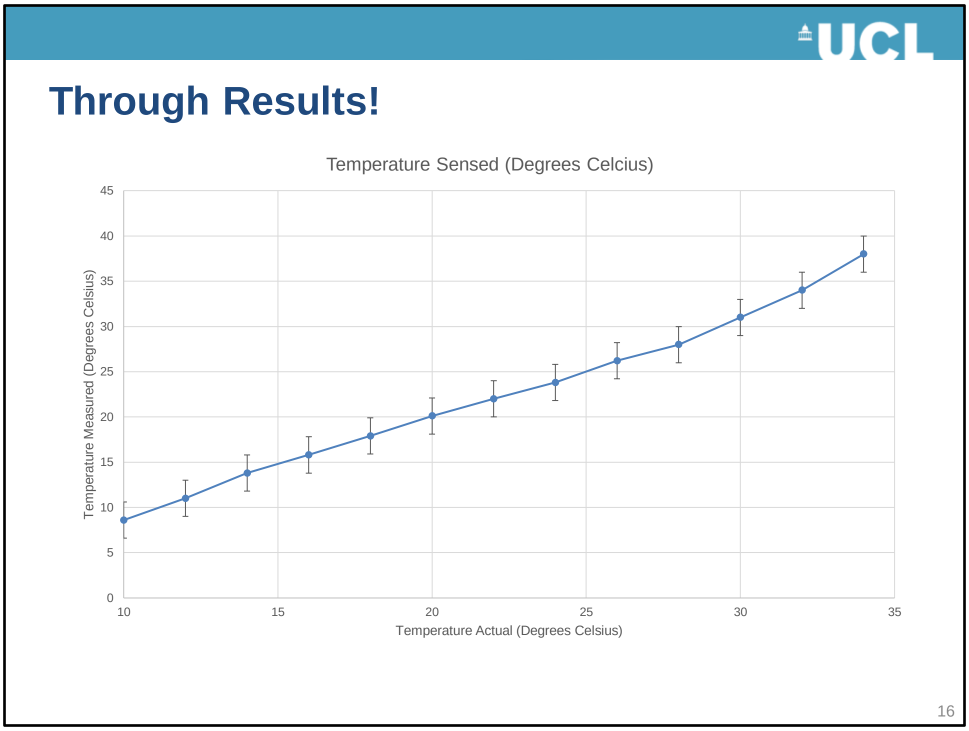
The answer to this question is No. As explained previously, your goal is to design and implement a system that meets a particular specification, and fits the needs of the user. Hence, while in the first instance, you will need to show that your system is actually functioning, for example, that the motor is spinning and that the heating element is heating, subsequently you will need to develop the algorithms and processes that will ensure this functionality is in accordance with the given design specification.

How can you prove your system has been designed properly and operates as specified?

So once you have implemented your system, how can you prove that you have been successful?



The answer is through results. Results and their subsequent analysis and discussion are THE most important aspect and contribution to this project. Generating sufficient results and analysing them appropriate will make or break your project. Hence, be sure to develop a comprehensive testing methodology that will consider the performance metrics that you will take into account, the graphs, figures and tables that you intend to produce, and how you will go about explaining the significance of these results in the context of the bioreactor control system, that is at the core of Challenge 2.

Think and explore

In your team, you should now identify and explain:

- What output is expected from each of the bioreactor input sensor devices.
- What inputs to each microcontroller are required.
- How the microcontroller will process these inputs.
- What is required of each microcontroller output.
- What is needed to drive each of the actuators (pumps, motors, heater) in the system.
- How the user interface will be connected.
- Where data will be stored.

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Now that you have watched this recording, you need to work together in your team to identify and explain:

What output is expected from each of the bioreactor input sensor devices.
What inputs to the microcontroller are required.
How the microcontroller will process these inputs.
What is required of each microcontroller output.
What is needed to drive each of the actuators (pumps, motors, heater) in the system.
How the user interface will be connected to the system.

Recall – Objectives and tasks

You need to produce:

- Block diagrams and structure charts for the overall bioreactor control system, and for each subsystem.
- Flow charts describing the functionality of each subsystem and the overall system.
- Wireframes for the display screens.

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To help you towards this task, refer to the design approaches and tools discussed earlier on, which will enable you to model your bioreactor system and its subsystems, describe its architecture and explain its functionality.

This concludes this recording. Thank you for watching and best of luck in modelling your bioreactor system!