For use by the Project lecturer	Approved		Revision required	

Feedback

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To be completed by the student				
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Title	Surname	Initials	Student no	Study leader (title, initials, surname)
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Project title

Design and implementation of a dual WiFi/cellular linked smart energy meter

Language editor name	Language editor signature
Jonathan Wagener	Jonathan Wagener
Student declaration I understand what plagiarism is and that I have to complete my project on my own.	**Study leader declaration** This is a clear and unambiguous description of what is required in this project. Approved for submission (Yes/No)
Student signature: Jonathan Wagener	Study leader signature and date: 28 JULY 2022

1. Project description

What is your project about? What does your system have to do? What is the problem to be solved?

With the growing popularity of connected devices and services, and amidst consumers' rising concerns of re-sustainable energy usage, there has been a growing desire for more information about the energy consumers use. Current "smart" energy meters which are accessible to consumers are limited as they are only able to report the total amount of energy consumed by all the devices connected to the circuit. If a consumer wanted to measure the energy consumption per load on the same circuit simultaneously it would require the use of multiple "smart" energy meters (one per load). The goal of this project is to design a single energy meter that can measure per device energy consumption on the same circuit when multiple loads are simultaneously in operation.

The system will have to identify individual loads using the energy profile/fingerprint of the individual loads when multiple loads are simultaneously in operation. This will then be used to calculate the energy consumed per load. The energy consumption data will be accessible to a user via a web page accessible over WiFi or cellular interface.

2. Technical challenges in this project

Describe the technical challenges that are *beyond* those encountered up to the end of third year and in other final year modules.

2.1 Primary *design* challenges

The main design challenge is designing an algorithm that can identify individual loads using the energy profile/fingerprint of the individual loads when multiple loads are in operation simultaneously. The design of this algorithm also needs to account for devices (such as dishwashers and washing machines) that go through cycles and, as a result, the energy profile/fingerprint and power usage of those devices is not always constant.

Many loads in households require little power to operate (LED lights) while some require large amounts of power to operate (kettles). The design challenge is the creation of a sampling subsystem that can account for this vast range of current draw while maintaining SNR at the low end. The subsystem needs to measure this small current draw signal reliably.

2.2 Primary *implementation* challenges

1) A live 230V service is dangerous – thus correct isolation is required. Safety measures should be implemented to ensure the safety of both the user and to protect the device. Should a failure occur, dangerous voltages and current should not be permitted to transfer to the rest of the device.

2) The target user of this device is likely not to have in-depth knowledge of energy or its measurement, so it should be intuitively usable and the data should be presented in such a way that laypersons will understand and interpret it.

3) Interfacing the machine learning model on an embedded platform to identify devices from the sampled data may present certain challenges.

3. Functional analysis

3.1 Functional description

Describe the design in terms of system functions as shown on the functional block diagram in section 3.2. This description should be in *narrative format*.

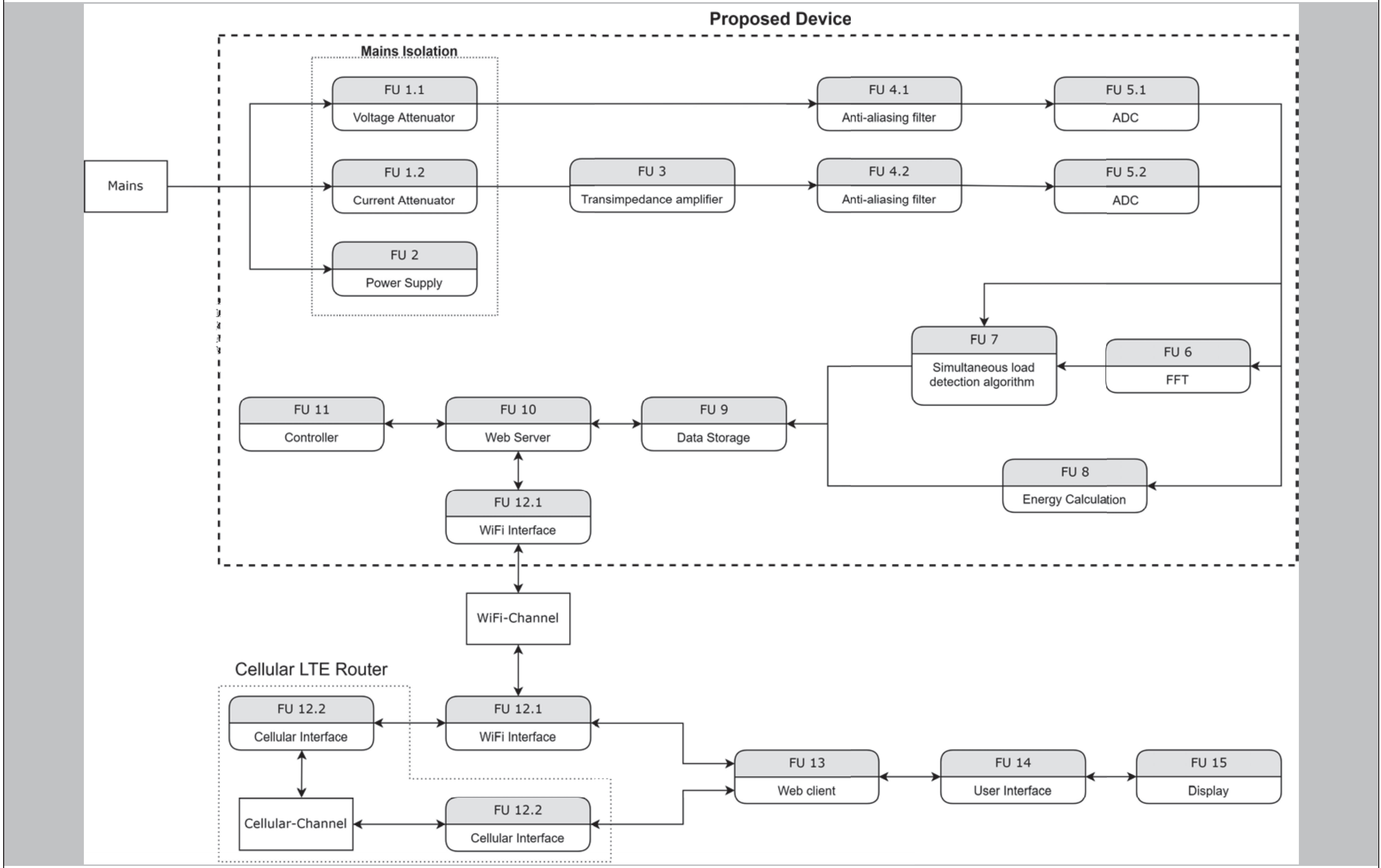
The device is connected to mains via a voltage attenuator (FU 1.1) and the current attenuator (FU 1.2) as well as a power supply (FU 2).

The voltage and current attenuators isolate the voltage and current, and convert it to levels that can be used to obtain the voltage and current measurements. The voltage signal is then passed through an anti-aliasing filter (FU 4.1) before it is sampled by an ADC (FU 5.1). The attenuated current signal follows the same steps as the voltage signal, but it is first converted to a voltage signal using a transimpedance amplifier (FU 3), then passed to the AA Filter (FU 4.2), and then sampled by an ADC (FU 5.2). The sampled voltage and current data is then passed through an FFT (FU 6).

Each of the loads that the device is designed to detect has a unique energy fingerprint. Functional Unit 7 (FU 7) is an algorithm which has been trained via machine learning to use the beforementioned energy fingerprints to detect which loads are simultaneously consuming energy. This is done by feeding the voltage (FU 5.1), current (FU 5.2), and FFT (FU 6) data into the model. FU 7 then processes this data and produces an output array containing the probabilities relating to the loads actively consuming energy at that moment in time.

The energy currently being consumed per identified load is calculated (FU 8). The consumed energy (FU 8) data and device identification (FU 7) data is then stored in a database (FU 9) which is then accessible through a web server (FU 10) and controlled by a controller (FU 11). The web server (FU 10) is accessible through a WiFi interface (FU 12.1) which is also connected to a cellular interface via an external WiFi Cellular Router - the latter also has a cellular interface (FU 12.2). The web client (FU 13) allows the user to interact via a user interface (FU 14) - the user can view the resulting data through a display (FU 15).

3.2 Functional block diagram



4. System requirements and specifications

These are the core requirements of the system or product (the mission-critical requirements) in table format IN ORDER OF IMPORTANCE. Requirement 1 is the most fundamental requirement.

	Requirement 1: the fundamental functional and performance requirement of your project	**Requirement 2**	**Requirement 3**
1. Core mission requirements of the system or product. Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.	Simultaneously and correctly differentiate between any combination of 5 - 10 devices.	Comply with the requirements stipulated by the IEC/AS 62053-21 to be classified as a class 2 energy meter.	Comply with the IEC 60038 Voltage Standards
2. What is the target specification (in *measurable* terms) to be met in order to achieve this requirement?	The device must be able to distinguish any combination of 5 - 10 household appliances that can be turned on simultaneously at unpredictable times, with a true positive rate (TPR) of 95%	The error in the power measurement of any combination of the loads that draw between 1.2 - 40 A connected should not exceed that of ±2.5%.	Able to measure a voltage in the range of 230V ±10% at 40 A (Most homes do not use more than 40 A at any one moment)
3. Motivation: *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)	A TPR of 95% will ensure that the correct loads are detected 28/30 times per minute, meaning that an incorrect detection lasts 2-4 seconds. The impact of a false positive identification on the total energy reported per load is, thus, negligible.	Meeting the above specifications will ensure that the energy measurement device is recognized as a class 2 energy meter and that it meets or exceeds the current standard for residential aplications.	The voltage line can vary between 207 - 253 Vrms. This means that the device needs to be able to measure over this range to comply with the above specification.
4. How will you demonstrate at the examination that this requirement (point 1 above) and specification (point 2 above) has been met?	The device will be connected to multiple loads in random unknown states. The device will then be powered on and report the sates of the connected loads. The states of the loads can then be altered at any point which will be reflected by the device	The combined energy measurement of the multiples of different device types connected will be confirmed to not exceed an error of ±2.5% regardless of the connected devices impedance.	The device will be set up over a number of days to monitor the power line. This will ensure that there is enough voltage variation to confirm that the device can tolerate the voltage fluctuations common in residential supplies.
5. Your own design contribution: what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*	The creation, implementation, training and deployment of the machine learning model used to identify loads that are consuming energy simultaneously.	Interfacing and accounting for tolerance errors in the mains interface and the ADC sampling stage.	The attenuation and sampling stage will be designed to meet or exceed the specifications by selecting the correct components.
6. What are the aspects to be taken off the shelf to meet this requirement? If none, indicate "none"	External device data sets will be used to develop the device fingerprinting. The embedded platform. The FFT algorithm.	Appliance/load with known and or measured energy consumption parameters. Discreate time based energy consumption formula.	The voltage and current interface devices will be taken off the shelf as well as the ADC.

System requirements and specifications page 2

	Requirement 4	Requirement 5	Requirement 6
1. **Core mission requirements of the system or product.** Focus on requirements that are core to solving the engineering problem. These will reflect the solution to the problem.	The system should be able to identify loads with low energy consumption.	The change in energy consumption of any connected device should be reflected in near realtime.	
2. **What is the target specification** (in *measurable* terms) to be met in order to achieve this requirement?	The device must be able to detect a load that consumes more than 2W of power.	The status of the energy consumption of any connected load should be updated in under 2 seconds.	
3. **Motivation:** *how* or *why* will meeting the specification given in point 2 above *solve the problem*? (Motivate the *specific* target specification selected)	Identifying loads that draw little power will allow the system to identify devices that are left on but, because they draw such little power, are often overlooked. This is problematic as such devices will still add to energy consumption over time.	Updating the energy consumption of any active device in under 2 seconds will result in an accurate energy meter that is able to allow a user to recognise active loads and their energy consumption near instantly.	
4. **How will you demonstrate at the examination** that this requirement (point 1 above) and specification (point 2 above) has been met?	The system will be connected to a load that is known to draw 2W of power along with other larger loads that are on simultaneously. The system will need to correctly identify and report the energy consumption of this load.	Multiple devices will be powered on. A load with the ability to alter it's power draw will be monitored. (e.g the power draw of a hair dryer) The device will report the change in power draw in under 2 seconds.	
5. **Your own design contribution:** what are the aspects that *you will design and implement yourself* to meet the requirement in point 2? If none, *remove this requirement.*	The detection and power measurement methods.	The detection algorithm.	
6. **What are the aspects to be taken off the shelf** to meet this requirement? If none, indicate "none"	The 2W load.	The clock source.	

5. Field conditions

These are the REAL WORLD CONDITIONS under which your project has to work and has to be demonstrated.

	Field condition 1	**Field condition 2**	**Field condition 3**
Field condition requirement. In which field conditions does the system have to operate? Indicate the one, two or three most important field conditions.	The system should be isolated from all other electrical loads which the system is not trained to detect.	The system should not be overloaded.	
Field condition specification. What is the specification (in measurable terms) for this field condition?	Only the specified loads which the system is designed to identify should be connected.	The combinations of loads connected to system should not exceed that of 8000W.	

6. Student tasks

6.1 Design and implementation tasks

List your primary design and implementation tasks in bullet list format (5-10 bullets). These are *not* product requirements, but *your* tasks.

- The design of a voltage attenuator.
- The design of a current attenuator.
- The design of a data logger subsystem to create data sets with known appliances.
- The design and training of a machine learning algorithm to detect individual appliances.
- The implementation of a machine learning algorithm on an embedded platform.

6.2 New knowledge to be acquired

Describe what the theoretical foundation to the project is, and which new knowledge you will acquire (*beyond* that covered in any other undergraduate modules).

- Require proficiency in professional level PCB design for final product to ensure a high quality device is delivered.
- Machine learning and model implantation on micro-controllers to correctly identify devices.
- Understanding and evaluating performance of identification models.
- Understanding safety standards (SANS, ISO, etc.) and designing the product accordingly.
- Professional documentation of the design process, as well as documentation regarding device usage.
- Modular component design to allow for simple integration and overall design.