James Dyson Undergraduate Bursary 2020/21

# Portable / Disposable System to Measure Liver Optical Backscatter

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## Introduction

The liver is a vital organ in the body, and is responsible for many important functions such as blood detoxification and producing chemicals required by the body. A patient with a faulty liver requires a liver transplant, with the NHS performing 922 transplants in the year 2019-20.

Sometimes the liver transplant can fail if the donor liver is too fatty, which can result in the patient dying. However, currently there is no rapid, near-patient, quantitative test to measure liver fat content. Instead, the opinion of the transplant surgeon is used, which is highly subjective and therefore can be inaccurate. A histological analysis could also be performed, but this increases the time the liver is outside the body, which in turn increases the risk of transplant failure. This project concerns the development of an optical probe which can be used to measure the fat content of donor livers.

This builds on research carried out by McLaughlin, Robertson et al. who discovered that measuring liver optical backscatter can give a good indication of whether a liver transplant will succeed or fail. When light is shone at a liver, some of the light is reflected back. The more fat droplets in the liver, the more light gets reflected. The reflected light can be measured and used to determine whether a liver is safe to transplant or not.

## System Requirements

A series of design requirements were made for the new system to ensure it performed as it was supposed to. The most important requirements were:

- The system needed to be simple for a surgeon to use with little prior training. Surgeries are often performed under high levels of stress, so the surgeon will not be able to focus solely on using the probe.
- The system needed to be low-cost to ensure that the NHS would see it as value for money and adopt it for clinical use. A suitable price is £45 for any disposable parts.
- The system needed to be sterilisable, so it was safe to use. The most common method of sterilisation in the NHS is the autoclave, where devices are heated to high temperatures (134°C) and pressures for 3-5 minutes. The system needed a hermetic seal to ensure that no pathogens could enter the device.

## System Architecture

To satisfy these requirements, the system was divided into two different devices: the remote unit and the base unit. The remote unit was a handheld unit which would take the measurements then transmit them back to the base unit. Only the remote unit needed to be fully sterilisable since it was the only part in direct contact with the liver. This meant that the minimum amount of electronics could be included in the remote to make it cheaper, so it could be disposed of if it was broken by the sterilisation process. The base unit could contain more expensive electronics, as it could be reused. The base would save the data to memory which could be uploaded to a computer when the surgery was finished. It also had a screen to show the surgeon what it was doing.

Because the remote unit was sealed, it had to be battery powered. Rechargeable batteries were selected, and a wireless charging system was required to charge these. A wireless communication system was also required for the remote unit to send the data back to the base. The full system architecture is shown in Figure 1.

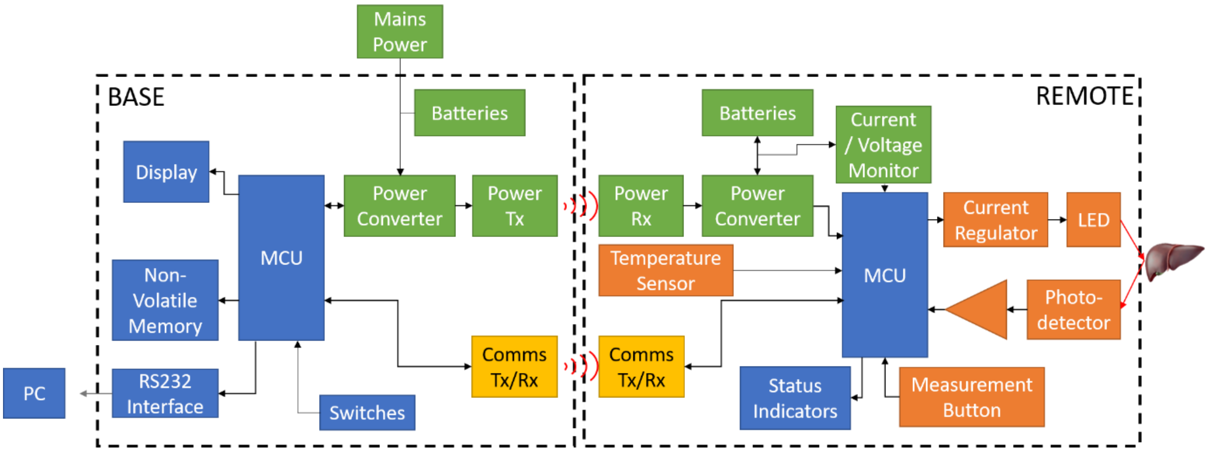


*Figure 1: System architecture, with key subsystems highlighted: measurements (orange), power (green), and communications (yellow).*

# Measurement System

The measurement system used an LED (light emitting diode) to shine infrared light at the liver, and a phototransistor to measure the reflected light. Phototransistors allow more current to flow if they have more light shining on them, so this signal indicated the fat content of the liver. This signal was amplified and input to a microcontroller, which could then process the information and send it to the base unit.

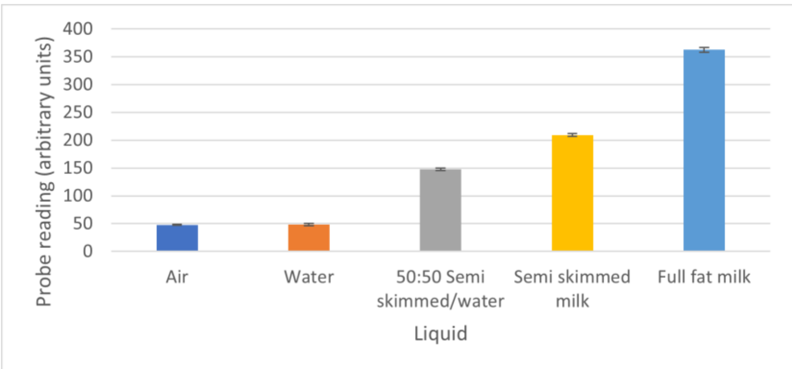


*Figure 2: System output when targeted at different liquids.*

The system was tested by aiming it at different liquids, which had different fat concentrations. Full fat and semi-skimmed milk were used, as they are biological substances and have different amounts of fat in them. Figure 2 shows that the system gives a much higher reading for full fat milk, and is much smaller for low-fat milk or water. The backscatter depends on whether there are lots of small droplets of fat in the liquid, which is why air and water give the same result as they are homogeneous.

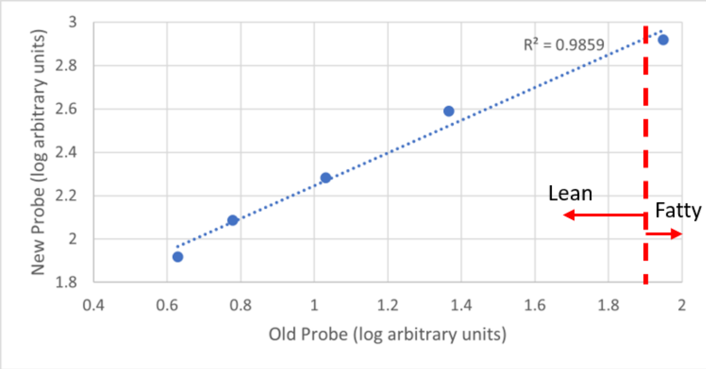


*Figure 3: Comparison of readings from the new probe and the original probe, when shone at white printer paper from different distances.*

The remote unit was also tested to see how well the readings correlated to the original design which underwent clinical trials. This was done by shining it at different distances from white printer paper, which simulated different fat concentrations as more reflected light is collected when the probe is closer to the paper. Figure 3 shows that the two devices are very well correlated, so the new version should perform similarly in clinic. The red line indicates the boundary between lean and fatty livers, so fatty livers can be simulated using a piece of paper 1cm away from the probe.

# Wireless Charger

*Figure 4: Two coils used in the wireless charger.*

The wireless charger used magnetic induction to provide power to the batteries. A square wave was applied to the primary coil, which generated an alternating magnetic field. This field coupled with a second coil, generating an alternating voltage in it. This was rectified to a DC signal which gave the charging current to the batteries.

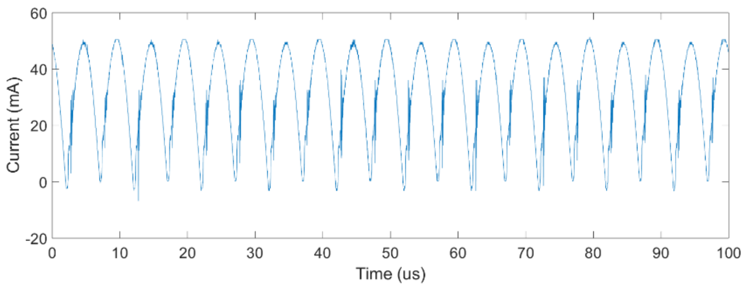


*Figure 5: Battery charging current waveform.*

Figure 5 shows the battery charging waveform, which has the shape of a rectified sinusoid. The DC average was 37mA, which would charge the batteries in 2 hours 10 minutes. This was a suitable “fast charge” time, to allow the device to be ready quickly when it is required for surgery.

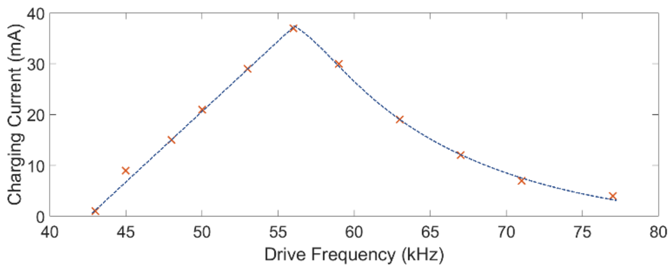


*Figure 6: Variation of the charging current with frequency.*

A resonant circuit was used to increase the current which could be delivered. The maximum current was given at 55kHz, and the current decreased as the drive frequency was moved away from this. This was useful, as it meant that the batteries could be kept on a constant "trickle charge" when they were not in use, which would make sure that they stayed charged but were not damaged by overcharging.

# Overall System

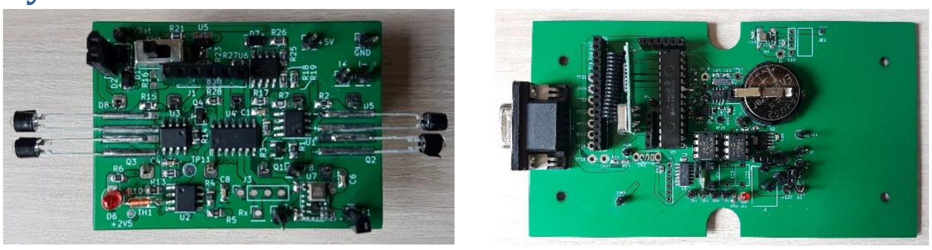

*Figure 7: Remote (left) and base (right) unit PCBs.*

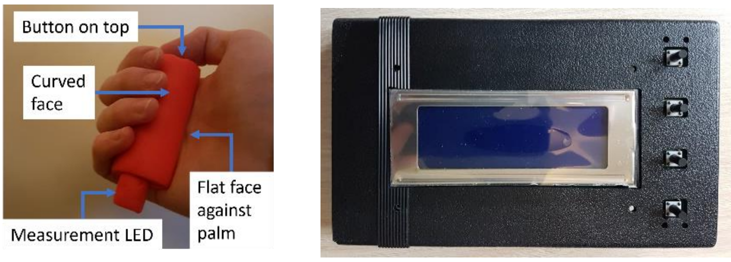


*Figure 8: Remote (left) and base (right) unit casings.*

Once the circuits were fully designed and prototyped, PCBs could be designed and manufactured (see Figure 7). Notably, on the remote unit PCB there are two LED phototransistor pairs, one at each end of the board. One of these is for the measurement system to scan the liver, and the other is an optical button for the surgeon to indicate when they want to take a measurement. When the surgeon places their thumb over the button, a lot of light is reflected to the probe, so the finger press can be detected.

Figure 8 shows the casings for the system. The remote unit will be cast in a resin to provide mechanical strength and a hermetic seal. It has a half cylinder shape, to ensure that it is placed the right way up on the charging pad, and to make it more comfortable to hold. The base unit includes an LCD screen to display measurements to the surgeon, and a series of buttons to select different options from the menu screen.

The overall system cost was £61, which was close to the recommended price of £45. This means the NHS will likely see it as value for money and adopt it for clinical use. Furthermore, the system has been designed to be reusable, which will also save costs and result in less waste. The initial results from the measurement system are promising, and in the future the device can progress to clinical trials to assert its utility.