EEEE3001

Final Year Individual Project Proposal

Fibre optic sensors for health monitoring

AUTHOR:	**Ms Kexin Yu**
ID NUMBER:	**20320941**
SUPERVISOR:	**Dr. Ricardo Correia**
MODERATOR:	**Dr. Mitchell Kenney**
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1 Overview

1.1 Background and Aim

As the population ages, older people are facing widespread health challenges. Hypertension affects more than 1 billion people globally and the UK has 1.32 billion records of cardiovascular disease medications dispensed between 2018 and 2021. [1] The advent of various modern biotechnology allows people to continuously detect their health parameters for better self-management and preventive measures. [2] The aim of this project is to compare two independent methods of measuring blood pressure on a non-invasive way, pulse arrival time and pulse transit time. This will be achieved by using conventional photoplephismography (PPG) and Fiber Bragg grating (FBG) for measurement of balistogram induced over the artery.
As shown in Figure 1.1, PPG sensor uses light from the LED to penetrate the skin, the blood absorbs different wavelengths of light and the photodiode measures the change in the amount of light absorbed to generate a pulse waveform signal for monitoring pulse.[3] As shown in Figure 1.2, the principle of FBG is through the grating structure in the optical fibre. When light encounters the grating, a specific wavelength of light is diffracted and forms a Bragg wavelength, pulse vibration causes a change in the wavelength, which can be used for pulse detection. [4] This project entails the creation of PPG, FBG sensors and models that can simulate blood flow in the human body. [5] Acquiring and analysing data from different devices under different motions can explore their correlations and complementarities, thus encouraging new sensor designs that better meet the needs of health monitoring and reduce the burden of healthcare expenditure.

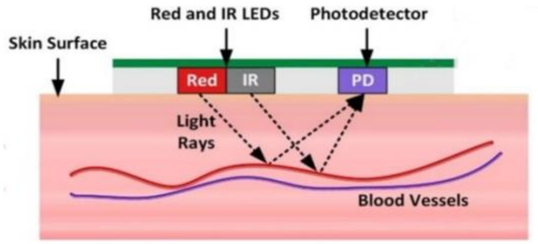

Figure 1.1: The working principle of PPG [3]

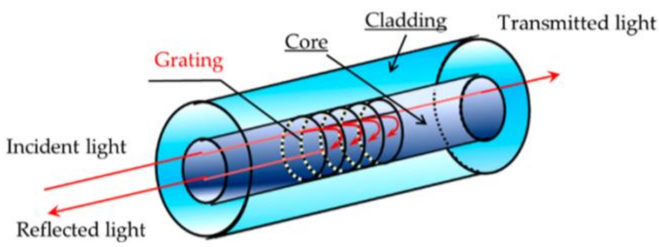

Figure 1.2: The working principle of FBG [4]

1.2 Block Diagram

Figure 1.3 shows the block diagram of this project which is divided into two parts based on software and hardware. The different experimental phases are also shown. The components required for the process and the key component-level design requirements are shown on the left and right sides of each subsystem.

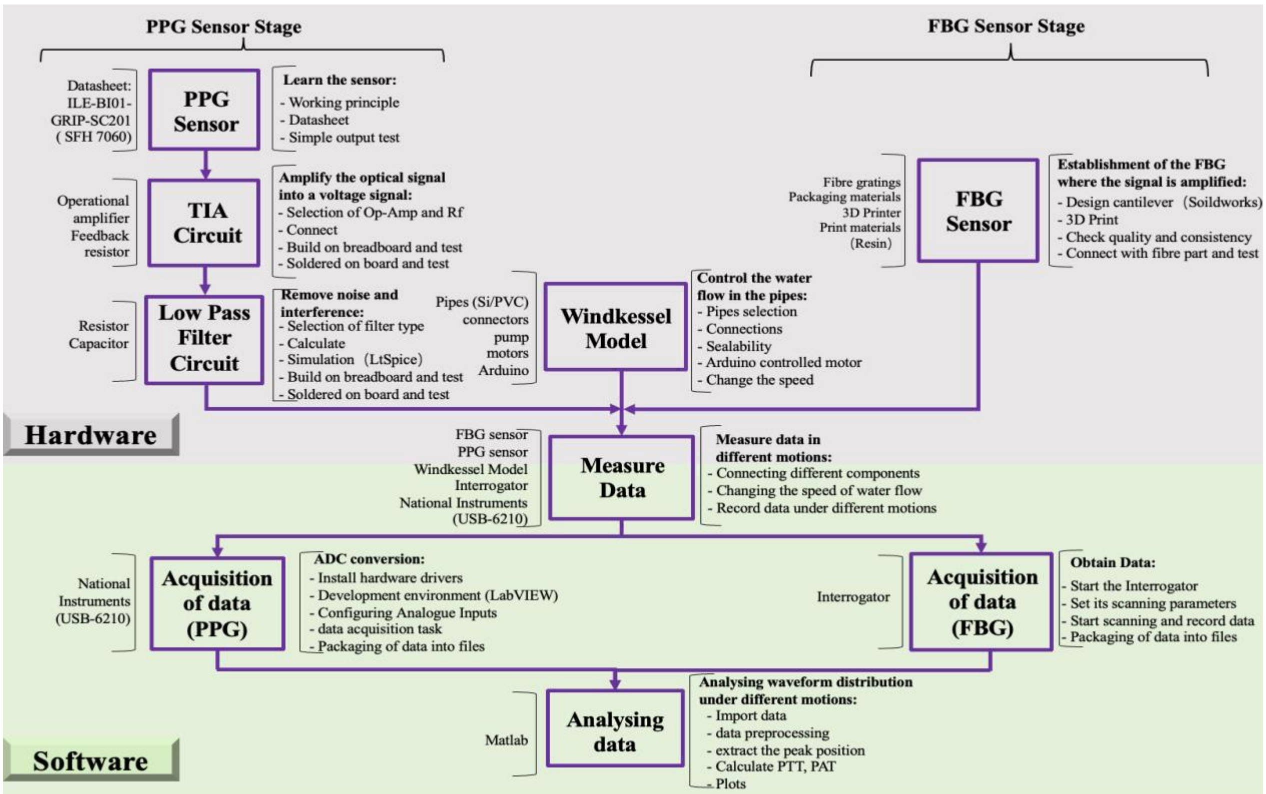

Figure 1.3: The block diagram of the FYP process

2 Specification (S)

Table 1: Requirements for FYP deliverables that can be used to measure the success of the project

Groups	Specification point Content and No.	Priority Level	Expected Challenges	Test methods and success criteria	Attainability and Realism
Hardware	**S1:** Build Windkessel model with steady water flow	High	1. Pipe sealing 2. Water flow stability 3. Motor control	1. When switching on the motor, check the stability of the water flow. 2. When changing the motor speed, check that the water speed changes.	Materials are available in the lab. Someone who has made a similar setup can give instructions, so it can be built in one day.
	S2: Build TIA Circuit that can convert and amplify signals	High	1. Op-Amp Selection 2. Rf Selection	Use a signal generator to input signals of different frequencies and observe the output on an oscilloscope to ensure that the circuit gain is as expected.	Op-amp and resistors can be found in the lab. Guidance from experienced, so it can be done in one week.
	S3: Build Low Pass Filter Circuit that can remove high frequency noise	Medium	1. Precise frequency selection 2. Signal amplitude variation	Use a signal generator to input signals of different frequencies and observe the output on an oscilloscope to ensure attenuation within the desired frequency range.	Capacitors, resistors can all be found in the lab, similar projects were done in previous lab week and can be completed in one day.
	S4: Build the overall PPG Sensor	High	1. Integrated circuits disturbed by noise 2. Ambient light sources affect its performance	Place it on the Windkessel model and use an oscilloscope to observe a stable signal with peaks characteristics.	Sensors can be purchased online. Instruments are available in the lab. Guidance from experienced, so it can be done in one week.
	S5: Build FBG and amplify signals with cantilever (Stretch: Optimise cantilever to improve signal amplification)	High (Stretch: Low)	1. 3D Printing Accuracy 2. Sensor size and steady (Stretch: Materials, size, quality of cantilever)	Consistent with design and amplified stable waveform with peaks is observed when connected to the FBG for testing. (Improved signal with more accuracy)	Materials and guidance from an experienced person are available so it can be done in two weeks. (Stretch needs one more week)
Software	**S6:** Acquire PPG signal with high quality and accurately timestamped	High	Unfamiliar with the use of NI and LabVIEW	Connect the hardware and write a code in LabVIEW to capture stable PPG signals and package it into a file as expected.	Most existing techniques use ESP32 or Arduino. NI can provide higher accuracy and it is available in the lab. The process can be completed in a fortnight.
	S7: Acquire FBG signal with high quality and accurately timestamped	High	Setting scanning values for Interrogator	Connect the FBG and interrogator. Start the interrogator to get stable data and package it into a file as expected.	Interrogator is available in the lab. [8]Easier and faster to get data than other methods, one week is enough
	S8: Use Matlab to draw the distribution of two methods under different motions (Stretch: Using machine learning algorithms to improve accuracy and reliability)	High (Stretch: Low)	1. Correctly imported data and pre-processed 2. Feature point location and calculation (Stretch: Learn Machine Learning Algorithms)	Write code in Matlab. The data can be read correctly, the pulse peaks are detected, and the graphs accurately reflect the distribution of PAT and PTT under different motions. (Optimised methods allow for automation and more efficient processing of data)	Relevant codes available online. Prior experience of using Matlab to process data and draw graphs, so can be completed in a fortnight (Stretch needs three weeks)

3 Methodology (M)

3.1 **Build Windkessel Model (M1):** Select suitable pipes (silicone/PVC), connectors, pump, small motors and connect them. Fill the pump with a certain amount of water. Switch on the motor and change the speed using Arduino programming. This model is used as the measured carrier, it is important for subsequent measurements. Choose this model can simplify the modelling process and save the time, as the methods of finding volunteers may delay the experimental cycle. [5] But this model is too simple compared to the real blood system to fully capture the biofluidic behaviour. Due to lack of experience, it is not possible to deeply understand the theory of the model. Therefore, it is better to read more articles.

3.2 **Build TIA Circuit (M2):** Select a suitable operational amplifier and determine the value of the feedback resistor (Rf). Build the circuit on a breadboard and test it with a signal generator and oscilloscope. Then, solder it to the board and test it again. This circuit is used to convert and amplify the PPG signal to make subsequent signals easier to record and analyse. The choice of Op-amp provides a high gain signal, but it is also more susceptible to noise and therefore requires the use of a low-pass filter in the next step.

3.3 **Build Low Pass Filter Circuit (M3):** Select the filter type and frequency range, calculate the capacitance value, resistance value and simulate it using LTSpice. Build the circuit on a breadboard and test it with a signal generator and oscilloscope. After that, solder it to the board, connect it to the TIA circuit and test it again. PPG signal after passing through this circuit can reduce the interference signal, which is very helpful for analysing the characteristic points.

3.4 **Build the whole PPG sensor (M4):** Study the specifications and pinout of the selected sensor (ILE-BI01-GRIP-SC201) and connect it to the TIA, low pass filter circuit. The module has high sensitivity in a specific wavelength range and is suitable for optical signal detection at specific wavelengths. Respond quickly to changes in optical signals and its specific package has good durability [6]. Querying a sensor in a field that has never been approached before, where there may be little information about the sensor, requires a deep study of the datasheet to be able to use it.

3.5 **Build FBG Circuit (M5):** A 3D model of the cantilever is designed using CAD software (SolidWorks) and imported into a 3D printer for printing (Resin). SolidWorks has an intuitive user interface that makes it easier to learn, and the resin used in the model allows for greater precision and durability. But even then, it takes some time to learn SolidWorks. Afterwards, the necessary reworking work and quality checks are carried out. Connect the FBG to the cantilever and test it with a signal generator and oscilloscope. These two components need to be connected more tightly to measurement pipes to obtain more accurate waveform data. However, the optical fibre used here can easily break and scratch the body [3]. Therefore, be careful of damage to the sensor. If time permits, the amplification of the signal can be improved by changing the material, size, geometry, and quality of the cantilever.

3.6 **Acquisition data for PPG (M6):** Install the hardware driver and development environment (LabVIEW). Connect the PPG outputs to the input channels of the NI (USB-6210) and connect the NI to the computer. Configure the analogue inputs using NI-DAQmx and write code in LabVIEW to start the data acquisition task using NI-DAQmx functions. Finally, package data into files. The data obtained can be used for subsequent waveform analysis. NI has better resolution and accuracy than microcontrollers like ESP32. [7] However, it is expensive to use and not easy to learn the LabVIEW programming language.

3.7 **Acquisition data for FBG (M7):** Connect FBG to the Interrogator, set scanning parameters to start scan and record spectral data. Finally, package the data into files. [8] With multi-channel support and high resolution, the interrogator accurately captures subtle changes in the FBG sensor for subsequent waveform analysis. However, it is expensive, less flexible and requires a certain working environment.

3.8 **Analysing data (M8):** Import data stored in files into Matlab ("Load" function). Perform a data preprocessing stage where the data is denoised, filtered, or aligned to ensure data quality and consistency (MATLAB's Signal Processing Toolbox). Uses an algorithm to extract the peak position of a pulse (Find Peaks function). Calculate PAT for PPG and PTT for FBG by locating feature points and sampling rates. [9] Then, use the same method for data under different motions. Plot the PAT and PTT distributions (box plots) under different motions. Matlab is relatively easy to learn and has a rich toolbox. If time permits, machine learning models can be selected and trained to perform feature specialisation on the data.

4 Risk Management and Mitigation

The following table is used to assess the risks and mitigation measures for this project. Different potential risks (R) have been numbered. The risks associated with the different methodologies (M) in Part III are also shown. The significance of the likelihood (L), severity (S), and risk level (RL) representations are shown below:

Likelihood (L): (1-5) 1--Very Low,2--Low,3--Possible, 4--Likely,5--Very likely
Severity (S): (1-5) 1--Very Low,2--Low,3--Moderate, 4--High,5--Very high
Risk Level (RL) = likelihood × Severity: (1-25)
1--Low,4--Lower Middle ,9--Middle, 16--Upper Middle,25--High

Table 2: Risk and Mitigation Measures Assessment Form for the FYP process

Occurrence Time	Type of Risks	Potential Risks	Mitigation Actions	L	S	RL	RL (Post)
Windkessel Model Stage	Cost / Time	**R1:** Motor breakdown **(M1)**	Purchase high-quality motors before the start of the project, test before the experiment and prepare spare motors as substitutes.	3	4	12	Low
	Time	**R2:** Leaking or blocked pipes **(M1)**	Ensure that the connections are intact before the experiment, use appropriately sized tubes and connectors. Avoid bends and angles.	3	3	9	Low
	Change in spec	**R3:** Water in the pump contacting circuit **(M1)**	Participate in safety training and follow safety procedures before project begins, cover circuits with enclosures and avoid contact with water.	2	5	10	Medium
PPG Senor Stage	Time	**R4:** Incorrect use of sensor pins **(M4)**	Contact the manufacturer for detailed specifications and pin definitions to ensure that understand the function and electrical characteristics of it.	3	3	9	Low
	Time /Change in spec	**R5:** Low-pass filter design errors **(M3)**	Perform circuit simulations such as LTSpice before designing the low-pass filter to ensure that the filter performs as expected.	3	3	9	Low
FBG Senor Stage	Time /Change in spec	**R6:** Sensor size mismatch **(M5)**	Ensure that the sensor size is matched to the measurement carrier during the design phase.	2	2	4	Low
	Time /Change in spec	**R7:** 3D model design and printing issues **(M5)**	Familiarise with 3D printing before this stage begins. Ensure that the design file is correct before printing, select the printer and material that meets the requirements, and adjust the printing parameters to ensure the quality of the product.	3	3	9	Low
Measuring and Analysing Data Stage	Time	**R8:** Hardware and software compatibility issues **(M6)**	Ensure that the selected hardware (NI USB-6210) is compatible with the LabVIEW version and install the latest drivers and LabVIEW development environment	3	4	12	Low
	Change in spec	**R9:** Sensor fixation and data logging issues **(M7)**	Ensure that the sensor is securely fastened to the test pipe to avoid loosening or shifting. Perform multiple data logging to ensure data consistency and accuracy.	3	3	9	Low
	Time	**R10:** Data acquisition task configuration error **(M6)**	Carefully plan the configuration of the data acquisition task before the project begins to avoid channel misconfigurations or sample rate setting problems. Set up a pre-test to ensure accuracy prior to formal data capture.	3	4	12	Low
	Change in spec	**R11:** Data analysis errors and noise**(M8)**	Data pre-processing, including denoising and filtering, using the Toolbox in MATLAB.	3	3	9	Low

5 Time Plan

Figure 5.1 shows the time plan of the project, as well as the Specification(S), Methodology(M), Risk(R), Deliverable(D) and Milestones(M) associated with each task. The content of each milestone and deliverable is located at the bottom. Alternative or parallel methods to certain tasks are in "()", and uncertainty in time is indicated by a lighter colour compared to normal.

Stage	S&M	D&Ms	R	Task	Weeks (Work 15hrs/week) 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33	Status
Preperation	/	/	/	Background reading		√
	/	D1	/	Lab induction, risk assessment forms and proposal		√
	S1,S4,S5	/	/	Learn the theory of the required hardware (FBG,PPG)		√
	S6,S8	/	/	Learn the theory of the required software (Labview)		
	/	Ms1	/	Complete introduction part for Final Year Report		
Hardware	S1&M1	D2	R1,2,3	Build Windkessel mode and test the seal first (Use two connections together)		
	S2&M2	/	/	Build TIA circuit and test on breadboard first		
	S3&M3	/	R5	Build Low pass filter circuit and test on breadboard first		
	S4&M4	D3	R4	Test the overall PPG sensor (Test individual modules first)		
	S5&M5	D4	R6,7	Build FBG sensor and amplify signal with cantilever (Use two types materials)	Winter Holiday; Exam Period; Spring Holiday	
	S5&M5	/	/	Stretch:Optimise cantilever to improve signal amplication		
	/	Ms2	/	Complete hardware part for Final Year Report		
Software	S6&M6	D5	R8,10	Acquire PPG signal by NI and LabVIEW (Or use Rasberry Pi)		
	S7&M7	D6&Ms3	R9	Acquire FBG signal by interrogator		
	S8&M8	D7&Ms4	R11	Use Matlab to to draw the distribution for FBG and PPG (Or use LabVIEW directly)		
	S8&M8	/	/	Stretch: Use machine learning to analysis data		
	/	D8&Ms5	/	Complete the overall Final Year Report		
Deliverables (D)					**D1:** A proposal about the overview, requirements, methods, risk assessment and time plan of the project.	√
					D2: A Windkessel model that simulates the flow of arteries in the human body under different conditions.	
					D3: A PPG sensor consists of a photoelectric módule, a TIA circuit, and a low pass filter circuit.	
					D4: An FBG sensor and a cantilever that amplifies its signal.	
					D5: A LabVIEW programming file can get PPG data.	
					D6: Acquired files of PPG and FBG data.	
					D7: A code file on Matlab capable of analysing data from different motion scenarios.	
					D8: A final year report and some transcripts of experimental procedures.	
Milestones (Ms)					**Ms1:** Accomplish all the preparation, including background reading, literature review and datasheet obtaining.	√
					Ms2: Complete hardware design. (Windkessel Model, PPG and FBG sensors).	
					Ms3: Acquire the measured PPG, FBG data and package it into files.	
					Ms4: Successfully analysing and comparing data measured by PPG and FBG under different motions.	
					Ms5: Finish final year report (Thesis).	

Figure 5.1: Time plan for the FYP

6 Reference

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