ESTIMATING CARDIAC OUTPUT FROM THE ARTERIAL BLOOD PRESSURE SIGNAL

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SUMMARY
Cardiac output (CO), the volume of blood pumped by the heart each minute, is routinely measured in critically-ill patients and during major surgery to provide information on the delivery of oxygen to the vital organs. Often the CO is estimated from the arterial blood pressure (ABP) signal based on a model of the circulation. These ABP-based methods require initial calibration using an independent technique, and can be used to monitor CO continuously thereafter. However, they have been found to be inaccurate, particularly when the state of the blood vessels changes. The aims of this project are: to assess the performance of algorithms to estimate CO from the ABP signal using a large clinical database; to identify factors which influence performance using simulated ABP pulse waves where reference cardiovascular properties are known precisely; and to develop a novel technique to automatically identify when the state of the blood vessels has changed, and therefore re-calibration is required.

1. INTRODUCTION
Cardiac output (CO), the volume of blood pumped by the heart each minute, is a key physiological parameter. A low CO may result in the vital organs are not receiving sufficient blood perfusion, and consequently being deprived of oxygen. CO is routinely measured during many surgical operations and in critically-ill patients. This enables clinicians to determine whether the CO is sufficient, or whether drugs and interventions are required to improve oxygen delivery. The most accurate ‘gold standard’ methods for measuring CO are either highly invasive, or can only provide intermittent CO estimates, making them unsuitable for use in several clinical scenarios. Several less accurate methods have been proposed for estimating CO from the arterial blood pressure (ABP) signal, with the advantages that this signal is already measured in many clinical scenarios so no additional invasive procedures are required, and they allow for continuous CO monitoring. These methods are based on a model of the circulation [1], which provides a theoretical basis for estimating CO from the shape of the ABP pulse wave. In practice, an initial gold standard measurement is taken, and this is used to calibrate the model, allowing CO to be monitored continuously thereafter using an ABP-based method. However, ABP-based methods become inaccurate if the state of the blood vessels changes, such as during the administration of drugs, since this affects the model calibration [1].

There are several outstanding questions about the use of ABP-based methods in clinical practice, including:

- How accurate are they, and which is most accurate?
- What factors affect performance by altering the state of the blood vessels, such as the administration of drugs?
- Is it possible to identify from the ABP signal when the state of the blood vessels has changed, and prompt clinicians to re-calibrate the device?

The aim of this project is to investigate these questions using both clinical data (allowing real-world performance to be assessed) and simulated data (allowing the effects of cardiovascular properties on performance to be assessed).

2. METHODS
Two databases will be used for this project: the MIMIC database, which contains ABP signals recorded from critically-ill patients [2], and (ii) a database of simulated ABP pulse waves [3]. The MIMIC database contains reference intermittent CO measurements acquired using the thermodilution method. Patients will be selected who had multiple reference CO measurements during their stay. The first reference measurement will be used to calibrate algorithms to estimate CO from the ABP signal, and then the performance of the algorithms will be assessed against subsequent reference CO measurements. This will allow the student to investigate the accuracy of the algorithms and identify the best-performing algorithm. The second database contains ABP pulse waves simulated under a range of cardiovascular conditions, including changes in CO, heart rate, arterial stiffness, and blood pressure. The reference values for CO and cardiovascular properties are known precisely. Similarly to the first database, algorithms will be calibrated using the baseline simulations, and then their performance will be assessed when different cardiovascular properties are changed. This will allow the student to investigate which cardiovascular properties influence the performance of CO algorithms.

The final, optional component of the project is to develop a technique to automatically identify when the state of the blood vessels has changed substantially, and therefore a re-calibration using a ‘gold-standard’ method is required. This technique will involve identifying when the shape of the ABP pulse wave has changed indicating that the blood vessels have changed. This will be performed using our in-house code for
analysing pulse waves, illustrated in Fig. 1 and described in [4].

3. OUTCOMES

In addition to the core outcomes of the Summer Research Module, this project provides opportunity to create a publicly available repository of CO estimation algorithms, providing the student with experience in making research resources publicly available. It is hoped that the student will submit a paper on their work to the 6th International Conference on Sensors and Applications, providing valuable experience in disseminating research to the wider scientific community.

4. RECOMMENDED READING

The following publications are recommended reading, and should form the basis of the literature review:

- The clinical importance of CO: [5, 6]
- Techniques for measuring CO: [7, 1, 8]
- Previous work on assessing CO algorithms using the MIMIC database: [9, 10, 11]
- Previous work on assessing CO algorithms using pulse wave modelling: [12]
- Other assessments of CO algorithms: [13]
- Statistical analysis of CO algorithm performance [14]

5. REFERENCES


