An Application of 24GHz RADAR for Contactless Heart Rate Monitoring

Department of Electronic and Computer Engineering

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LM118 Electronic & Computer Engineering – General Stream

Introduction

This project was specified in consultation with and partly funded by the Automated Transport & Safety department of Analog Devices, Inc. Limerick, with a large portion of the testing being conducted on University of Limerick campus. The goal is:

- Use the ADI Demorad 24GHz RADAR platform to measure cardiopulmonary movement at a distance of 1m from the subject with an accuracy of 90% or greater

This system would find its place in intelligent vehicles, more specifically the automated emergency services contact system of intelligent vehicles.

Aim

Write a prototype MATLAB script to control the Demorad and read Heart Rate data from it. When the prototype has been confirmed to be functional, test it in as noiseless an environment as can be found.

Using the an appropriate error metric, test whether the prototype passes the accuracy requirement outlined in the project definition.

Ideally at the end of this project one or more designs will exist which meet this accuracy requirement. These designs will go on to form the basis for the further research of this project

Method

This section will detail both the design method and the testing method employed during the course of this project.

Design Method:

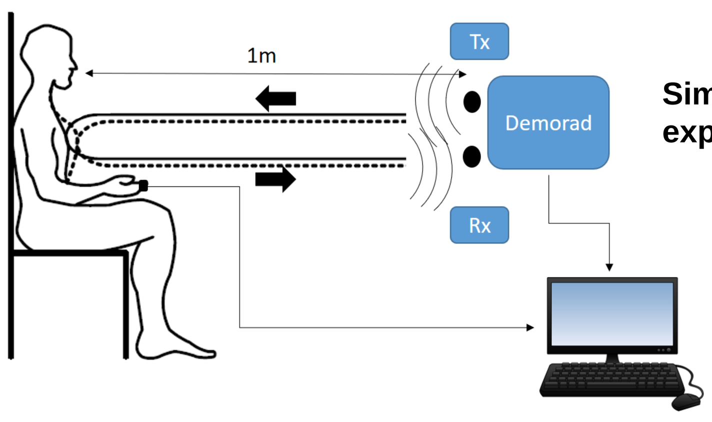
The resulting prototype from this design process will measure the distance from itself to the patient's chest wall over time and use this to discern the patient's heart rate. This design must therefore account for every factor contributing to the movement of the chest wall.

Main while loop of code, where data capture and signal processing in performed. Omitting code that establishes connection to board

Method

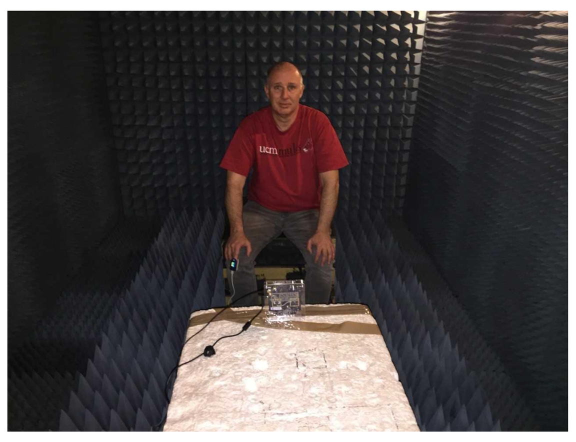
Testing Method:

In the interest of characterisation, this prototype was tested in the Anechoic chamber found in Main building, C-block, floor 0. Here a version of a Method Comparison study was performed (however the typical analysis performed on a Method Comparison Study was not appropriate for this experiment, as discussed in the results section), where the measurement taken from this prototype was compared against the "Gold Standard" SpO2 fingertip optical sensor.



Simplified diagram of experiment setup

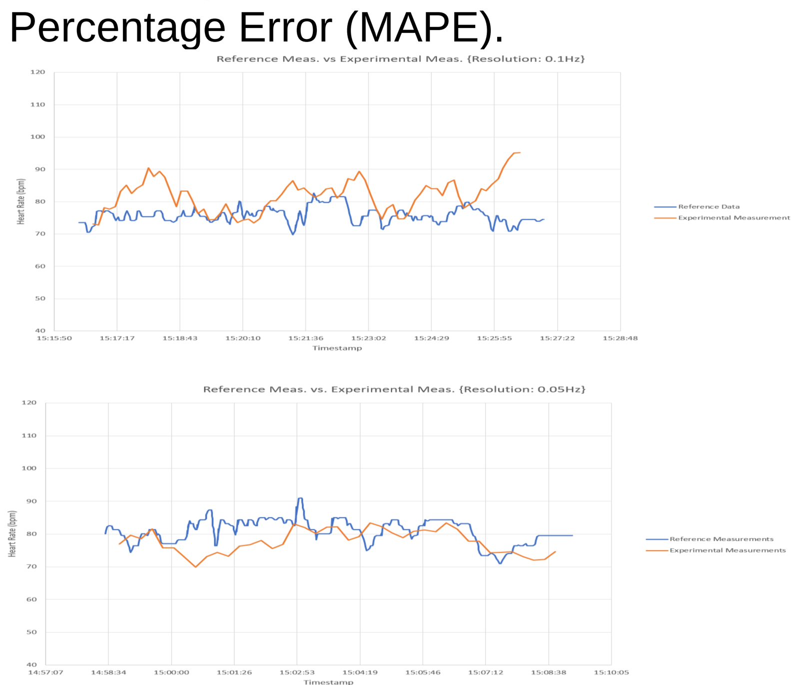
Dr. Bob Strunz in the Anechoic chamber during testing



Contec Pulse Oximeter; Sp02 measurement device. Used as a reference for this experiment.

Results

As mentioned previously, Method Comparison Study analysis was not appropriate for this project. This is because method comparisons need data which has a wide input value range. Here, the heart rate of the subject remained in the 70-90 bpm range, meaning that a scatter-plot drawn from this data would be clustered around one set of values. Performing time-series analysis proved far more useful. From the data gathered in the experiment the maximum error, average error and standard deviation of the error were tabulated for each design. Later, each design was compared based on their Mean Absolute Percentage Error (MAPE).



These are the output plots from the two best designs (1-Tap Sliding Average at 0.1Hz and 0.05Hz Resolution)

Table 1: 8-Tap Moving Average Filter – Resolution 0.1Hz

Maximum Error %	Average Error %	Standard Deviation %
58.4161	30.249	11.7456

Table 2: Gaussian Filter – Resolution 0.1Hz

Maximum Error %	Average Error %	Standard Deviation %
40.7561	0.2864	20.6596

Table 3: Gaussian Filter – Resolution 0.05Hz

Maximum Error %	Average Error %	Standard Deviation %
44.2768	-5.6783	20.5086

Table 4: 4-Tap Moving Average Filter – Resolution 0.1Hz

Maximum Error %	Average Error %	Standard Deviation %
26.7827	6.9336	10.2765

Table 5: 4-Tap Moving Average Filter – Resolution 0.05Hz

Maximum Error %	Average Error %	Standard Deviation %
29.5172	1.7969	13.9173

Table 6: 1-Tap Sliding Window Filter – Resolution 0.1Hz

Maximum Error %	Average Error %	Standard Deviation %
33.7621	7.8724	8.3567

Table 7: 1-Tap Sliding Window Filter – Resolution 0.05Hz

Maximum Error %	Average Error %	Standard Deviation %
15.9021	-3.715	5.334

Next we define Mean Absolute Percentage Error as:

$$MAPE = \frac{100\%}{n} \sum_{i=1}^{n} \left| \frac{Exp. - Ref.}{Ref.} \right|$$

And chart the MAPE of each design, ordered from worst to best:

Table 8: Rank – Ordering Filter Designs

Filter Design	Mean Absolute Percentage Error (%)
8-Tap Moving Average (0.1Hz)	30.249
Gaussian Filter (0.1Hz)	17.1244
Gaussian Filter (0.05Hz)	17.7495
4-Tap Moving Average (0.05Hz)	12.0955
4-Tap Moving Average (0.1Hz)	9.247
1-Tap Sliding Window (0.1Hz)	8.6673
1-Tap Sliding Window (0.05Hz)	5.1508

The 1-Tap Sliding Window design, with frequency resolution set to 0.05Hz performed the best, achieving error of 5.15% (accuracy = 94.85%). Two other designs also passed the test criteria, though with marginally worse performance.

Conclusion and personal reflection

As seen above, this prototype design more than achieved the accuracy requirement outlined at the beginning of the project. If this project were to be done again greater variations on test conditions would be attempted: more test subjects under different conditions (some who are deliberately slowing heart rate, others who are speeding it up, etc).

There is also a lot to be said for defining the type of experiment being carried out early on, here the data is gathered and analysed later. A more efficient approach would have been to figure out how to analyse the data immediately, then have that pre-programmed into the script. This would doubtless have saved time, but the end result would have been the same.

Acknowledgements

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