Charlie Maclean

Synthesis of Heart-Rate Detection Methods

Computer Science Tripos – Part II

King's College

December 27, 2019

Proforma

Name:	**Charlie Maclean**
College:	**King's College**
Project Title:	**Synthesis of Heart-Rate Detection Methods**
Examination:	**Computer Science Tripos – Part II, July 2020**
Word Count:	**TODO**[1]
Project Originator:	Dr Robert Harle
Supervisor:	Dr Robert Harle

Original Aims of the Project

To research and implement the detection of heart rate from smartwatch sensors. To investigate the effectiveness of a selection of filters and peak finding algorithms. To use accelerometer data to find motion artifacts within the data, and compare methods of removing these artifacts.

Work Completed

All that has been completed appears in this dissertation.

Special Difficulties

Learning how to incorporate encapulated postscript into a LaTeX document on both Ubuntu Linux and OS X.

[1]This word count was computed by `detex diss.tex | tr -cd '0-9A-Za-z \n' | wc -w`

Declaration

I, Charlie Maclean of King's College, being a candidate for Part II of the Computer Science Tripos, hereby declare that this dissertation and the work described in it are my own work, unaided except as may be specified below, and that the dissertation does not contain material that has already been used to any substantial extent for a comparable purpose.

Signed [signature]

Date [date]

Contents

List of Figures

Acknowledgements

This document owes much to an earlier version written by Simon Moore [1]. His help, encouragement and advice was greatly appreciated.

Chapter 1

Introduction

Elite runners have historically used heart rate to provide an accurate measure of fitness, and allow them to train more effectively. [Expand on uses of heart rate]. Previously, Electrocardiography (ECG) chest straps have been used to measure heart rate, by detecting the electrical signals controlling the expansion and contraction of the heart. They are accurate devices however often prohibitively expensive, and hence inaccessible to casual runners.

In recent years, a new technology has emerged - Photoplethysmogram (PPG) - light is directed at the skin, and sensors measure how much blood vessels scatter it. PPG sensors are cheaper than ECG sensors, and hence are available in a variety of products, particularly smartwatches. This innovation has bought a new wave of advanced training and monitoring onto the wrists of any runner.

Switching from ECG to PPG is not without flaws though - ECG sensors return a clean signal, as opposed to PPG signals which are contaminated with noise. [More details about noise].

In particular when running, the motion can cause blood velocity to change [3], and the sensor can slip across the skin [2]to the signal known as a motion artifact (MA). Fortunately, smartwatches contain other sensors, such as accelerometers and gyroscopes which can be used to predict the presence of MAs, and hence compensate for them.

My project is to research and develop a heart rate detection algorithm for smartwatches worn during running.

Chapter 2

Preparation

In this chapter we introduce the relevant concepts for this project.

2.1 Analysis of Existing Heart Rate Detection Methods

?? Do we want this ??

2.2 Heart Rate Detection

2.2.1 Filtering

Chapter 3

Implementation

3.1 Verbatim text

Verbatim text can be included using `\begin{verbatim}` and `\end{verbatim}`. I normally use a slightly smaller font and often squeeze the lines a little closer together, as in:

```
GET "libhdr"

GLOBAL { count:200; all  }

LET try(ld, row, rd) BE TEST row=all
                        THEN count := count + 1
                        ELSE { LET poss = all & ~(ld | row | rd)
                               UNTIL poss=0 DO
                               { LET p = poss & -poss
                                 poss := poss - p
                                 try(ld+p << 1, row+p, rd+p >> 1)
                               }
                             }
LET start() = VALOF
{ all := 1
  FOR i = 1 TO 12 DO
  { count := 0
    try(0, 0, 0)
    writef("Number of solutions to %i2-queens is %i5*n", i, count)
    all := 2*all + 1
  }
  RESULTIS 0
}
```

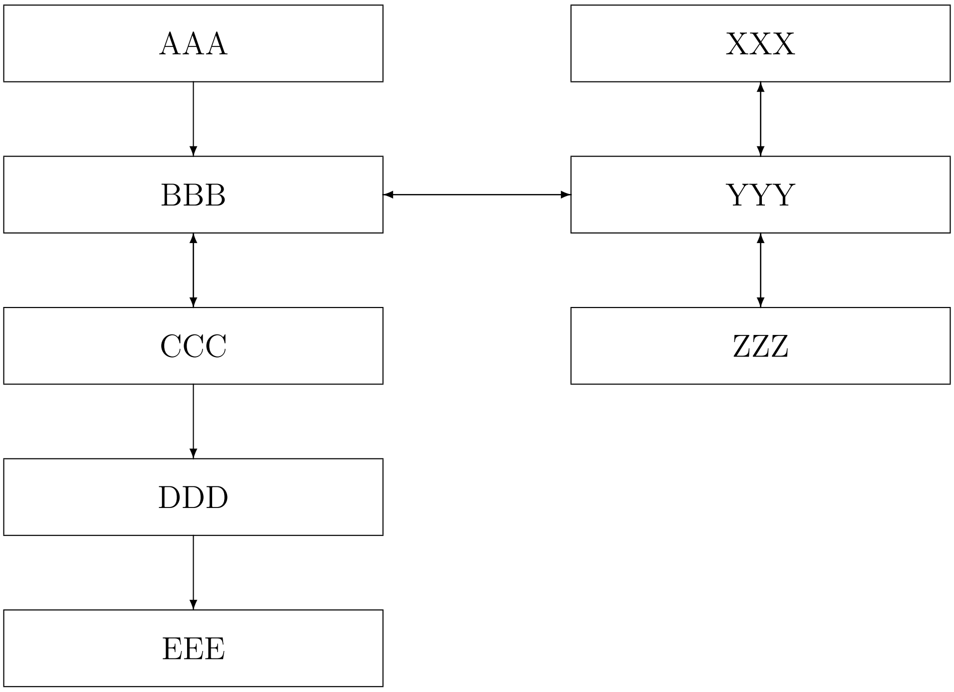

Figure 3.1: A picture composed of boxes and vectors.

3.2 Tables

Here is a simple example[1] of a table.

Left Justified	Centred	Right Justified
First	A	XXX
Second	AA	XX
Last	AAA	X

There is another example table in the proforma.

3.3 Simple diagrams

Simple diagrams can be written directly in LaTeX. For example, see figure 3.1 on page 14 and see figure 3.2 on page 15.

3.4 Adding more complicated graphics

The use of LaTeX format can be tedious and it is often better to use encapsulated postscript (EPS) or PDF to represent complicated graphics. Figure 3.3 and 3.5 on page 16 are

[1] A footnote

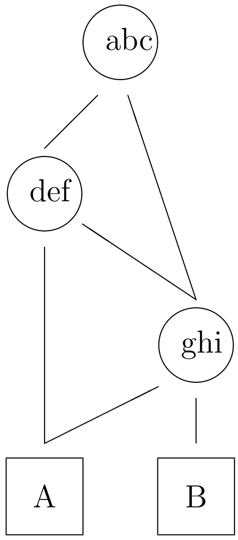

Figure 3.2: A diagram composed of circles, lines and boxes.

examples. The second figure was drawn using `xfig` and exported in `.eps` format. This is my recommended way of drawing all diagrams.

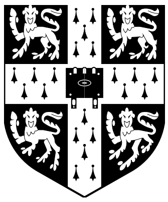

Figure 3.3: Example figure using encapsulated postscript

Figure 3.4: Example figure where a picture can be pasted in

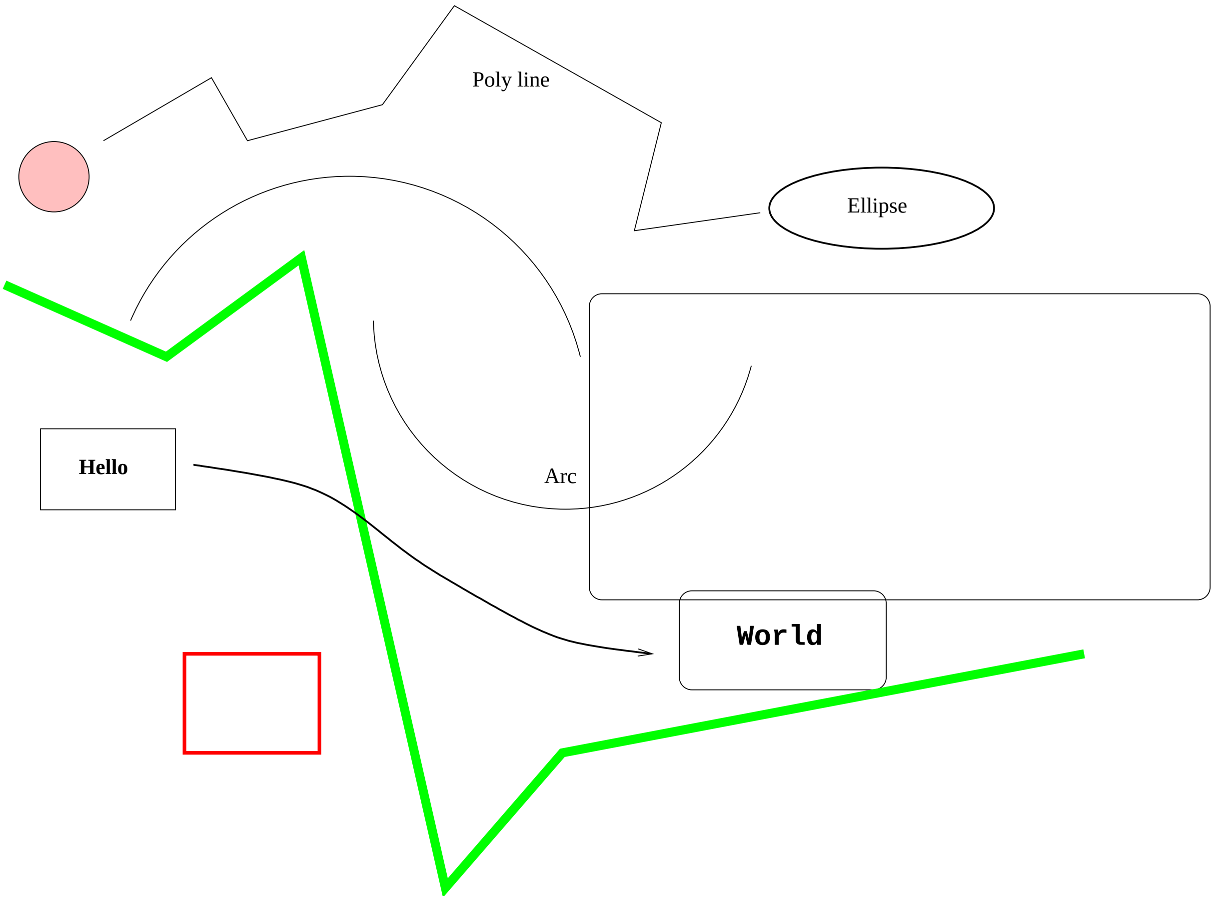

Figure 3.5: Example diagram drawn using `xfig`

Chapter 4

Evaluation

4.1 Printing and binding

Use a "duplex" laser printer that can print on both sides to print two copies of your dissertation. Then bind them, for example using the comb binder in the Computer Laboratory Library.

4.2 Further information

See the Unix Tools notes at
`http://www.cl.cam.ac.uk/teaching/current-1/UnixTools/materials.html`

Chapter 5

Conclusion

I hope that this rough guide to writing a dissertation is LaTeX has been helpful and saved you time.

Bibliography

[1] S.W. Moore. How to prepare a dissertation in latex, 1995.

[2] R. W. C. G. R. Wijshoff, M. Mischi, and R. M. Aarts. Reduction of periodic motion artifacts in photoplethysmography. *IEEE Transactions on Biomedical Engineering*, 64(1):196–207, Jan 2017.

[3] L. B. Wood and H. H. Asada. Noise cancellation model validation for reduced motion artifact wearable ppg sensors using mems accelerometers. In *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, pages 3525–3528, Aug 2006.

Appendix A

Latex source

A.1 diss.tex

```
% Template for a Computer Science Tripos Part II project dissertation
\documentclass[12pt,a4paper,twoside,openright]{report}
\usepackage[pdfborder={0 0 0}]{hyperref}    % turns references into hyperlinks
\usepackage[margin=25mm]{geometry}  % adjusts page layout
\usepackage{graphicx}  % allows inclusion of PDF, PNG and JPG images
\usepackage{verbatim}
\usepackage{pdfpages}


\raggedbottom                           % try to avoid widows and orphans
\sloppy
\clubpenalty1000%
\widowpenalty1000%

\renewcommand{\baselinestretch}{1.1}    % adjust line spacing to make
                                        % more readable

\begin{document}

\bibliographystyle{plain}


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Title


\pagestyle{empty}

\rightline{\LARGE \textbf{Charlie Maclean}}

\vspace*{60mm}
\begin{center}
\Huge
\textbf{Synthesis of Heart-Rate Detection Methods} \\[5mm]
Computer Science Tripos -- Part II \\[5mm]
King's College \\[5mm]
\today  % today's date
\end{center}

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Proforma, table of contents and list of figures

\pagestyle{plain}

\chapter*{Proforma}
```

```
{\large
\begin{tabular}{ll}
Name:               & \bf Charlie Maclean                       \\
College:            & \bf King's College \\
Project Title:      & \bf Synthesis of Heart-Rate Detection Methods  \\
Examination:        & \bf Computer Science Tripos -- Part II, July 2020  \\
Word Count:         & \bf TODO\footnotemark[1] \\
Project Originator: & Dr Robert Harle                   \\
Supervisor:         & Dr Robert Harle                   \\
\end{tabular}
}
\footnotetext[1]{This word count was computed
by \texttt{detex diss.tex | tr -cd '0-9A-Za-z $\tt\backslash$n' | wc -w}
}
\stepcounter{footnote}


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\bigskip
\leftline{Signed [signature]}

\medskip
\leftline{Date [date]}

\tableofcontents

\listoffigures

\newpage
\section*{Acknowledgements}

This document owes much to an earlier version written by Simon Moore
\cite{Moore95}.  His help, encouragement and advice was greatly
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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% now for the chapters

\pagestyle{headings}

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Elite runners have historically used heart rate to provide an accurate
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\subsection{Filtering}


\chapter{Implementation}

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{\renewcommand{\baselinestretch}{0.8}\small
\begin{verbatim}
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GLOBAL { count:200; all  }

LET try(ld, row, rd) BE TEST row=all
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                               UNTIL poss=0 DO
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                                 poss := poss - p
                                 try(ld+p << 1, row+p, rd+p >> 1)
                               }
                             }
LET start() = VALOF
{ all := 1
```

```
  FOR i = 1 TO 12 DO
  { count := 0
    try(0, 0, 0)
    writef("Number of solutions to %i2-queens is %i5*n", i, count)
    all := 2*all + 1
  }
  RESULTIS 0
}
\end{verbatim}
}

\section{Tables}

\begin{samepage}
Here is a simple example\footnote{A footnote} of a table.

\begin{center}
\begin{tabular}{l|c|r}
Left      & Centred & Right \\
Justified &         & Justified \\[3mm]
%\hline\\%[-2mm]
First     & A       & XXX \\
Second    & AA      & XX  \\
Last      & AAA     & X   \\
\end{tabular}
\end{center}

\noindent
There is another example table in the proforma.
\end{samepage}

\section{Simple diagrams}

Simple diagrams can be written directly in \LaTeX.  For example, see
figure~\ref{latexpic1} on page~\pageref{latexpic1} and see
figure~\ref{latexpic2} on page~\pageref{latexpic2}.

\begin{figure}
\setlength{\unitlength}{1mm}
\begin{center}
\begin{picture}(125,100)
\put(0,80){\framebox(50,10){AAA}}
\put(0,60){\framebox(50,10){BBB}}
\put(0,40){\framebox(50,10){CCC}}
\put(0,20){\framebox(50,10){DDD}}
\put(0,00){\framebox(50,10){EEE}}

\put(75,80){\framebox(50,10){XXX}}
\put(75,60){\framebox(50,10){YYY}}
\put(75,40){\framebox(50,10){ZZZ}}

\put(25,80){\vector(0,-1){10}}
\put(25,60){\vector(0,-1){10}}
\put(25,50){\vector(0,1){10}}
\put(25,40){\vector(0,-1){10}}
\put(25,20){\vector(0,-1){10}}

\put(100,80){\vector(0,-1){10}}
\put(100,70){\vector(0,1){10}}
\put(100,60){\vector(0,-1){10}}
\put(100,50){\vector(0,1){10}}

\put(50,65){\vector(1,0){25}}
\put(75,65){\vector(-1,0){25}}
\end{picture}
\end{center}
\caption{A picture composed of boxes and vectors.}
```

```
\label{latexpic1}
\end{figure}

\begin{figure}
\setlength{\unitlength}{1mm}
\begin{center}

\begin{picture}(100,70)
\put(47,65){\circle{10}}
\put(45,64){abc}

\put(37,45){\circle{10}}
\put(37,51){\line(1,1){7}}
\put(35,44){def}

\put(57,25){\circle{10}}
\put(57,31){\line(-1,3){9}}
\put(57,31){\line(-3,2){15}}
\put(55,24){ghi}

\put(32,0){\framebox(10,10){A}}
\put(52,0){\framebox(10,10){B}}
\put(37,12){\line(0,1){26}}
\put(37,12){\line(2,1){15}}
\put(57,12){\line(0,2){6}}
\end{picture}

\end{center}
\caption{A diagram composed of circles, lines and boxes.}
\label{latexpic2}
\end{figure}



\section{Adding more complicated graphics}

The use of \LaTeX\ format can be tedious and it is often better to use
encapsulated postscript (EPS) or PDF to represent complicated graphics.
Figure~\ref{epsfig} and~\ref{xfig} on page \pageref{xfig} are
examples. The second figure was drawn using \texttt{xfig} and exported in
{\tt.eps} format. This is my recommended way of drawing all diagrams.


\begin{figure}[tbh]
\centerline{\includegraphics{figs/cuarms.pdf}}
\caption{Example figure using encapsulated postscript}
\label{epsfig}
\end{figure}

\begin{figure}[tbh]
\vspace{4in}
\caption{Example figure where a picture can be pasted in}
\label{pastedfig}
\end{figure}


\begin{figure}[tbh]
\centerline{\includegraphics{figs/diagram.pdf}}
\caption{Example diagram drawn using \texttt{xfig}}
\label{xfig}
\end{figure}


\chapter{Evaluation}

\section{Printing and binding}
```

```
Use a ``duplex'' laser printer that can print on both sides to print
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\section{Further information}

See the Unix Tools notes at

\url{http://www.cl.cam.ac.uk/teaching/current-1/UnixTools/materials.html}


\chapter{Conclusion}

I hope that this rough guide to writing a dissertation is \LaTeX\ has
been helpful and saved you time.


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% the bibliography
\addcontentsline{toc}{chapter}{Bibliography}
\bibliography{refs}

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% the appendices
\appendix


\chapter{Latex source}

\section{diss.tex}
{\scriptsize\verbatiminput{diss.tex}}

\chapter{Makefile}

\section{makefile}\label{makefile}
{\scriptsize\verbatiminput{makefile.txt}}

\section{refs.bib}
{\scriptsize\verbatiminput{refs.bib}}


\chapter{Project Proposal}

\includepdf[pages=-,pagecommand={},width=\textwidth]{proposal.pdf}

\end{document}
```

Appendix B

Makefile

B.1 makefile

```
# This is the makefile for the Part II demonstration dissertation
#
# Note that continuation lines require '\' and
# that a TAB character preceeds any shell command line

.DELETE_ON_ERROR:

# Rules for building LaTeX documents (see Unix Tools course)
%.pdf %.aux %.idx: %.tex
	pdflatex -halt-on-error $<
	while grep 'Rerun to get ' $*.log ; do pdflatex $< ; done
%.ind: %.idx
	makeindex $*
%.bbl: %.aux
	bibtex $*
# Rules for exporting xfig diagrams into PDF or EPS
%.pdf: %.eps
	epstopdf --outfile=$@ $<
%.eps: %.fig
	fig2dev -L eps $< $@
%.pdftex %.pdftex_t: %.fig
	fig2dev -L pdftex_t -p $*.pdftex $< $*.pdftex_t
	fig2dev -L pdftex $< $*.pdftex

help:
	@echo
	@echo "USAGE:"
	@echo
	@echo "make                display help information"
	@echo "make proposal.pdf   format the proposal as PDF"
	@echo "make diss.pdf       format the dissertation as PDF"
	@echo "make all            make proposal.pdf and diss.pfd"
	@echo "make view-proposal  format and view the proposal"
	@echo "make view-diss      format and view the dissertation"
	@echo "make count          display an estimated word count"
	@echo "make pub            put demodiss.pdf onto your homepage"
	@echo "make clean          delete all intermediate files"
	@echo

view-%: %.pdf
	( okular --unique $< || evince $< ) &

diss.pdf: figs/cuarms.pdf figs/diagram.pdf makefile.txt diss.bbl

makefile.txt: makefile
```

```
        expand makefile >makefile.txt

count:
        detex diss.tex | tr -cd '0-9A-Za-z \n' | wc -w

all: proposal.pdf diss.pdf

pub: diss.pdf
        rsync -t $+ $(HOME)/public_html/demodiss.pdf

clean:
        rm -f *.aux *.log *.err *.out
        rm -f *~ *.lof *.toc *.blg *.bbl
        rm -f makefile.txt

distclean: clean
        rm -f figs/*.pdf proposal.pdf diss.pdf
```

B.2 refs.bib

```
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and reference manual",
AUTHOR = "Lamport, L.",
PUBLISHER = "Addison-Wesley",
YEAR = "1986"}

@REPORT{Moore95,
TITLE = "How to prepare a dissertation in LaTeX",
AUTHOR = "Moore, S.W.",
YEAR = "1995"}

@INPROCEEDINGS{Wood06,
author={L. B. {Wood} and H. H. {Asada}},
booktitle={2006 International Conference of the IEEE Engineering in Medicine and Biology Society},
title={Noise Cancellation Model Validation for Reduced Motion Artifact Wearable PPG Sensors Using MEMS Accelerometers},
year={2006},
pages={3525-3528},
doi={10.1109/IEMBS.2006.260359},
ISSN={1557-170X},
month={Aug},}

@ARTICLE{Wijshoff17,
author={R. W. C. G. R. {Wijshoff} and M. {Mischi} and R. M. {Aarts}},
journal={IEEE Transactions on Biomedical Engineering},
title={Reduction of Periodic Motion Artifacts in Photoplethysmography},
year={2017},
volume={64},
number={1},
pages={196-207},
doi={10.1109/TBME.2016.2553060},
ISSN={1558-2531},
month={Jan},}
```

Appendix C

Project Proposal

Charlie Maclean
King's
cm927

Diploma in Computer Science Project Proposal

Synthesis of Heart-Rate Detection Methods

December 18, 2019

Project Originator: Dr Robert Harle

Project Supervisor: *Dr Robert Harle*

Signature:

Director of Studies: *Dr Timothy Griffin*

Signature:

Overseers: *Dr Anil Madhavapeddy* and *Professor John Daugman*

Signatures: *<no need to obtain Overseers' signatures yourself>*

Introduction and Description of the Work

Heart-rate signals from watches are unreliable while exercising. Watches make use of photoplethysmography (PPG) sensors - sensors which detect the volume of blood in the skin and use variances in this to reconstruct a heart-rate. PPG sensors are preferred to the more accurate electrocardiogram (ECG) due to user comfort. However, the signals they provide are harder to process - I want to compare strategies to process these signals to extract heart rate.

There are several sources of noise within a PPG signal. There is often high frequency contamination caused by electrical interference or light from external sources. Additionally, there is a constant low frequency variation in the DC background of the signal, as a result of capillary density, blood volume and temperature variations.

In the context of running, motion caused by the arms swinging forward and back causes the sensor to slide along the skin, creating motion artifacts (MAs). These are particularly challenging as they can have a much larger amplitude than the pulse we are looking for. Additionally, they can be at the same frequency as the heart rate signal, making them challenging to filter out. Therefore, there is research [1][2] that suggests using accelerometer data in order to predict MAs. I will implement algorithms which find the MAs based on data from the accelerometer. Following this, I will look into the implementation of filters to remove these MAs.

In order to get accurate heart-rate measurements with which to compare the PPG signals, I will make use of an chest-mounted portable ECG. I will need to synchronize the signals received from the ECG and PPG, due to clock skew between the different devices. Potentially, there could be drift between the two clocks as well.

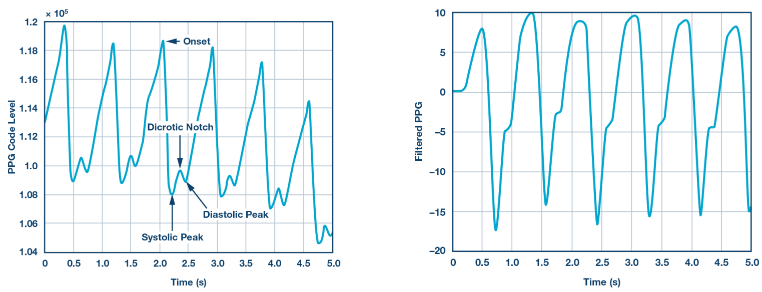

Figure 1: PPG signals before and after filtering [3]

Starting Point

Wearable Development

I will need to develop an application for the smart watch which will record PPG and motion signals without interruption. I will use Android Studio and Kotlin.

I have never used Kotlin before and have used Android Studio once before, but never to develop something for a wearable.

Digital Signal Processing

Manipulation of the PPG signals I receive will require much digital processing, and there are two languages I am considering using: MATLAB and Python.

I have never used MATLAB before, but I am familiar with Python.

Substance and Structure of the Project

Core

1. Developing a wearable application to capture PPG signals and motion data. I would like to develop this using Android Studio and Kotlin. I will need to make use of wake locks in order to ensure that the application can continuously record data.

2. Collecting data using a PPG-enabled watch and a portable ECG. I will record my heartbeat over the course of several runs.

3. Synchronizing signals. Implementation of an algorithm to synchronize the data output from the watch records to the data output from the portable ECG. I will have to develop a program to find the lag between the two signals.

4. Removing noise. Due to the various sources of noise, I will investigate potential low and high pass filters, to remove both high and low frequency disturbance.

5. Peak finding - implementing algorithms to find the actual beat given a clean PPG signal. Some potential algorithms are:

   (a) Adaptive threshold [4]

   (b) Wavelet transformation [5]

6. Finding MAs - implement an algorithm which uses the accelerometer in order to detect segments of the PPG which are likely to have been affected by motion.

7. Removal of MAs - implementation of filters to remove the previously detected MAs.

Possible Extensions

- Investigating PPG-enabled earbuds
  - Evaluation of the quality of heart-rate provided by earbuds
  - Exploring the potential to merge signals from a smartwatch and earbuds in order to provide a higher quality signal.
- There is research [6] to suggest gyroscope information is also helpful in filtering out MAs. I could include gyroscope data in my MA filtering technique.
- Comparing more heart-rate detection algorithms:
  - Digital filters
  - Adaptive filters
  - Singular value decomposition
  - Empirical mode decomposition
  - Spectrum analysis

References

[1] Z. Zhang. Photoplethysmography-based heart rate monitoring in physical activities via joint sparse spectrum reconstruction. *IEEE Transactions on Biomedical Engineering*, 62(8):1902–1910, Aug 2015.

[2] Z. Zhang, Z. Pi, and B. Liu. Troika: A general framework for heart rate monitoring using wrist-type photoplethysmographic signals during intensive physical exercise. *IEEE Transactions on Biomedical Engineering*, 62(2):522–531, Feb 2015.

[3] Foroohar Foroozan. Music-based algorithm for on-demand heart rate estimation using photoplethysmographic (ppg) signals on wrist, 2018.

[4] Ivaylo I. Christov. Real time electrocardiogram qrs detection using combined adaptive threshold. *BioMedical Engineering OnLine*, 3(1):28, 2004.

[5] Jake D. Campbell, Christopher G. Pretty, J. Geoffrey Chase, and Phillip J. Bones. Near-real-time detection of pulse oximeter ppg peaks using wavelet decomposition. *IFAC-PapersOnLine*, 51(27):146 – 151, 2018. 10th IFAC Symposium on Biological and Medical Systems BMS 2018.

[6] Alexander J. Casson, Arturo Vazquez Galvez, and Delaram Jarchi. Gyroscope vs. accelerometer measurements of motion from wrist ppg during physical exercise. *ICT Express*, 2(4):175 – 179, 2016. Special Issue on Emerging Technologies for Medical Diagnostics.

Success Criteria

The following should be achieved:

- Develop an application which records and stores PPG signals on a watch.
- Create program which synchronises ECG signals with PPG signals.
- Implement at least two filtering algorithms, demonstrate filtering works by displaying signals before and after filtering.
- Implement at least two peak finding algorithms, demonstrate they work by comparing peaks on the PPG signal to peaks on the ECG signal.
- Implement a MA detection algorithm.
- Be able to remove MAs, demonstrating that the peak finding algorithm is not affected by signals caused by motion.

Resources Required

I will use my own laptop. I will regularly backup my project to GitHub and an external HDD, so that I can recover data in the event of hardware failure. I accept full responsibility for this machine and and I have made contingency plans to protect myself against hardware and/or software failure.

I will use a smart watch, and a chest-mounted ECG sensor in order to collect data.

Timetable and Milestones

Weeks 1-2 (28/10/19 - 10/11/19)

- Project set-up:
  - Installation and setup of Android Studio.

  - Investigate and install an IDE for Python or MATLAB.
  - Use GitHub to set up a backup system for the project.
  - Learn to use Kotlin for the wearable app.

- Create a wearable app to record and store PPG and motion data, using Android Studio and Kotlin. Research into wake logs and interface design.

- Additionally, test application by recording data while running.

Weeks 3-4 (11/11/19 - 24/11/19)

- Collect data from runs.

- Build program to synchronize data between ECG and PPG (based on either heart rate variation or motion information).

- Researching and then implementing filters to remove both high and low frequency noise from the PPG signal.

Weeks 5-6 (25/11/19 - 08/12/19)

- Implement program to detect peaks in the signal.

- Begin writing dissertation document.

I will take the next week off.

Weeks 7-8 (16/12/19 - 29/12/19)

- Implement MA detection algorithm.

- Continue writing dissertation.

Weeks 9-10 (30/12/19 - 12/01/20)

- Implement MA removal algorithm.

- Continue writing dissertation.

Weeks 11-12 (13/01/20 - 26/01/20)

- Begin extension work, testing earbud HR detection against wrist-watches and portable ECGs.
- Continue writing dissertation.

Friday 31st January - Progress Report due

Weeks 13-14 (27/01/20 - 09/02/20)

- Extension work, testing whether earbud HR can be merged with wristwatch signal to create a more accurate output.
- Continue writing dissertation.

Weeks 15-16 (10/02/2020 - 23/02/2020)

- Extension work, including gyroscope feedback into the MA detection algorithm.
- Continue writing dissertation.

Weeks 17-18 (24/02/2020 - 08/03/2020)

- Extension work, including gyroscope feedback into the MA detection algorithm.
- Continue writing dissertation.

Weeks 19-20 (09/03/2020 - 22/03/2020)

- Writing dissertation.

Weeks 20-21 (23/03/2020 - 05/04/2020)

- Writing dissertation, aim to have first draft by second week of Easter holiday.

Weeks 22-26 (06/04/2020 - 08/05/2020)

- Continue improving dissertation.
- Leaving time for exam preparation.

Final deadline for dissertation 08/05/2020