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# Frequency-domain analysis of heart rate variability in passenger's motion sickness using fast fourier transform and autoregressive modeling

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**ABSTRACT** – Frequency-domain analysis of heart rate variability has been commonly used in determining the severity of motion sickness experienced by a human passenger in real road automated driving study. In this study, the analysis was done in terms of ratio of low-frequency (LF) over high-frequency (HF) component, using both Fast Fourier Transform (FFT) and Autoregressive Modelling (AR), based on the data of 14 participants. Results indicated that the average ratio of LF/HF analysed using the AR is lower than the one investigated using the FFT for every stage of the study.

## 1. INTRODUCTION

Different kinds of physiological measurements have been used in the past to investigate the severity of motion sickness. Analysis of heart rate activities in terms of beats per minute (BPM) has been used as the marker to indicate the severity of motion sickness experienced by the passenger inside an automated vehicle (AV). However, the increment or decrement of heart rate variability (HRV) does not indicate the regulations that occur in the human autonomic nervous system, namely its subdivisions the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). The SNS is responsible for preparing the body for a stressful condition ("fight or flight"). For example, the SNS helps the heart to work in a stressful situation by increasing the cardiac output. The PNS is responsible for bringing the body to a relaxation state ("rest or digest").

PNS withdrawal has been shown to indicate the development of motion sickness [1]. The withdrawal shows a response in preparation for a defensive stance or escapes from a potential threat such as motion sickness [2]. When motion sickness occurs, the stomach's activities (gastrointestinal) will shut down, and the flow of the blood will be directed to the other parts of the body (i.e., heart) under the "flight or fight" response. The digestion processes (gastrointestinal) will be paused until the threat is no longer present [2]. The regulations of the autonomic events by both the SNS and PNS can be quantified using the time- and frequency-domain analysis of ECG data.

## 2. METHODOLOGY

In this study, 14 people (6 males and 8 females aged between 24 and 34 years old (Mean = 28.4, SD = 2.7)) participated in this study participants were driven in a backseat of an instrumented vehicle which was built to mimic an AV in terms of driving and appearance (please see [3] for further explanation on the test setup). Only participants with mild and severe susceptibility were selected based on the Motion Sickness Susceptibility Questionnaire's scores (Mean = 79.9%, SD = 18.1%). All of the AV's test rides were done within the Eindhoven University of Technology's compound where Dutch traffic laws and regulations apply. The route consisted of three laps of 22 turns to the right, and 16 turns to the left (cornering radii, Mean = 9.2 m, SD = 3.3 m).

This research complied with the Netherlands Code of Conduct for Scientific Practice (principle 1.2 on page 5) [4]. In this study, the total time for the test ride was about 22 to 25 minutes. The first 5 minutes, HRV readings were taken in the rest or baseline condition where the participants were resting and performing a reading on a tablet. Then the next 12 to 15 minutes, the HRV readings were taken during the automated driving test ride (ADTR) along the route mentioned above while the participant was asked to continue performing the reading. The ADTRs were performed using a defensive automated driving style, as proposed by [5]. The HRV readings were kept to be taken for another 5 minutes after the vehicle was stopped, and the participant continued performing the reading using the tablet.

For the frequency-domain analysis of the HRV, the ECG signal was first transformed into different bands using the Fast Fourier Transform (FFT), which is the most used and accessible, and the newer autoregressive modelling (AR) [6]. The low-frequency (LF) band ranges from 0.04 to 0.15 Hz, while the high-frequency (HF) is between 0.15 to 0.40 Hz. The analysis was done using National Instrument LabVIEW Biomedical Toolkit

software. The ratio of LF to HF was calculated to reflect the sympathovagal balance. An increased LF/HF ratio indicates low vagal activation, which suggests the increase of experienced motion sickness [7].

## 3. RESULTS AND DISCUSSION

The ratio of LF over HF was analysed using FFT and AR spectral analysis and tabulated over the 25 minutes (see Table 1). The average ratio of LF/HF was found to be between 1.5 and 2.4 during the whole test rides. These results are in agreement with [8] for frequency analysis with at least 5 minutes of continuous recordings. The results were also plotted using the mean of the 14 participants' data over the three stages of the experiment (rest, driven, rest) (see Figure 1).

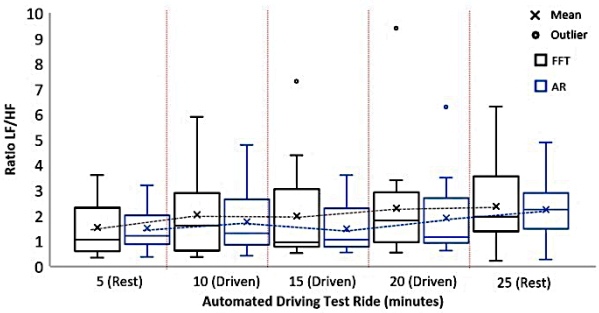


Figure 1 Ratio of LF/HF analysed using FFT and AR methods with mean and outlier values.

Table 1 Ratio of LF over HF Calculated using FFT and AR methods over the 25 minutes of ADTR

| | 1st 5 min (Rest) | | 10th min (Driven) | | 15th min (Driven) | | 20th min (Driven) | | Final 5 min (Rest) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FFT | AR | FFT | AR | FFT | AR | FFT | AR | FFT | AR |
| ID 001 | 3.0 | 3.0 | 5.9 | 4.8 | 2.8 | 2.2 | 2.8 | 2.6 | 3.5 | 2.8 |
| ID 002 | 1.6 | 1.6 | 2.5 | 2.5 | 3.8 | 2.6 | 3.3 | 3.0 | 2.5 | 2.6 |
| ID 003 | 1.0 | 1.2 | 0.6 | 1.1 | 0.7 | 0.8 | 1.0 | 0.7 | 0.2 | 0.3 |
| ID 004 | 1.1 | 1.4 | 0.4 | 0.4 | 1.0 | 0.7 | 0.8 | 1.0 | 1.7 | 1.6 |
| ID 005 | 3.2 | 3.0 | 2.5 | 2.1 | 2.0 | 1.1 | 1.1 | 0.9 | 3.9 | 3.9 |
| ID 006 | 2.1 | 1.2 | 2.1 | 1.3 | 1.4 | 1.1 | 2.1 | 1.2 | 1.9 | 2.5 |
| ID 007 | 1.0 | 1.0 | 3.8 | 3.3 | 4.4 | 3.6 | 3.4 | 3.5 | 1.3 | 2.2 |
| ID 008 | 2.0 | 1.7 | 0.6 | 0.7 | 0.5 | 0.9 | 0.9 | 1.0 | 2.0 | 1.7 |
| ID 009 | 0.6 | 0.7 | 1.1 | 1.5 | 0.5 | 0.6 | 1.8 | 2.0 | 1.4 | 1.1 |
| ID 010 | 3.6 | 3.2 | 2.6 | 1.3 | 0.9 | 1.7 | 1.8 | 1.1 | 2.7 | 3.2 |
| ID 011 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 | 1.0 | 1.1 | 0.9 | 1.6 | 1.7 |
| ID 012 | 0.6 | 1.0 | 4.1 | 3.1 | 7.3 | 3.0 | 9.4 | 6.3 | 3.7 | 2.3 |
| ID 013 | 0.4 | 0.4 | 0.9 | 0.7 | 0.8 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 |
| ID 014 | 0.4 | 0.7 | 0.6 | 0.9 | 0.9 | 1.0 | 2.2 | 1.8 | 6.3 | 4.9 |
| Avg. | 1.5 | 1.5 | 2.0 | 1.8 | 2.0 | 1.5 | 2.3 | 1.9 | 2.4 | 2.2 |

The analysis was done using FFT shown results that in general, are always higher in value compared to when AR was used. This results complied with a study in the past that FFT results are slightly higher than the AR when the same set of data were analysed, especially when in sitting position [9]. Besides, the data indicated that the passengers indicated higher LF/HF ratio during the automated driving stage when compared to the initial rest stage, both by using FFT or AR. The increment of the LF/HF pointed to the low vagal activation, which indicates the increase of experienced motion sickness.

## 4. CONCLUSION

Overall the results suggest that there are slight differences between analysis done using FFT and AR. The results found in this study are in agreement with past studies that show the FFT analysis value is usually higher than those found using AR analysis.

## ACKNOWLEDGEMENT

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# Editorial Preface

This open access e-proceedings contains a compilation of 170 selected papers from the 7th Mechanical Engineering Research Day (MERD'20) that was held virtually at Kampus Teknologi UTeM, Melaka, Malaysia, on 16 December 2020. The event was jointly organized by the Faculty of Mechanical Engineering and Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka. This year, MERD is also be co-organized by Graduate School of Engineering, Nagoya University, Japan.

It was gratifying to all of us when the response for MERD'20 is overwhelming as the technical committees received 230 submissions from various areas of mechanical engineering and related fields to facilitate the mutual understanding of fundamentals, theory and applications including Automotive, Additive Manufacturing, Advanced Materials and Processes, Computer Modeling and Simulation, CBM, Mechanical Vibration and Control, Energy Engineering and Management, Engineering Education, Mechanical Design and Optimization, Structural and Mechanical Testing, Surface Engineering and Tribology, Thermal and Fluids. All submitted papers are then peer-reviewed, revised according to the reviewers' comments and ultimately 170 papers were accepted for publication in this proceeding. This open access e-proceedings can be viewed or downloaded via www3.utem.edu.my/care/proceedings. We hope that this proceeding will serve as a valuable reference for researchers.

With the large number of submissions, the event has achieved its main objective which is to bring together educators, researchers, and practitioners to share their findings and perhaps sustaining the research culture in the university and industry.

As the editors-in-chief, we would like to express our gratitude to the fellow review members for their tireless effort in reviewing the submitted papers for this proceeding. We also would like to say special thanks to all the authors for promptly revising their papers according to the proceeding requirements. Special thanks are extended to the organizer of the MERD'20.

Thank you

*Mohd Fadzli Bin Abdollah*
*Hilmi Amiruddin*
*Amrik Singh Phawan Singh*
Editors-in-Chief
*Universiti Teknikal Malaysia Melaka*

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