School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg
ELEN3014 – Biomedical Signals, Systems and Control

Project – Human Lung Respiratory Mechanics

1 Introduction

The relationship between lung volume and pressure of the air breathed in can be modelled using an inductor, resistor, capacitor (IRC) respiratory mechanics model [1], [2], [3]. There are numerous types of respiratory models: the RC model, IRC model and Mead Model [2], [4]. This project will focus on the IRC model, which is shown in Figure 1 from [1].

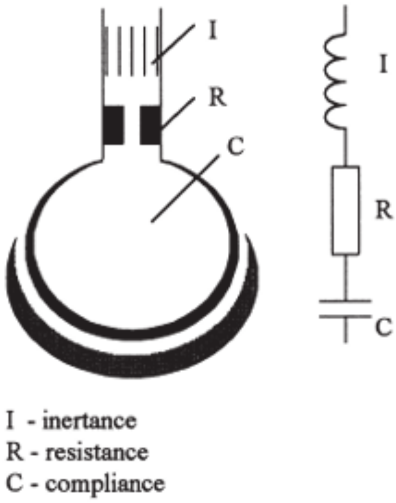

Figure 1: IRC respiratory mechanics lung model where I is the inertance of air and tissue, R is the flow resistance of the airway and the viscous properties of the tissue, and C is the elastic properties of lung and chest wall.

This project forms part of the summative assessment of the course, as defined by rule G13. It must be done individually. This project aims to expose students to the practical use of modelling, signal analysis techniques and control theory to explore the behaviour of a human physiological system.

2 Tasks

You are required to perform the following tasks, using Matlab to assist you.

1. Calculate the transfer function that relates the compliance (volume) of the lung to the pressure of the air breathed. This includes finding suitable values for components *I, R* and *C*.
2. Model and generate two suitable input time-series signals (15s long each), one for normal breathing and one for a person breathing when exercising.
3. Using your results from steps 1 and 2, generate the output time-series signals for both scenarios (normal breathing and breathing when exercising).

4. Analyse the frequency spectrums of the input and output signals for the two scenarios (normal breathing and breathing when exercising) for your IRC lung mechanics' model.
5. Discuss your results from steps 3 and 4 compared to typical physiological behaviour.

Furthermore, consider the case where the person exercising has got Asthma which primarily affects the airways of the lungs, causing inflammation, swelling, and increased mucus production [5]. These reactions lead to the narrowing of the airways, making it difficult to breathe. The alterations to the physical characteristics of the lung-airways translate to factor multiplications of the relevant parameters in the IRC lung mechanics model, resulting in a new plant model $P_2(s)$. You are required to identify which parameters of the IRC model are affected, the corresponding multiplication factors. Thereafter, correct for this change (as best as possible) using a control feedback system, as shown in Figure 2. Basically, you are aiming to return to the output waveform to normal.

6. Calculate the closed-loop transfer function $T(s)$. $X(s)$ will now serve as the input to the system and will thus be the same as the signal you generated in step 2.
7. Determine suitable gain values for controllers K and F to make the necessary correction.
8. Generate the corrected output waveform and compare to the corresponding responses of $P(s)$ and $P_2(s)$.
9. Compute the frequency response (Bode plot) of the closed-loop transfer function, $T(s)$ and compare to the corresponding responses of $P(s)$ and $P_2(s)$.

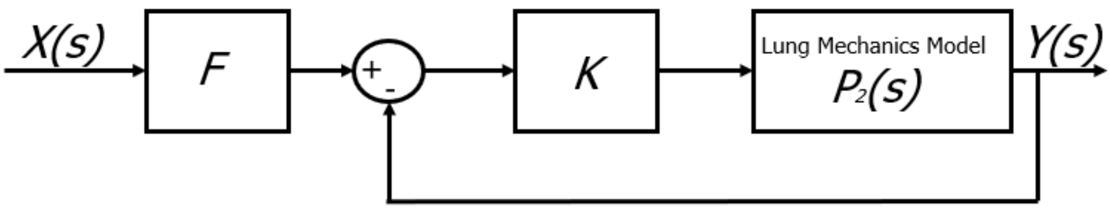

Figure 2: Negative feedback control system to correct for changes in the model $P(s)$. K and F are proportional gain controllers.

3 Assessment Criteria

The assignment will be assessed through a single report, in line with the outcomes of the course in terms of the following:

- Descriptively model systems and signals using block diagrams, mathematical equations and circuit diagrams. This involves relating the behaviour of the physical aortic system to parameters in the model and suitable choices of circuit components and input signal parameters.
- Employ mathematical tools (differential equations, Laplace/Fourier Transforms, and digital signal processing) to analyse systems and signals.

- Analyse the change in system behaviour based on changes to the system model parameters.
- Analysis of impact of control feedback system
- Report formatting

4 Report Structure

The report must follow the guidelines provided in the booklet “Communication and the Engineer". If you have not got one . . . GET ONE!!!

The report must be typed. The main text must be formatted as follows: **single-column, size 12 font, 1.5 line spacing.** Top, bottom, right and left margins must not be smaller than 2 cm. Text in tables and figures must not be less than 10 font. The report must be no longer than **five** A4 sides (excluding references). **No appendices are allowed.** Your Matlab code is must be submitted as a zipped file online only. Not more than 20% of the references may be web or internet articles. (Web articles do not include journals, books and conference papers that are found online.)

The report must be structured logically to address all the project tasks and assessment criteria described in Sections 2 and 3 respectively. It is strongly suggested that the report maximises on clear communication, concise sentences and a logical flow of information to make marking easier. Furthermore, the report must follow the following structure:

Section Number	Section name	Must include (but not limited to)
1	Introduction	• background of problem • summary of the application-specific problem • summary of solution • purpose of report • guide to rest of report
2	Modelling of systems in signals	• brief calculation of transfer function of P(s) • explain the development of the input signal • brief calculation of transfer function of $P_2(s)$ • brief calculation of transfer function of T(s) • Relate model parameters and signal pattern to reality
3	Time-series analysis	• Brief explanation of how outputs were calculated • Plots of outputs of P(s), P2(s) and T(s) • Comparison of waveforms to reality • Comparison of outputs from P(s) and T(s)
4	Frequency analysis	• Brief explanation of how FFTs were calculated • FFT plots of input and output signals • Show and compare Bode plots of P(s), P2(s) and T(s)
5	Critical analysis	• Description of how the disease impacted the behaviour of the lung system • Description of the positive and negative aspects your feedback control system to correct the lung breathing behaviour • An idea of how the feedback system could be implemented in reality
6	Summary and conclusions	

A separate title page must be added, which includes:

1. The title of the project, which must mention part 1
2. Course code
3. Your name
4. Your student number
5. Date of submission
6. Abstract

Your report project must be submitted o**nline (using Ulwazi)** in a single pdf document by the published deadline. Submit your Matlab code as a separate zip file via Ulwazi.

The School's policy on late submissions will be applied strictly to both submission formats. Both formats of report 1 must be handed in by the deadline: **12h00, 29 September 2025.**

5 References

[1] M. Schmidt, B. Foitzik, O. Hochmuth, and G. Schmalisch, "Computer simulation of the measured respiratory impedance in newborn infants and the effect of the measurement equipment," *Med. Eng. Phys.*, vol. 20, no. 3, pp. 220–228, 1998, doi: 10.1016/s1350-4533(98)00006-x.

[2] Z. Li, Y. Pei, Y. Wang, and Q. Tian, "An enhanced respiratory mechanics model based on double-exponential and fractional calculus," Front. Physiol., vol. 14, p. 1273645, 2023, doi: 10.3389/fphys.2023.1273645.

[3] P. Ghafarian, H. Jamaati, and S. M. Hashemian, "A review on human respiratory modeling," *Tanaffos*, vol. 15, no. 2, pp. 61, 2016

[4] A. B. Otis, C. B. McKerrow, R. A. Bartlett, J. Mead, M. B. McIlroy, N. J. Selverstone, and E. P. Radford Jr, "Mechanical factors in distribution of pulmonary ventilation," *J. Appl. Physiol.*, vol. 8, no. 4, pp. 427–443, 1956, doi: 10.1152/jappl.1956.8.4.427.

[5] D. A. Kaminsky and D. G. Chapman, "Asthma and lung mechanics," Compr. Physiol., vol. 10, no. 3, pp. 975–1007, 2020, doi: 10.1002/cphy.c190020.