Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

forward together
sonke siya phambili
saam vorentoe

Air quality measurement and logging in taxi ranks and inside of taxis

Willem Cornelis Rossouw
22823700

Report presented in partial fulfilment of the requirements of the module Project (E) 448 for the degree Baccalaureus in Engineering (Electrical and Electronic) in the Faculty of Engineering at Stellenbosch University.

Supervisor: Prof. MJ (Thinus) Booysen

May 2023

Acknowledgements

I would like to thank my supervisor Thinus Booysen for giving me this skripsie topic and for his enthusiasm in his work. I would also like to thank my friend and co-(soon-to-be)-engineer Phillip, for keeping me sane for most of my degree.

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT | forward together sonke siya phambili saam vorentoe

Plagiaatverklaring / *Plagiarism Declaration*

1. Plagiaat is die oorneem en gebruik van die idees, materiaal en ander intellektuele eiendom van ander persone asof dit jou eie werk is.
   Plagiarism is the use of ideas, material and other intellectual property of another's work and to present is as my own.

2. Ek erken dat die pleeg van plagiaat 'n strafbare oortreding is aangesien dit 'n vorm van diefstal is.
   I agree that plagiarism is a punishable offence because it constitutes theft.

3. Ek verstaan ook dat direkte vertalings plagiaat is.
   I also understand that direct translations are plagiarism.

4. Dienooreenkomstig is alle aanhalings en bydraes vanuit enige bron (ingesluit die internet) volledig verwys (erken). Ek erken dat die woordelikse aanhaal van teks sonder aanhalingstekens (selfs al word die bron volledig erken) plagiaat is.
   Accordingly all quotations and contributions from any source whatsoever (including the internet) have been cited fully. I understand that the reproduction of text without quotation marks (even when the source is cited) is plagiarism

5. Ek verklaar dat die werk in hierdie skryfstuk vervat, behalwe waar anders aangedui, my eie oorspronklike werk is en dat ek dit nie vantevore in die geheel of gedeeltelik ingehandig het vir bepunting in hierdie module/werkstuk of 'n ander module/werkstuk nie.
   I declare that the work contained in this assignment, except where otherwise stated, is my original work and that I have not previously (in its entirety or in part) submitted it for grading in this module/assignment or another module/assignment.

22823700 Studentenommer / *Student number*	 Handtekening / *Signature*
W.C. Rossouw Voorletters en van / *Initials and surname*	April 8, 2023 Datum / *Date*

Abstract

English

The English abstract.

Afrikaans

Die Afrikaanse uittreksel.

Contents

Declaration ii

Abstract iii

List of Figures vi

List of Tables vii

Nomenclature viii

1. Introduction 1
- 1.1. Background . . . 1
- 1.2. Problem Statement . . . 1
- 1.3. Objectives . . . 2
- 1.4. Scope . . . 2
- 1.5. Report Overview . . . 2

2. Background Study 3
- 2.1. Related Work and Existing Solutions . . . 3
  - 2.1.1. Related Work . . . 3
  - 2.1.2. Existing Solutions . . . 4

3. System Design 5
- 3.1. Microcontroller . . . 5
- 3.2. ESPNow/WiFi . . . 5
- 3.3. Sensors . . . 5
  - 3.3.1. $\mathbf{CO_2}$ . . . 5
  - 3.3.2. PM, $\mathbf{NO_x}$, VOC . . . 5
- 3.4. Metrics . . . 5

4. Detailed System Design 6
- 4.1. ESP32 . . . 6
- 4.2. Sensors . . . 6
  - 4.2.1. $\mathbf{CO_2}$ . . . 6
  - 4.2.2. PM, $\mathbf{NO_x}$, VOC . . . 6

5. Results **7**

6. Summary and Conclusion **8**

Bibliography **9**

A. Project Planning Schedule **10**

B. Outcomes Compliance **11**

C. Appendix **12**

List of Figures

1.1. Unleaded 1
1.2. Metal+ Unleaded 1
1.3. Diesel 1

3.1. Hardware and Interface Overview (Base station on the left and Satellite station on the right) 5

C.1. Airthings table 12

List of Tables

Nomenclature

Acronyms and abbreviations

PM	Particulate Matter
VOC	Volatile Organic Compounds
UART	Universal Asynchronous Receiver / Transmitter
i2c	Inter-Integrated Circuit
UFP	Ultrafine Particle
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
PPM	Parts Per Million
PPB	Parts Per Billion

Chapter 1

Introduction

1.1. Background

The majority of South Africa's public sector uses taxis as a means of transport. Millions of commuters use taxis frequently and depend on them for all of their mobility needs [1]. The South African government has recognized the impact of taxi emissions on air quality and has taken steps to address the issue. In 2006, the government gazetted regulations that required taxi operators to convert their vehicles to run on cleaner fuels, such as liquefied petroleum gas (LPG), compressed natural gas (CNG), or diesel with lower sulfur content [2]. However, the implementation of these regulations has been slow and often ineffective as seen in the extract below in figures 1.1, 1.2 and 1.3, resulting in continued poor air quality in many areas. Instead of using expensive and inconvenient formal public transportation like buses and trains, they offer an accessible and affordable substitute. As a result, the effects of air quality in taxis on human health and the impact of taxi exhaust emissions are issues unique to South Africa.

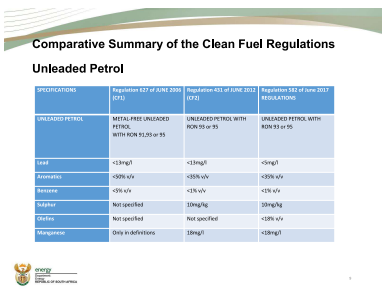


Figure 1.1: Unleaded

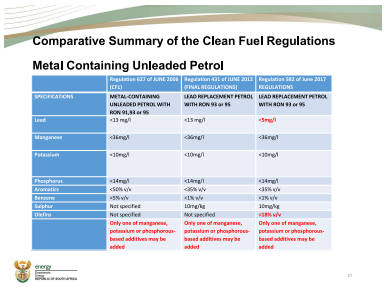


Figure 1.2: Metal+ Unleaded

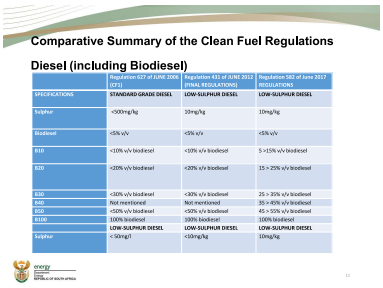


Figure 1.3: Diesel

Charts provided by [2]

1.2. Problem Statement

Despite the popularity and importance of taxis in South Africa, there is a lack of research on the air quality inside and outside of these vehicles. Air quality is a crucial factor for human health and well-being, especially for commuters who spend long hours in taxis

exposed to various pollutants. Moreover, taxi emissions contribute to the overall air pollution in crowded spaces(in this case taxi ranks), which affects the environment and the quality of life of the passers by. The closest studies being that of inside single cab taxis [3], road based pollution [4] and general pollution [5]. Therefore, there is a need for a comprehensive study on the air quality in taxis and taxi ranks and its impacts on human health and the environment.

1.3. Objectives

The objective of the study will be as follows:

- To measure and compare the levels of CO2, VOC, particulate matter and NOx both inside taxis and in taxi ranks to that of a known baseline.
- Identify the primary sources of air pollution in taxi ranks and within taxis and evaluate the impact of environmental factors, such as traffic congestion and weather conditions(optional- time limited).
- To investigate the potential health risks associated with exposure to air pollution in taxi ranks and within taxis, particularly for passengers, drivers and potential third parties.
- To evaluate the effectiveness of current measures in place to reduce air pollution from taxis, such as emission standards and regulations.
- Propose potential strategies to mitigate the impact of from taxis on public health and the environment such as implementing new technologies.

1.4. Scope

The scope of the project encompasses only the following:

- Building of base station and portable sensor module
- Development of communication network for satellite module and base station as well as data storage and backup
- Deployment of sensor and network
- Analysis of data gathered

1.5. Report Overview

Chapter 2

Background Study

2.1. Related Work and Existing Solutions

2.1.1. Related Work

Air quality at bus stops [6]

This article was a case study of air quality monitoring at a bus stop in an underpass on the campus of Lancaster University. The bus stop was suspected to have high levels of air pollution due to the large number of vehicles passing through the tunnel. They used an Aeroqual AQY Micro Air Quality Station to measure the concentrations of NO_2, PM_{10} and $PM_{2.5}$ at the bus stop.

Exposure to traffic air pollutants in taxicabs [3]

This study reviewed the level of pollutants present inside taxi cabs(American style taxis). The article reports that the exposure studies show that traffic related air pollutants concentrations inside taxicabs are higher than their urban background. This was a research based study.

An investigation into the environmental impact of the taxi industry in Butterworth [5]

This study analysed the environmental impact of the taxi industry in South Africa, by surveying a fleet of taxis in Butterworth, they do simple analogue measures such as dust gauges and soil and water analysis.

2.1.2. Existing Solutions

Aeroqual AQY

This sensor was used in a similar study done to determine the air quality at bus stops [6]. The sensor solution used consists of sensors for the following along with provided ranges [7]:

- Particulate matter ($PM_{2.5}$ & PM_{10}) 0-1000 µg
- Ozone
- Nitrogen Dioxide 0-500 ppb
- Temperature and Relative Humidity
- Dew point

This sensor lacks Carbon Dioxide measuring and lacks detailed specification on ranges' error.

Airthings View Plus

This sensor suite was designed for home use, it features:

- Particulate matter ($PM_{2.5}$ 0-200µg
- Carbon dioxide 400–5000 ppm
- VOC
- Radon

This sensor was not intended to be extremely accurate and seems to be more for sensing danger than accurate measuring. It does include a handy chart for what should be considered normal levels for the different sensors as seen in Figure C.1

Chapter 3

System Design

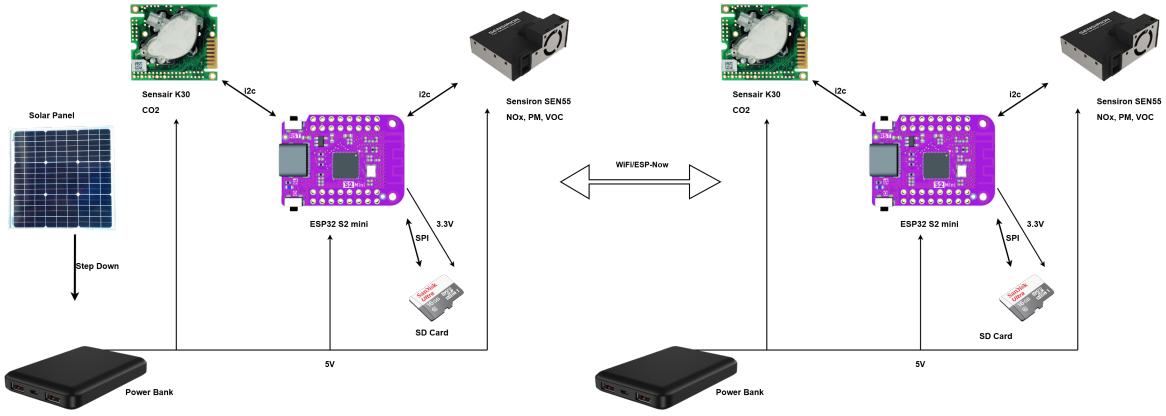


Figure 3.1: Hardware and Interface Overview
(Base station on the left and Satellite station on the right)

3.1. Microcontroller

3.2. ESPNow/WiFi

3.3. Sensors

3.3.1. CO_2

3.3.2. PM, NO_x, VOC

3.4. Metrics

Chapter 4

Detailed System Design

4.1. ESP32

4.2. Sensors

4.2.1. CO_2

4.2.2. PM, NO_x, VOC

Chapter 5

Results

Chapter 6

Summary and Conclusion

Bibliography

[1] "Public transport," https://www.transport.gov.za/public-transport, 2023, accessed: 2023-03-12.

[2] "South africa clean fuels strategy," https://www.samsa.org.za/Other%20Forms/Workshop%20Presentations/Marpol%20Sulphur%20Cap%202019%20Presentations/South%20Africa%27s%20Clean%20Fuels%20Strategy.pdf, 2019, accessed: 2023-04-04.

[3] M. Hachem, N. Saleh, A.-C. Paunescu, I. Momas, and L. Bensefa-Colas, "Exposure to traffic air pollutants in taxicabs and acute adverse respiratory effects: A systematic review," *Science of The Total Environment*, vol. 693, p. 133439, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048969719333595

[4] Y. Sun, P. Brimblecombe, P. Wei, Y. Duan, J. Pan, Q. Liu, Q. Fu, Z. Peng, S. Xu, Y. Wang, and Z. Ning, "High resolution on-road air pollution using a large taxi-based mobile sensor network," *Sensors*, vol. 22, no. 16, 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/16/6005

[5] M. NOAH, "An investigation into the environmental impact of the taxi industry in butterworth," p. 13, 01 2002. [Online]. Available: https://repository.up.ac.za/bitstream/handle/2263/7888/090.pdf?sequence=1&isAllowed=y

[6] F. S. B. McGann, "Air quality monitoring at bus stops – lancaster university case study," Mar 2020. [Online]. Available: https://www.linkedin.com/pulse/air-quality-monitoring-bus-stops-lancaster-university-francine

[7] AQMD, "Aeroqual aqy v1.0." [Online]. Available: http://www.aqmd.gov/aq-spec/sensordetail/aeroqual-aqy-v1.0

Appendix A

Project Planning Schedule

This is an appendix.

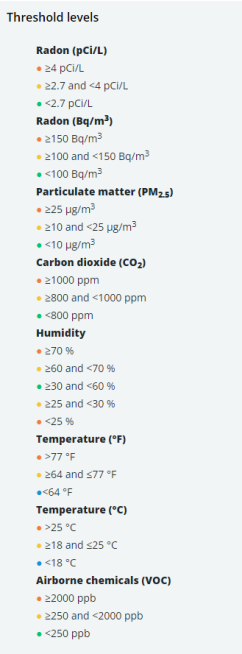
Appendix B

Outcomes Compliance

This is another appendix.

Appendix C

Appendix



Threshold levels

Radon (pCi/L)
- ≥4 pCi/L
- ≥2.7 and <4 pCi/L
- <2.7 pCi/L

Radon (Bq/m³)
- ≥150 Bq/m³
- ≥100 and <150 Bq/m³
- <100 Bq/m³

Particulate matter ($PM_{2.5}$)
- ≥25 µg/m³
- ≥10 and <25 µg/m³
- <10 µg/m³

Carbon dioxide (CO_2)
- ≥1000 ppm
- ≥800 and <1000 ppm
- <800 ppm

Humidity
- ≥70 %
- ≥60 and <70 %
- ≥30 and <60 %
- ≥25 and <30 %
- <25 %

Temperature (°F)
- >77 °F
- ≥64 and ≤77 °F
- <64 °F

Temperature (°C)
- >25 °C
- ≥18 and ≤25 °C
- <18 °C

Airborne chemicals (VOC)
- ≥2000 ppb
- ≥250 and <2000 ppb
- <250 ppb

Figure C.1: Airthings table