Low Cost Sensor Monitoring using Mesh Connected Ultra-Low Power Long-Range Transceivers

by

Pieter Goos

Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Electrical and Electronic) in the Faculty of Engineering at Stellenbosch University

Supervisor: Mr. A. Barnard

March 2021

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: ....2020/11/01..........

Abstract

Low Cost Sensor Monitoring using Mesh Connected Ultra-Low Power Long-Range Transceivers

P. Goos

Department of Electrical and Electronic Engineering,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Thesis: MEng (EE)

March 2021

Vibrating a tillage tool is an effective way of reducing the draft force required to pull it through the soil. The degree of draft force reduction is dependent on the combination of operating parameters and soil conditions. It is thus necessary to optimize the vibratory implement for different conditions.

Numerical modelling is more flexible than experimental testing and analytical models, and less costly than experimental testing. The Discrete Element Method (DEM) was specifically developed for granular materials such as soils and can be used to model a vibrating tillage tool for its design and optimization. The goal was thus to evaluate the ability of DEM to model a vibratory subsoiler and to investigate the cause of the draft force reduction.

The DEM model was evaluated against data ...

Uittreksel

Lae Koste Sensor Monitor Systeem wat Mesh-Verbind, Ultra-lae Krag, Lang Aftstands Versenders Gebruik

("Low Cost Sensor Monitoring using Mesh Connected Ultra-Low Power Long-Range Transceivers")

P. Goos

Departement Elektries en Elektroniese Ingenieurswese,
Universiteit van Stellenbosch,
Privaatsak X1, Matieland 7602, Suid Afrika.

Tesis: MIng (EE)

Maart 2021

Om 'n tand implement te vibreer is 'n effektiewe manier om die trekkrag, wat benodig word om dit deur die grond te trek, te verminder. Die graad van krag vermindering is afhanklik van die kombinasie van werks parameters en die grond toestand. Dus is dit nodig om die vibrerende implement te optimeer vir verskillende omstandighede.

Numeriese modulering is meer buigsaam en goedkoper as eksperimentele opstellings en analitiese modelle. Die Diskrete Element Metode (DEM) was spesifiek vir korrelrige materiaal, soos grond, ontwikkel en kan gebruik word vir die modellering van 'n vibrerende implement vir die ontwerp en optimering daarvan. Die doel was dus om die vermoë van DEM om 'n vibrerende skeurploeg the modelleer, te evalueer, en om die oorsaak van die krag vermindering te ondersoek.

Die DEM model was geïvalueer teen data ...

Acknowledgements

I would like to express my sincere gratitude to the following people and organisations ...

Dedications

Hierdie tesis word opgedra aan …

Contents

Declaration **i**

Abstract **ii**

Uittreksel **iii**

Acknowledgements **iv**

Dedications **v**

Contents **vi**

List of Figures **viii**

List of Tables **ix**

Nomenclature **x**

1 Introduction **1**
1.1 Background 1
1.2 Objectives 2
1.3 Methodology 2
1.4 Scope of the Research 2
1.5 Thesis Structure 2

2 Background **3**
2.1 SatSim 3

3 SatSim **4**
3.1 Terrestrial 4

4 Verifying SatSim Results **5**
4.1 Scope 5

5 Hardware Selection **6**
5.1 Scope 6

6 Hardware Design with Software Implementation **7**
6.1 Scope 7

7 Hardware Verification and Comparison to SatSim **8**
7.1 Scope 8

8 Conclusions **9**
8.1 Scope 9

Appendices **10**

A Discrete Element Method Theory **11**
A.1 Ball elements 11

List of References **12**

List of Figures

A.1 Ball Element Parameters 11

List of Tables

Nomenclature

Constants

g =	$9.81\,\mathrm{m/s^2}$	

Variables

Re_{D}	Reynolds number (diameter)	[ ]
x	Coordinate	[m]
$\ddot{x}$	Acceleration	[$\mathrm{m/s^2}$]
θ	Rotation angle	[rad]
τ	Moment	[N·m]

Vectors and Tensors

$\vec{\boldsymbol{v}}$	Physical vector, see equation ...

Subscripts

a	Adiabatic
a	Coordinate

Chapter 1

Introduction

1.1 Background

Unmanned Aerial Vehicles (UAVs) are a technology that have gained popularity in various applications recently[1]. Originally, UAVs required a ground pilot to manoeuvre them, but are becoming an increasingly automated technology. Applications where UAV automation has been used include, but are not limited to, structure inspections[2], smart farming[3], disaster management[4], power line inspections[5], surveillance[6] and wildfire tracking[7].

Most of the research mentioned was done on the premise of using multi-rotor UAVs, quad-rotor vehicles in particular. It is important to note that the term UAVs also encompasses other aircraft types, like single rotor and fixed wing UAVs. Hybrids also exist that contain both rotary-wing and fixed-wing components[1].

Using UAVs poses a considerable advantage in applications like the ones mentioned when compared to unmanned ground vehicles (UGVs). Their capacity to fly over landscapes and around three dimensional structures makes their potential functionality increase substantially. Relatively high altitude flying is a key reason why they are well suited to the application suggested in this paper, which is coverage path planning for search and rescue missions.

Coverage path planning (CPP) is a variant of the general motion planning problem. Originally, motion planning algorithms were predominantly used to find solutions for start-goal problems[8]. This implies finding a sequence of actions to get an object from some starting state to some goal state. An example would be finding a sequence of movements to get a robotic arm from one orientation to another. In the context of path planning it means getting an agent, a UAV for example, from some starting position to some goal position in an environment[9].

Coverage path planning is different from start-goal path planning in that it tries to determine a path for an agent to pass over all points in an environment[8]. It can be used with ground vehicles, for example, to automate field machines for smart farming[10]. Further examples include vacuum cleaning robots, spray painting robots[11], window cleaning robots[12] and automated lawn mowers[13]. For underwater vehicles it can be used for the inspection of difficult to reach underwater structures[14].

Furthermore, there have been developments in the use of UAVs to perform automated search and rescue operations. One such example is a project by DroneSAR where they use DJI drones to perform search rescue tasks. Their implementation focuses on the automatic coverage of a manually designated area using a single drone. This implementation is the first of it's kind and has already showed promise in shortening the time it takes to locate victims. Included in their design is imaging and tracking technology to help locate victims in search and rescue operations.

1.2 Objectives

The main objective of this thesis was to develop a coverage path planning algorithm that utilises multiple UAVs to search a known environment. This research is intended to be applicable to search and rescue operations. [1]

1.3 Methodology

1.4 Scope of the Research

1.5 Thesis Structure

Chapter 2

Background

2.1 SatSim

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the "hard sphere", event-driven method , where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called "soft particle" molecular dynamics pioneered by where the particles are allowed to overlap or penetrate each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 3

SatSim

3.1 Terrestrial

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the “hard sphere”, event-driven method , where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called “soft particle” molecular dynamics pioneered by each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 4

Verifying SatSim Results

4.1 Scope

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the “hard sphere”, event-driven method , where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called “soft particle” molecular dynamics pioneered by each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 5

Hardware Selection

5.1 Scope

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the “hard sphere”, event-driven method , where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called “soft particle” molecular dynamics pioneered by each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 6

Hardware Design with Software Implementation

6.1 Scope

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the “hard sphere”, event-driven method , where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called “soft particle” molecular dynamics pioneered by each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 7

Hardware Verification and Comparison to SatSim

7.1 Scope

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the "hard sphere", event-driven method where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called "soft particle" molecular dynamics pioneered by each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Chapter 8

Conclusions

8.1 Scope

In granular or particle flow simulations with Discrete Element Method (DEM), the mechanical behavior of a system of particles are simulated. The basic building blocks of DEM are finite sized particles and walls. It is generally classified into two basically different approaches.

The first is the “hard sphere”, event-driven method where particles are assumed to be perfectly rigid and they follow an undisturbed motion until a collision occurs. Due to the rigidity of the interaction, the collisions occur instantaneously with accompanying momentum transfer. It is mainly used for collisional, dissipative granular gases.

The second is the so-called “soft particle” molecular dynamics pioneered by where the particles are allowed to overlap or penetrate each other. Constrains on the physical space that a particle can occupy at a specific time is included with contact or penalty forces related to the amount of overlap and contact velocity between particles or between particles and walls. The motion of the system is modelled by the integration of Newton-Euler equations for motion of every individual particle.

Appendices

Appendix A

Discrete Element Method Theory

A.1 Ball elements

A.1.1 Ball mass and inertia parameters

Consider a volume element $\mathrm{d}V$ with respect to a static base S of an arbitrary solid body with density ρ. The mass of the body is obtained by integrating over the volume of the body,

$$m = \int_{\text{body}} \rho \, \mathrm{d}V \tag{A.1}$$

In figure A.1, a ball with radius R_i and uniform density ρ_i is depicted. The mass of the ball is after integration of equation (A.1)

$$m_i = \tfrac{4}{3}\pi\rho_i \, R_i^3. \tag{A.2}$$

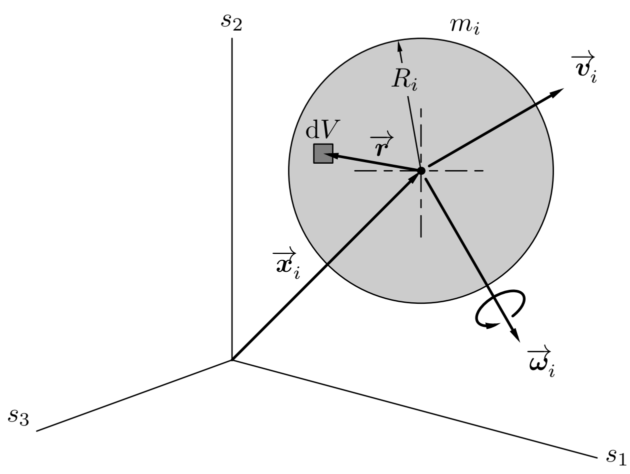

Figure A.1: Ball Element Parameters

List of References

[1] T. M. Cabreira, L. B. Brisolara, and R. Ferreira Paulo, "Survey on coverage path planning with unmanned aerial vehicles," *MDPI*, 2019.

[2] J. A. Guerrero and Y. Bestaoui, "UAV path planning for structure inspection in windy environments," *Journal of Intelligent and Robotic Systems: Theory and Applications*, 2013.

[3] P. Lottes, R. Khanna, J. Pfeifer, R. Siegwart, and C. Stachniss, "UAV-based crop and weed classification for smart farming," *Proceedings - IEEE International Conference on Robotics and Automation*, 2017.

[4] I. Maza, F. Caballero, J. Capitán, J. R. Martínez-De-Dios, and A. Ollero, "Experimental results in multi-UAV coordination for disaster management and civil security applications," *Journal of Intelligent and Robotic Systems: Theory and Applications*, 2011.

[5] W. Chang, G. Yang, J. Yu, Z. Liang, L. Cheng, and C. Zhou, "Development of a power line inspection robot with hybrid operation modes," *IEEE International Conference on Intelligent Robots and Systems*, 2017.

[6] N. Basilico and S. Carpin, "Deploying teams of heterogeneous UAVs in cooperative two-level surveillance missions," *IEEE International Conference on Intelligent Robots and Systems*, 2015.

[7] H. X. Pham, H. M. La, D. Feil-Seifer, and M. Deans, "A distributed control framework for a team of unmanned aerial vehicles for dynamic wildfire tracking," *IEEE International Conference on Intelligent Robots and Systems*, 2017.

[8] H. Choset, "Coverage for robotics - A survey of recent results," *Annals of Mathematics and Artificial Intelligence*, 2001.

[9] K. K. M. Lynch and F. C. Park, *Modern robotics : mechanics, planning, and control*. Cambridge University Press, 2017.

[10] I. A. Hameed, "Intelligent coverage path planning for agricultural robots and autonomous machines on three-dimensional terrain," *Journal of Intelligent and Robotic Systems: Theory and Applications*, 2013.

[11] P. N. Atkar, A. Greenfield, D. C. Conner, H. Choset, and A. A. Rizzi, "Uniform coverage of automotive surface patches," *International Journal of Robotics Research*, 2005.

[12] N. Mir-Nasiri, J. Hudyjaya Siswoyo, and M. H. Ali, “Portable Autonomous Window Cleaning Robot,” *Procedia Computer Science*, 2018. [Online]. Available: https://doi.org/10.1016/j.procs.2018.07.024

[13] E. M. Arkin, S. P. Fekete, and J. S. Mitchell, “Approximation algorithms for lawn mowing and milling,” *Computational Geometry: Theory and Applications*, 1999.

[14] B. Englot and F. S. Hover, “Sampling-based coverage path planning for inspection of complex structures,” *ICAPS 2012 - Proceedings of the 22nd International Conference on Automated Planning and Scheduling*, pp. 29–37, 2012.