UNIVERSITEIT VAN PRETORIA
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Profiling of rough terrain

by

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Profiling of rough terrain

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Abstract

In the automotive industry one of the methods used in accelerating the design, testing and development of a system or a vehicle is the use of virtual vehicle simulations. The simulations cut costs in the form of fewer prototypes required for actual testing and accelerated fault finding in the design of a system.

The simulation results are very dependent on the model used for the simulation and the inputs to the system. Feasible results can often be obtained with a simplified model if the correct input data is supplied to the simulation.

In South Africa, the commercial, military and off-road vehicle industries mainly use the test tracks at the Gerotek Test Facilities for ride comfort and durability tests over repeatable terrains. Terrain profiles of these tracks are not available and cannot be measured using commercially available inertial profilometers due to the severe roughness of the terrain.

This study concentrates on obtaining the input data in the form of the terrain profile used for vehicle simulations and field tests in which a vehicle is driving on rough terrains. The input data is referred to as the profile of the terrain and the profiled terrains are the actual terrains used for testing.

Three different methods are used in measuring the profile of the terrain namely a mechanical profilometer, photogrammetry and a 3-D scanner using a laser displacement sensor. These methods are evaluated by profiling the same section of the Belgian paving and calculating the Displacement Spectral Densities. The most efficient method is used to profile additional terrains.

The terrain profiles thus obtained is used as input to an existing off-road vehicle simulation model built in MSC Adams View. This model has previously been verified over discrete obstacles where excellent correlation with experimental results was obtained. Comparison between simulated and measured results over the terrains profiled in this study also gives good correlation, establishing further confidence in the measured terrain profiles.

Keywords: road profiling, rough roads, displacement spectral densities, profilometer, vehicle simulations

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Profiel opmeting van rowwe terrein

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Opsomming

In die voertuigindustrie is voertuigsimulasies, een van die metodes wat gebruik word om die ontwerp, toets en ontwikkeling van ‘n stelsel of ‘n voertuig te versnel. Die simulasies is meer koste-effektief om dat minder prototipes benodig word vir die werklike toets van die stelsel of voertuig en ontwerpsdefekte vinniger opgespoor kan word.

Die simulasieresultate is afhanklik van die model wat gebruik word asook die insette na die model. Bruikbare resultate kan dikwels verkry word met ‘n vereenvoudigde model, indien die korrekte insetdata aan die simulasie verskaf word. Aan die ander kant kan komplekse modelle, met foutiewe insetdata, nooit goeie antwoorde lewer nie.

In Suid-Afrika, word die Gerotek toetsfasiliteit se toetsbane deur die kommersiële, militêre en die 4x4 voertuigindustrie gebruik vir hoofsaakllik ritgemak- en leeftydstoetse oor herhaalbare terrein. Terreinprofiele van die toetsbane is nie beskikbaar nie en kan nie gemeet word met die beskikbare kommersiële traagheidsprofilometers nie, as gevolg van die hoë rofheid van die bane.

Die studie konsentreer op die verkryging van insetdata, in die vorm van die terreinprofiel wat gebruik word vir voertuigsimulasies en terreintoetse waar ‘n voertuig op rowwe terrein bestuur word. Die insetdata word na verwys as die terreinprofiel, waar die saamgestelde profiel van die terrein die werklike toetsterrein weerspieël.

Drie verskillende metodes word gebruik om die profiel van die terrein te meet naamlik, ’n meganiese profilometer, fotogrammetrie en ‘n 3-D laser aftaster. Die metodes word geëvalueer deur die profiel van dieselfde seksie van die Belgiese plaveisel te bepaal en die verplasingspektraaldigtheid te bereken. Die mees doeltreffende metode word gebruik om saamgestelde profiele van addisionele terreine op te stel.

Die terreinprofiele wat verkry is word gebruik as ‘n inset tot ’n bestaande simulasiemodel van ’n vierwielaangedrewe veldry (heg-en-steg) voertuig, in MSC Adams View. Die model is voorheen gevalideer oor diskrete hindernisse, waar uitstekende ooreenstemming met eksperimentele resultate verkry is. ‘n Vergelyking tussen gesimuleerde en gemete resultate oor die saamgestelde profiel terrein, in die studie, lewer ook bevredigende resultate wat verdere vertroue vestig in die meting van die terreinprofiele.

Sleutelwoorde: Padprofiele, rowwe terrein, profilometer, voertuig simulasies, verplasingspektraaldigtheid

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List of symbols

• English letters and symbols

A = Roughness coefficient

C = Unit vector in the XY plane of measured length l

C = Capacitance [Farad]

c = Damper rate

d = Diameter [m]

d = Distance along road [m]

F = Frequency variable

f = Frequency [Hz]

f_c = Cut-off frequency [Hz]

g = Gravitational acceleration [9.81 m/s^2]

H = Height [m]

k_s = Spring rate

k_t = Tyre spring rate

L = Length [m]

m_s = sprung mass

m_u = unsprung mass

n = Number of points in the profile

n = Road index

R = Resistance [ohm]

R_{xx} = Autocorrelation function

r = Radius [m]

S_{xx} = Power spectral density

S_z = Vertical displacement spectral density

T = End time

t = Time [seconds]

v = Velocity [m/s]

X = Fourier transform

x = Road height [mm]

x = X component of measured length L [m]

X,Y = Measured point

y = Error in the vertical direction of the profile

y = Y component of measured length L [m]

z = Vertical resolution [mm]

- **Greek symbols**

α = Angle [Degrees]

β = Angle [Degrees]

γ = Angle [Degrees]

Δ = Difference

δ = Change in distance [m]

φ = Spatial frequency [cycles/m]

θ = Angle [Degrees]

ϑ = Angle [Degrees]

τ = Change in time [seconds]

τ = Time constant of RC filter [seconds]

ω = Angular frequency [rad/s]

• Abbreviations

3-D	Three – Dimensional
$4S_4$	4 State Semi-Active Suspension System
ADAMS	Automatic Dynamic Analysis of Mechanical Systems (Computer Software)
APL	Longitudinal Profile Analyzer, APL in French
ASTM	American Society for Testing and Materials
CCD	Charged-Coupled Device
CSIR	Council for Scientific and Industrial Research
DGPS	Differential Global Positioning System
DSD	Displacement Spectral Density
FFT	Fast Fourier Transform
FM	Frequency Modulation
GIS	Geographic Information System
GPS	Global Positioning System
HSP	High Speed Profilometer

INS	Inertial Navigation System
IMU	Inertial Measuring Unit
IRI	International Roughness Index
ISO	International Organization for Standardization
IVP	Integrated Vision Products
LF	Left Front
LR	Left Rear
MIT	Massachusetts Institute of Technology
mW	milliWatt
PGC	Photo Ground Control
PSD	Power Spectral Density
RDF	Road Definition File
RF	Right Front
RMS	Root Mean Square
RMSE	Root Mean Square Error
RR	Right Rear
RTK	Real Time Kinematic
RQI	Road Quality Index
SCEOS	Sheffield Centre for Earth Observation Science
TIN	Triangle Network
TINA	Tina Is No Acronym
UMTRI	University of Michigan Transportation Research Institute
UTK	University of Tennessee, Knoxville
UV	Ultraviolet
VTMS	Vehicle Terrain Measurement System