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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



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 ontwerpdefekte 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 simulاسie 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 hoofsaaklik ritgemak- en leeftydstoetse oor herhaalbare terrein. Terreinprofile 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 verplasingsspektraaldigtheid te bereken. Die mees doeltreffende metode word gebruik om saamgestelde profile van addisionele terreine op te stel.

Die terreinprofile 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 terreinprofile.

Slutelwoorde: Padprofile, rowwe terrein, profilometer, voertuig simulasies, verplasingsspektraaldigtheid



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Contents

1.	Introduction	1
2.	Literature survey	3
2.1.	Road profilometers	3
2.1.1.	High Speed Profilometers (HSP)	3
2.1.2.	Inertial Profilometer	6
2.1.3.	Longitudinal Profile Analyser	8
2.2.	Off-road Profilometers	9
2.2.1.	Rod and Level	9
2.2.2.	The Dipstick.....	10
2.2.3.	Vehicle Terrain Measurement System.....	12
2.2.4.	Profilometers used in South Africa for profiling off-road terrain	13
2.3.	Stereo Vision Measurement System	15
2.4.	Aerial Photography	17
2.5.	Stereoscopes.....	19
2.6.	Laser Displacement Scanners.....	20
2.7.	Road Profile statistics	22
2.8.	Displacement Spectral Densities (DSD)	22
2.9.	International Roughness Index (IRI)	26
2.10.	Summary on literature survey.....	28
3.	Test Equipment.....	31
3.1.	Can-Can Machine.....	31
3.1.1.	Test sections for Can-Can Machine	43
3.2.	Photogrammetric Profiling	48
3.2.1.	Camera calibration	48
3.2.2.	Ground control.....	49
3.2.3.	Mapping.....	50
3.2.4.	Triangulation inner orientation	52
3.2.5.	Aerial Triangulation.....	52
3.2.6.	Test section for photogrammetry	53
3.3.	Laser Scanner	55
3.3.1.	Test section for Laser Scanner.....	59
3.4.	Summary of the three profiling methods.....	61
4.	Profiling simple obstacles with the Can-Can	62
4.1.	Discrete bumps.....	62
4.1.1.	100 mm semi-circular bump	62
4.1.2.	Parallel and angled corrugations	63
4.1.3.	Pot-Holes.....	66
4.2.	Summary on discrete bumps	69
5.	Profiling 3-Dimensional rough road	70
5.1.	Suspension Track - Belgian Paving.....	71
5.1.1.	Can-Can Machine.....	71
5.1.2.	Photogrammetry	73
5.1.3.	Laser scanner.....	77
5.2.	Fatigue track.....	79
5.3.	Ride and Handling track	81
5.4.	Rough track	84



5.5.	Displacement Spectral Densities of profiled tracks (DSD)	89
5.5.1.	Belgian paving	89
5.5.2.	Fatigue track	93
5.5.3.	Parallel and angled corrugations	94
5.5.4.	Pothole track	95
5.5.5.	Ride and Handling track	95
5.5.6.	Rough track	97
5.5.7.	Determining Roughness coefficient	97
5.6.	International Roughness Index (IRI)	100
5.7.	Summary on rough road profiling	103
6.	3-D road profiles in multi-body simulation models	104
6.1.	Simulation and data verification	105
6.1.1.	Simulations on the Belgian paving	107
6.1.2.	Simulation of Land Rover ride comfort	115
6.2.	Simulation and data verification	120
7.	Conclusions and recommendations	122
7.1.	Conclusions	122
7.2.	Recommendations for future work	124
	References	125
	Appendix A:	A-1
	□ Certificate of Conformance for Crossbow Tilt Sensor	A-1
	□ Calibration certificate of Sony Cyber Shot 5 mega pixel Digital Camera	A-1
	□ Calibration certificate of Pentax K10D Digital Camera	A-1
	Appendix B: Datasheet on S80-MH-5 Data sensor	B-1
	Appendix C: Blank example of a Road Definition File	C-1
	Appendix D: International Roughness Index plots of profiled terrains	D-1
	Appendix E: Weighted FFT from the Simulation and Land Rover data	E-1
	Appendix F: Filtered vertical accelerations from simulations and Land Rover data	F-1
	Appendix G: 8 Hz Low Pass Filtered Fast Fourier Transforms of Simulations and Land Rover Vertical Accelerations	G-1

List of Figures

Figure 1: The HSP of the CSIR (Anon, 2005).	4
Figure 2: Longitudinally tined concrete, direction of travel from bottom to top (Karamihas and Gillespie, 2002).....	5
Figure 3: Transversely tined concrete, direction of travel from left to right (Karamihas and Gillespie, 2002).....	5
Figure 4: Schematic drawing of an Inertial Profilometer by Imine and Delanne (2005).	6
Figure 5: International Cybernetics Corporation Lightweight Profilometer, profiling moderately rough asphalt (Karamihas and Gillespie, 2002).	7
Figure 6: Walking Profilometer (Karamihas and Gillespie, 2002).....	8
Figure 7: Longitudinal Profilometer Analyser (Imine and Delanne, 2005).	9
Figure 8: Visual representation of the Rod and Level Profilometer (Sayers and Karamihas, 1998).	10
Figure 9: A basic representation of the Dipstick (Sayers and Karamihas, 1998).	11
Figure 10: Vehicle Terrain Measurement System mounted on host vehicle (Kern, 2007).....	12
Figure 11: Zaayman's description of his concept (Zaayman, 1988).....	15
Figure 12: A schematic view of the Stereo Vision Measurement System (McDonald et.al., 2000).	16
Figure 13: Giant eye-base described by Ritchie in Surveying and mapping for field scientists (Ritchie et.al., 1991).	18
Figure 14: Overlap requirements for complete photographic coverage and stereoscopic viewing described by Ritchie (1991).	19
Figure 15: Mirror stereoscope and lens stereoscope (Ritchie et.al., 1991). ...	20
Figure 16: UTK's Mobile Scanning System consisting of a vehicle, laser range scanner, GPS, INS and high-resolution video camera (Grinstead et.al., 2005).	21
Figure 17: ISO 8606 road classification, (ISO, 1995).....	24
Figure 18: IRI ranges representing different classes of road (Sayers and Karamihas, 1998).	27
Figure 19: Golden car, IRI quarter-car model (Sayers and Karamihas, 1998).	28
Figure 20: The Can-Can Machine on the Fatigue track at Gerotek.....	32
Figure 21: Wiring diagram of speed control for the Can-Can profilometer.	33
Figure 22: Thirty arms mounted on the rear beam of the Can-Can.....	33
Figure 23: Close up of the arms and the potentiometers.	34
Figure 24: 5 Volt power supply for potentiometers.....	35
Figure 25: Calibration of potentiometers with the use of a dividing head.	35
Figure 26: Calibration graph of potentiometers.	36
Figure 27: Description of the arm movement.	38
Figure 28: Encoder used to trigger data acquisition system.....	39
Figure 29: Crossbow tilt sensor mounted on an actuator at 43 degrees.	40
Figure 30: Response of tilt sensor to a random input.....	41
Figure 31: 0.1 Hz RC Filter.	42
Figure 32: 0.1 Hz Low-pass filtered response of tilt sensor to a random input.	42



Figure 33: 55 mm flat-top bump profiled with Can-Can Machine.	43
Figure 34: Profile of flat concrete surface.	45
Figure 35: Difference in the profile of the flat concrete surface with and without the orientation of the profilometer.	45
Figure 36: Profile of channel 1 for flat test section with Can-Can Machine. ...	46
Figure 37: Final test section for Can-Can Machine.	47
Figure 38: Profile of final test section for Can-Can Machine.	47
Figure 39: Profiles from channel 1 for final test section with Can-Can Machine.	48
Figure 40: Calibration grid used for camera calibration.....	49
Figure 41: Ground control points surveyed using a Total Station.	50
Figure 42: Cradle used for photogrammetry test section.	51
Figure 43: Digital photogrammetric workstation.	51
Figure 44: Stereo pairs, von Gruber points and ground control.	52
Figure 45 (a) and (b): Example of break lines and triangles.	53
Figure 46: Top view of test section as captured with digital camera.	54
Figure 47: Model of top view for test section.....	54
Figure 48: Three-dimensional view of test section.	55
Figure 49: Three-dimensional model of test section.	55
Figure 50: Gimball containing two stepper motors and a DM-80 Laser Distance Sensor.	56
Figure 51: Top view of the laser movement.	57
Figure 52: Measured data of a flat surface.	58
Figure 53: Description of coordinate system used for Laser Scanner calculations.	59
Figure 54: Test block for Laser Scanner with 500 x 360 x 58 mm concrete block on a flat surface.	60
Figure 55: Measure profile of a flat concrete surface with a concrete block on top.....	61
Figure 56: 100 mm semi-circular bump.....	62
Figure 57: Profiled and actual 100 mm bump.	63
Figure 58: Profile of a corrugation bump.....	64
Figure 59: Parallel corrugations at Gerotek.	64
Figure 60: Profiled parallel corrugations.	65
Figure 61: Angled corrugations at Gerotek.	65
Figure 62: Profiled angled corrugations.	66
Figure 63: The actual profile and the Can-Can profile of the pothole.....	67
Figure 64: Pothole track at Gerotek.	68
Figure 65: Profiled pothole track.	68
Figure 66: Gerotek Test Facility (Google Earth, 2007).....	70
Figure 67: Belgian paving at Gerotek.....	71
Figure 68: Can-Can Machine profiling Belgian paving.	72
Figure 69: Can-Can profile of Belgian paving.	72
Figure 70: Tripod used to capture photographs.	73
Figure 71: Sample photograph used for photogrammetry.....	74
Figure 72: Belgian paving profile from Photogrammetry.	75
Figure 73: Belgian paving profile from Photogrammetry, plotted with Matlab.....	75
Figure 74: Lens distortion of the Pentax lens.	76
Figure 75: Lens distortions of the medium format Hasselblad lens.....	77
Figure 76: Laser scanner in operation on the Belgian paving at night.	78



Figure 77: Laser Scanner profile of Belgian paving.	79
Figure 78: The Can-Can Machine profiling the Fatigue track.....	80
Figure 79: Can-Can profile of the Fatigue track.	80
Figure 80: The profiled section of the Ride and Handling track at Gerotek.	81
Figure 81: Trigger mechanism on Can-Can Machine.	82
Figure 82: Ride and Handling track profiled with Can-Can Machine.....	83
Figure 83: Close-up of Ride and Handling track with model Can-Can Machine.	83
Figure 84: Close-up of the Ride and Handling track profile.....	84
Figure 85: Profiled section of Rough track.	85
Figure 86: A section of the Rough track at Gerotek.	86
Figure 87: Can-Can Machine crossing from one beam to another.....	87
Figure 88: Profile of the Rough Track at Gerotek.....	87
Figure 89: Close-up of the Rough track profile.	88
Figure 90: Displacement Spectral Density of the Can-Can profile of the Belgian paving.	90
Figure 91: Belgian paving DSD from Photogrammetry profile.	91
Figure 92: Displacement Spectral Density of the Belgian paving profiled with the Laser profile.	92
Figure 93: DSD's of all three Belgian paving profiles together with a class-A, class-D and class-H road.....	93
Figure 94: DSD of the fatigue track.....	94
Figure 95: DSD of the parallel and angled corrugations tracks.....	95
Figure 96: DSD of the pothole track.....	96
Figure 97: DSD of the Ride and Handling track.	96
Figure 98: DSD of the Rough track.....	97
Figure 99: Inverse Power Law plot on Belgian paving.	99
Figure 100: IRI vs. the distance travelled over the Belgian paving.	101
Figure 101: International Roughness Index	102
Figure 102: Definition of Road Mesh used in MSC ADAMS, (MSC Software, 2007).	105
Figure 103: Placement of rear accelerometers in Land Rover Defender 110.	106
Figure 104: Placement of front accelerometer on chassis of Land Rover Defender 110.	107
Figure 105: Front suspension layout.....	108
Figure 106: Front suspension schematic.	108
Figure 107: Rear suspension layout.	109
Figure 108: Rear suspension schematic.....	109
Figure 109: Tyre side-force vs. slip angle characteristic.	110
Figure 110: Trapezoidal Bump.....	111
Figure 111: Model validation results for passing over 100 mm trapezoidal bump at 25 km/h.	112
Figure 112: Model of Land Rover Defender 110 on the Belgian paving in ADAMS.....	114
Figure 113: Close-up of the wire frame of the wheel on the Belgian paving mesh.....	115
Figure 114: BS 6841 weighting function.	116
Figure 115: Weighted Fast Fourier Transforms of the Simulation and Land Rover data @ 40 km/h.....	117



Figure 116: 8 Hz Low Pass Filtered FFT of the simulation and Land Rover data @ 40km/h. 117

Figure 117: Filtered Right Rear Body vertical accelerations from simulation and Land Rover @ 40km/h..... 118

Figure 118: RMS values from Simulations and measured Land Rover data. 119

Figure 119: Difference in Simulations RMS values and Land Rover RMS values. 120

Figure 120: IRI Belgian paving..... D-2

Figure 121: IRI Fatigue Track..... D-2

Figure 122: IRI Parallel Corrugations Track..... D-3

Figure 123: IRI Angled Corrugations Track..... D-3

Figure 124: IRI Pothole Track..... D-4

Figure 125: IRI Rough Track..... D-4

Figure 126: Weighted FFT from the Simulation and Land Rover data @ 15km/h..... E-2

Figure 127: Weighted FFT from the Simulation and Land Rover data @ 26km/h..... E-2

Figure 128: Weighted FFT from the Simulation and Land Rover data @ 40km/h..... E-3

Figure 129: Weighted FFT from the Simulation and Land Rover data @ 57km/h..... E-3

Figure 130: Weighted FFT from the Simulation and Land Rover data @ 73km/h..... E-4

Figure 131: Simulation vertical accelerations @ 15km/h. F-2

Figure 132: Land Rover vertical accelerations @ 15km/h..... F-2

Figure 133: Right Rear Body vertical accelerations from Simulation and Land Rover @ 15km/h..... F-3

Figure 134: Simulation vertical accelerations @ 26km/h. F-3

Figure 135: Land Rover vertical accelerations @ 26km/h..... F-4

Figure 136: Right Rear Body vertical accelerations from simulation and Land Rover @ 26km/h..... F-4

Figure 137: Simulation vertical accelerations @ 40km/h. F-5

Figure 138: Land Rover vertical accelerations @ 40km/h..... F-5

Figure 139: Right Rear Body vertical accelerations from simulation and Land Rover @ 40km/h..... F-6

Figure 140: Simulation vertical accelerations @ 57km/h. F-6

Figure 141: Land Rover vertical accelerations @ 57km/h..... F-7

Figure 142: Right Rear Body vertical accelerations from simulation and Land Rover @ 57km/h..... F-7

Figure 143: Simulation vertical accelerations @ 73km/h. F-8

Figure 144: Land Rover vertical accelerations @ 73km/h..... F-8

Figure 145: Right Rear Body vertical accelerations from simulation and Land Rover @ 73km..... F-9

Figure 146: Filtered FFT of vertical accelerations @ 15km/h..... G-2

Figure 147: Filtered FFT of vertical accelerations @ 26km/h..... G-2

Figure 148: Filtered FFT of vertical accelerations @ 40km/h..... G-3

Figure 149: Filtered FFT of vertical accelerations @ 56km/h..... G-3

Figure 150: Filtered FFT of vertical accelerations @ 73km/h..... G-4



List of Tables

Table 1: IRI values for different roads.....	27
Table 2: Inverse Power Law values.....	99
Table 3: Instrumentation used for baseline vehicle tests.....	111
Table 4: Typical applications for each tyre model (ADAMS/Tire, 2007).....	113

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
- 4S₄ 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