2011 ISTVS Conference

THE INTERNATIONAL SOCIETY FOR TERRAIN-VEHICLE SYSTEMS







September 18-22, 2011



The Inn at Virginia Tech and Skelton Conference Center Blacksburg, Virginia, USA



Conference Technical Committee

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Thank you to our Sponsors

College of Engineering at Virginia Tech Virginia International Performance and Engineering Research (VIPER) Virginia International Raceway (VIR)

Thank you to our Exhibitors

Kistler Instrument Corporation Keweenaw Research Center USACE Engineering Research and Development Center

Dear Colleagues,

Welcome to the 17th International Conference of the International Society for Terrain-Vehicle Systems (ISTVS)! On behalf of the technical organizing committee I would like to thank all of you for participating in this conference, hosted this year by Virginia Tech. We hope you will enjoy it!

The International Society for Terrain-Vehicle Systems (ISTVS) is an educational, non-profit, and non-political organization whose mission is to promote activities that help acquire and advance knowledge of the mechanics of terrain-vehicle systems and machinery interacting with soils in all environments.

The 2011 international conference of ISTVS is an anniversary edition, celebrating half a century since the 1st conference in 1961 in Turin, Italy, which signifies the beginning of ISTVS. In sessions especially organized for this occasion, we have invited guests that witnessed the birth of ISTVS and graciously agreed to share some of their memories with us, as well as experts that testify on the contributions and impact of the terramechanics to the society.

The 2011 ISTVS conference brings together researchers from a large spectrum of interests, past and present members, students, as well as non-member professionals in related fields. Participants represent fifteen countries on four continents, including USA, Canada, Japan, Korea, China, South Africa, Germany, Italy, France, Great Britain, Sweden, Hungary, Czech Republic, Poland, and Iraq. The conference proceedings include over 60 peer-reviewed papers; more than 60 oral presentations will be given, and 14 posters will be displayed. The papers and presentations submitted were grouped based on their topic in seven tracks: Soil and terrain modeling and characterization, Planetary rovers and mobile robotics, Running gear characterization and modeling, Agricultural and earth moving equipment, Operation on snow and ice, Vehicle dynamics, mobility, and safety, and Terramechanics.

During the conference, the attendees have the opportunity to visit the booths of three exhibitors: Kistler Instruments, Keweenaw Research Center (KRC), and Engineer Research and Development Center (ERDC). A full day of technical tours is included in the program, with visits to Virginia Institute for Performance Engineering and Research (VIPER), Virginia International Raceway (VIR), and Martinsville Speedway. In the tradition of past ISTVS conferences, a full program is also organized for the companions of the attendees, as well as joint social activities. I hope that this conference will represent a reference point for the directions of future research in terramechanics and for ISTVS. It is with great joy that I extend my warmest welcome to all of you at the 17th International Conference of the ISTVS!

Corina Sandu, Associate Professor 2011 ISTVS Conference Chair



Schedule

Sunday, September 18, 2011

3:00 pm – 7:00 pm	Registration T. White, R. Melendy, H. Wimmer-McClanahan	Latham Foyer
3:00 pm – 7:00 pm	Board of Directors meeting	Room: Solitude
7:00 pm – 10:00 pm	Ice breaker reception Jazz by <i>Prestige Collective</i>	Room: Latham CDEF

Monday, September 19, 2011

7:00 am – 8:00 am	Breakfast	Room: Latham AB
7:00 am – 5:00 pm	Registration T. White, R. Melendy, H. Wimmer-McClanaha	Latham Foyer n
8:00 am – 8:15 am	ISTVS 2011 Opening Remarks, Prof. Corina S	andu
8:15 am – 8:25 am	ISTVS Current President Remarks, Prof. Kazu	yoshi Tateyama
8:25 am – 8:45 am	ISTVS Website/Newsletter/Member service,	Dr. L. Richter and Ms. J. Dixon
8:45 am – 9:05 am	Journal of Terramechanics update, Dr. Georg	ge Mason
9:05 am – 9:25 am	Virginia Tech College of Engineering Dean W	/elcome, Assoc. Dean Jack Lesko
9:25 am – 9:45 am	Coffee break and snacks	
9:45 am – 10:20 am	Bekker-Reece-Radforth Award Presentation,	Dr. J. Y. Wong
10:20 am – 11:25 am	St. Christopher Lecture Presentation, Dr. K. T	ateyama
11:25 am – 12:40 pm	Lunch with Presenter Prof. Dennis Hong (RoMeLa)	Room: Latham DEF
12:40 pm – 2:40 pm	 50th Anniversary Session (part 1), Drs. Shoe 1. Prof. Itzhak "Shmilo" Shmulevich: 50th ann 2. Prof. Keiji Watanabe: ISTVS in the Asia-Pacinin nuclear accident through Great East Japa 3. Prof. Zoltan Janosi: Early days of the ISTVS 	op, Kiss, Watanabe niversary terramechanics R&D activity in Israel fic Area, and special update on Intelligent vehicle proved an Earthquake Disaster occurred in March 11 2011. 5 and the Land Locomotion Lab
2:40 pm – 3:00 pm	Coffee break and snacks	
3:00 pm – 5:00 pm	 50th Anniversary Session (part 2), Drs. Shoe 4. General (Ret) Guenter Hohl: a. 1984 European conference held in Vien b. History of terrain vehicle from ancient t 5. Dr. George Mason: WES Mobility Systems 6. Mr. Henry Hodges: Why mobility is even r 7. Optional Panel Discussion – TBD 	op, Kiss, Watanabe na; imes to today and ISTVS interactions past, present, and future nore relevant now
5:00 pm – 5:30 pm	Free time. Prepare for Mountain Lake	
5:30 pm – 6:00 pm	Drive to Mountain Lake (by buses)	
6:00 pm – 7:00 pm	Dirty Dancing Tour	
7:00 pm – 10:00 pm	Dinner and entertainment Oktoberfest style	with The Sauerkraut Band
10:00 pm – 10:30 pm	Return to Hotels (by buses)	

Tuesday, September 20, 2011

7:00 am – 8:00 am	Breakfast	Room: Latham AB
7:00 am – 8:00 am	Registration T. White, R. Melendy, H. Wimmer-McClanahan	Latham Foyer
8:00 am – 10:30 am	Travel for Technical Tour to Virginia International Performance (movie #1 on the bus)	and Engineering Research (VIPER);
10:30 am – 10:45 am	Break	
10:30 am – 11:45 am	Tour VIPER, Host: Prof. Steve Southward	
11:45 am – 12:00 pm	Drive to Virginia International Raceway (VIR)	
12:00 pm – 1:00 pm	Lunch at VIR	
1:00 pm – 3:30 pm	Tour VIR, Host: Ms. Terrie Lantor	
3:30 pm – 3:45 pm	Break	
3:45 pm	Depart for Martinsville; snacks on the bus; (movie #2 on the bu	is)
5:00 pm – 5:45 pm	Visit Martinsville Speedway, Host: Mr. Michael Smith	
5:45 pm – 7:00 pm	Return to Blacksburg if not going to Chateau Morrisette	
5:45 pm – 9:00 pm	Optional wine tasting/dinner/shopping at Chateau Morrisette	(\$40), Host: Ms. Mechelle O'Neal
9:00 pm – 10:00 pm	Return to Blacksburg if going to Chateau Morrisette	

Wednesday, September 21, 2011

7:00 am – 8:00 am	Breakfast	Room: Latham AB
7:00 am – 8:00 am	Registration	Latham Foyer
8:00 am – 4:00 pm	Poster set-up and Exhibitors	Room: Latham DEF
8:00 am – 8:15 am	Morning Announcements (one per room) Drs. Sandu, Richter	
9.15 am 10.15 am	Concurrent Sessions	

8:15 am – 10:15 am Concurrent Sessions

Track 1. Session 1/2 Room: Latham C Soil and terrain modeling and characterization (20 min/paper)

Chair: Mr. Randolph Jones; Co-chair: Dr. Kyeong Uk Kim

- 1. "Direct Shear Behaviour of Dry, Granular Soils Subject to Low Normal Stresses", by C. Senatore and K. lagnemma (paper, presentation, poster)
- 2. "Effect of Tire Inflation Pressure on Soil Strength Estimated Using Wheel Sinkage", by J. S. Nam and K. U. Kim (*presentation, poster*)
- "Modeling of Soil Displacement and Soil Strain Distribution Calculation Under the Traveling Wheel", by K. Saengprachatanarug, M. Ueno, E. Taira, and T. Okayasu (paper, presentation)
- 4. "Development of a Dynamic Visco-Elastic Vehicle-Soil Interaction Model for Rut Depth, Energy and Power Determinations", by P. Ayers, G. Bozdech, J. Freeman, A. Reid, and J. O'kins (*presentation*)
- 5. "The Effect of the Lateral Distance of the Shallow Tines on the Energy Utilization Efficiency of the Subsoiler", by S. Aday (presentation)
- 6. "Sophisticated Improvement of the Soil Compaction State Evaluation", by P. Prikner and R. Kodešová (*paper, presentation*)
- Poster only: "Reconfigurable Vegetated Soil Strength Instrument for Mobility Measurements", by K. MacDonald, B. Coutermarsh, and S. A. Shoop (*abstract*)
- Poster only: "Soil Strength as a Function of Soil and Ground Cover Types", by S. Shoop, R. Affleck, C. Smith, K. Gagnon, and R. Stone (*abstract*)

Track 2. Session 1/4Room: Assembly HallPlanetary rovers and mobile robotics (20 min/paper)Chair: Dr. Lutz Richter; Co-chair: Dr. James Lever

- 1. "Conceptual Study of Small Excavation Systems for Future Lunar Exploration", by T. Yokoyama and K. Tateyama (paper, presentation)
- 2. "Advantageous Bucket-Wheel Configuration for Lightweight Planetary Excavators", by K. Skonieczny, S. J. Moreland, D. S. Wettergreen, and W. L. Whittaker (*paper, presentation*)
- 3. "Mobile Payload Element: Concept Study for a Sample Fetching Rover for the Esa Lunar Lander Mission", by L. Richter, M. Apfelbeck, F. Claasen, R. Haarmann, P. Hofmann, S. Klinkner, and J. Schwendner (*presentation*)
- 4. "Report from the 2011 Summer Series of Workshops on "xTerramechanics", B. Trease, R. Lindemann, J. Andrade, K. lagnemma, I. Vlahinić (*presentation*)
- 5. "Soil Motion Analysis System for Examining Wheel-Soil Shearing", by S. Moreland, K. Skonieczny, D. Wettergreen, C. Creager, and V. Asnani (*paper, presentation*)
- 6. "Microscopic Study on Dynamic Behavior of Lunar Regolith under Driving Wheel in Micro-Gravity Circumstance", by Z. Meng, J. Jian-qiao, and L. Guo-min (*paper, presentation*)
- Poster only: "Terramechanics Simulation for Mobility Planning of the Mars Exploration Rovers", B. Trease, R. Arvidson, K. Bennett, F. Zhou, R. Lindemann, K. lagnemma, C. Senatore, and L. Van Dyke (*abstract*)

10:15 am - 10:30 am Coffee break and snacks

10:30 am – 12:30 pm 🛛 🔾	Concurrent Sessions
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Track 3. Session 1/1

Room: Latham C

Running gear characterization and modeling (20 min/paper)

Chair: Dr. Paul Ayers; Co-Chair: Dr. Pieter Schalk Els

- 1. "A Review of the Tractive Performance of Wheeled Tractors and Soil Management in Lowland Intensive Rice Production", by A. Keen, N. W. Hall, P. Soni, M. D. Gholkar, S. E. Cooper, and J. Ferdous (*paper, presentation, poster*)
- 2. "Validation of Military Vehicle Terrain Impact Models at Multiple Locations", by D. J. Koch, P. D. Ayers, H. R. Howard, and A. B. Anderson (*paper, presentation*)
- 3. "Numerical Investigation of Gross Traction Generated at Grouser-Soil Interface by DEM", by H. Nakashima, X. L. Wang, T. Yoshida, H. Shimizu, J. Miyasaka, and K. Ohdoi (paper, presentation, poster)
- 4. "Modal Analysis on a Large Off-Road Tyre using Scanning Laser Vibrometry", by C. M. Becker and P. S. Els (*paper, presentation*)
- 5. "Characterisation and Modelling of Off-Road Tyres", by P. S. Els and C. M. Becker (*paper, presentation*)
- 6. "Off-Road Soft Soil Tire Model Development and Proposed Experimental Testing", by C. Sandu, E. Pinto, S. Naranjo, P. Jayakumar, A. Andonian, D. Hubbell, and B. Ross (paper, presentation, poster)
- Written paper only: "A Non-Linear Model for a Turning Wheel on Deformable Surfaces", by J. Pytka and P. Tarkowski

Track 4. Session 1/1

Room: Assembly Hall

Agricultural and earth moving equipment (20 min/paper) Chair: Dr. Antonino Bonanno; Co-chair: Mr. Jody Priddy

- 1. "Fundamentals of Driveline and Traction Control Systems Fusion for Improving Traction of a 4x4 Single Bucket Loader", by M. Patterson, J. P. Gray, D. Holmes, G. Bortolin, and V. Vantsevich (*paper, presentation*)
- "Modification and Performance Evaluation of Tractor Drawn Improved Till Plant Machine under Vertisol", by A. K. Shrivastava and S. Jha (paper, presentation)
- 3. "Axle Torque Distribution in Four-Wheel Drive Tractors", by I. J. Guy, D. A. Crolla, R. J. Godwin, and D. R. White (paper, presentation)
- 4. "Vehicle Dynamic Simulation for Efficiency Improvement in Agricultural Tractors", by A. Bonanno and R. Paoluzzi (*paper, presentation*)
- 5. "Prediction of the Draft Force and the Energy Utilization Efficiency of Longitudinally Arranged Double Tines Subsoiler", by S. Aday (*paper, presentation*)
- 6. "The Control of Tractor 3 Point Linkage Control Systems", by J. Ward, D. A. Crolla, D. R. White, and R. J. Godwin (paper, presentation)
- Written paper only: "Consideration on Supporting Force for Lunar Exploration Rovers using Piles to Traverse Loose Soil with Steep Slope", by K. lizuka, H. Komatsu, and T. Sasaki
- Written paper only: "Heat Exchanger Study and Optimization Approach for Engine Efficiency Improvement", L. Benini, A. Bonanno, and R. Paoluzzi

12:30 pm – 1:30 pm Lunch with Presentation Room: Latham AB Prof. Kenneth Ball, (Department Head of the Mechanical Engineering Department)

1:30 pm – 3:30 pm Concurrent Sessions

Room: Latham C

Operation on snow and ice (20 min/paper)

Track 5. Session 1/2

Chair: Dr. Sally Shoop; Co-Chair: Dr. Jonah Lee

- 1. "Statistical Experimental Studies of a Vehicle Interacting with Natural Snowy Terrain for Combined Longitudinal and Lateral Slip", by J. Lee, D. Huang, and T. Johnson (*paper, presentation*)
- 2. "High-Efficiency Fuel Sleds for Polar Traverses", by J. Lever and J. Weale (*paper, presentation*)
- 3. "Measuring Vehicle Impacts on Snow Roads", by S. Shoop, M. Knuth, W. Wieder, R. Affleck, and M. Preston (*paper, presentation, poster*)
- 4. "Development of Processed Snow Roads in Antarctica", by R. Alger, S. Shoop, M. Knuth, and G. Blaisdell *(paper, presentation)*
- 5. "Maintenance on Snow Roads in Antarctica", by K. Gervais, M. Knuth, S. Shoop, and T. Melendy, Jr. (*presentation, poster*)
- 6. "Impact of Snow Road Maintenance on Road Strength at McMurdo Station, Antarctica", by T. D. Melendy, Jr., S. A. Shoop, and M. A. Knuth (*paper, presentation, poster*)

3:30 pm – 3:45 pm Coffee break and snacks

Track 6. Session 1/2

Room: Assembly Hall

Vehicle dynamics, mobility, and safety (20 min/paper) Chair: Dr. Peter Kiss; Co-chair: Prof. Iwan Wästerlund

- 1. "On and Off Road Mobility Performance Evaluation in DGA ANGERS", by M. Grima (*paper, presentation, poster*)
- 2. "Fuzzy Logic Traction Control System for a Golf Cart", by A. Rahman, A. Mohiuddin, A. Hossain, Z. Alam, and M. Rashid (*paper, presentation*)
- 3. "Computation of Vehicle Run-Off-The-Road Velocity", by L. Laib, L. Máthé, and P. Kiss (*paper, presentation*)
- 4. "Determination of Vehicle Speed from Terrain Tracks in Forensic Investigation", by L. Máthé and L. Laib (*paper, presentation*)
- 5. "Investigation and Parameter Study of a Completely Semi-Active Suspension System for Full Spring Mounted Tractors", by J. Krueger, S. Hammes, and H. Meyer (*paper, presentation*)
- 6. "Investigation of Simulation Based Vehicle Control Training", by M. Parker, B. Coutermarsh, and D. Taylor (*paper, presentation*)

Dr. Tateyama/Dr. Shoop

3:45 pm – 5:05 pm	Concurrent Sessions		
Track 7. Session 1/2 Terramechanics (20 min/ Chair: Dr. George Maso	Room: Latham C /paper) n; Co-Chair: Dr. Peter Kiss	Track 2. Session 2/4 Planetary rovers and Chair: Dr. Lutz Richter;	Room: Assembly Hall mobile robotics (20 min/paper) Co-chair: Dr. James Lever
 "Multipass Coefficients for Terrain Impacts Based on Military Vehicle Type, Size and Dynamic Operating Properties", by J. Kane, P. Ayers, H. Howard, A. Anderson, and D. Koch (paper, 		 "A Comparison of Scuff Tests from the Martian Rover, Opportunity, and a Discrete Element Method Model", by M. A. Knuth and M. Hopkins (<i>paper, presentation</i>) 	
 presentation) 2. "Vehicle Recovery Resistance Force Results in Soft-Soils", by A. M. Effinger, G. L. Mason, and B. W. Towne (paper, presentation) 		 "3D Simulation in Pressure-Sinkage Characteristics of Martian Soil Simulant by Discrete Element Method", by R. Zhang, G. Chen, G. Zhou, S. Xu, and J. Li (<i>paper, presentation</i>) 	
 "Modeling the Energetics of Tire-Soil Interaction", by G. Pillinger and P. Kiss (paper, presentation) "Soil-Wheel Interaction Analysis with ALE Finite Element Method", by J. Yamakawa (paper, presentation, poster) 		3. "Research on the Relationship Between Ruts of Lunar Rover Wheel and the Mechanical Properties of Lunar Soil Simulant", by L. Jianqiao, F. Wenfeng, H. Ling, Z. Meng, L. Linlin, L. Hao (paper, presentation)	
		 "Study on the Cone In Simulant under Differ Y. Wang, W. Fan, and L 	dex and Bulk Density of Lunar Soil ent Deposit Statuses", by J. Li, H. Li, L. He, . Liu (<i>paper, presentation</i>)
5:05 pm – 6:25 pm	Poster session		Room: Latham DEF
6:25 pm – 7:00 pm	Free time. Prepare for the banquet at Tl	he Inn at Virginia Tech	
7:00 pm – 10:00 pm	Dinner Banquet at The Inn at Virginia Te Music by <i>Le Trio</i>	ech	Room: Latham AB
	Awards Ceremony		
	2012 ISTVS Conference Venue		
	Current President/New President		

Track 1. Session 2/2

Thursday, September 22, 2011

7:00 am – 8:00 am	Breakfast
7:00 am – 8:00 am	Registration
8:00 am – 3:30 pm	Poster set-up and Exhibitors
8:00 am – 8:15 am	Morning Announcements (one per room) Drs. Sandu/Richter
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8:15 am – 9:55 am Concurrent Sessions

Room: Latham C

Soil and terrain modeling and characterization (20 min/paper) Chair: Mr. Randolph Jones; Co-chair: Ms. Patricia Sullivan

- 1. "Automatic Microsurface Terrain Acquisition and Modeling System", by S. Sandomirsky, E. A. Baylot, E. Keung, M. Naumov, and V. Khizhnichenko (*paper, presentation*)
- 2. "Managing Field Operations for the Protection of Buried Archaeological Artifacts", A. P. Dain-Owens, M. Kibblewhite, R. J. Godwin, and M. J. Hann (*presentation*)
- 3. "GIS for Operative Support", by G. Bygdén (paper, presentation)
- "Investigation of Excavation Behavior via Model Experiment and Distinct Element Method (DEM) Simulation using Irregularly Shaped Particles", by S. S. Wakabayashi, Y. Kawamoto, K. Nagato, S. Muto, A. Okada, M. Nakao, and T. Hamaguchi (paper, presentation)
- "Review of Current Military Training and Landcare Operations Relative to Subsurface Pressure Transfer and Protection of Subsurface Soil Condition", A. Dain-Owens, H. Howard, D. Koch, M. Kibblewhite, and R. Godwin (paper, presentation)

9:55 am – 10:10 am Coffee break and snacks

10:10 am – 12:10 am Concurrent Sessions

Room: Latham C

Track 5. Session 2/2 Operation on snow and ice and

Track 7. Session 2/2 Terramechanics (20 min/paper) Chair: Dr. Wendell Gray; Co-chair: Dr. George Mason

- 1. "A Method of Using a Snow Micro Penetrometer to Obtain Mechanical Properties of Snow", by D. Huang and J. Lee (paper, presentation)
- 2. "Using Acoustic Sounding to Measure Bulk Density and Depth of Snow", by J. Lee, K. Gard, and D. Misra (*paper, presentation*)
- 3. "On the Necessity of Terramechanics Science and a Prospective Vision", by G. Korlath (*presentation*)

Track 2. Session 3/4Room: Assembly HallPlanetary rovers and mobile robotics (20 min/paper)Chair: Dr. Lutz Richter; Co-chair: Ms. Margaret Knuth

Room: *Latham AB Latham Foyer* Room: *Latham DEF*

- 1. "Development of a Real and Simulation Testbed for Legged Robot Soil Interaction", by M. Ahmed, L. Quack, M. Römmermann, and Y.-H. Yoo (*paper, presentation, poster*)
- 2. "Modeling of Leg Soil Interaction using Genetic Algorithms", by M. Römmermann, M. Ahmed, L. Quack, and Y. Kassahun (paper, presentation)
- 3. "Evaluation of Influence of Surface Shape of Wheel on Traveling Performance of Planetary Rovers over Slope", by M. Sutoh, K. Nagatani, and K. Yoshida (*paper, presentation*)
- 4. "Toward Establishing a Comprehensive Pressure-Sinkage Model for Small Diameter Wheels on Deformable Terrains", by G. N. Meirion-Griffith and M. Spenko (*paper, presentation*)
- 5. "Flexible Planetary Rover Tire Model with Volumetric Wheel/Soil Interface", by W. Petersen, C. P. Vyasarayani, and J. McPhee (paper, presentation)

Track 6. Session 2/2

Room: Assembly Hall

Vehicle dynamics, mobility, and safety (20 min/paper) Chair: Mr. Jody Priddy; Co-chair: Dr. Pieter Schalk Els

- 1. "Slow Active Suspension Control for Rollover Prevention", by S. F. van der Westhuizen and P. S. Els (*paper, presentation*)
- 2. "GPS-Based, Mission Specific Mobility Power/Energy Analysis of Military Vehicles", by G. Bozdech and P. Ayers (*paper*, *presentation*)
- 3. "Increased Harvesting Operation using Adapted Ground Pressure to Soil Conditions", by I. Wästerlund, and E. Andersson (paper, presentation, poster)
- 4. "Off-Highway Vehicle Braking and Sign Recognition Study", by M. Osborne, R. Alger, E. Eubanks, and D. Meadows (paper, presentation)
- 5. "Application of the Smart Tire for Vehicle Chassis Control", by M. A. Arat and S. Taheri (*presentation*)
- 6. "Leaf Spring Modelling", by C.-J. Kat and P. S. Els (paper, presentation)

12:10 am – 1:30 pm	Lunch with Presentation Mayor Ron Rordam	Room: <i>Latham AB</i>
1:30 pm – 2:50 pm	Session	
Track 2. Session 4/4 Planetary rovers and Chair: Dr. Lutz Richter;	Room: Assembly Hall mobile robotics (20 min/paper) Co-chair: Dr. James Lever	
1. "Terrain Classification Proprioceptive Sensor M. Bajracharya, and M	using Machine Learning and rs", by D. A. Dumond, L. Ray, . Turmon <i>(paper, presentation)</i>	
2. "A Novel Method for P Spaces", by P. N. Currie	rediction of Mobile Robot Maneuvering r and A. L. Wicks (<i>paper, presentation)</i>	
3. "High Speed Autonon by T. R. Botha and P. S.	nous Off-Road Vehicle Steering", Els (<i>paper, presentation)</i>	
4. "Load Distribution Co Rough Terrain", by T. K K. Tateyama (<i>paper, pr</i>	ntrol of a Six-Wheeled Robotic Vehicle in obayashi, G. Ishigami, K. Nagatani, and <i>esentation)</i>	
2:50 pm – 3:05 pm	Coffee break and snacks	
3:05 pm – 4:00 pm	Poster session and posters pick-up	Room: Latham DEF
4:00 pm – 4:30 pm	Closing Session Drs. Sandu, Shoop	Room: Latham C
4:30 pm – 5:00 pm	Free time. Prepare for optional CVeS	5 tour
5:00 pm – 6:30 pm	Optional Tour of the Center for Vehic Host: Prof. C. Sandu, (Director AVDL)	le Systems and Safety (CVeSS)

Companion Schedule

Sunday, September 18, 2011

7:00 pm – 10:00 pm Ice breaker reception The Inn at Virginia Tech (joint with conference)

Monday, September 19, 2011 (water and snacks available on the van)

7:00 am – 8:00 am	Breakfast at The Inn at Virginia Tech (joint with conference)	2:00 pm – 3:00 pm	Tour Local Art Galleries and Downtown shops
8:00 am – 8:15 am	Opening Remarks (joint with conference)	3:00 pm – 4:15 pm	Mini-Golf
		4:30 pm – 5:30 pm	Free time. Prepare for evening at
8:15 am – 8:30 am	Prepare for the campus tour		Mountain Lake
8:30 am – 9:30 am	Campus Tour	5:30 pm – 6:00 pm	Leave for and arrive at Mountain Lake (4 Buses) (joint with conference)
9:30 am – 11:25 pm	Tour of Historical Smithfield Plantation and return to The Inn at Virginia Tech		
		7:00 pm – 10:00 pm	Dinner and entertainment
11:25 am – 12:40 pm	Lunch at The Inn at Virginia Tech (joint with conference)		Oktoberfest style with The Sauerkraut Band (joint with conference)
12:40 pm – 2:00 pm	Tour of Hahn Horticulture Garden	40.00	
		10:00 pm – 10:30 pm	Return to Hotels (joint with conference)

Tuesday, September 20, 2011

Visit to Virginia International Performance and Engineering Research (VIPER) (joint with the conference)

Wednesday, September 21, 2011 (water and snacks available on the van)

7:00 am - 8:00 am	Breakfast at The Inn at Virginia Tech (joint with conference)	2:30 pm - 5:00 pm	Shopping & Visit Museums Taubman Museum of Art
8:00 am - 8:15 am	Morning Announcements (joint with conference)		Virginia Museum of Transportation The Harrison Museum of
8:15 am	Leave for the Homestead Creamery		African American Culture
9:30 am - 11:00 am To so	Tour of Homestead Creamery and souvenir shopping	5:00 pm – 5:45 pm	Return to Hotels
		5:45 pm – 7:00 pm	Free time. Prepare for the banquet at The Inn at Virginia Tech
11:00 am - 11:45 am	Lunch at the Homestead Creamery		
11:45 am	Depart for the Mill Mountain, Roanoke Zoo	7:00 pm – 10:00 pm	Dinner Banquet at The Inn at Virginia Tech (joint with the conference)
12:15 pm - 2:15 pm	Visit at the Zoo		
2:15 pm - 2:30 pm	Drive to downtown Roanoke		

Thursday, September 22, 2011 (water and snacks available on the van)

7:00 am – 8:00 am	Breakfast at The Inn at Virginia Tech (joint with conference)	8: 30 am – 5:30 pm	Blue Ridge Parkway trip • Christmas in the Meadows • Settlers Museum • Candy Store • Mabry Mill
8:00 am – 8:15 am	Morning Announcements (joint with conference)		
8:15 am – 8:30 am	Prenare for the Blue Ridge Parkway		Mabry Mill
	trip	12:00 pm – 1:00 pm	Lunch at Mabry Mill
		4:00 pm – 5:30 pm	Arrive at Hotels

Companion Tours

Smithfield Plantation

The Historic Smithfield Plantation is a wonderful historical site. This 1774 plantation home is located on the edge of the Virginia Tech campus and is a living document of the rich history of the area. It was here, that the leader of westward expansion and Revolutionary War patriot William Preston established Smithfield Plantation. Smithfield was first opened to the public in 1964, and today is a living document of the past, a testimony to the bravery and devotion to country of the Preston's who made it their home.

Hahn Horticulture Garden

The Hahn Horticulture Garden is nearly six acres of teaching and display gardens located on the campus of Virginia Tech. Established in 1984 by Horticulture faculty, the garden serves undergraduate students and the local community as a learning resource for plant material, landscaping concepts, and environmental awareness. Garden features include perennial borders, water gardens, shade gardens, meadow garden, and the Peggy Lee Hahn Garden Pavilion.

Mountain Lake Hotel

Historic Mountain Lake Conservancy & Hotel, a pristine 2,600 acre Virginia mountaintop property.

Virginia International Performance and Engineering Research (VIPER)

The Virginia Institute for Performance Engineering and Research (VIPER) is a unique collaborative venture which combines world class talent and state-of-the-art testing and development assets with the research capabilities of both Virginia Tech and Old Dominion University to provide performance engineering services to a broad spectrum of customers. With facilities located at Virginia International Raceway and NASA Langley, VIPER can provide your organization with a full suite of performance engineering services, research opportunities, and educational programs.

Homestead Creamery

The Homestead Creamery was established in Franklin County, near Roanoke, Virginia, in 2001. By 2006, the company had gained hundreds of customers, delivering milk, eggs, coffee beans and ice cream door-to-door in the Roanoke area as well as to supermarkets in the area and their own store in Burnt Chimney. The Homestead Creamery offers tours to the general public

Mill Mountain Zoo

The Mill Mountain Zoo is a member of AZA, (The Association of Zoos and Aquariums. Mill Mountain is located on top of Mill Mountain next to the giant STAR that overlooks the beautiful city of Roanoke.

Species in Mill Mountain Zoo's PMP include: Western Tufted Deer, Wolverine, Crested Porcupine, Wrinkled Hornbill, Hooded Crane, Dart Frog, Burmese Mountain Tortoise, Parma Wallaby, Sichuan Takin, Chestnut-breasted Malkoha, Luzon Bleeding Heart Dove, New Guinea Masked Lapwing, Scarlet Ibis, White-crested Laughing Jay Thrush, Crested Wood Partridge, Palawan Peacock Pheasant, Collard Finchbill, Victoria Crowned Pigeon, Cougar, Blue-crowned Motmot, Blue-bellied Roller, Yellow-breasted Ground Dove, Prehensiletail Skink, Canadian Lynx SSP Asian Small Clawed Otter SSP Pallas Cat SSP All SSP and PMP animals are part of captive breeding programs.

Taubman Museum of Art

Located in the heart of downtown Roanoke, this contemporary structure evokes the drama of the surrounding mountainous landscape.

Virginia Museum of Transportation

The Museum is located in Roanoke, Virginia, one of America's great rail centers and home of the original headquarters of the Norfolk & Western Railway for 100 years. The legendary Roanoke Shops of the N&W designed and built the most modern and powerful steam engines in the world. The N&W's employees combined hard work and incredible talents to hone these great locomotives known worldwide for their muscle. The last two left of the J and the A series, 611 and 1218, are here at the Museum. To see them together will take your breath away!

The Harrison Museum of African American Culture

The Harrison Museum of African American Cultures, Inc. (HMAAC) is a cultural and educational institution committed to advocating, showcasing, preserving and celebrating the art and history of African Americans for Roanoke Valley citizens and visitors. Our purpose is to cultivate awareness and appreciation of the significant contributions of people of **African descent**.

The Blue Ridge Parkway

This very popular unit of the National Park System is celebrating its 75th anniversary this year. The parkway winds 469 miles through mountain meadows and features remarkable vistas.

Abstracts

Track 1. Session 1 $_-$

Direct Shear Behaviour of Dry, Granular Soils for Low Normal Stress with Application to Lightweight Robotic Vehicle Modelling

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Modelling of soil shearing behaviour under wheeled or tracked vehicles requires the knowledge of three soil properties: cohesion, angle of internal friction, and shear modulus. For lightweight robots it is necessary to characterize the soil for small normal stress (<15kPa) while most of the data collected in the literature regards higher stress testing conditions. Soil failure at low stress may diverge from Mohr-Coulomb envelope invalidating the fundamental assumptions behind classical terramechanics approach. Through the analysis of direct shearing performance of a dry, granular, soil, this paper address several issues related to off-road traction mechanics (not necessarily limited to low stress cases). We present an improved approach for shear modulus calculation that overcome the inaccuracies introduced by Wong method. We analyze the importance of density in modifying terrain response. Moreover, we show how erroneous estimation of soil cohesion and angle of internal friction may limit the applicability of Bekker/Wong theory to lightweight tracked vehicles.

Keywords: Direct Shear Test, Mojave Mars Simulant, Shear modulus, Low stress, Lightweight robot

Effect of Tire Inflation Pressure on Soil Strength Estimation Using Wheel Sinkage

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The empirical equation developed by Willoughby et al. predicts wheel sinkage as a function of unloaded tire width, unloaded tire section height, unloaded tire diameter, loaded tire deflection, vertical tire load, tire slip and rating cone index of soil. It has been shown that soil strength represented by the rating cone index (RCI) may be estimated by solving this empirical equation for the rating cone index with measured wheel sinkage. For this way of RCI estimation to be reliable, the same RCIs must be estimated in the given soil conditions regardless of inflation pressure and load of the tire used for measuring the wheel sinkage. To investigate the effects of tire inflation pres-sure on the RCI estimation, a large number of RCI simulations were made using a model developed to this end. Although no definite conclusions could be made from the simulation results, it appears that the RCI can be estimated with less effect of tire inflation pressure under the limited conditions of soil and tire load. A general trend was that as the exponent of soil deformation and tire load increase, the effect of inflation pressure of tire on the RCI de-creases. Although further researches may be required until an exact effect of tire inflation pressure could be descri-bed, the simulation results indicate that the tire inflation pressure is likely to affect the RCI estimated using Wil-loughby equation. In other words, wheel sinkage must be measured with properly inflated tires to estimate more reliable soil strength using the Willoughby equation.

Keywords: soil strength, rating cone index, tire inflation pressure

Modeling of Soil Displacement and Soil Strain Distribution Under the Traveling Wheel

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The empirical Gaussian-based mathematical model of soil displacement increment under the traveling wheel was extended to be applicable to any depth of soil layer under the ground contact surface of the wheel. The unknown coefficients were obtained by least mean-square fitting with the soil displacement curve measured through laboratory sophisticated soil bin test. Then those coefficients were rederived as a function of depth. The movement of soil particles at the ground contact surface was modeled by dividing into 2 kinds; first, the free movement of soil particles before contact with the wheel and the movement of the particles after they are separated from the wheel surface and the second type represent soil movement during attachment to the wheel surface. By combining the models for the ground contact surface of the wheel with that for all soil layers, the extended model that can describe soil displacement increment in both the vertical and horizontal directions using one equation was established. The predicted results obtained using the extended model fitted quite well with the measured values. The predicted strain increment distributions show the same trends as the measured distributions.

Keywords: Soil displacement, mathematical model, soil bin test, soil strain

Development of a Dynamic Visco-Elastic Vehicle-Soil Interaction Model for Rut Depth, Energy and Power Determinations

Paul D. Ayers, George Bozdech, Jeff Freeman, Alexander Reid, and James O'kins

Oral presentation only Submission Text: Power and energy from vehicle-induced soil displacement is critical in understanding time-dependent mobility power in soft soil. This paper describes the development of a physics-based vehicle-soil interaction model to predict terrain deformation and vehicle energy/power requirements. Time-dependent soil deformation based on subsurface stress distribution and resulting compression is determined. Time constants and rebound of soil is used to predict the dynamic soil response. Vehicle tire multipass is also included in the model. An example of the model performance is conducted using an 8-wheel Stryker with 12R20 XML tires on a terrain existing at Ethan Allen Firing Range, Vermont. The influence of variations in vehicle speed on multi-pass soil rutting, energy and power is analyzed.

UNCLASSIFIED: Dist A. Approved for public release

The Effect of the Lateral Distance of the Shallow Tines on the Energy Utilization Efficiency of the Subsoiler

Shaker Aday

The most successful and desirable agriculture machine is the one which gives the required results when used in the field and has high EUE which expresses the ability of the machine to use the energy to do the useful work. The most energy consumptive agriculture machine is the subsoiler but it is the most desirable machine to manipulate the heavy texture soils and to shatter the hard pan at depth which is widely found in silty clay soils. EUE of a modified subsoiler (the subsoiler provided with shallow tines and wings) was studied to determine the best subsoiler combination, operating depth and lateral distance between the shallow tines giving the highest EUE.

EUE for S+sh increased as the operating depth increased. The highest EUE for S+sh was recorded to the deepest operating 60cm (10.47m3/MJ) where as EUE for the conventional subsoiler (S) at the shallow depth of 30cm is 7.78m3/MJ. EUE increased as the lateral distance between the shallow tines increased and the highest value of EUE (10.04m3/MJ) was recorded to the widest lateral distance tested of 60cm (S+sh60) while for S is 8.52m3/MJ. When the conventional subsoiler was provided with wings (SW), EUE increased to 9.18m3/MJ but increased further to 12.25 when SW was also provided with shallow tines (SW+sh) for operating depth of 60cm. The highest value of EUE (14.62m3/MJ) was recorded to the subsoiler which was provided with wings and shallow tines at the widest lateral distance of 60cm (SW+sh60) and at the deepest operating depth of 60cm and it was greater than that for S at the shallow depth of 30cm by 89%.

The results showed that using the subsoiler with wings and shallow tines at narrow distance (40cm) (SW+sh40) gave lower EUE than the subsoiler with wings (SW) at shallow operating depth of 30cm. When the operating depth increased the controversy occurred but EUE values of SW+sh40 remained close to that of SW.

The operating depth is more effective on EUE values than the wings and the shallow tines, while the wings became the second decisive factor. When those factors interacted they gave the highest values of EUE.

Sophisticated Improvement of the Soil Compaction State Evaluation

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Penetration resistance is one of the complemented parameters specifying the soil compacting state. Commonly, universality of penetration resistance empirical models to assess soil dry density is still unimportant subject of research. The application of simple method to assess the soil dry density using the progressive ways has a potential under homogeneous soil conditions. A semi-empirical model estimating soil dry density from penetration resistance in modelled clay-silt loam soil profile, pore size distribution, gravimetric soil water content and depth was developed and verified for standardized laboratory soil conditions. The series of experiments were performed under two different soil moisture conditions and various soil compactions to obtain a databank relating the pore radius (corresponding to the mean of a pressure head natural logarithm obtained from fitting the soilwater retention curve using a log-normal distribution curve) and penetration resistance below the centre of a loading device (so called penetration functions). The accuracy of compared compaction functions for different moistures shows, that the semi-empirical penetration model based on pedotransfer matches reliably the observed soil dry density and this application can be recommended as an additional, sophisticated way for soil compaction research and standardized testing conditions establishment, respectively.

Keywords: penetration resistance, pore size distribution, soil dry density, soil compaction

Reconfigurable Vegetated Soil Strength Instrument for Mobility Measurements

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The U.S. Army is concerned with the most effective and environmentally sustainable use of its military training lands. Repeated trafficking of these lands can alter the state and strength of the soil and cause soil erosion. Efforts to study the effects of soil, vegetation, and treatments of vegetated military training lands are part of the Optimal Allocation of Land for Training and Non-Training Uses: Soil Strength Interactions project. Combined soil and vegetation strength measurements provide an indication of soil's ability to withstand trafficking. An instrument was designed and constructed to help quantify the effects of vegetation (biomass) on soil strength as it relates to mobility and trafficability. The basic components of the instrument are a 1000 lb capacity load cell, linear position transducer, tire analog, and an electric motor. The instrument was designed to measure the shear force of various configurations of tire analogs over different vegetated soil types. It is capable of dragging spikes of varying length, chevrons, cleats, or tire treads through various test sections of biomass. Test beds were constructed of clay-loam and fine sand and planted with Kentucky Bluegrass. Preliminary results will be presented that show the effects of different analogs on soil/vegetation strength. Quantifying the effects of vegetation on soil strength will prove to be vital in making recommendation for the use and land treatment of vegetated military training lands.

Keywords: Soil Strength, soil shear, vegetated soils, soil and vegetation interaction, vegetation strength, trafficking

Soil Strength as a Function of Soil and Ground Cover Types

Sally Shoop, Rosa Affleck, Charles Smith, Kelsey Gagnon, and Robin Stone

Military training exercises increase the erosion of lands by disturbing soils with heavy vehicles and other disturbances. In this study, the strength of soils in a laboratory setting are measured to assess their resilience to such traffic. Soil type and ground cover type were examined as possible factors influencing soil strength. The study was conducted under controlled indoor conditions. Strength measurements included penetration of a weight and deceleration of weights of varying sizes. Density and moisture of the soils was also measured, as these are influenced by soil and cover types and may influence strength measurements. Significant effects on strength measurements were soil and cover type, and in some cases, the interaction between the two. Penetration and deceleration measurements yielded somewhat different trends. Optimization for all strength measurements simultaneously indicated a bare clay as the best treatment, although other treatments performed well for some strength responses.

Track 1. Session 2 _

Automatic Microsurface Terrain Acquisition and Modeling System

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The Automatic Microsurface Terrain Acquisition and Modeling (AMSTAM) system is designed for fast and efficient collection of microsurface terrain elevation and soil stiffness data. The measurements are saved in a database and converted into terrain roughness models needed for mission planning and vehicle durability analysis. Microsurface terrain roughness is a main source of high-frequency vehicle vibrations and discrete impacts on a vehicle's suspension. The AMSTAM system architecture is an integration of a terrain profilometer and microsurface terrain modeling and mapping software. The AMSTAM profilometer is based on data from noninvasive differential laser triangulation sensors integrated with an orientation sensor and installed on a front wheel axle, minimizing the impact of vehicle vibration on elevation measurement. The mapping software is developed as ArcObjects, in ESRITM ArcInfo software environment. The modeling software detrends source elevation profiles by spatial filtration in a frequency domain and calculates the root-mean-square of the variation from the fractal dimension and radius of autocorrelation for source and detrended profiles. The system was tested on various terrain types in California (Hungry Valley) and in Mississippi (Letourneau ride courses). Introduction of the AMSTAM system into U.S. military or commercial fleet vehicle systems will enhance capabilities for improving/implementing condition-based maintenance of current and future vehicles.

Keywords: profilometer, laser, GIS, fractal, detrending, RMS, autocorrelation, fast Fourier transform.

Managing Field Operations for the Protection of Buried Archaeological Artifacts

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The military is responsible for maintaining compliance to federal regulation of cultural resources while fulfilling training needs. This work presents a cumulative summary and conclusions of research investigating the influence of surface loading from agricultural field operations (paralleling military landcare operations) on damage to buried pot and aged bone archaeological artifacts.

Results from laboratory artifact breakage and field pressure generation experiments were utilized to: a) develop and test a model for predicting the effects of dynamic surface loading on buried objects; and b) explore ways of identifying damage potential to buried artifacts under field operations. An empirical relationship between buried object damage and subsurface pressure magnitude was developed and utilized in the statistical analysis correlating breakage to the subsurface pressures under each field operation. Relationships were observed between vehicle specification, subsurface pressure generation, and consequential artifact breakage.

This research developed a functional predictive relationship between damage to buried artifacts from subsurface soil pressures generated by surface traffic. This provides knowledge about how field operations, choice of track or tire type, and inflation pressures can be managed in order to protect or mitigate damage to buried archaeological artifacts, whether in an agricultural or military context.

Keywords: Agricultural operations, soil dynamics, subsurface pressure transfer, buried archaeology, military training, land rehabilitation

GIS for Operative Support

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Geographic Information Systems (GIS) is often used for planning purposes in forestry. This is mainly to give directives for the operators where to cut the trees and nowadays also for marking of areas with high environmental values where considerations should be made. The minor used techniques is to incorporate soil information maps as an overlay to give information to forest machine operators where less good trafficability is to be expected, especially after a heavy rain. By marking areas with bad bearing capacity the operators may save both time and money not bogging down with the machine. When the soils bearing capacity is less than 0.7 MPa and the ground pressure of the machine is more than 80 kPa either smaller machines must be used or bogey tracks should be used to decrease the risk for getting stuck or causing severe rutting. By choosing good types of bogey tracks both rutting and fuel consumption will be decreased for the health of forest land and the contractor.

Investigation of Excavation Behavior via Model Experiment and Distinct Element Method (DEM) Simulation using Irregularly Shaped Particles

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In the design of buckets of wheel loaders, the need for a computational approach to soil simulation has been increasing recently. In particular, evaluation of the reaction force is the most important. To analyze this force, the distinct element method (DEM) simulation has been attracting attention. Thus, it was approached using DEM and, model experiments. In this study, the model experiments with irregularly shaped particles fabricated from polypropylene (PP) were carried out. The bucket forces in the model experiment were compared with those in the simulation using the clamped model, which is the same size as that used in the model experiment. As a result, the bucket forces in the simulation were nearly equal to those in the experiment. To confirm that the bucket forces are affected by the particle shape, the experiments were carried out with three types of particles PP particle, pumice and gravel. Comparison of the results of PP particles with those of pumice shows that the particle shape has a large effect on the bucket forces. On the other hand, the density and friction coefficient have a lesser effect on the bucket forces than the particle shape.

Keywords: distinct element method, soil excavation, model experiment, wheel loader, irregularly shaped particles

Review of Current Military Training and Landcare Operations Relative to Subsurface Pressure Transfer and Protection of Subsurface Soil Condition

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Cultural and natural resource management on Military training lands is currently compliance-driven, and supports sustainable training and overall mission readiness. A key component to maintaining sustainable training lands is the performance of essential landcare maintenance operations, which is able to enhance land capability for improve mission readiness.

In the Military, areas where training has been proven to have adverse effects on natural and/or cultural resources are avoided, or designated for controlled-access. As Military training needs continually increase and overall training range areas decrease, more pressure is placed on finding ways to keep land in-training. Much research pertains to natural resource management relative to military training impacts; however, less relates to management of subsurface resources. Both military training vehicle impacts and land maintenance operations have the potential to be evaluated relative to their effects on subsurface soil condition.

A preliminary review has been conducted to survey training uses and current landcare operations on select military installations. A subsequent evaluation is presented comparing the ways in which landcare is implemented in the military versus agriculture, with assessment of potential effects of these field operations on subsurface soil conditions. Recommendations for further study and suggestions for impact mitigation will also be presented.

Keywords: Agricultural operations, military land care, subsurface pressure transfer, buried archaeology, military training, land rehabilitation

Track 2. Session 1 $_-$

Conceptual Study of Small Excavation Systems for Future Lunar Exploration

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Excavating to the lunar surface is an indispensable technology for scientific lunar exploration and also for lunar resource using in the future. But it is difficult to use the same excavating operation of the Earth because the moon has no atmosphere and water. And the sand deposited on the lunar surface that called Regolith, has very height density under 20 cm from the surface, require a large reaction force in excavating operation. Especially in the early phase of lunar exploration, the weight of the equipment will be brought to the lunar surface are limited. This study examined the concept of a smaller, lighter excavating machine with a simple mechanism for lunar exploration.

Keywords: moon, regolith, vibratory transportation, excavation

Advantageous Bucket-Wheel Configuration for Lightweight Planetary Excavators

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Robotic regolith excavation on the Moon and Mars enables outposts, fuel depots, and sustained space exploration. In any space mission, mass is always at a premium because it is the main driver behind launch costs. Low mass and reduced gravity (1/6 of Earth gravity on the Moon, 1/3 on Mars) results in machines with limited weight available to produce traction or plunge tools into regolith. Bucket-wheel excavators have been shown to produce low resistance forces that enable lightweight operation, but in the past have had difficulty transferring regolith from bucket-wheel to collection bin. Exposed conveyors and chains fare poorly in harsh lunar regolith and vacuum. A novel excavator configuration, with bucket-wheel mounted centrally and transverse to driving direction, achieves direct transfer into a collection bin. Experiments with a bucket-wheel digging in lunar simulant show that transverse bucket-wheel orientation does not increase resistance significantly. Excavation resistance is shown to depend mostly on the ratio of bucket-wheel rotation rate to forward advance rate.

Keywords: Excavation, planetary rovers, bucket-wheel

Mobile Payload Element: Concept Study for a Sample Fetching Rover for the ESA Lunar Lander Mission

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On behalf of the European Space Agency (ESA), European space industry have been conducting a feasibility study of a robotic lunar lander mission to a site close to the south pole of the Moon. Recent lunar orbiter missions have confirmed that this general region contains patches of terrain several 100 meters across which are in near-perpetual sunlight while being in close proximity of eternally dark low lying terrains (shadowed crater floors) which have been demonstrated by radar remote sensing and an impactor experiment to contain frozen volatiles. The projected ESA mission, referred to as 'ESA Lunar Lander' (LL) and scheduled for launch in 2018, is tasked to achieve an autonomous soft landing at one such favorably illuminated locale, followed by a multi-month long surface mission to characterize for the first time the lunar south pole region. Under contract to the German Space Agency DLR, a team of industry and academia from Germany led by the company Kayser-Threde, is currently performing a concept study for a small rover - the Mobile Payload Element (MPE) that would be part of the lander payload. At a projected 12 kg of total mass, this vehicle would by far be the smallest rover to be operated on the surface of the Moon, following up on the Soviet Lunokhod's and the crewed Apollo Lunar Roving Vehicles of the 1970's, but also on the Indian Chandravaan-2 rover scheduled for 2013. In mass and size, the MPE is however very similar to the US Mars Pathfinder MFEX ('Sojourner') micro rover technology experiment operated on Mars in 1997. The novel capability of the MPE – thus far not matched by any other planetary rover but eventually required for future

robotic Mars sample return missions – will be to acquire samples of lunar soil some distance away from the actual lander, and to bring them back to the spacecraft for analysis by on-board instruments. This will enable access to soils that are less contaminated by lander descent propulsion system plumes to increase the chances of detection of any indigenous lunar volatiles contained within the samples. Starting from the requirements imposed on the rover, this paper describes the trade-off's performed on the mobility and overall system design with a focus on the mobility and power subsystems, followed by a description of the conceptual design, the predicted mobility performance under lunar conditions, and plans for brassboarding and associated testing in the 2012/2013 timeframe.

Report from the 2011 Summer Series of Workshops on "xTerramechanics"

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A series of workshops were held in the summer of 2011 at Caltech in Pasadena, CA on the topic of "xTerramechanics". These workshops were sponsored by the Keck Institute for Space Studies (KISS) with co-leads from JPL, Caltech, and MIT (listed here as authors of this paper). This paper will present a brief synopsis of the workshop, including motivations, content, insights, and future prospects for research and space missions.

xTerramechanics (XTM) is a discipline that broadly entails the study and modeling of interactions between spacecraft (e.g., rovers) and extraterrestrial geomaterials (e.g., Martian soils). By bringing together key technical experts from across, the workshops aimed to initiate a transformative advancement in the capabilities available to NASA missions. We introduced our study by focusing on the canonical case of surface interactions stemming from mobility issues related to Martian rovers to deepen our understanding of key mission life-cycle processes: formulation trades, design, mission operations, and in-situ science context and integration. The collaborations that resulted in these workshops were born from experiences of the Spirit rover's embedding incident on Mars, with concern for future operations of the MSL Opportunity rover when it lands on Mars in August 2012.

The events began with a half-day short course on the fundamentals of planetary terramechanics, as presented by NASA project scientists and academic partners in the fields of robotics and computational soil mechanics. To facilitate a positive, synergistic group dynamic, our roster was capped at thirty participants, including planetary scientists, engineers, roboticists, soil mechanicians, modelers, and analysts. Attendees came from JPL and other NASA centers, Caltech and several other universities, and industrial partners including Caterpillar. Much of the first workshop was spent defining the limitations and horizons of the field. A core

theme was parameter identification, correlation, extraction, and reduction, with a goal of converting mechanical mobility systems into "N+1" science instruments.

A working study period was held to further delineate possible modes of collaboration and work toward a possible overall community research architecture. We focused on a multipronged modeling strategy supported by experimentalists, scientists, and engineering practitioners. Such a framework supports movement toward two goals: (1) long-term goals of full physics-based modeling as a means for enabling new, radical mission concepts, and (2) short-term goals of providing the best possible tools to assist in rover mission driving operations. These second set of goals will be supported by an active reduced order modeling effort alongside the full-model development. The final consensus of the group was that a strong modeling and simulation community will be required by NASA to remain competitive and innovative as new mobility, sample acquisition, and sample return challenges are presented in environments of unknown characteristics and no ability to be represented in terrestrial physical testbeds.

Soil Motion Analysis System for Examining Wheel-Soil Shearing

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Though much research has been conducted regarding traction of tires in soft granular terrain, little empirical data ex-ist on the motion of soil particles beneath a tire. A novel experimentation and analysis technique has been developed to enable investigation of terramechanics fundamentals in great detail. This technique, the Shear Interface Imaging Anal-ysis Tool, provides visualization and analysis capability of soil motion at and below the wheel-soil interface. The me-thod places a wheel (or other traction device) in granular soil up against a transparent sidewall. While driving or towing the tire, images are taken of the sub-surface soil, and are processed with optical flow software. Analysis of the resulting displacement field identifies clusters of soil motion and shear interfaces. Complexities in soil flow patterns greatly affect soil structure below the wheel and the resulting tractive capability. The Shear Interface Imaging Analysis Tool visualizes and helps analyze these complexities in richer detail than possible before, and allows for a deeper understand-ing of the physics behind wheel-terrain interaction. Results are presented for rigid wheels at various slip conditions, and various wheel configurations such as diameter, grouser spacing and compliance.

Keywords: terramechanics, rover, robotics, regolith, wheel

Microscopic Study on Dynamic Behavior of Lunar Regolith under Driving Wheel in Micro-Gravity Circumstance

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The rigid wheel passing the regolith is simulated by discrete element method (DEM), and microscopic study the particles track, velocity distribution and the dynamic process of the porosity ratio of the lunar regolith in micro-gravity circumstance by monitoring five typical particles and a 5cm radius measurement circle under the driving wheel. The results show that the track could be separated push, press and rebound part when the lunar regolith particles under the smooth wheel. And it could be separated two kinds when the lunar regolith particle under the lug wheel. If the particles outside the circularity, the track is similar to the track under the smooth wheel. If the particles inside the circularity, the track could be separated press, toss and drop part. The lunar regolith under the driving wheel has forward and backward floating area when the slip ratio is between 0 to 100%. The porosity ratio of the lunar regolith is descended when the wheel passing, and then it has some rebound after the wheel passing, but as a whole it is less than that before the passage.

Keyword: micro-gravity; discrete element method (DEM); driving wheel; slip ratio; track

Terramechanics Simulation for Mobility Planning of the Mars Exploration Rovers

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To help minimize risk of high sinkage and slippage during drives and to better understand soil properties and rover terramechanics from drive data, a multidisciplinary team was formed under the Mars Exploration Rover Project to develop and utilize dynamic computer-based models for rover drives over realistic terrains. The resulting tool, named ARTEMIS (Adams-based Rover Terramechanics and Mobility Interaction Simulator), consists of the dynamic model in MSC-Adams, a library of terramechanics subroutines, and high-resolution digital elevation maps of the Mars surface. The models include the rut-formation effect of deformable soils, using the classical Bekker-Wong implementation of compaction resistances and bull-dozing effects. Numerous simulations have been run for drives of both Spirit and Opportunity.

The paper presents the details and implementation of the model, as well as several case studies. The first study specifically addresses the Spirit Rover embedding situation at the "Troy" site on Mars. Four of the six rover wheels became partially-to-nearly-completely buried, percent slip was on the order of 95-

98%, and images of the underbelly showed that the warm electronics box may be high-centered on a rock. This is well beyond the range of intended and studied driving conditions. We have correlated the ARTEMIS results with In Situ Laboratory (JPL) test data and replicated the drives into Troy using simulated elevation maps generated from flight data.

The second study focuses on simulating an Opportunity terramechanics ripple-crossing experiment. This test was motivated by the need to get Opportunity across a field of hundreds of ripples to its current science destination at the rim of Endeavour crater. The final study illustrates our current campaign to assist Opportunity in the ascent up the steep ridges of Endeavor Crater. Our model will be able to make risk assessments on the various path trajectories, which include 20 degree slopes and soft-soil hazards.

Track 2. Session 2

A Comparison of Scuff Tests from the Martian Rover, Opportunity, and a Discrete Element Method Model

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A three dimensional discrete element method (DEM) wheel model has been developed to simulate digging and scuffs completed during the Mars Exploration Rover (MER) mission. Two in situ scuffs from the rover Opportunity near Endurance and Victoria Craters will be examined and simu-lated here. The rover wheel has an intricate non-uniform geometry because of a cavity used to at-tach the rover to the lander and that important feature is incorporated in the model. In the DEM wheel model we are able to investigate variations in soil characteristics and find a model soil that best represents the in situ data based on sinkage and torgue measurements. The best-fit model soil will be tested in a DEM geotechnical triaxial strength cell (GTSC) to relate grain properties to bulk soil strength properties and measure soil deformation and shear strength as a function of confine-ment pressure. Initial DEM scuff results using poly-ellipsoid soil particles resulted in greater sinka-ge than found on Mars, while sinkage results using polyhedral particles where closer to martian results.

Keywords: Mars Exploration Rover (MER), rover, discrete element method

3D Simulation in Pressure-Sinkage Characteristics of Martian Soil Simulant by Discrete Element Method

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Study on the pressure-sinkage characteristics of Martian soil simulant is helpful for the optimization of wheels, structures and instruments working on Martian surface. Strength of the Martian gravitational field is 0.38 times terrestrial. The pressuresinkage characteristics of Martian soil simulant under the Martian gravity vary from terrestrial. This present research is to study the pressure-sinkage characteristics by numerical simulation. Based on the properties of Martian soil simulant, the nonlinear contact-model between the Martian soil simulant particles was established by using three-dimensional Discrete Element Method (DEM). The value of the DEM parameters was conducted by the pressure-sinkage relationship in the laboratory experiment. The changes of contact-force chains and velocity fields of Martian soil simulant were analyzed and compared with those in 1g condition. Based on the pressure-sinkage relationship in simulation, the pressure-sinkage parameters under 1g and 0.38g gravity condition were obtained.

Keywords: Martian soil simulant; pressure-sinkage characteristics; low gravitational field; 3-D Discrete Element Method; numerical simulation

Research on the Relationship Between Ruts of Lunar Rover Wheel and the Mechanical Properties of Lunar Soil Simulant

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It is necessary to understand the lunar soil behavior under the wheels of rover because lunar soil covered on the lunar surface is thick and loose, and the lunar rover is light in weight and compact in structure. Therefore, research on the mechanism of the interaction between wheel and the lunar soil simulation is of great importance for rover test in laboratory. The lunar soil simulation used in the test was made of which the pressure capability, shear stress, and bulk density were similar to those of real lunar soil. The rover wheel tests were conducted in soil bin with different normal pressure and the forward speed on the wheels to obtain different ruts. Different wheels generated different shape, size and depth of ruts on the lunar soil stimulant. By statistics the test data of slip, efficiency coefficient and drawbar pull of the wheel, and compared with simulation results to the tested data, the relationship between the rut shape with properties of lunar soil stimulant were fixed. Research work will be useful for making decision to remote control lunar rover in situ of moon.

Keywords: rut, lunar soil stimulant, mechanical properties, rover wheel

Study on the Cone Index and Bulk Density of Lunar Soil Simulant under Different Deposit Statuses

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It is important to research the relationship between wheels and the lunar soil simulant in laboratory for the lunar rover experiment. The mechanical and physical properties of lunar soil simulant used in the laboratory test will greatly influence the precision and reliability of the rover test results. This article discusses the range of the cone index and the bulk density of lunar soil simulant which is under different preparation process. The research results could be used as a criterion to deal with the lunar soil simulant for the test of lunar rover. Based on the ultimate bearing capacity of a conical-shape foundation which is given approximately by the Terzaghi equation, modified by Meyerhof, the experimental curves of the bulk density and bearing capacity were made. The results of the analysis show a good agreement between the experimental data and the theoretical curve.

Keywords: Lunar soil simulant, terrain mechanics, bulk density, cone index

Track 2. Session 3 _

Development of a Real and Simulation Testbed for Legged Robot Soil Interaction

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For legged robots, evaluation of the overall mobility performance on different soil types is a requirement to guarantee a good walking behavior. Therefore, it is important to develop models and simulations of the overall leg-soil interaction and terramechanical behavior, making use of semi-empirical and physical models.

To help build these interaction models and for the verification and validation of the simulation, intensive robot testing in a lab environment is necessary and should occur hand in hand with their development.

This paper describes the design and development of a new testbed for legged robot systems. This testbed consists of a soil testbed, a 7DoF robotic arm, and software architecture to perform both real and simulated experiments with different robot legs and other test objects.

The testbed is used to study and analyse the test objects interaction with the soil and their terramechanical properties to help build models that are used in the design of real robots and in the overall simulations of these systems. Results with analysis for real experiments and simulations are presented together with the testbed setup design.

Keywords: terramechanics, testbed, soil contact interactions, legged robots, simulation

Modeling of Leg-Soil Interaction using Genetic Algorithms

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In the field of legged robotics, the use of walking and climbing robots becomes very useful for extraterrestrial applications, e.g., collection of samples from lunar crater beds. To efficiently simulate such a space mission, a realistic robot leg-soil interaction model is required.

In this paper an approach is presented that constructs such a model using a genetic algorithm that evolves an artificial neural network using experimental data. The data is collected through a series of experiments performed with an industrial robotic arm equipped with a six axes force/torque sensor and a state of the art walking and climbing robot foot. The genetic algorithm evolves the structure and the parameters of the neural network which is represented with an indirect graph.

The paper describes the neural network, the genetic algorithm, and the indirect graph representation. Moreover, the integration of the model into a full rigid body robot simulator is presented.

Keywords. Terrain interaction, legged robots, simulation, genetic algorithms, neural networks.

Evaluation of Influence of Surface Shape of Wheel on Traveling Performance of Planetary Rovers over Slope

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Planetary rovers play a significant role in lunar and Martian surface explorations. However, because of wheel slippage, the wheels of planetary rovers can get stuck in loose soil, causing the exploration mission to fail. To avoid slippage and increase the drawbar pull, the wheels of planetary rovers typically have lugs (i.e., grousers) on their surface. Recent studies report that these lugs can substantially improve the travelling performances of planetary rovers. Therefore, in this study, we conducted experiments using lightweight two-wheeled rover testbeds in a sandbox to provide a quantitative confirmation of the influence of lugs on the travelling performances of planetary rovers. Based on our experimental results, we confirmed that although lugs have some effect on the travelling performances over gentle slopes, they have a greater effect on the travelling performances over steep slopes.

Keywords: Planetary rover, wheel, loose soil

Toward Establishing a Comprehensive Pressure-Sinkage Model for Small Diameter Wheels on Deformable Terrains

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Traditional terramechanics theorems utilise pressure-sinkage models based on the assumption that the contact area between a tyre and soil can be approximated as a flat plate. Examples include work by Bekker, Reece, and Ishigami. Recently, the authors have demonstrated that 1) this approximation does not hold for wheels with a diameter less than approximately 50 cm and 2) an improved diameter-dependent pressure-sinkage model can yield more accurate results. In this paper, further improvements to the pressure-sinkage model for small diameter wheels are presented. First the diameterdependent pressure-sinkage model is augmented with a geometric relationship to account for the normal stress distribution at the wheel-soil interface. Second, the effect of wheel width is investigated. The models are verified with field tests using a man-portable unmanned ground vehi-cle on wet sand and laboratory experiments on dilative (dry quartz sand) and compactive (kaolin-clay/silt mix) soils. Results indicate that the diameter-dependent pressure-sinkage model outperforms previous models in predicting drawbar pull as a function of slip and that the effect of wheel width on the pressuresinkage model is highly dependent on the soil type.

Keywords: Pressure-sinkage, sinkage, wheel diameter, wheel width

Flexible Planetary Rover Tire Model with Volumetric Wheel/Soil Interface

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In recent years, flexible wheels have been used in planetary exploration rover projects in order to increase traction capabilities of such vehicles. These flexible wheels can increase performance and prevent the rover from getting stuck in the soft terrains. These flexible wheel systems consist of a rigid hub which is connected to the flexible tire circumference through a number of radial springs. For simulation purposes, a model of such a system is developed using rigid body dynamics for the wheel hub motion and Euler-Bernoulli beam theory for the elastic deformation of the flexible tire tread. The contact between the flexible wheel and the soft soil is modelled using a volumetric contact model in form of an elastic Winkler foundation model. The equations of motion are derived using Lagrange's equations. To allow for faster simulations and future parameter optimization studies, a second non-dimensional model is developed and its validity is tested in a number of driving simulations.

Keywords: Flexible wheel, Volumetrtic contact, Planetary rovers, Distributed parameter models

Track 2. Session 4

Terrain Classification using Machine Learning and Proprioceptive Sensors

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We present a supervised machine learning approach to terrain classification using proprioceptive sensors. The method incorporates an extended Kalman-Bucy filter to estimate resistive torque and wheel slip from motor currents, wheel speeds, and ground speed of a wheeled mobile robot. The estimated resistive torque vs. slip data form feature vectors that are used to train a series of Hidden Markov Models (HMMs) using data from hand-labeled terrain classes. Experimental evaluation using a 75 kg four-wheel drive, all-electric mobile robot shows 67-100% effectiveness in using the HMMs to classify test data from three snow-covered terrain classes.

Keywords: robot mobility, autonomous terrain classification, proprioceptive sensors, Hidden Markov Model

A Novel Method for Prediction of Mobile Robot Maneuvering Spaces

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As the operational uses of mobile robots continue to expand, it becomes useful to be able to predict the admissible maneuvering space to prevent the robot from executing unsafe maneuvers. A novel method is proposed to address this need by using force-moment diagrams to characterize the robot's maneuvering space. Using the proposed techniques, these diagrams can then be transformed in realtime to provide a representation of the permissible maneuvering space while allowing for changes in the robot's loading and terrain conditions. The result is a potential expansion in the ability to integrate predictive vehicle dynamics into autonomous controllers for mobile robots and a corresponding potential to safely increase operating speeds.

Keywords: mobile robots, maneuvering spaces, predictive dynamics

High Speed Autonomous Off-Road Vehicle Steering

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High speed cornering of an off-road vehicle poses considerable challenges to the development of an autonomous vehicle due to the non-linear dynamics of the tyre road interface as well as those of the vehicle as a whole during high lateral accelerations. Most autonomous driver models are developed for low speed applications using linear control methods under the assumption of linear vehicle dynamics. The dynamics of a vehicle however become highly nonlinear as the lateral acceleration increases, thus rendering these linear models almost unusable during high speed manoeuvres. This paper presents the results of a robust driver model implemented on an off-road vehicle performing a severe double lane change at various speeds up to 80km/h. At the highest speed approximately 90% of the vehicle's maximum achievable lateral acceleration is reached with the vehicle remaining stable throughout the manoeuvre.

Keywords: high speed, autonomous, driver model, steering control

Load Distribution Control of a Six-Wheeled Robotic Vehicle in Rough Terrain

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In future lunar/planetary exploration missions, wheeled rovers will be promising robots to perform wide-area explorations. Wheeled robots, however, are prone to slip in soft and uneven terrain, and therefore, securing the mobility performance is a critical problem. This paper first describes a simple soil-wheel interaction model which enables slipratio estimation from a combination of wheel load and traction. Second, a drive control method for maintaining vehicle mobility is discussed and a sixwheeled robot which implements the control system was developed. The robot has six wheels and six vertical suspensions with built-in linear actuators. Load cells are installed between each wheel and suspension to monitor the wheel load, and the positions of wheels are individually controlled by moving the suspensions up and/or down so as to keep the desired wheel loads. In this study, a simple algorithm for distributing equivalent load to every wheel was implemented in the control system. Experiments were performed and the effectiveness of the drive control method was examined.

Keywords: lunar/planetary exploration, mobile robot, slip ratio, drive control, rough terrain, wheel load

Track 3. Session 1____

A Review of the Tractive Performance of Wheeled Tractors and Soil Management in Lowland Intensive Rice Production

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This paper reviews the cultivation practices and tractive performance using wheeled tractors, and how these interact with soil management, in lowland intensive rice production. The paper explores the issues of long term sustainable soil use and the energy inputs required. The paddy soil environment demonstrates very significant changes in soil properties with depth, in particular soil density, penetrometer resistance, soil structure and pore interconnectivity, water content and movement, and soil biology. This is related to the management of the soil hard pan in relation to machinery operations and machinery use.

One of the issues appears to be that the hard pan can be deeper than required with consequently unnecessarily high energy inputs. The tractive performance of wheeled tractors on different surface conditions is considered with respect to tractive efficiency and maintenance of a soil hard pan that has the required characteristics for sustainable production. Alternatives to conventional tyres, cage wheels and tracks, are considered. The cultivation operations are evaluated in relation to soil management, crop requirements and energy use. Variation in hard pan characteristics may be disadvantageous and provides opportunities for precision operations.

Keywords: tractive performance, soil management, energy use, rice production, sustainability and precision operations

Validation of Military Vehicle Terrain Impact Models at Multiple Locations

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Off-road military vehicle training can result in reduced vegetation cover and increased erosion rates. Effective military land management requires knowledge and prediction of impacts from these off-road maneuver exercises. Theoretical, processed-based models were developed previously to predict the impacts of tracked and wheeled vehicles in off-road conditions. Inputs for the models include the dynamic vehicle properties (e.g., velocity and turning radius), static vehicle properties (e.g., vehicle mass, track and wheel width, tread width), and terrain properties. Multiple model validation tests were performed at Fort Riley, Eglin AFB, and Pohakuloa Training Area (PTA). Terrain impacts were predicted from data collected by global positioning system (GPS) based tracking systems during live training exercises. This paper compares the actual vehicle impacts (disturbed width and impact severity) measured after each exercise with the model predicted values and discusses possible changes to the models to improve accuracy.

Keywords. Military vehicle impacts, off-road, GPS, land management, disturbed width, impact severity.

Numerical Investigation of Gross Traction Generated at Grouser-Soil Interface by DEM

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The cross-section shape of a single grouser shoe is one of governing factors for generating gross traction of tracked vehicles working on deformable terrain. Previous studies revealed that not only the height of grouser but also the thick-ness of grouser affected the gross traction, although the sinkage of grouser was fixed against the ground contact load. To obtain an insight into the slip-sinkage effect of a grouser, we applied 2D DEM to an analysis of gross traction, where the grouser thickness and height were varied as contributing factors for gross traction. In the analysis, dry sand was modelled by a mixture of discrete elements of two representative radii, and the replacement of contact-based roll-ing friction subroutine by increased polar moment was introduced, and the frequency of element allocation into indexes was reduced to update the in-house 2D DEM code in terms of computational economy. Numerical results showed larger gross traction for smaller thickness ratio λ and for increasing grouser height, which differed from the result of experiments where clear peak of gross traction was observed for $\lambda = 0.1$. In case of $\lambda = 0.5$, deteriorating behavior of gross traction can be seen in DEM as in the experiments. Moreover, generated gross traction in DEM mostly came from the action of vertical face of grouser height in case of $\lambda = 0.1$.

Keywords: gross traction, grouser, DEM, grouser height, grouser thickness, parametric study

Modal Analysis on a Large Off-Road Tyre using Scanning Laser Vibrometry

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A modal analysis was conducted on a large off-road tyre with the use of a Scanning Laser Vibrometer with no load applied to the tyre. The modal analysis was conducted by combining the response of the sidewall as well as the response of the tread of the tyre. Different excitation force input magnitudes are used to investigate the non-linearities in the tyre response. Tests were performed at different tyre pressures for on- and off-road use. The first six mode shapes were detected at frequencies much lower than for typical passenger car tyres. Results indicate that the first few mode shapes of the large off-road tyre may significantly influence the dynamics of the vehicle. This is due to the frequency range of the first few mode shapes being within the vibration response frequency range of the vehicle's suspension and steering systems.

Keywords: Modal analysis, off-road tyre, Scanning Laser Vibrometer, mode shapes

Characterisation and Modelling of Off-Road Tyres

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Most tyre research efforts worldwide have focussed on characterising tyres and developing tyre models for on-road use and not for off-road use. The focus was also on the types of tyres used on passenger cars and commercial vehicles. This resulted in the development and validation of tyre models that may be adequate for on-road use, but give unsatisfactory results with large off-road tyres when driving over rough offroad terrain. Off-road tyres are used in agriculture, forestry, mining and military applications.

Many off-road tyre models only take the longitudinal (traction) characteristics into account and not the vertical and lateral characteristics required for ride comfort and handling. Ride comfort modelling and simulation results of wheeled vehicles compare favourably with measured data at low frequencies when driving over smooth roads and discrete obstacles. As road roughness increases, tyre enveloping effects and non-linearities play an increasingly important role, resulting in a dramatic increase in modelling errors. Lateral tyre models and characteristics on off-road terrain are virtually non-existent.

This paper discusses the progress made with a renewed research effort to correct this gap in current knowledge to ensure that future off-road vehicle models and simulation efforts are conducted with confidence. The focus is on obtaining tyre properties for use in ride comfort and handling models and not on traction properties. The development, validation and calibration of field test equipment for measuring vertical and lateral tyre characteristics are discussed. The equipment includes tyre test trailers as well as 6-component wheel force transducers to measure tyre forces. Test results are given.

Keywords: Tyre characteristics, off-road, modeling, testing, validation

Off-Road Soft Soil Tire Model Development and Proposed Experimental Testing

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The goal of this paper is to present an accurate, comprehensive, and efficient, off-road tire model for soft soil applications (traction, handling, ride, and vehicle durability) as needed to support current Army simulation needs. The literature review revealed that, while FEM lead to the most detailed tire-soil models, their complexity and extensive computational effort make them less than ideal for the applications envisioned. The proposed approach is a detailed semi-analytical tire model for soft soil that utilizes tire construction details which parallel commercially available on-road tire models. The novelty relies on increasing the level of details for the tire model, in improving the tiresoil interface model by enhancing the resolution of the tire model at the contact patch, and by accounting for effects and phenomena not considered in existing models. The model will be validated against experimental data. For low speed, testing will be done on a single tire on sandy loam in the terramechanics rig at Virginia Tech. The influence of tire and vehicle parameters on the contact patch forces and on the forces transmitted to the axle will be investigated. The effect of soil characteristics on the tire dynamics will be studied. Validation against data collected from full vehicle testing is included in the proposed future work.

Keywords: tire model, soft soil, terramechanics, vehicle dynamics, indoor testing

Track 4. Session 1

Fundamentals of Driveline and Traction Control Systems Fusion for Improving Traction of a 4x4 Single Bucket Loader

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Brake-based traction control systems, which utilize the brake of a spinning wheel, are widely used in various types of vehicles. Recently, those traction control systems (TC) were applied to all-wheel drive construction equipment. Such machines employ various types of driveline systems (i.e., interaxle power-dividing units and axle differentials) to control torque split between the drive wheels and thus improve vehicle traction performance. As experimental research showed, the interaction between the traction control system and the axle drive can lead to unpredictable changes in vehicle traction. Lack of analytical work motivated a study of the interaction and impact of the two systems on each other and then traction a 4x4 single bucket loader.

This paper presents an analytical and computer model of the loader's driveline system, which includes a positive engagement of the inter-axle drive (i.e., the transfer case is fully locked) and two inter-wheel limited slip differentials (LSD) with different torque biases. The operation of this driveline system is mathematically integrated with the brake mechanisms, which apply braking moments to spinning wheels. Mechanical power flows/distributions between the four driving wheels are analyzed when a brake mechanism of a spinning wheel is on.

The developed math and computer model of the fused driveline and traction control systems was integrated in a computer model of the 4x4 loader, which is beyond the scope of the paper. Computer simulations were conducted on surfaces with different grip conditions of the left/right and front/rear wheels, with longitudinal and lateral inclination of the loader when scooping the material in the bucket. The paper discusses results of computer simulations and presents fundamentals for the fusion of the driveline and traction control systems to improve the loader's traction.

Keywords: 4x4 loader, traction control, brake-based, limited slip differentials, fusion, computer model, traction improvement, construction

Modification and Performance Evaluation of Tractor Drawn Improved Till Plant Machine under Vertisol

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A tractor drawn (TD) till plant machine was designed and developed with the help of computer aided design package for adoption of minimum till technology by the farmers, in black cotton soil conditions. This machine was evaluated and compared with the performance of a zero till drill and conventional practices at Jawaharlal Nehru Agricultural University farms as well as at a farmer's fields. It was found that the total time and cost required for tillage and sowing operations by till plant machine was 5.09 h/ha and Rs. 410.37/ ha, which is 72.23 per cent less time required than conventional practices of wheat cultivation but is 28.83 per cent more time required than zero till drill practices. The average yield by tractor till plant machine was 26.96 q/ha, whereas, by conventional practices and tractor drawn zero till drill was 25.91 and 22.72 q/ha. respectively. The soil conditions were also found better in the case of the T.D. till plant machine.

Axle Torque Distribution in Four Wheel Drive Tractors

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Four wheel drive (4WD) tractors now dominate their two wheel drive counterparts in many regions of the world – in particular Europe and the USA. The benefits in terms of increased drawbar pull and work rate are well understood. 4WD tractors vary in the design of the power split between front and rear axles; from equal wheels F:R implying approximately a 50:50 power spilt to much smaller front wheels – often referred to as front-wheel-assist – which may have a F:R split of around 20:80. in optimising the tractive performance of 4WD tractors it is necessary to understand the details of the power flows, torque distributions and losses within the driveline system

However, a review of previous works suggests that these driveline torques and power splits are sur-prisingly not well understood - in particular there are three areas of uncertainty. First, since the 4WD systems on agricultural tractors are normally arranged through a fixed gear ratio F:R, there is the problem of selecting this value so that the peripheral speeds of the front and rear wheels are the same - in practice, variations are caused by different tyre sizes, pressures and wear conditions for example. Second, the tractive conditions for the rear wheels may be significantly different from those at the front, because they travel in the compacted ruts established by the leading front tyres. And third during turning, the front steered wheels are kinematically constrained to move on differ-ent radii, and therefore travel faster than the rears. Taking all these factors into account, it is fairly common in choosing a compromise gear ratio to build in a small amount of lead, in which the front wheels move faster, say 2 to 4%, than the rears.

In the literature, there is no universal agreement about the relationship between lead ratio and over-all tractive efficiency. This situation is not helped by the fact that there have been relatively few attempts to measure F:R axle powers and torques in normal field operating conditions.

The aim of the research presented here is to use a new method based on non-contact torque sensors in the front and rear axles of a 67kW front-wheel-assist tractor in order to measure the power and torque flows in the driveline during normal draught cultivation operations.

Keywords: A novel axle torque measurement system for off-road vehicles

Vehicle Dynamic Simulation for Efficiency Improvement in Agricultural Tractors

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The paper describes the activity performed within the frame of the research "Innovative solution for power saving in hydraulic circuits of agricultural tractors" Italian National Research Program (PRIN-2007). It aims at showing a new paradigm in the study of the agricultural machine energy saving solutions by means of an agricultural tractor global simulation model developed at IMAMOTER-C.N.R.

A multi-body model of an agricultural tractor has been made. The transmission system, the handling and loading system, and the auxiliary actuation sub-systems have been modeled using a traditional specialized simulation program and then integrated in the tractor dynamic model. Two different transmission systems have been compared: the power split transmission and the full power shift transmission. For both of them, a study of the control problems related to the optimal management of the engine and the transmission has been performed. For the full power shift transmission the main objective was the optimization of the dynamic interaction between the hydraulic actuators and the multiple clutches control system to investigate the behavior of a standard mechanical two-shaft transmission. The integration of the detail models into the tractor dynamic model made a direct comparison possible, under a prescribed, yet flexible, mission profile.

The model has been used to assist the global optimization of parameters, using as objective functions general indicators of the global machine productivity, rather than often misleading partial efficiency values. Thanks to this approach, it was possible to study the main hydraulic circuits of midpower agricultural tractors (90-150 kW), with the ability to tell those conceptual innovations and design developments needed to enhance their global efficiency and to increase a power saving on a larger scale.

Keywords: power saving, hydraulic actuation, load sensing system, transmission system, optimization

Prediction the Draft Force and the Energy Utilization Efficiency of Longitudinally Arranged Double Tines Subsoiler

Shaker H. Aday

Longitudinally arranged double tines subsoiler was designed to improve the field performance of the single tine subsoiler. The longitudinal and lateral distances between the two tines are 70cm and 70 cm respectively. The length, width and thickness of the two tines are 81, 16cm and 3.3cm respectively. The forward inclination angle (rake angle) of the stems is 66 degree. The tines were provided with foot. The foot length, width and height are 43, 8 and 10cm respectively. The inclination angle of the foot with the leg is 120 degrees. The attack angle (penetration angle) of the front of the foot is 35 degrees. The tines were provided with wings at some stages of the experiments. The effective width of the wings is 30cm.

The subsoiler was tested in silty clay soils using four operating depths (30, 40, 50 and 60cm). It was used with and without wings. The draft requirement and the soil disturbed area manipulated by the subsoiler were measured. The energy utilization efficiency which represents the number of cubic meter of soil manipulated for one mega Joule (MJ) consumed by the subsoiler was calculated.

Using double tines resulted in greater disturbed area comparing with single tine. The value of the disturbed area depends on the soil moisture content and the operating depth of the subsoiler. The range of increase is between 82% to 57% in the soil of mc of 15.1% for the operating depths of 30 and 60cm respectively while, it is between 106% to 64% in the soil of mc. of 20.4% for the same operating depths respectively. Addition of wings to the double tines increased the soil manipulated volume considerably; and the increase is between 68% and 80% in both soils and for operating depths of 30 and 60cm respectively.

The disturbed area of doubled tines subsoiler increased by 158% in both soils for 46% increase in the draft force when the operating depth increased from 30 to 60 cm.

The double tines also improved EUE clearly and the effect of the double tines increased when wings were used on the foot in both Moisture contents. The improvement in EUE means more energy used in manipulating the soil. EUE of double tines increased by 20% to 12% for operating depths of 30 and 60cm respectively in the soil of M.C of 15.14% and by 36.7% to 22% for the same operating depths respectively in the soil M.C content of 20.59% compared with single tines. When wings were used on foots of the double tines subsoiler EUE increased by 73% and 67% (on average) compared with out wings in soil M.C of 15.14% and 20.59% respectively.

The shape of the disturbed soil by the double tines was determined in the field and it was used to calculate the volume of the soil and was also used to predict the draft force and EUE. The shape of the disturbed in front of the tines is half a cone. The action of the double tines interfere which produce interfering soil disturbance.

Keywords: Energy utilization efficiency, disturbed area, specific resistan

The Control of Tractor 3 Point Linkage Control Systems

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Over recent years, there has been a resurgence of interest in tractor-implement operating efficiencies – driven by high fossil fuel prices and environmental issues linked to emissions and CO2 usage. The tractor 3 point linkage is actually a key element in this quest for optimum efficiency since it controls two important elements; first, by controlling the dynamic fluctuations of draught force it can enable the tractor to operate closer to its maximum tractive efficiency and second, by controlling the depth of the tillage process it can contribute to good crop growth conditions and ultimately to the maximum yield.

The kinematics, dynamics and control of the 3 point linkage attracted a considerable amount of interest in the 1970s – and these analyses were used to influence calculations of optimum tractor-implement operating conditions. However, since that period, the fundamental control aspects of the 3 point linkage have received surprisingly little attention in the off-road vehicle research community. The current systems which are available on commercial tractors remain in principle remarkably similar to the original configuration proposed by Harry Ferguson. However, two significant changes have occurred; first, the systems now make considerable use of electronics – in contrast to the original hydro-mechanical layouts and second, from the operator's viewpoint in the cabin, the range of control options, settings, levers and knobs can appear overwhelmingly complicated.

The research described here is part of a comprehensive study of tractor-implement-linkage systems. A complete kinematic model to characterise the motion and geometry of the linkage has been developed. A measurement system to obtain linkage forces, linkage positions and implement depth has been designed, built and tested. And finally, an initial set of field experiments using a 216kW tractor and a five tine cultivator has been carried out. The experimental results have highlighted some interesting aspects of the trade-off between control of draught force and implement depth – and how these in turn affect the overall tractor-implement operating efficiency.

Keywords: Tractor, implement, 3 point linkage, control system, tractive efficiency, draught control, position control, linkage kinematics.

Track 5. Session 1_

Statistical Experimental Studies of a Vehicle Interacting with Natural Snowy Terrain for Combined Longitudinal and Lateral Slip

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The performance of a vehicle on natural snowy terrain depends on the vertical load transmitted to the tire, the depth and mechanical properties of the snow, and the longitudinal and lateral slip, among other parameters. In [1], the lead author's research group presented experimental results from measurements of the interfacial forces (traction, drawbar pull and motion resistance) between a test vehicle and snow, and the sinkage of tire as a function of longitudinal slip. The curves of interfacial forces versus longitudinal slip from the tests follow the trend of vehicle traversing over soft terrain as well as the trend of predictions from high-delity nite element tiresnow interaction simulations [2]. Vehicle maneuvers naturally involve combined longitudinal and lateral slip, which are much more complicated in tandem than purely longitudinal slip, as demonstrated in the high-delity nite element simulations. In order to validate combined-slip models developed by the lead author's research group and collaborators in recent years, this paper presents experimental data from a test vehicle interacting with a natural snow cover for combined slip. The maneuvers of the vehicle to produce the desirable range of longitudinal and lateral slip simultaneously will rst be discussed, followed by interfacial forces, tire sinkage, snow depth and snow material properties. The trend of the interfacial forces obtained from experiments is similar to that of existing model.

Keywords: longitudinal slip, slip angle, drawbar pull, lateral force, traction, snow depth, snow strength, snow density, tire sinkage, roll, pitch and yaw

High Efficiency Fuel Sleds for Polar Traverses

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The National Science Foundation has implemented oversnow traverses to resupply its research stations at South Pole, Antarctica, and Summit, Greenland. Traverse fleets consist of rubbertracked tractors towing groups of sleds over natural snow, with fuel being the primary cargo.

We describe here the evolution of lightweight, high-efficiency fuel sleds for Polar traverses. These sleds consist of flexible bladders strapped to sheets of high molecular weight polyethylene (HMW-PE). They cost 1/6th, weigh 1/10th and triple the fuel delivered per tractor compared with steel sleds. An eight-tractor fleet has conducted three 3,400-km roundtrips to South Pole (2008 – 11) with each traverse delivering ~ 320,000 kg of fuel while emitting <1% the pollutants, consuming 1/2 the fuel and saving ~ \$1.6M compared with aircraft resupply. A two-tractor fleet in Greenland recently delivered ~ 83,000 kg of fuel in bladder sleds to Summit with similar benefits.

Annual performance monitoring of both traverse fleets has revealed that bladder-sled towing resistance is largely governed by sliding friction. The flexible, low ground-pressure (~7 kPa) sleds produce very little snow-compaction resistance. Sliding friction can start high ($\mu \sim 0.2$) and drop in half as sleds warm up in response to frictional heating. As with conventional skis, frictional heating probably produces a thin water layer that lubricates the sled-snow interface. Consequently, towing resistance depends on the thermal budget of the sled. For example, black fuel bladders increase solar gain and thus decrease sled resistance; data suggest they could double again the fuel delivered per tractor. While sled durability still needs improvement, the outstanding efficiency and low cost of these sleds has transformed fuel delivery to US Polar research stations.

Keywords: over-snow mobility, towing resistance, sliding friction, transport efficiency, Antarctica, Greenland, resupply operations

Measuring Vehicle Impacts on Snow Roads

S. Shoop, M. Knuth, W. Wieder, R. Affleck, and M. Preston

During the austral summer of 2009-2010, a study was conducted on the ice shelf near McMurdo Station, Antarctica to determine the impact of various vehicle and tire types on the condition of the snow roads. The snow roads at McMurdo Station are the primary transport corridors to move personnel and material from the airfields servicing intra- and intercontinental air traffic for resupply. Thus, they are a critical transportation component and are particularly susceptible to deterioration during the warmest parts of the austral summer when above-freezing temperatures can occur for several days at a time. This study served to explore methodology that could quantify the impact of various vehicles, tires, driving speeds and maneuvers on the snow road conditions. Basic maneuvers were used to isolate the impact of turning, acceleration, braking and speed using spirals, circles, and straight-line testing on a flat, smooth snow pavement. In addition, a road course was set up to include corners and roughness using portions of the active snow roads for more realistic conditions. Measurements included snow surface strength both in and between tire tracks, tire track rut depth and width, and the height and width of the resulting snow piles adjacent to the tire tracks. Since this type of testing had not been done on snow before, or using these vehicle types, the experiments yielded valuable guidance regarding what types of maneuvers, test surfaces, and measurements could most easily differentiate performance. Results indicate the impacts of driving speed and vehicle type including the importance of the tire and suspension components for preserving the road surfaces through the melt season.

Keywords: strength, disturbance, rut, rammsonde, Clegg, Delta, Terrabus, maneuver, turning

Development of Processed Snow Roads in Antarctica

Russ Alger (MTU), Sally Shoop (USACRREL), Maggie Knuth (USACRREL), and George Blaisdell (NSF/OPP)

The development of strong, durable snow pavements in deep snow is critical to operations in both Antarctica and in deep snow regions of the north. The movement of supplies, equipment, and personnel in both vehicles and aircraft is hampered by weak and soft snow resulting in lost time and extra expense. Poor snow conditions can seriously limit payloads for all types of vehicles, including airplanes.

The Keweenaw Research Center of Michigan Tech, the Cold Regions Research and Engineering Laboratory (CRREL), and the National Science Foundation (NSF) have teamed together on a project to assess the feasibility of use of grooming and milling equipment to build snow pavements in Antarctica. A milling unit developed specifically for use on snow was built and shipped to McMurdo in November 2010. This piece of equipment was used to build several snow pavement sections that were monitored throughout the austral summer of 2010-2011 by MTU, USACRREL, and NSF/Raytheon.

This paper focuses on this development and testing and discusses results from the project. This includes an overview of the history of the design of the miller unit and some of the data collected in McMurdo during the period.

Maintenance on Snow Roads in Antarctica

Kaila Gervais, Margaret Knuth, Sally A. Shoop, and Terry D. Melendy, Jr.

During the 2010-2011 austral summer in Antarctica, a second snow road and transportation study was carried out at McMurdo Station. This study included looking at the maintenance of the snow roads traveling from McMurdo Station to the Pegasus Airfield. The road spans approximately 13 miles and includes up to three lanes each 50 ft wide. Each of the lanes requires an extensive amount of maintenance and up keep which is completed by multiple crews on day and night shifts. This season, the Cold Regions Research and Engineering Laboratory (CRREL) implemented a new maintenance form that would be used to record date. location and type of maintenance completed. A variety of equipment was used during the maintenance of the snow roads ranging from drags to smooth the snow to weight carts for compacting it. These forms also allowed CRREL to look at the amount of work performed on each individual lane of the road as the season progressed. Operators' maintenance procedures have been unknown to date and will help us to provide recommendations that could be made to improve the McMurdo transportation infrastructure.

Impact of Snow Road Maintenance on Road Strength at McMurdo Station, Antarctica

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During the 2010-2011 Antarctic field season a snow roads and transportation study was carried out for a second year by the Cold Regions Research and Engineering Laboratory (CRREL) at McMurdo Station. Part of this season's study was to track the road maintenance, temperature and test the strength at predetermined mile markers along the 13 miles of snow roads located on a permanent ice shelf that connects the Pegasus Airfield to McMurdo Station. This data was recorded for each lane of road, at 6 locations, over a 5 month period. A Clegg Impact Hammer and a Rammsonde Cone Penetrometer were used to capture not only the surface strength but the strength of the road with regard to depth. The temperature data was collected using a hand held probe to measure temperature of the air, surface, approximately 7.6-cm and 15.2-cm deep.

Analysis of the data provides insight as to the direct effects of the various maintenance and environmental factors on the strength of the roads. Understanding the effects of these variables on the snow roads will ensure the roads are kept operational for as long as possible and increase the efficiency of McMurdo Station transportation infrastructure. This data will also contribute to the creation of standard operating procedures for maintaining the snow roads at McMurdo Station.

Keywords: Snow Roads, Road Strength, Antarctica

Track 5 and 7. Session 2_

A Method of Using a Snow Micro Penetrometer to Obtain Mechanical Properties of Snow

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Accurate modelling and prediction of the behaviour of a vehicle that traverses snow requires an accurate quantitative description of the snow on the ground, including its microstructural properties and its response to load. Penetration into snow using a cone penetrometer attached to a load cell has been shown to be useful in quantifying snow mechanical properties, especially in the field, for use in both avalanche prediction and modelling, and predicting snow properties as applied to ground-vehicle interaction models. A snow micropenetrometer has been developed, which has a fixed cone radius and included angle, to obtain mechanical properties of snow. For random heterogeneous materials such as snow, it is known that the response of a penetrometer should be dependent on the size and geometry of the penetrometer tip relative to that of the snow microstructure, an effect which has not been systematically studied. This paper discusses the

results of experimentally studying the size effect of varying the geometry of the snow micropentrometer. This study utilized a small, portable cone penetrometer under different field conditions, and has replicated the penetration results in a controlled laboratory environment. Micro-level strength, macro-level strength, and texture index have all been confirmed against direct measurement techniques. The cone tip angle and radius were varied in the laboratory, and the results were compared against theoretical expectations and found to correlate reasonably well.

Keywords: snow, snow penetration, penetration, penetrometer

Using Acoustic Sounding to Measure Bulk Density and Depth of Snow

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For a vehicle traversing a snowy terrain, two fundamental properties need to be measured: bulk density and depth. The strength of snow, important for the interfacial forces between snow and vehicle, is related to the density of snow, whereas the depth of snow is related to the mobility and motion resistance of a vehicle. Lee and Wang [1] presented results of depth and density of layered snow measured simultaneously and nondestructively using a Ground Penetrating Radar (GPR). However, GPR is not the ideal method for determining these properties since the hardware involved in generating, receiving and processing electromagnetic waves can be complicated and expensive. A viable alternative to GPR could be the Acoustic Sounding Method (ASM) [2], which could be used to determine depth and density, simultaneously, of a snowpack in a more exible and cost eective way. Many existing radar technologies can be adapted and leveraged for ASM such as the Frequency Modulated Continuous Wave (FMCW) radar with dierent modulation schemes. It is the purpose of this paper to present a FMCW-based ASM to measure the density and depth of snow by sending an acoustic frequency-modulated waveform into the snowpack from a source. Three signicant new contributions of our work are: 1) acoustic impedance of snow is accurately calculated by using realistic microgeometry of snow obtained using 3-D X-Ray Microtomography in the laboratory, 2) an analytical model based on the transmission line theory is developed to simulate the acoustic signal propagating through snow, 3) the sound signals are analyzed using the Hilbert-Huang Transform (HHT) with high accuracy than traditional method. Comparisons of results between theory and model are generally very good for snow of varying porosity and depth.

Keywords: snow depth, snow density, tortuosity, acoustics, impedance, transmission line theory, X-Ray MicroTomography, Hilbert-Huang Transform, FMCW radar

On the Necessity of Terramechanic Sciences and a Prospective Vision

Guido Korlath

Today's most prevailing scientific achievements and technical developments in terramechanics are commonly based on highly complex simulation models. These highly complex models are predominantly based on an uncountable number of parameters, difficult to identify for general or daily use. This difficulty often turns out to be the barrier, that all this highly scientific models enter the industrial business or even being accepted by the industry. But this industrial/daily business is the promoter of scientific results.

The gap between fundamental science in terramechanics and industry seems to be wider than ever before.

This presentation aims to focus on the real principal fundamentals and the importance of terramechanic systems and the science behind to enter the common awareness.

Track 6. Session 1_

On and Off Road Mobility Performance Evaluation in DGA ANGERS

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The aim of this paper is to present part of the facilities used in mobility performance evaluation process carried out in DGA ANGERS: a test centre belonging to French Ministry of Defence. This process is mainly based on an experi-mental method which takes advantage of investments made at this test centre. The objective is to correctly evaluate on and off road performance of systems under tests, in controlled conditions, i.e.environmental and terrains conditions. Due to difficulties specific to on and off road environments, procedures need to be used in order to control test environment and to ensure reproductibility of tests. Focus is made on standards and on test devices used to assess terrain characteristics and on and off road vehicle performance.

Keywords: vehicle mobility, tests, roads, terrains.

Fuzzy Logic Traction Control System for a Golf Cart

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This study presents on the development of an intelligent traction control system (ITCS) to optimize the power consumption with precisely maintain the traction of the vehicle in different terrain conditions. Compared with

conventional control approach, fuzzy logic approach is more efficient for nonlinear dynamic systems and embedding existing structured human knowledge into workable mathematics. This study also investigates the relationship between vehicle's input parameters of power supply (PI) and moisture content (MC) and output parameter of traction force (TF). Experiment has been conducted in the field to investigate the vehicle traction and the result has been compared with the developed fuzzy logic system (FLS) based on Mamdani approach. Results show that the mean relative error of actual and predicted values from the FLS model on TF is found as 7.68 %, which is less than the acceptable limit of 10%. The goodness of fit of the prediction value from FLS is found close to 1.0 as expected and hence shows the good performance of the developed system.

Keywords: Traction force; Fuzzy Logic System; Power demand; Nonlinear dynamics.

Computation of Run-Off-Road Vehicle Velocity by Simulation

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The motion of a vehicle which adjacent terrain is determined by the physical and mechanical laws of terrain-vehicle interaction. From that moment the tire-soil interaction affects the mobility of the vehicle. Analysis of a "run-off" accident requires a knowledge of the physical properties of the soil, otherwise any evaluation can only be approximate. In order to reconstruct a run-off accident one must examine the soil's mechanical parameters and create a soil database. The purpose of our project was to create a soil database and a computer simulation to determine the speed of a vehicle at the point where it left the road. A series of measurements was performed for this purpose at the Department of Automotive Technology of the Szent István University. In our paper we introduce a set of computations capable of computing the vehicle's initial velocity.

Keywords: terramechanics, terrain characterization, soil-mechanical parameters

Determination of Vehicle Speed from Terrain Tracks in Forensic Investigation

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A series of measurements was performed by the Department of Automotive Technology of Szent István University, Gödölli, Hungary, in August 2010 to obtain data for a soil database as part of a project to develop a run-off-the-road accident simulation model. The model is designed to determine the speed of the vehicle as it leaves the road. Knowledge of this speed is crucial in the investigation of such accidents, and investigators have to estimate it from vehicle tracks left on the road and on the adjacent terrain. Exact measurements are difficult to perform on terrain, and so investigators rely on empirical data. The proposed model offers a more precise calculation of the run-off speed by determining the soilvehicle resistances from soil parameters (cone index, shear strength, moisture content) and applying these to the weight of the vehicle and the distance it covered on the terrain before coming to a halt. The model may be validated and verified by determining the soil-vehicle resistances on relevant terrain. This was carried out as part of the current research by measuring the deceleration of vehicles on agricultural land in different states: stubble, disc-tilled and cultivator-tilled. Comparative measurements were also performed on concrete surfaces.

Keywords: accident analysis, terramechanics, soil-vehicle interaction, pulling test

Investigation and Parameter Study of a Completely Semi-Active Suspension System for Full Spring Mounted Tractors

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Suspension systems should provide an optimal ride comfort insulating the driver from vibrations while keeping the variations of the contact force between wheel and track as low as possible for safe handling. Conventional tractors are very often not equipped with a suspension system although different suspension systems such as seat-, cabin- or chassis suspension have the potential to fulfil the demand for comfort in a better way. This paper will present the capability of a semi-active suspension for full spring mounted tractors.

Based on a tractor with conventional rigid axles, a new hydropneumatic chassis suspension for front and rear axle was developed, including sensors, hydraulic actuators and an electronic controller. Different parameters such as rod side preload pressure, speed, number of sprung axis as well as passive and semi-active suspension were examined to determine their influence on seat acceleration and roll angle.

The results show a big influence of the driving speed on the comfort of the driver when riding with a passive suspension. A seat acceleration decrease of 35%, comparing the full suspension concept and a front axle suspension, was measured. A reduction of 8% of the seat accelerations in the z-direction was measured when a semi-active suspension was used instead of a passive suspension but further research has to be done to reduce roll motion.

Keywords: driving safety, driving comfort, suspension, hydro-pneumatic, tractor

Investigation of Simulation Based Vehicle Control Training

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Motor vehicle accidents are a leading cause of death for our troops both in military and civil environments. This work investigates the value of a motion base simulator for teaching drivers how to control vehicles in challenging driving situations. A simulated environment allows the student to experience vehicles with different centers of gravity (top heavy, high center of gravity (CG) vehicles, and low CG sedan like vehicles) and different braking configurations (ABS and non-ABS). The different vehicle models coupled with challenging driving situations such as rollover recovery, accident avoidance with and without anti-locking brakes, and soft shoulder scenarios are designed to teach an extensive range of vehicle control techniques. Conducting this training in a simulated environment allows drivers to be placed in difficult situations without risking their lives or damaging expensive vehicles. A progressive approach is taken when training the drivers by starting them in a low CG vehicle on an easier scenario and working toward the high CG vehicle on the more difficult scenarios. This allows drivers to grasp the fundamentals and apply them to the more difficult situations. Separate military and civilian scenes are being developed to allow drivers to experience similar, potentially lethal, situations in both environments with the appropriate vehicles. This work teaches vehicle control practices over a wide variety of driving situations allowing for more favorable outcomes when drivers are presented with similar real world situations.

Keywords: Driving simulator, vehicle control, simulated environments, accident avoidance, driver training

Track 6. Session 2

Slow Active Suspension Control for Rollover Prevention

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Rollover prevention in Sports Utility Vehicles (SUV's) offers a great challenge in vehicle safety. By reducing the body roll angle of the vehicle the load transfer will increase and thus decrease the lateral force that can be generated by the tires. This decrease in the lateral force can cause the vehicle to slide rather than to roll over. This paper presents the possibility of using slow active suspension control to reduce the body roll and thus reduce the rollover propensity. Using a validated Adams model to simulate a double lane change manoeuvre

at 60 km/h performed by a SUV it is shown that a significant improvement in body roll can be obtained with relatively low energy requirements.

Keywords: Suspension control, Hydropneumatic suspension, Roll stability, Sports Utility Vehicle, Rollover prevention

GPS-Based, Mission-Specific Mobility Power/ Energy Analysis of Military Vehicles

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Cost effective methods for predicting the power and energy of vehicles operating in on and off-road terrains is of importance when evaluating the performance of the vehicle. The number of military vehicles with hybrid-electric drivetrains for improved stealth capability has increased in recent years. The ability to accurately estimate the power and energy required by the electric motors that power the tractive elements of these vehicles is of critical importance. A GPSbased, mobility power/energy analysis is one approach that may be able to estimate the condition specific, power requirements of a vehicle. The dynamic vehicle parameters needed to estimate the forces developed during locomotion are determined from the GPS data, and these forces include the following: the gravitational, acceleration, motion resistance, aerodynamic drag, and drawbar forces. The concept relies upon the Waterways Experiment Station (WES) model for estimating the motion resistive force generated at the tire/soil interface. GPS tracking data for three of the U.S. military's Stryker vehicles that conducted live-fire range training and proofing missions at the Pokahuloa Training Area in Hawaii was analyzed to predict the mission-specific, mobility power and energy requirements for the vehicle operating at the given terrain conditions. The proofing mission required 14.1 % greater positive mobility power, and the greater than 50 kW duty cycles were also greater in magnitude. During the proofing mission, the off-road maneuvers conducted by the Strykers required 11.6 % more positive mobility power than the on-road maneuvers. The specific energy consumption and the daily specific energy consumption were 25.8 and 651 % greater respectively during the proofing mission compared to the live-fire training exercises.

Keywords: GPS, mobility, power, energy, Stryker

Increased Harvesting Operation using Adapted Ground Pressure to Soil Conditions

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The forest industry aim at an even flow of timber from the forest, and the ground damage has to be as low as possible. The two biggest causes for ground-damage are the bearing

capacity of the forest ground and the ground-pressure of the harvesting machines. The aim of this study was to find out some rules for the machine choice considering ground pressure, when harvesting on ground with low bearing capacity.

A field study, using a Valmet 890.3 forwarder, was carried out where different ground pressures and their effect on the ground were studied on two different types of ground. Additionally, an inventory of damaged harvesting grounds was made. These data, as well as data from two previous studies was used to study a possible trend for the rut depth according to used ground-pressure.

The result showed that rut depth as well as soil compaction is less if the ground pressure from the forwarder is reduced by using tracks. For forwarders with high ground pressure (> 80 kPa), the rut depth increased significantly when operating on ground with cone-index (0.70 MPa) or softer. The model for machine-choice is a guideline for machine-use that fits the carrying capacity of the forest ground. However it is important to point out that the forest ground is very complex in its composition, and that it is difficult to predict damage.

Key words: Machine choice, ground damage, rut depth, soil compaction, cone index

Off-Highway Vehicle Braking and Sign Recognition Study

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The U.S. Forest Service manages thousands of miles of Off-Highway Vehicle (OHV) trails throughout the United States. These trails are used by ATV, motorcycle and snowmobile enthusiasts to explore various regions of the country. Proper signage is imperative for the safety of those using the trails. The use of 30-cm signs instead of larger signs could make a significant cost difference. The signage must take into account a range of rider experience, trail situations, terrain conditions and a variety of OHVs. Braking tests were conducted using ATVs, a UTV, a motorcycle and snowmobiles on gravel, sandy loam, loose sand, and packed snow on various grade ranges, with a novice and experienced driver, to create a general braking distance curve for each type of terrain and vehicle type. Tests were conducted to determine sign recognition for 30, 46 and 61 cm sign sizes. Braking and sign recognition data were used to develop tables with recommended sign placement distances, one for ATVs and motorcycles and one for snowmobiles. These tables were validated by setting up a trail layout with warning sign distances recommended by the final tables and tested with volunteer riders. This paper discusses the ATV portion.

Keywords: OHVs, braking, terrains, sign recognition

Application of the Smart Tire for Vehicle Chassis Control

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With rapidly increasing number of vehicles on the roads, a more intelligent vehicle with an advanced control system has become essential to avoid accidents and traffic congestions. One very important part in developing such a system is modeling and monitoring the required vehicle states as correct as possible. Today's available monitoring systems use two major methods to provide information to the controllers, they can either measure the variable directly (if feasible and physically possible), or they use virtual sensors which basically utilize nonlinear estimators to calculate the desired variable from the available sensor readings. On a dynamic vehicle, the tire/road contact is one of the most compelling mechanisms to obtain information from due to its responsibility of converting the available torque in the wheels into vehicle motion. Therefore it conceals very valuable variables for a control system, such as the friction potential, slip rate and angle, or lateral, longitudinal and vertical loads on the wheels. Many studies have been done on estimating these variables from accessible vehicle states or various sensor signals. Nevertheless these estimator models heavily rely on vehicle kinematic formulations which make them prone to break down in case of an unexpected change which would override those formulations. Thanks to the advances in sensor technology and the increasing demand for vehicle safety and handling performances, research in this field is directed towards receiving information directly from the tire by instrumenting the tire to turn it into a sensor all by itself. This study intends to observe possible uses of the information obtained directly from an instrumented tire (smart tire) in a vehicle stability controller (VSC). A direct yaw control (DYC) algorithm is developed based on the Lyapunov stability criteria which takes advantage of the tire slip angle information provided by a smart tire. The resulting corrective yaw moments for front and rear axles are generated by utilizing differential braking. The results show that the proposed algorithm can still stabilize the vehicle in a double lane change scenario with a slight improvement, which is a promising step towards the ultimate goal of replacing the chassis-attached monitoring units with smart tires

Leaf Spring Modelling

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This paper applies and extends a novel elasto-plastic leaf spring model, previously used to model a multi-leaf spring, to model a parabolic leaf spring. The model's capabilities are extended by including a simple method which enables the model to include effects due to changes in the loaded length of the leaf spring. The loaded length is an important aspect of the simply supported type leaf spring. The importance of using validated suspension models in terrain-vehicle interaction simulation models is well known and addressed in this paper by comparing the results from the model with experimental measurements. The predictions obtained from the model show good correlation with the experimental data for both the elasto-plastic leaf spring model emulating the parabolic leaf spring and the model accounting for changes in the loaded length of the leaf spring.

Keywords: elasto-plastic leaf spring model, multi-leaf spring, parabolic leaf spring, loaded length, experimental validation

Track 7. Session 1

Multipass Coefficients for Terrain Impacts Based on Military Vehicle Type, Size and Dynamic Operating Properties

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Quantification of multipass vehicle impacts is needed to accurately determine terrain disturbance during military training. This study, conducted at Fort Riley, Kansas on a clay loam soil, evaluated the multipass terrain impacts of four commonly used tracked and wheeled military vehicles: the M1A1 Main Battle Tank, M998 HMMWV, M985 HEMTT, and M113 APC. Disturbed width and impact severity were assessed along 14 spirals subjected to a maximum of eight consecutive passes for a total of 696 impact points.

The project goals included evaluating vegetation impacts by tracked and wheeled military vehicles across multiple passes in order to develop coefficients allowing more accurate predictive modeling of vehicle multipass impacts. Multiple passes produce increased vegetative impacts, with multipass coefficients (MPC) ranging from 0.98 to 4.44 (compared to the commonly accepted value of 2.00) depending on vehicle type, size and turn severity. Tracked vehicles were found to have a higher multipass coefficients increasing with vehicle weight and the sharpness of turns. Understanding multipass vehicle dynamics will allow installation land managers to more accurately determine the extent and severity of vehicle terrain impacts on military training areas, and quickly evaluate vehicle environmental impacts when used in conjunction with a GPS-based vehicle tracking system (VTS).

Keywords: multipass, tracked, wheeled, military lands, predictive modeling

UNCLASSIFIED

Vehicle Recovery Resistance Force Results in Soft-Soils

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The ability to extract a vehicle from soft-soil terrain in a situation where the vehicle has become immobilized is an important consideration for vehicles operating in off-road environments. Understanding the pull force required to extract the vehicle is critical in designing extraction equipment such as winches or recovery vehicles. The objective of this study was to measure and compare the recovery resistance forces required to extract immobilized heavy armored, wheeled vehicles from soft-soil terrain. This testing phase addressed the influence of tire pressure, tire size, vehicle weight, and Central Tire Inflation System (CTIS) settings on vehicle recovery forces in a situation of immobilization. The vehicles considered in this study included a 6x6 wheeled vehicle at a gross vehicle weight (GVW) of 52,505 lbs and a 4x4 wheeled vehicle at a GVW of 31,920 lbs with 395/85R20 tires and at a GVW of 34,373 lbs with 16.00R20 tires. The 6x6 vehicle was tested at two configurations. One configuration had the tire pressures set to the mud-sand-snow setting and the other to the highway setting. The 4x4 vehicle was tested at three configurations. Two configurations had 395/85R20 tires with the first configuration set to the cross-country tire pressure setting and the second configuration set to the The third 4x4 vehicle highway tire pressure setting. configuration had 16.00R20 tires set to the cross-country tire pressures. The Rating Cone Index (RCI) soil metric was the principal test used to relate the mobility performance to a soil condition. The forces required to extract a vehicle were recorded during standard soft-soil testing in "fat" clay soils, which is the standard soil type used to evaluate maneuverability on soft-soil terrain. Results indicated maximum extraction forces were less with larger tires, and that tires set at a lower pressure required less extraction force for recovery.

Keywords: Vehicle mobility, Rating Cone Index, soil conditions, maneuverability, soft-soil terrain, vehicle configurations, tires, tire pressure, vehicle recovery, pull forces, winches

¹Rating Cone Index (RCI). An index of soil shear-strength that includes consideration of the sensitivity of soil to strength losses under vehicular traffic. It is defined as the product of Cone Index (CI) and Remold Index (RI) for the particular layer of soil. For soils with relatively high CI soil strengths (around 200 psi and greater), it is equal to CI since the RI is equal to one.

Modeling the Energetics of Tire-Soil Interaction

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The purpose of vehicle energetics research is the determination of the portion of engine power available for promoting vehicle motion and for overcoming resistances. By studying this process one can expect to develop improvements in vehicle design and operation. The movement of an off-road vehicle is determined by the physical and mechanical terrain-vehicle interaction. The most important factors influencing vehicle motion are the physical and mechanical properties of the soil, the tractive force generated at the soil-tire interface, the rolling resistance and terrain characteristics. Drawbar pull tests were performed to support the mathematical modeling of the energetics involved in the tire-soil interaction. Furthermore we tested and recorded the vertical accelerations imparted to the vehicle by the terrain. We determined the motion resistance encountered in the tire-soil interface (rolling resistance, slip) as well as other losses relative to vehicle motion (due to slope, acceleration, air resistance etc.). In our model we considered the increased deformation of the soil and the tire caused by vertical acceleration generated by the terrain. In this paper we present our model and supporting test results.

Keywords: terramechanics, tire-soil interaction, drawbar pull test

Soil-Wheel Interaction Analysis with ALE Finite Element Method

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Soil-vehicle interaction is important for predicting trafficability of off-road vehicles. Forces applied to wheels or crawlers due to contact with soil can be estimated by soil deformation analysis around the contact area. This project is to develop a spatial mesh allocation scheme for finite element method (FEM) enduring large soil flow or deformation. This numerical scheme, called Arbitrary Lagrange-Euler (ALE) method, allows the mash to move in the space during simulation independent of the soil motion, and expands FEM versatility as a strong tool of soil-vehicle interaction analysis. Rolling wheel and sand contact simulation has been successfully conducted with the program.

Keywords: ALE, FEM, Large deformation, Moving wheel, Sand

Posters

A Review of the Tractive Performance of Wheeled Tractors and Soil Management in Lowland **Intensive Rice Production**

Alex Keen, Nigel Hall, Peeyush Soni, Madhav D. Gholkar, Simon Cooper, and Jannatul Ferdous

Development of a Real and Simulation Testbed for Legged Robot Soil Interaction Mohammed Ahmed, Lorenz Quack, Malte Römmermann, and Yong-Ho Yoo

Direct Shear Behaviour of Dry, Granular Soils for Low Normal Stress with Application to Lightweight **Robotic Vehicle Modelling**

C. Senatore and K. D. Jagnemma

Effect of Tire Inflation Pressure on Soil Strength Estimation Using Wheel Sinkage Ju Seok Nam and Kyeong Uk Kim

Impact of Snow Road Maintenance on Road Strength at McMurdo Station, Antarctica T. D. Melendy, Jr., S. A. Shoop, and M. A. Knuth

Increased Harvesting Operation using Adapted Ground Pressure to Soil Conditions Iwan Wästerlund and Erik Andersson

Maintenance on Snow Roads in Antarctica Kaila Gervais, Margaret Knuth, Sally A. Shoop, and Terry D. Melendy, Jr.

Measuring Vehicle Impacts on Snow Roads

S. Shoop, M. Knuth, W. Wieder, R. Affleck, and M. Preston

Numerical Investigation of Gross Traction Generated at Grouser-Soil Interface by DEM Hiroshi Nakashima, Xiu Lun Wang, Taiki Yoshida, Hiroshi Shimizu, Juro Miyasaka, and Katsuaki Ohdoi

Off-Road Soft Soil Tire Model Development and Proposed Experimental Testing Corina Sandu, Eduardo Pinto, Scott Naranjo, Paramsothy Jayakumar, Archie Andonian, Dave Hubbell, and Brant Ross

On and Off Road Mobility Performance Evaluation in DGA ANGERS Michel Grima

Reconfigurable Vegetated Soil Strength Instrument for Mobility Measurements

K. MacDonald, B. Coutermarsh, and S. Shoop

Soil Strength as a Function of Soil and Ground Cover Types

Sally Shoop, Rosa Affleck, Charles Smith, Kelsey Gagnon, and Robin Stone

Soil-Wheel Interaction Analysis with ALE Finite Element Method

Junya Yamakawa

Terramechanics Simulation for Mobility Planning of the Mars Exploration Rovers

Brian Trease, Raymond Arvidson, Keith Bennett, Feng Zhou, Randy Lindemann, Karl lagnemma, Carmine Senatore, and Lauren Van Dyke

Notes





MAIN CAMPUS MAP



The Inn at Virginia Tech and Skelton Conference Center Floorplan



Second Floor

