8th AMERICAS REGIONAL CONFERENCE OF THE INTERNATIONAL SOCIETY FOR TERRAIN VEHICLE SYSTEMS

TROY, MICHIGAN, U.S.A.
SEPTEMBER 12 – 14, 2016

CONFERENCE PROGRAM

Ground Vehicle Mobility, Agile Dynamics, and Energy Efficiency in Severe, Unsafe, and Non-Secure Environments of Roads and Unprepared Terrains

International Society for Terrain Vehicle Systems
www.istvs.org

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WELCOME

Welcome to the 8th Americas Regional Conference of the International Society for Terrain Vehicle Systems!

On behalf of the Technical and Organizing Committees we would like to thank all of you for your participation, support and contribution to the Conference. We hope that all of you would enjoy the Conference events. This Conference Program provides details on the Technical Tour to the US Army TARDEC, Technical Panel Discussion, and Presentation at Lunch time, Program for Guests, and other social activities that will make your time in Detroit enjoyable.

We would like to express our sincere gratitude to our supporters and exhibitors, including Caterpillar Inc., the US Army Research Office, the US Army TARDEC, CM Labs Simulations, dSPACE Inc., General Dynamics Land Systems, MSC.Software Corp., and Advance System Design.

This year Conference brings together ISTVS veterans, ISTVS members and non-members from academia, both faculty and students, research agencies and industry. The Conference Participants represent 16 countries, including U.S.A., Canada, China, Germany, Hungary, Japan, Korea, Nigeria, Poland, Russian Federation, South Africa, Spain, Sweden, Turkey, United Kingdom, and Vietnam.

The Conference Proceedings will be distributed to the Participants on flash memory sticks during the Conference. The Proceedings include

- 64 peer-reviewed research papers that will be presented at the Conference sessions
- 11 PDF with presentation slides that also will be delivered during the Conference (so named "Oral Presentations"), and
- 3 written only papers.

We look forward to meeting all of you in Detroit.

Sincerely,

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CONFERENCE SCHEDULE

Sunday, September 11, 2016

Time	Event	Location
12:30 - 13:00	Conference Registration of Members of ISTVS Board of Directors	***Conference Lobby***
14:00 - 18:00	ISTVS Board of Directors Meeting (*Invite Only*)	***Athens Room***
14:00 - 18:30	Conference Registration (*General Attendees*)	***Conference Lobby***
18:30 - 20:30	Ice Breaker Reception (*for those who have RSVP'd*)	***Mediterranean Room***

Monday, September 12, 2016

Time	Event	Location
7:30 - 17:00	Conference Registration	***Conference Lobby***
7:30 - 8:20	Breakfast, Networking	***Mediterranean Room***
	Booth Exhibits	***Conference Lobby***
8:30 - 9:00	**Conference Opening Ceremony** Dr. Sally Shoop, Deputy General Secretary for ISTVS Americas Dr. Lutz Richter, ISTVS General Secretary Dr. Peter Kiss, ISTVS President Dr. David Gorsich, Chief Scientist, US Army TARDEC Prof. Lal Kushwaha, Editor-in-Chief, *Journal of Terramechanics* Prof. Vladimir Vantsevich, Dr. Jeremy P. Gray and Prof. Bharat Soni	***Mediterranean Room***
9:00 - 10:00	**Track 1: Terramechanics, locomotion and soil/terrain modeling** **1.1. Recent accomplishments in terramechanics research and education** Session co-Chairs: Prof. Corina Sandu and Prof. Peter Kiss Papers and Oral presentations: 24, 39, 44 (Oral), 106 (Oral) Paper 24. CODE ENHANCEMENTS, UPGRADES AND BUG FIXES – NRMM3.0 *Susan Frankenstein and Paul W. Richmond* Paper 39. MODELING OF WHEEL-SOIL INTERACTION MECHANISMS BASED ON ACCURATE MEASUREMENT OF PRESSURE DISTRIBUTION FOR LIGHTWEIGHT VEHICLE *Hiroki Tsubaki and Genya Ishigami*	***Mediterranean Room***

Time	Event	Location
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Time	Event	Location
12:45 - 14:30	**Track 1: Terramechanics, locomotion and soil/terrain modeling** **1.2. Locomotion systems** Session co-Chairs: Dr. George Mason, Dr. Mehari Tekeste, Dr. Peter Schihl Papers and Oral presentations: 15, 50, 56, 72, 97, 40 (Oral), 81 (Oral) Paper 15. NORMAL AND TANGENTIAL STRESSES ON A CONTACT SURFACE OF TIRE BY 2D FE–DEM *Kenta Nishiyama, Hiroshi Nakashima, Hiroshi Shimizu, Juro Miyasaka, Katsuaki Ohdoi* Paper 50. ON-LINE ESTIMATION OF SKID-STEER INSTANTANEOUS CENTERS OF ROTATION IN GPS-DENIED ENVIRONMENTS *Jesse Pentzer, Jariulla Safi, Sean Brennan and Karl Reichard* Paper 56. EXPERIMENTAL INVESTIGATION OF STUCK WHEEL CHARACTERISTICS IN LOOSE SAND *Takuya Omura and Genya Ishigami* Paper 72. HANDLING FRICTION AND CONTACT IN VEHICLE/GRANULAR-TERRAIN INTERACTION USING A DIFFERENTIAL VARIATIONAL INEQUALITY-BASED APPROACH *Daniel Melanz, Paramsothy Jayakumar, Dan Negrut* Paper 97. INSTRUMENTATION AND TESTING OF A HIGH MOBILITY MULTIPURPOSE WHEELED VEHICLE *Ariana Sopher, Sally Shoop, Jesse Stanley, Schalk Els, Carl Becker, and Theunis Botha* Oral Presentation 40. DISCRETE ELEMENT METHOD ANALYSIS FOR SLIP OF A WHEEL DRIVING ON THE OFF-ROAD GROUND *JeseungMoon, Gwanyoung Kim, Soojin Lee and Kyu-Jin Lee* Oral Presentation 81. MOTION DYNAMICS OF UTOPUS PUSH-PULL VEHICLE WITH NARROW TINES FOR TRACTION *Volker Nannen, Damian Bover, and Dieter Zöbel*	***Mediterranean Room***
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Time	Event	Location
15:15 - 17:00	**Track 1: Terramechanics, locomotion and soil/terrain modeling**	***Mediterranean Room***

1.3. Soil and terrain modeling and characterization

Session co-Chairs: Prof. Lal Kushwaha, Dr. Alex Keen, David Ostberg

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Yuji MORI and Tadaomi EGUCHI

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Rui He and Corina Sandu

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UPDATING OF SELECTED VEHICLE-TERRAIN INTERFACE EQUATIONS THROUGH BAYESIAN CALIBRATION
Ian Dettwiller, Masoud Rais-Rohani, Farshid Vahedifard, George L. Mason, and Jody D. Priddy

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PHYSICALLY BASED MODELING OF DEFORMABLE SOIL FOR MACHINE DESIGN AND OPERATOR TRAINING
Daniel Holz, Ali Azimi, Michel Carignan, Marek Teichmann, Jaehong Kim

Paper 62.
FEM-BASED TERRAMECHANICS ANALYSIS OF TIRE TRAVELING ON MULTI-LAYERED GROUND
Shingo Ozaki, Hirotaka Suzuki, Shinya Kondo, and Kouji Uematsu

Paper 67.
DISPLACEMENT PATTERNS BENEATH A RIGID BEAM INDENTING ON LAYERED SOIL
Z. K. Jahanger, S.J. Antony and L. Richter

Paper 68.
PARAMETERIZATION OF NORFOLK SANDY LOAM PROPERTIES FOR STOCHASTIC MODELING OF LIGHT IN-WHEEL MOTOR UGV
Mostafa A. Salama, Thomas R. Way, Vladimir V. Vantsevich

Time	Event	Location
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18:00 - 18:30	Social Time before Banquet Dinner	***Mediterranean Room***
18:30 - 18:40	Words from ISTVS Leadership: Prof. Peter Kiss, ISTVS President Dr. Sally Shoop, Deputy General Secretary for the ISTVS Americas	
18:40	Banquet Dinner and Concert	***Mediterranean Room***

Tuesday, September 13, 2016

Time	Event	Location
7:00 - 7:45	Breakfast, Networking	***Mediterranean Room***
	Conference Registration and Booth Exhibits	***Conference Lobby***
7:45 - 9:15	**Panel Discussion**:	***Mediterranean Room***
	Future research direction in terramechanics/mobility and off/on-road vehicle engineering for complex road/terrain and cyber environments Panelists: *Dr. David Gorsich*, Chief Scientist, US Army TARDEC *Ken Mick*, Senior Director, Advanced Programs and Technology, General Dynamics Land Systems *Dr. Thomas Gillespie*, Mechanical Simulation Corporation *Michael Kirk*, Director of Driveline and Axle Engineering, Fiat-Chrysler Automobiles *Dr. Sally Shoop*, ERDC, Cold Regions Research and Engineering Laboratory *Dr. Lutz Richter*, ISTVS Secretary General, OHB System *Dr. Vladimir Vantsevich* (Moderator)	
8:45	**Guest Program**: Guests who registered for the Guest Program gather at the ***Registration Desk*** at 8:45. Departure at 9:00. Person of Contact: Ms. Renee Melendy.	
9:15 - 9:45	Coffee Break, Booth Exhibit	

9:45 - 10:45 Parallel Sessions

Mediterranean Room	Athens Room
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Paper 85. COMPARISON OF SOIL STRENGTH MEASUREMENTS OF AGRICULTURAL SOILS IN NEBRASKA *Wendy Wieder, Sally Shoop, and Lynette Barna*	Paper 57. DRIVING FORCE DISTRIBUTION FOR INDEPENDENT WHEEL DRIVE VEHICLE ON ROUGH GOUND *Ryosuke Eto, Kazuomi Sakata, and Junya Yamakawa*

10:45 - 11:00 Break

11:00 - 12:00 Parallel Sessions

Mediterranean Room	Athens Room
Track 3: Agricultural and forestry machines, construction and mining equipment	**Track 2: Advances in mobility, energy efficiency and ground vehicle dynamics**
Session co-Chairs: Dr. Carol Plouffe and Dr. Thomas Way Papers and Oral presentations: 11, 19, 18, 29 (Oral)	Session co-Chairs: Prof. Paul Ayers, Prof. Schalk Els, Kenneth D. Norman Papers: 66, 79, 43, 83
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Paper 19. SEEDING EQUIPMENT DYNAMICS AT HIGH GROUND SPEED *Ian W. Paulson, Scott D. Noble, and Allan T. Dolovich*	Paper 79. POWER CONSUMPTION MODEL FOR SLOPE TRAVERSAL OF WHEELED ROBOT BASED ON DYNAMIC SIMULATION *Go Sakayori and Genya Ishigami*
Paper 18. IMPROVEMENT OF COMPUTATIONAL MODELS OF TRACKED TIMBER HARVESTING MACHINE TRANSMISSION LOADING DEPENDING ON MOVEMENT EXTERNAL CONDITIONS *Klubnichkin Vladislav E. and Klubnichkin Evgeny E.*	Paper 43. MEASUREMENT OF TIRE CARCASS INSIDE DEFORMATION *Glenn Guthrie, Theunis Botha , Carl Becker, Schalk Els, Ariana Sopher and Sally Shoop*
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12:00 - 13:30 Lunch — ***Mediterranean Room***

Booth Exhibits — ***Conference Lobby***

13:30 - 15:00 Parallel Sessions

Mediterranean Room	Athens Room
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Ozoemena A. Ani, Benjamin B.Uzoejinwa and Godswill Chukwu

Paper 38.
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Volker Nannen, Damian Bover, Dieter Zöbel, Francisco Parma, Katie Marascio and Blair M. McKenzie

Paper 100.
INERTIA-BASED PROPELLED UNDERWATER ROBOTIC VEHICLES DYMANICS MODELING AND PERFORMANCE
Elżbieta M. Jarzębowska

15:00 - 15:30 Coffee Break — ***Mediterranean Room***
Booth Exhibits — ***Conference Lobby***

15:30 - 17:00 Parallel Sessions

Mediterranean Room	**Athens Room**
Track 3: Agricultural and forestry machines, construction and mining equipment	**Track 4: Mobile robotics for ground applications, planet exploration and other environments**
Session co-Chairs: Dr. Carol Plouffe and Dr. Thomas Way Papers: 95, 88, 89, 104, 93, 103	Session co-Chairs: Dr. Lutz Richter and Prof. M. Blundell Papers and Oral presentations: 75, 64, 14(Oral), 53 (Oral), 27
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Paper 88. 6X6 TERRAIN ARTICULATED TRUCK: DRIVELINE - SUSPENSION COUPLED DYNAMICS AND ENERGY EFFICIENCY EVALUATION *Vladimir Vantsevich and Jan Dersjö*	Paper 64. ONLINE ESTIMATION OF WHEEL SINKAGE AND SLIPPAGE USING A TOF CAMERA ON LOOSE SOIL *Shoya Higa, Kenji Nagaoka, and Kazuya Yoshida*

Paper 89.
ROPS DESIGNS TO PROTECT OPERATORS DURING TRACTOR ROLLOVERS
Paul Ayers , Farzaneh Khorsandi, Xinyan Wang and Guilherme Araujo

Paper 104.
EVALUATION OF 4 YEARS RUTTING EXPERIMENTS
Iwan Wästerlund

Paper 93.
GOOD VIBRATIONS
Gunnar Bygdén, Lage Burström and Iwan Wästerlund

Paper 103.
ANALYSIS AND EXPERIMENT OF STEADY-STATE STEERING OF TRACKED VEHICLE UNDER CONCENTRATED LOAD DISTRIBUTION
Guo Jing， Zou Tian-gang， Zhang Jin-le， Chen Bing， Wang Hong-yan, Rui Qiang

Oral Presentation 14.
NOVEL OBSERVATION METHOD OF THE UNMANNED GROUND VEHICLE WITH ARTICULATED SUSPENSION WHEEL FORCE BASED ON THE STRAIN MEASUREMENT OF THE ROCKER ARM
Zhang Xing

Oral Presentation 53.
HIGH WHEEL SLIP SINKAGE AND DRAWBAR PULL IN DEFORMABLE SOIL: MARS EXPLORATION ROVER WHEEL MOBILITY
J. B. Johnson, A. Kulchitsky, P. Duvoy, R. Arvidson, C. Creager, J. M. Moore, F. Zhou

Paper 27.
EVALUATION AND OPTIMIZATION OF A 6X6 INDEPENDENT SUSPENSION VEHICLE FOR SMALL SCALE ROBOTIC DOZING
Gregory Colvin and Dimi Apostolopoulos

17:15 - 18:15 **ISTVS Robotics Group Meeting,** Dr. Lutz Richter ***Mediterranean Room***

Wednesday, September 14, 2016

Time	Event	Location
6:30 - 7:15	Breakfast, Networking	***Mediterranean Room***
7:20 - 10:30	**Technical Tour** Technical Tour to the US Army TARDEC Laboratory Facilities for *Registered Conference Participants only*. **Meet at 7:20 outside Marriott Lobby.** **Busses depart from Marriott promptly at 7:30** Person of Contact: Dr. Jeremy P. Gray	***Outside Marriott***
11:00 - 12:15	Lunch, Networking	***Marriott Restaurant***

Time	Event	Location
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13:15 - 15:00	**Track 6: Innovative system designs for terrain/road vehicle applications** Session co-Chairs: Dr. Jianbo Lu and Dr. Dariusz Mikulski Papers: 26, 22, 31, 54, 74, 51, 69 Paper 26. MULTI-TRACK DRIVETRAIN AND SUSPENSION FOR HYBRID AND ELECTRIC ALL-TERRAIN VEHICLES *Mikhail Kostkin and Alexander Popovich* Paper 22. ELECTRONIC STABILITY CONTROL TESTING OF MILITARY WHEELED VEHICLES *Bernard E. Duplan and Gregory A. Schultz* Paper 31. DESIGN AND SIMULATION OF A POD-BASED MOBILITY CONCEPT *JingHan Fu, R.C. Hill, and Nassif Rayess*	***Mediterranean Room***

Paper 54.
SOIL EMBEDDING AVOIDANCE FOR PLANETARY EXPLORATION ROVERS
Ramon Gonzalez, Karl Iagnemma

Paper 74.
TIRE TO TRACK TRASFORMIG SYSTEM (4TS)
Dan Laux and Jason Alef

Paper 51.
HEAVY TRANSPORT SYSTEMS WITH ACTIVE TRANSMISSION
Rinat Kurmaev, Sergey Shukhman and Vladimir Malyarevich

Paper 69.
MOBILITY VS. ENERGY EFFICIENCY OF A 4X4 HYBRID-ELECTRIC VEHICLE WITH AN ACTIVE DRIVELINE SYSTEM
Blair K. Farley, Jesse R. Paldan, Vladimir V. Vantsevich

15:00 - 15:30 Coffee Break ***Mediterranean Room***
Booth Exhibits ***Conference Lobby***

15:30 - 16:30 **Track 6: Innovative system designs for terrain/road vehicle applications** ***Mediterranean Room***

Session co-Chairs: Dr. Jianbo Lu and Dr. Dariusz Mikulski
Papers and Oral Presentations: 73, 76(Oral), 87, 105

Paper 73.
AN INTRODUCTION TO DROVE: DATABASE RECORDS FOR OFF-ROAD VEHICLE ENVIRONMENTS
Farshid Vahedifard, James M. Williams, George L. Mason, Isaac L. Howard, Jody D. Priddy

Oral Presentation 76.
LAB-BASED DEVELOPMENT AND VALIDATION OF ADAS
Kunal Patil

Paper 87.
GROUND VEHICLE DYNAMIC STABILITY ANALYSIS WITH RANKING OF STABILIZING CONTROL LAWS USING THE SIGN STRUCTURE OF ITS STABILITY DERIVATIVES AND CLOSED LOOP DYNAMICS
Rama K. Yedavalli

Paper 105.
AN ANALYSIS OF A WHEEL SPEED SENSOR SIGNAL FOR AGILE TIRE SLIPPAGE DYNAMICS
Jesse Paldan, Vladimir Vantsevich, Jeremy P. Gray

Time	Event	Location
16:30 - 17:30	**Closing Ceremony:**	***Mediterranean Room***

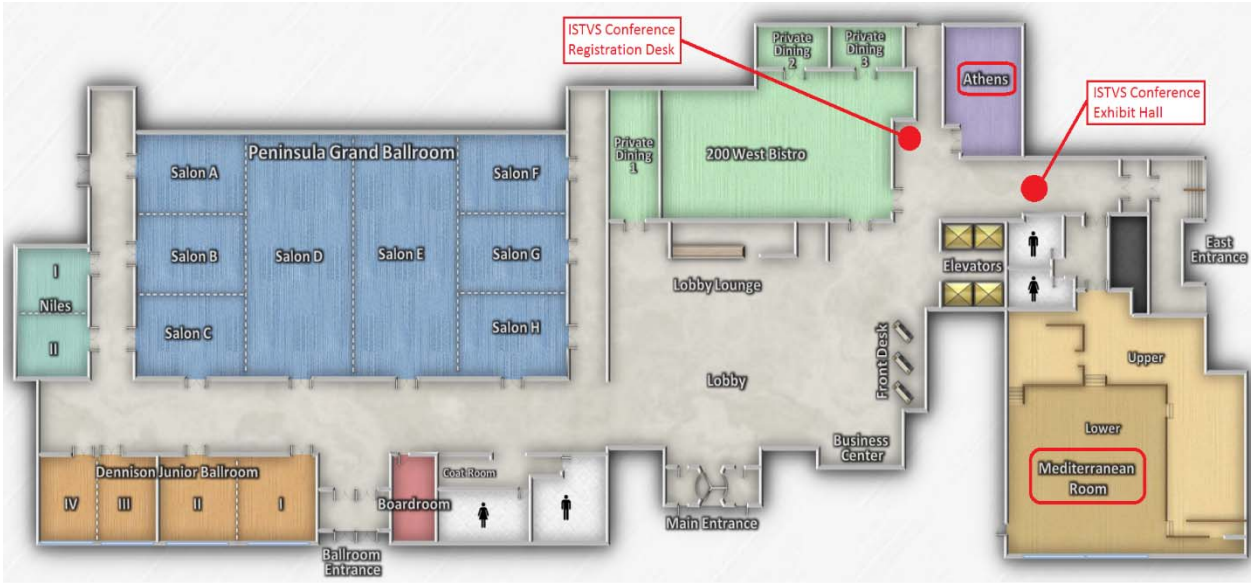
- **Best Paper Awards -** Prof. Lal Kushwaha and Dr. Sally Shoop
- **Conference Summary and Conclusion** Prof. Vladimir Vantsevich, Dr. Jeremy P. Gray, Prof. Bharat Soni - closing remarks
- **Next ISTVS Conference -** Prof. Peter Kiss, ISTVS President

VENUE ADDRESS AND FLOOR PLAN OF MARRIOTT AND LOCAL TRANSPORTATION

The 2016 8th Americas Regional Conference of the International Society for Terrain-Vehicle Systems will be held at the Detroit/Troy Marriott Hotel in Tory, Michigan, USA:

200 West Big Beaver Road
Troy, Michigan 48084, USA
Phone: (248) 680-9797

A floor plan below shows location of the Conference Registration Desk, Exhibit Hall, and Mediterranean and Athens Conference Rooms:



The Detroit/Troy Marriott Hotel is located approximately 30 miles northeast of the Detroit Metropolitan Wayne County Airport (DTW). The hotel does not provide an airport shuttle service, but there are many ground transportation companies that can taxi/shuttle you to Troy, MI. Please visit the DTW Ground Transportation website (http://www.metroairport.com/GroundTransportation.aspx) for more information.

TECHNICAL TOUR

The 2016 8th America's Regional Conference of the International Society for Terrain-Vehicle Systems (ISTVS) conducts a technical tour at the U.S. Army Tank-Automotive Research Development and Engineering Center (TARDEC) located at the Detroit Arsenal, Warren, Michigan.

Only authorized conference participants may attend the tour. Check your authorization at the Conference Registration Desk upon arrival to the Conference.

Following an early breakfast, registered tour attendees will meet outside Marriot Hotel lobby at 7:20 and board buses for transportation to TARDEC's facilities. **Busses depart from Marriot promptly at 7:30**. Person of Contact: Dr. Jeremy P. Gray.

Attendee visitor badges will be distributed on the buses. Upon completion of the tour at TARDEC, the buses will return attendees to the Troy Marriot prior to lunch to continue the remaining of the conference program agenda.

GUEST TOUR

The conference has organized a guided sightseeing tour of the Henry Ford Museum and Greenfield Village on Tuesday, September 13, 2016. $75.00 each guest, transportation included. Meals are not included on this trip. Your guest/s should not register for conference lunch on Tuesday if s/he attends the sightseeing tour. Advanced registration is necessary, please sign up on the http://conference.istvs.org/registration-detroit

Guests who registered for the Guest Program gather at the ***Registration Desk*** at 8:45. Departure at 9:00. Person of Contact: Ms. Renee Melendy.

TECHNICAL TRACKS AND ABSTRACTS OF PAPERS

List of Technical Tracks

Track 1. Terramechanics, locomotion and soil/terrain modeling (three symposia)
- 1.1. Recent accomplishments in terramechanics research and education
- 1.2. Locomotion systems
- 1.3. Soil and terrain modeling and characterization

Track 2. Advances in mobility, energy efficiency and ground vehicle dynamics
Track 3. Agricultural and forestry machines, construction and mining equipment
Track 4. Mobile robotics for ground applications, planet exploration and other environments
Track 5. Military ground vehicle robotics
Track 6. Innovative system designs for terrain and road vehicle applications

Descriptions of Technical Tracks

1. Terramechanics, locomotion and soil/terrain modeling (three symposia)
1.1. Recent accomplishments in terramechanics research and education
1.2. Locomotion systems
1.3. Soil and terrain modeling and characterization
These three symposia concentrate on new research directions in terramechanics science and its applications to vehicle engineering and academic education, including areas of modeling, computer simulation and design of tire/wheel, track and other locomotion/vehicle systems, various types of soil and snow modeling and characterization, uncertainties and stochastic characteristics of vehicle-environment interaction.

2. Advances in mobility, energy efficiency and ground vehicle dynamics
Topics include analytical and experimental methods of energy efficiency improvement, terrain vehicle mobility off-line and real-time estimation, operational and tactical vehicle mobility, agile dynamics and performance in severe environmental and traffic conditions, coupled and interactive dynamics of vehicle multi-physics systems, conflicting multi-input-output system dynamics.

3. Agricultural and forestry machines, construction and mining equipment
This symposium invites papers on specifics of mobility, vehicle dynamics and design of farm tractors and machinery, construction equipment, forestry, earth moving and mining machines. Topics include energy efficiency and engineering productivity, power hop, mobility, etc.

4. Mobile robotics for ground applications, planet exploration and other environments
Papers on planet vehicle exploration, mobile ground robots, underwater and surface robotic vehicles are invited to present advances in mission/task fulfilment, mobility and energy efficiency, dynamics and innovative system designs.

5. Military ground vehicle robotics
This symposium covers surface and topographical terrain mobility, operational and tactical mobility, battlefield mobility of unmanned and remotely controlled vehicles and vehicle convoys. Topics include, but not limited to, agile performance and adaptive perception of vehicle dynamics, optimization of the required motion and mission accomplishment with minimal energy consumption.

6. Innovative system designs for terrain and road vehicle applications
This symposium focuses on innovative system designs and controls, sensing and actuation with mechatronic implementation in conventional and driverless vehicle applications. Topics include, but not limited to, cyber-physical systems in vehicle dynamics, mobility and agility control, sensor/data fusion, vehicle system communication and connected vehicles, active and passive safety and vehicle protection.

Track 1. Terramechanics, locomotion and soil/terrain modeling

Session 1.1. Recent accomplishments in terramechanics research and education

Paper 24.

CODE ENHANCEMENTS, UPGRADES AND BUG FIXES – NRMM3.0

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Abstract
A new version of the NATO Reference Mobility Model (NRMM) has recently been released. The new version (NRMM 3.0) adheres to fortran 95 standards or higher while the old code was an amalgamation of various standards from fortran 66 – 95 making it nearly impossible to compile. In the process of upgrading to meet fortran 95 standards, many bugs were found such as conversion errors, assumptions that multiple vehicle information are contained in a single file, and failure to initialize variables, to name a few. Unlike the previous version, the new version will run in all operating systems. To facilitate this, a new subroutine was added to facilitate reading of input files created on Windows, Linux and OS X platforms. Most of the code enhancements concern improvements to the snow, freeze/thaw algorithms as well
as terrain input file format simplifications. Finally, we will discuss how these changes translate to vehicle speed predictions.
Keywords: NRMM, mobility model

Paper 39.

MODELING OF WHEEL-SOIL INTERACTION MECHANISMS BASED ON ACCURATE MEASUREMENT OF PRESSURE DISTRIBUTION FOR LIGHTWEIGHT VEHICLE

Hiroki Tsubaki and Genya Ishigami
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Abstract
This paper aims to develop a wheel-soil interaction model for a lightweight wheeled vehicle with focusing on a pressure distribution beneath the wheel. The proposed model for the pressure distribution is formulated with taking into account the following three phenomena that have not been considered in the classical one: for the lightweight vehicle, (1) the pressure distribution forms like a Gaussian distribution; (2) the pressure distribution is generated particularly in the front region of the contact patch of the wheel; and (3) the distribution is divided into two areas as the

boundary determined by the maximum pressure angle. The experimental data obtained from a single wheel test bench has proven that the proposed model shows qualitatively better reproducibility for pressure distribution shape with different wheel slip ratio than the classical model does. The experimental result also implies that the proposed model can be applicable in different types of soil (silica sand #5 and toyoura sand) as long as those soil show similar relationship between slip ratio and a value of the maximum pressure.
Keywords: Wheel-soil interaction model, Pressure distribution, Lightweight vehicle

Oral Presentation 44.
See PDF slides in the Conference Proceedings

THE DEVELOPMENT OF HIGH PERFORMANCE COMPLIANT TIRES FOR MARS ROVERS

Colin Creager, Kyle Johnson, Scott Moreland

Oral Presentation 106.
See PDF slides in the Conference Proceedings

Recent Terramechanics Related Activities at the Jet Propulsion Laboratory

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Paper 98.

IMAGE ANALYSIS AND CLASSIFICATION BASED ON SOIL STRENGTH

Ariana Sopher[a], Sally Shoop[a], Jesse Stanley[a], and Brian Tracy[a]
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Ariana.M.Sopher@erdc.dren.mil, Sally.A.Shoop@erdc.dren.mil, Jesse.M.Stanley@erdc.dren.mil, Brian.T.Tracy@erdc.dren.mil

Abstract
Satellite imagery classification is useful for a variety of commonly used applications, such as land use classification, agriculture, wetland delineation, forestry, geology, and landslide otential. However, image classification for physical properties of the soil is often obscured by other surface conditions, such as moisture and vegetation, although these are also indicators of soil strength. This project used remote methods of terrain analysis to search for areas suitable for maneuverability based on slope, roughness, vegetation, soil type, and wetness but also performed direct classification of imagery based on soil strength. Using a maximum likelihood supervised classification approach, trained by a limited amount of ground truth strength measurements, a soil strength classification was applied to WorldView-2 multispectral satellite imagery with surprisingly reasonable results. This paper presents the work done on the imagery classification for soil strength, the apparent relationship between reflectance and soil strength, and the ongoing work to expand the technique to new imagery by using existing training sets.
Keywords: remote sensing, soil strength, digital image classification

Paper 23.

TEMPERATURE DISTRIBUTION AND TRACTION MEASUREMENTS AT THE TIRE-ICE INTERFACE

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Abstract

With the reduction of traction available at the surface in icy conditions, the dynamics of the vehicle becomes more unpredictable as the system can becomes unstable. In order to design an appropriate safety system, the tire-ice interaction must be closely investigated. This paper aims at enhancing the understanding of the tire-ice contact interaction at the contact patch through experimental studies for a pneumatic tire traversing over solid ice. A design of experiment has been formulated that gives insight into the effect of operational parameters, specifically: wheel slip, toe angle, camber angle, normal load, inflation pressure, ice surface temperature, and traction performance. The temperature distribution in the contact patch has been recorded using a novel method based on thermocouples embedded in the tire tread. Furthermore, the experimental results obtained provide appropriate validation data required for the Tire-Ice contact Model (TIM) previously developed at Virginia Tech. The TIM is validated for two parameters, namely temperature rise in the contact patch and the friction level generated at the tire-ice interface. Temperature rise from simulations are validated against temperature distribution measurements at the contact patch under various operating conditions using K-Type thermocouples. The drawbar pull was measured at different conditions of normal load, inflation pressure, and ice temperatures as well as various steering configurations. As shown by both, the simulations from the TIM and the test data, a rise in temperature was observed from the leading edge to the trailing edge of the contact patch. The rise in temperature can be quantified with respect to the load on the tire. As the wheel load increases, the difference in temperature rise increases, as also reflected in the experimental study.

Keywords: Terramechanics, Tire-Ice Model, Temperature, Contact Patch

Oral Presentation 107.

See PDF slides in the Conference Proceedings

i3: IMAGINE, INSPIRE & INNOVATE ENVIRONMENT – TRANSFORMING VEHICLE TECHNOLOGY AND SMART MOBILITY

Bharat Soni and Vladimir Vantsevich

Track 1. Terramechanics, locomotion and soil/terrain modeling
Session 1.2. Locomotion systems

Paper 15.

NORMAL AND TANGENTIAL STRESSES ON A CONTACT SURFACE OF TIRE BY 2D FE–DEM

Kenta Nishiyama[a,b], Hiroshi Nakashima[a], Hiroshi Shimizu[a], Juro Miyasaka[a], Katsuaki Ohdoi[a]

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Abstract

Normal and tangential stresses acting on a contact interface of a driven tire moving on dry sand were investigated using our in-house 2D FE–DEM code. A simple averaging method for contact reaction was introduced, where computational segments were defined over lower semicircle of tire that translate without rotation with the tire and the contact stresses were calculated segment by segment. It was assumed that the tire was in rigid contact mode and would travel on the modeled sand terrain in stationary condition in the analysis. The integration of normal and tangential stresses with respect to the rotation angle was applied to calculate vertical contact load, gross tractive effort, net traction, and running resistance of the tire by semi-empirical (or parametric) analysis. The result of tractive performance obtained through the parametric approach using contact stresses was similar to the result of tractive performance directly obtained by the application of 2D FE–DEM. A forward shift of the rotation angle of tire for maximum normal stress with the increase of slip could also be observed in the result of contact stresses by FE–DEM.

Keywords: tire, FE-DEM, normal stress, tangential stress

Paper 50.

ON-LINE ESTIMATION OF SKID-STEER INSTANTANEOUS CENTERS OF ROTATION IN GPS-DENIED ENVIRONMENTS

Jesse Pentzer[a], Jariulla Safi[b], Sean Brennan[b], and Karl Reichard[a]

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Abstract

The vast majority of explosive ordinance disposal and hazardous area inspection ground robots utilize skid-steer locomotion technology due to the design's robustness, simplicity, and maneuverability advantages. Autonomous algorithms are difficult to adapt to these platforms because dynamic models predicting skid-steer movement are complex and rely heavily on prior knowledge of surface and vehicle parameters. This paper will discuss the use of skid-steer instantaneous center of rotation (ICR) kinematics for predicting robot motion with limited prior knowledge of vehicle design or surface condition. Prior work has shown that ICR kinematics can be estimated using an extended Kalman filter (EKF) when measurements of input track/wheel speed, position, and heading are available. The resulting ICR estimates were shown to produce

accurate predictions of vehicle movement; much more accurate than a naïve two-wheel robot kinematic approach using identical inputs. The results for two implementations of an ICR EKF using measurements obtained from a LIDAR based simultaneous localization and mapping (SLAM) algorithm in one case and measurements from a stereo visual odometry algorithm in the second will be presented. Results show that the SLAM algorithm, implemented on a wheeled skid-steer platform, and the visual odometry algorithm, implemented on a tracked platform, produce ICR estimates which accurately model the motion of the vehicle. Such ICR estimates can then be used for model-predictive control, path planning, and other improvements to skid-steer autonomy.
Keywords: Skid-Steer, Motion Modeling, Kalman Filtering

Paper 56.

EXPERIMENTAL INVESTIGATION OF STUCK WHEEL CHARACTERISTICS IN LOOSE SAND

Takuya Omura and Genya Ishigami
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Abstract
In this study, a wheel stuck phenomenon on loose soil is experimentally clarified using a single wheel test bed. This experiment employs an in-wheel sensor system that can measure wheel contact angles as well as force distribution beneath the wheel. The wheel stuck phenomenon during the experiment is simulated by controlling the wheel traveling velocity such that a slip magnitude (slip ratio) increases based on a first-order system with different time constants.
The experimental result has revealed that the stuck and non-stuck wheels show the following characteristics: 1) the maximum force angle of the non-stuck wheel increases with time (as the wheel rotates) while that of the stuck wheel first increases in transient state (the slip ratio being less than 1.0), but it then reaches maximum value at slip ratio of approximately 1.0 and subsequently decreases; and 2) the exit angle of the non-stuck wheel decreases with time, but that of the stuck wheel increases. These results indicate that the abovementioned characteristics can be used to predict a quasi-stuck wheel or to prevent an immobilizing wheel slip.
Keywords: Rover, Stuck Wheel, In-Wheel Sensor System

Paper 72.

INTERACTION USING A DIFFERENTIAL VARIATIONAL INEQUALITY-BASED APPROACH

Daniel Melanz[a,b], Paramsothy Jayakumar[a], Dan Negrut[b]
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Abstract
The observation motivating this contribution was a perceived lack of expeditious deformable terrain models that can match in mobility analysis studies the level of fidelity delivered by today's vehicle models. Typically, the deformable terrain-tire interaction has been modeled using finite

element method (FEM), which continues to require prohibitively long analysis times owing to the complexity of soil behavior. Recent attempts to model deformable terrain have resorted to the use of the discrete element method (DEM) to capture the soil's complex interaction with a wheeled vehicle. We assess herein a DEM approach that employs a complementarity condition to enforce non-penetration between colliding rigid bodies that make up the deformable terrain. To this end, we consider three standard terramechanics experiments: direct shear, pressure-sinkage, and single-wheel tests. We report on the validation of the complementarity form of contact dynamics with friction, assess the potential of the DEM-based exploration of fundamental phenomena in terramechanics, and identify numerical solution challenges associated with solving large-scale, quadratic optimization problems with conic constraints.

Keywords: Terramechanics, Discrete Element Method, Friction and Contact, Differential Variational Inequality, Validation, Calibration, Direct Shear Test, Pressure-Sinkage Test, Single Wheel Test, Deformable Terrain

Paper 97.

INSTRUMENTATION AND TESTING OF A HIGH MOBILITY MULTIPURPOSE WHEELED VEHICLE

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Abstract

Vehicle performance measurement technology geared toward the commercial sector is often not suitable for tactical military vehicles. Furthermore, soldiers are often placed in large and cumbersome vehicles over unfamiliar and rough terrain. Therefore, instrumentation and testing techniques specifically geared toward military vehicles is of primary importance for improving vehicle performance and for real-time understanding of how complex terrain impacts maneuvers. This paper describes the instrumentation and testing of a High Mobility Multipurpose Wheeled Vehicle (HMMWV) in various terrain conditions including gravel, mud, ice, and snow. A model 1097 HMMWV was outfitted with numerous sensors to measure vehicle parameters including, but not limited to, triaxial forces and moments on each tire, tire angle, motion, position, and orientation. For this study, digital image correlation techniques were used to measure longitudinal and lateral tire slip. Lateral traction, acceleration and braking, and slalom tests were performed. The instrumented HMMWV provides valuable feedback on the performance of the military vehicle over varying terrain surfaces. The techniques described in this paper can also be applied to other military vehicles to further understanding of their vehicle performance metrics.

Keywords: Terrain, Mobility, Snow, Ice, Vehicle Performance, Instrumentation

Oral Presentation 40.
See PDF slides in the Conference Proceedings
DISCRETE ELEMENT METHOD ANALYSIS FOR SLIP OF A WHEEL DRIVING ON THE OFF-ROAD GROUND
JeseungMoon, Gwanyoung Kim, Soojin Lee and Kyu-Jin Lee

Oral Presentation 81.
See PDF slides in the Conference Proceedings
MOTION DYNAMICS OF UTOPUS PUSH-PULL VEHICLE WITH NARROW TINES FOR TRACTION
Volker Nannen, Damian Bover, and Dieter Zöbel

Track 1. Terramechanics, locomotion and soil/terrain modeling
Session 1.3. Soil and terrain modeling and characterization

Paper 99.
CHARGING CHARACTERISTICS OF LUNAR SOIL SIMULANTS AND METAL PLATES
Yuji MORI[a] and Tadaomi EGUCHI[a]
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Abstract
The work performance of construction machinery is closely related to the wear of the working parts at engineering works. Therefore, elucidation of the mechanism of wear can provide an important method for stabilizing work and preventing unexpected events. Furthermore, engineering works are assumed in component technology research for lunar resource exploitation, which has been actively conducted in recent years; however, research on the lunar surface must be conducted under a particular environment present there. Hence, elucidating the mechanism of wear considering these conditions is important for the management of lunar resource exploitation. In this study, we attempt to elucidate the mechanism of wear on the basis of electrostatic charging, which, to our knowledge, has not been done yet. Specifically, we fabricated a device comprising a combination of a cascade device and Faraday cage and then observed the charging status and wear status when a metal plate (used to simulate a work part) was contacted with lunar soil simulant. Consequently, a singular behavior for electrostatic charging was observed upon contact; moreover, wear, surface peeling, and adhesion were observed at the surface upon contact. Thus, our results demonstrate the possibility of a correlation between electrostatic charging and wear.
Keywords: lunar soil simulant, electrostatic charging, wear

Oral Presentation 34.
See PDF slides in the Conference Proceedings
A Technical Survey on Equipment and Techniques for Testing and Parametrization of Soft Soil for Vehicular Applications,
Rui He and Corina Sandu

Paper 52.

UPDATING OF SELECTED VEHICLE-TERRAIN INTERFACE EQUATIONS THROUGH BAYESIAN CALIBRATION

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Abstract

Effective modelling of off-road vehicle mobility at diverse fidelities and on various terrains is an important task for many vehicle design applications. The Vehicle-Terrain Interface (VTI) model is a low-fidelity model often used to support virtual prototyping of off-road vehicle designs. The VTI model is an assembly of several equations which predict vehicle performance through high-resolution empirical modelling of the forces and displacements at the traction-terrain element interface. A recently developed database of wheeled vehicle performance tests over loose, dry sand, DROVE (Database Records for Off-road Vehicle Environments) is used along with a two-stage Bayesian calibration process to update the coefficient values in the VTI equations for drawbar pull and traction. Improvements to both models are evaluated through their performance in root-mean square error (RMSE) and square of the coefficient of determination (R2).

The updated coefficients result in RMSE improvements of 17.3% for drawbar pull and 5.5% for traction. The calibrated equation for drawbar pull also shows improvement in R2 of 2.8% and the calibrated traction equation performs similarly to the original VTI equation in R2. The improvements for both models were validated through a test dataset from DROVE and convergence of the Bayesian calibration process demonstrated with two indicators of convergence.

Keywords: Off-road Mobility; Vehicle Terrain Interface (VTI) model, Bayesian Calibration (BC), Metropolis Algorithm, Sand, Drawbar pull (DBP), Traction (T), Database Records for Off-road Vehicle Environments (DROVE)

Paper 48.

PHYSICALLY BASED MODELING OF DEFORMABLE SOIL FOR MACHINE DESIGN AND OPERATOR TRAINING

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Abstract
In recent years, realistic simulation of vehicles on soft soil has been increasingly gaining importance due to its use in operator training, mission planning and design. Soil exhibits a multitude of different behaviors depending on material properties and deformation history, which makes simulation of soil a challenging task, especially at interactive rates. In this work, a real-time soft soil simulation method is presented which strikes a balance between sufficient fidelity for design in engineering, and sufficient performance for Virtual Reality training applications. The method employs models from terramechanics and soil mechanics in order to represent the interaction of vehicles and their digging tools with a deformable terrain, supporting the simulation of a broad range of vehicles with earth moving equipment on soft ground in real-time. The impact of both wheel–ground and tool–ground interactions on the vehicle behavior is considered through use of a fully coupled dynamics model of the vehicle and its environment, which includes effects such as non-linear stress–strain relationships as well as highly plastic material deformation and flow, soil erosion and compaction. Simulation studies are presented which show that the method produces believable terrain deformations and plausible soil reaction forces at real-time frame rates. Furthermore, in verification experiments it is shown that the employed wheel–ground interaction model yields vehicle trajectories in simulation which closely match trajectories observed in experiments with the actual vehicle.
Keywords: Physics-based simulation; simulation-based engineering, deformable soil modeling, bucket-soil interaction, wheel-soil interaction; real-time simulation

Paper 62.

FEM-BASED TERRAMECHANICS ANALYSIS OF TIRE TRAVELING ON MULTI-LAYERED GROUND

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Abstract
In this study, we focused on semi-empirical modeling of the pneumatic tire of mining dump truck. In order to obtain terramechanics parameters for “oil sand” under temperature condition of-30 C^o ~30 C^o, in the analyses, we adopted a concept of equivalent soil properties, which is obtained by FEM analysis of multi-layered ground model. To identify the pressure-sinkage relation, we conducted sinkage calculations of pneumatic tire for four seasons, i.e. early spring, late spring, summer, autumn. Then, the qualitative applicability of the proposed concept was discussed by comparing it to results of FEM. In addition to single tire analysis, we applied the proposed concept to the multi-body dynamics analysis of full vehicle model, by a user subroutine of ADAMS.
Keywords: Terrain Mobility, Multi-body dynamics, FEM, Dump track, multi-layer ground

Paper 67.

DISPLACEMENT PATTERNS BENEATH A RIGID BEAM INDENTING ON LAYERED SOIL

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[b]*Water Resources Engineering Department, College of Engineering, University of Baghdad, Iraq*

[c]*OHB System AG, Munich, Germany*

Abstract

Often ground vehicles come across interacting with soil profiles of non-homogeneous and complex nature. In this research, the variation of failure envelopes and deformation patterns of a layered sandy soil system beneath a rigid beam under the plain-strain condition have been studied using Digital Particle Image velocimetry (DPIV). Based on the model tests of a rigid beam (width B) resting on a dense sand layer of limited thickness (*H*) overlaid by loose sand media, the evolution of grain-scale velocity fields and slip surfaces in the sand for different loading levels is studied. Normalised vertical displacement (*Sv/B*) profiles with depth (*z/B*) from the bottom surface of the beam at different loading levels are presented. The bearing capacity of the beam resting on the layered sandy soils is compared with the results obtained from theoretical analysis reported in the literature.

Keywords: Terramechanics, layered soil, granular mechanics, DPIV

Paper 68.

PARAMETERIZATION OF NORFOLK SANDY LOAM PROPERTIES FOR STOCHASTIC MODELING OF LIGHT IN-WHEEL MOTOR UGV

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Abstract

In order to accurately develop a mathematical model for an IWM UGV on soft terrain, parameterization of terrain properties is essential to stochastically model tire-terrain interaction for each wheel independently. Operating in off-road conditions requires paying close attention to tire-terrain interaction as it impacts the IWM UGV energy efficiency greatly. Developing a mathematical model for the IWM UGV on soft terrain is a complex task due to the uncertainty behavior such as stochastic terrain properties, terrain irregularities and multi-pass effect. Sources of uncertainties include spatial variability of soil properties and changes in the soil moisture content. In addition to variability of soil properties, terrain surface irregularities have an influence on vehicle performance because of changes in contact forces between tires and terrain. Thus it is important to incorporate terrain surface irregularities with stochastic terrain properties modelling. This can be achieved empirically by using Bekker's technique which relates tire sinkage and normal pressure distribution at the contact patch and the Janosi and Hanamoto approach for calculating shear stress at the contact patch in order to calculate stochastic wheel rolling resistance for each wheel. In addition, attention was payed to consider pneumatic tires for lightweight IWM

UGVs moving on off-road terrain (Norfolk Sandy Loam soil) and taking into account the multi-pass effect to appropriately model terrain properties for both front and rear wheels.
Based on terramechanics equations, there are six main terrain parameters that have direct effects on the calculations of the normal and shear stresses and on the wheel rolling resistance produced in the tire-terrain contact. All six terrain parameters were modelled stochastically by obtaining those values experimentally using cone penetrometer, Cohron sheargraph, soil bulk density, moisture content and rut depth measurement methods for both trafficked and untrafficked terrain. Then, uncertainties for those parameters were represented as uncorrelated random variables with normal distributions using the Monte Carlo method.
Keywords: Norfolk Sandy Loam, Soil Properties Parameterization, Stochastic Terrain Modeling, and Lightweight IWM UGV.

Paper 58

MEASUREMENT OF VEHICLE PERFORMANCE TRAVELING ON ASPHALT-PAVED ROADS COVERED WITH VOLCANIC ASH

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Abstract
Japan has a lot of volcanic mountains and some of them have recently started increasing their volcanic activity. A large-scale eruption spreads volcanic ash over a broad area, which causes serious damage to social infrastructure. Even at times of disaster, vehicles have an important role in the rescue effort and transportation to help people. Accumulation of ash on paved roads has a significant influence on vehicle traveling performance and trafficability. This study examined the effects of volcanic ash on driving vehicles in terms of mechanics. Single wheel test equipment was used to measure the interaction such as friction coefficient and rolling resistance between a tire and volcanic ash on a paved road. The test equipment was 10 m long to measure forces exerted on the tire in the longitudinal direction under driving and rolling conditions. An asphalt mat of about 1 cm thick was glued on the metal hard test bed, and covered by volcanic ash with a controlled thickness. The test result showed that a very thin layer of ash was found to be very slippery, and the friction depends on the depth of the tire tread groove for a thickness of ash less than 10 mm. Over 10 mm thickness, the rolling resistance increased and the friction reduced with the thickness. Over 40 mm, the friction coefficient was nearly as low as that on a road covered with snow. A thickness over 100 mm made it difficult for vehicles to overcome the motion resistance. The set of tests on the indoor equipment was restricted to the wheel traveling at a very low velocity. An instrumented vehicle was introduced to measure the parameters with increased speed outside on an asphalt road covered with volcanic ash.
Keywords: Volcanic Ash, Vehicle Motion, Friction Coefficient, Rolling Resistance, Sinkage

Paper 41

THREE-DIMENSIONAL RUT PROFILE MEASUREMENT IN SNOW AND MUD

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Abstract

Vehicle mobility testing under winter conditions, especially on snow and ice, is challenging. One of the important parameters to measure is rut depth. Rut depth provides a measure of vehicle tractability as well as the impact on the environment. Current techniques are manual, labour intensive contact methods. Contact based measurements can also be difficult to use on soft material due to terrain deformation. Rut depth is not uniform on natural terrain but measurements are usually only possible at relatively few points. It is also difficult to synchronize rut depth with other measurements such as vehicle speed and drawbar pull.

With the proliferation of cheap digital cameras, Digital Image Correlation (DIC) becomes an attractive option to measure critical vehicle and terrain parameters during off-road driving over varying terrain conditions. This can be achieved using largely commercial off-the-shelf (COTS) components but with dedicated software. This paper investigates the feasibility of using DIC to measure terrain profiles, both un-deformed (terrain roughness) and deformed (rut depth). Tests were performed on different vehicles, for various dynamic vehicle manoeuvres, over varying terrain conditions. Results were validated using existing measurement methods, a measurement stick, that have been used over many years. Results were also compared with measurements on hard terrains.

Mobility under off-road conditions can change rapidly due to environmental conditions e.g. rain or snow, complicating the driver's task. The techniques described can assist in gathering terrain and vehicle mobility data during driving that can be used directly to assist the driver in making safety related decisions. These techniques offer unique possibilities for inclusion in Advanced Driver Assist Systems (ADAS).

Keywords: tyre deformation, rough terrain, longitudinal slip, 3D rut profile, snow, mud

Paper 42

TIRE SLIP AND SLIP ANGLE MEASUREMENT IN SNOW AND MUD USING STEREO IMAGING SYSTEM

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Abstract

Two of the most important tire characteristics required for vehicle dynamics and mobility modelling are the longitudinal force versus longitudinal slip, as well as lateral force versus slip angle characteristics. Many techniques have been used to measure these parameters under field test conditions but the cost and reliability rapidly deteriorates as conditions become more severe. Longitudinal slip is often inferred from vehicle speed and wheel speed measurements by assuming

a constant tire rolling radius. This can result in large errors on soft and rough terrains. Slip angle measurement under dynamic conditions is notoriously difficult. Although good commercial sensors exist, they generally work well only on smooth roads (where vertical motion is small) and at speeds above about 15 km/h. Their measurement range is also restricted to low slip angles in the range of 20 degrees. Accurately measuring slip angle under winter conditions, especially on snow and ice, is challenging. The terrain is usually not smooth, speeds are generally very low and slip angles can be very high during loss of control, which makes commercial sensors unsuitable for these conditions.

This paper investigates the feasibility of using inexpensive cameras and Digital Image Correlation to measure longitudinal tire slip and lateral tire slip angle. Tests are performed on different vehicles, for various dynamic vehicle manoeuvres, over varying terrain conditions. The results show that the slip-angle measurement techniques works on snow and mud, however the longitudinal slip measurement faces problems with soil covering the tyre-terrain interface.

The parameters measured using these techniques can provide invaluable data for improving vehicle dynamics control systems such as ABS brakes and electronic stability control, replacing current slip estimators real measurements. These techniques offer unique possibilities for inclusion in Advanced Driver Assist Systems (ADAS).

Keywords: Terrain Mobility, Snow, Ice, Longitudinal slip, Slip angle, Digital image correlation

Paper 85

COMPARISON OF SOIL STRENGTH MEASUREMENTS OF AGRICULTURAL SOILS IN NEBRASKA

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Abstract

In September 2014 the University of Nebraska, Lincoln (UNL), undertook a field testing program at three sites to investigate a soil moisture mapping system as a crop management tool. In conjunction with this work, the US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL) deployed a team to perform soil characterization and strength measurements. The purpose of ERDC-CRREL test program was an investigation of the Lightweight Deflectometer (LWD) as a soil surface strength tool for the purposes of assessing bearing capacity of soft soils. The LWD measurements were performed with those from more "standard" tests, i.e. the Dynamic Cone Penetrometer, Cone Penetrometer (Trafficability Cone), and Clegg Impact Hammer to determine if the LWD produced results that correlated with the other test methods. The test data from the various equipment were also used to calculate California Bearing Ratio (CBR) values using existing equations in order to see if the different test methods produced similar CBR values that could in turn be used to predict the bearing capacity of the sites.

Keywords: Agricultural soils, soil strength, bearing capacity, DCP, CI, CIH, LWD

Written Only Paper 36.

ESTABLISHMENT OF A DAMPING MODEL FOR TIRE–SOIL SYSTEM

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Abstract

This paper proposes a linear damping model of tire–soil system using semi-empirical method. A test rig was designed and developed to measure the vertical equivalent linear damping ratio of tire only and tire–soil system using Free-Vibration Logarithmic Decay Method. The test were performed with two kinds of tractor tires using a combination of five inflation pressure levels, two soil depths and four soil moisture contents in the paddy soil. The results revealed that the linear damping ratio of tires increased with the decrease in tire inflation pressure; the linear damping ratio of tire-soil system also increased with the decrease in tire inflation pressure and increased with the increase in soil depth (observed at 80 and 120 mm). It also increased with relative increase in soil moisture contents (observed at 37.9%, 48.8%, 66.7% and 77.4%). The results also revealed that the damping ratio of tire–soil system was higher than that of tire only. A linear damping model of tire-soil system is proposed as a damping model in parallel which is established based on experimental results and vibration theory. This model will have a great significance affect in research and prediction of tractor vibration.

Keywords: Linear damping ratio, Logarithm decay method, Tire-soil system

Track 2. Advances in mobility, energy efficiency and ground vehicle dynamics

Paper 8.

MODEL FOR RUN-OFF-ROAD VEHICLE SPEED ANALYSIS

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Abstract

A series of field measurements were carried out with the primary aim of recording data for a soil database to be used in the simulation of motion of vehicles involved in run-off accidents. The measurements were used to determine travel resistances, a required parameter for the determination of the speed of a vehicle entering terrain at the moment it runs off the road.

Previous vehicle-terrain interaction theory research by the Department of Automotive Engineering of Szent István University has proved very useful during the investigation, because the motion of a vehicle running on to terrain after an accident is governed by the vehicle-soil and tire-soil interactions.

With knowledge of the vehicle mass, the distance travelled on the terrain, and the effects of the soil parameters, then if the other forces acting on the vehicle are known, the speed of the vehicle as it left the road may be calculated (providing that it came to a halt on the terrain).

Keywords: Terrain Mobility, Run-Off-Road Accidents, Soil-Tire Interaction

Paper 13.

STEADY-STATE CHARACTERISTICS OF SKID- STEERING FOR HIGH-SPEED TRACKED VEHICLES

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Abstract

Steering characteristics of vehicles play a significant role in the procedure of their design and control. Some realities observed in the field indicate that traditional steering theory is not suitable for high-speed tracked vehicles due to over-simplification. The nonlinear interaction between the track and the terrain can't be neglected. Starting from a semi-empirical track-terrain model based on Bekker–Wong theory, this paper presents an analytical lateral dynamic model to analyze the skid-steering characteristics for high-speed tracked vehicle which conducts steady-state turning on the deformable terrain. Using this model, the main factors (normal pressure distribution, position of gravity center, ratio of *L* and *B*) effecting the steady state characteristics of skid steering are discussed. The normal pressure distribution is idealized as trapezoid and dual trapezoid distribution to embody same common traveling situation. The under-steer parameter is introduced in this paper to quantitatively evaluate the steady-state characteristics of skid steering for tracked vehicle. The results of steady-state analysis show that the steering input Δu/u is more suited to the high-speed tracked vehicle. The vehicle with dual trapezoid normal pressure distribution slightly tending to localize in the middle of track or with slight rearward position of gravity center has better handling stability characteristics.

Keywords: Tracked Vehicle, Unmanned Vehicle, Skid Steering, Lateral Dynamics, Steering Characteristics

Paper 47.

TRANSIENT TRACKED VEHICLE STEERING MODEL

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Abstract

The objective of this study is to develop a general transient steering model for tracked vehicles which is simple, accurate, and agreeing with the test results to a satisfactory level. In this study, such a model is developed in Matlab/Simulink platform.

The model represents a general tracked vehicle having rear or front sprockets, with variable center of gravity and wheel positions, and number of wheels. The vehicle hull is modelled as a rigid body having 3 degree of freedom; translation in the longitudinal and lateral directions, and yaw rotation. The terrain is modelled as flat non-deformable terrain. The model involves the calculation of

contact forces between the track and the terrain, and calculation of longitudinal and lateral forces acting on the hull. Contact forces between the track elements and the terrain are calculated for each wheel taking the track tension into account. The effects of lateral accelerations during steering, and longitudinal accelerations in traction or braking are included in contact force calculations. To be able to calculate longitudinal and lateral forces, a transient shear model is used. The shear model utilizes determination of slip velocities, slip displacements, the shear stress on the track pad surface under each road wheel, and the resulting shear forces. Shear stress is assumed to be a function of shear displacement. The inputs to the vehicle model are left and right sprocket speeds and the outputs are vehicle position, velocity, and acceleration in the longitudinal, lateral, and yaw directions, and side slip angle.
A comprehensive program of road tests has been performed. The results from the model study and the road test program involving various steering scenarios show that the agreement between them is satisfactory both in the steady state and transient steering simulations.
Keywords: Tracked Vehicle, Transient Steering Dynamics, Shear Model

Paper 57.

DRIVING FORCE DISTRIBUTION FOR INDEPENDENT WHEEL DRIVE VEHICLE ON ROUGH GOUND

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Abstract
The wheel driving force is an important factor for traveling performance on rough ground. Excessive driving force induces large slip and insufficient driving force disables vehicle for passing over obstacles. Therefore, optimal driving force distribution is necessary to improve the off-road vehicle traveling performance on rough ground. In this study, the driving force distribution of four independent drive wheels based on energy loss rates of the wheel was proposed. The energy loss rate was calculated from wheel slip and vertical load. The proposed distribution method minimized the square sum of energy loss rates of all wheels. In order to examine the proposed method, traveling tests by a model vehicle on rough rigid ground and soft ground, and simulation tests on rough rigid ground were carried out. The results of proposed method were compared with the ones of the distribution based on the tire workload, the even force distribution, and the wheel velocity control. As the experimental and simulation results, it was confirmed that the proposed method was the most efficient on rigid ground for vehicle movement. On soft ground, the proposed method was the most stable for movement.
Keywords: off-road vehicle, driving force distribution, slip, rough ground, driving efficiency

Paper 66.

OFF-ROAD TYRE STATE AND PARAMETER ESTIMATION

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Abstract
Knowledge of the tyre states and parameters is very important to the successful implementation of advanced driver assist systems (ADAS) such as traction control and anti-lock braking systems. Often, rigid body assumptions with regards to the tyre states (specifically the longitudinal tyre slip) are made and the tyre dynamics are neglected. This assumption fails on rough terrains and leads to the decreased performance of ADAS control systems under changing tyre operating conditions such as inflation pressure, tyre wear and aging, and varying terrain conditions (specifically off-road conditions). This study estimates the tyre longitudinal slip and tyre sidewall stiffness and damping, torsional stiffness and damping and effective kinetic rolling radius with the use of an Unscented Kalman Filter. A modified rigid ring tyre model is used as an observer model. The study is simulation based and results from brake tests in Adams Car are used as inputs and measurements to the estimation algorithm. An FTire model is used on two different rough roads, a Belgian paving and parallel corrugations.
Keywords: Off-road tyres, state estimation, parameter estimation

Paper 79.
POWER CONSUMPTION MODEL FOR SLOPE TRAVERSAL OF WHEELED ROBOT BASED ON DYNAMIC SIMULATION

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Abstract
Planetary robots have verified the effectiveness of the use of unmanned mobile robot for precursor mission on the outer planet. Because of the limited and unstable power available for the robot in such scenario, less power consumption of the robot needs to be sufficiently considered. In this paper we propose a power consumption model of a wheeled robot on loose terrain, particularly in slope traversal scenario. The power consumption model is obtained through a dynamic simulation of the robot which consists of vehicle and wheel dynamics: the former provides motion state variables such as traction load and vertical load, and the latter calculates wheel state variables including slip ratio and slip angle. In the slope traversing simulation at different slope angles and robot heading directions, a given robot motion is achieved by applying a feedback control to the actuators of the robot. Here, the power consumed by the actuators are estimated from each simulation. The results indicate that the power consumption quasi-linearly increases as the slope angle while that has non-linear relationship with the robot heading direction. Based on these findings over a few hundred of simulations, the power consumption model is approximated as a polynomial function composed of slope angle and heading direction.
Keywords: Robot Mobility, Power Consumption, Rover

Paper 43.

MEASUREMENT OF TIRE CARCASS INSIDE DEFORMATION

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Abstract

Understanding tire-terrain interaction is crucial to modeling and testing of wheeled vehicles. The interface between the tire and the terrain is however hidden from view and therefore it is extremely difficult to experimentally determine this interaction. Some success has been achieved with sensors buried in the terrain or mounted to the tire tread but these often give only a small number of measurement points and require extensive preparation of small test sections, mostly on terramechanics test rigs. One of the difficult parameters to obtain accurately is the effective rolling radius of the tire as this is not constant and depends on the three-dimensional deformation of the tire and soil. The rolling radius is crucial in determining the slip between the tire and the terrain.

This paper explores the possibilities for measuring the three-dimensional deformation of the inside of the tire, in the region of the contact patch, using digital cameras and Digital Image Correlation (DIC) techniques. The test setup used is the so-called Tire-Terrain Camera system or T2CAM. A calibrated stereographic rig is mounted inside the tire on a modified rim and stabilized with a mechanical mechanism so that they always remain pointed at the same area of the tire contact patch. The system is integrated with a six-component wheel force transducer, wheel angle sensor and wheel speed sensor. Tests are performed with the T2CAM system mounted on the CRREL Instrumented Vehicle (CIV). Various dynamic tests are performed on different terrains ranging from hard surfaces to fresh snow. The system is shown to successfully capture tire deformation under dynamic conditions.

Keywords: Terrain Mobility, Dynamic tire deflection, Longitudinal slip, Digital image correlation

Paper 83.

EVALUATION OF DIGITAL IMAGE CORRELATION TECHNIQUE FOR OFF-ROAD MOBILITY IN ALL-SEASON CONDITIONS

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Abstract

Digital Image Correlation (DIC) technology developed for off-road vehicle dynamics at the University of Pretoria, South Africa, was recently assessed for all-season and all-terrain viability through a Foreign Technology Assessment Support (FTAS) program at the US Army, Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Advancements in camera technology and computational power has allowed algorithms to determine feature and

depth tracking of surfaces in sequential images at near real time. These advancements have enabled the application of DIC to measure surface and velocity profiles as well as deformation from a reference state for terrain or for tires. In large off-road vehicle dynamics DIC can be used to assess and validate the terramechanics models by monitoring the road or terrain surface before and after the tire along with the motion of the vehicle or tire; and, when used as real-time feedback with driver assists or control software, to improve maneuverability of vehicles. From these measurements the terrain roughness and deformation can provide terrain trafficability, and the relative terrain and tire motion used for vehicle safety systems.
The project objectives were to evaluate the application of DIC on military vehicles to measure deformation and vehicle motion on variable terrain surfaces with the ultimate goal of providing additional information to the driver, vehicle control system, or real-time data assimilation for mobility and maneuver optimization. The technology was tested and validated using the CRREL Instrumented Vehicle, an instrumented HMMWV (M1097) , and the much larger Heavy Expanded Mobility Tactical Truck (HEMTT). Validation testing was conducted using a variety of maneuvers on snow, ice, water, asphalt, concrete and vegetated ground surfaces.
Keywords: Terrain, Mobility, Winter, Snow, Ice, Mud, Instrumentation, Image

Track 3. Agricultural and forestry machines, construction and mining equipment

Paper 11.

THE EFFECT OF OBSTACLE INDUCED WHEEL LOAD FLUCTUATIONS ON THE LATERAL FORCE TRANSMISSION WITH THE HOHENHEIM TYRE MODEL

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Abstract
The Hohenheim Tyre Model was presented as an approach to investigate driving comfort and driving safety of agricultural machinery due to its ability to reproduce tyre passes over obstacles. Model validation in vertical and longitudinal directions was likewise previously presented. The model behaviour in lateral direction is of great interest for the use in driving dynamics simulations. The transmission of lateral forces on uneven surface is a transient process and therefore dependent on time and type of excitation. Wheel load fluctuations occur due to different types of excitation of the tyre. They can be wheel- and track-induced. As special case of track-induced wheel load fluctuations, tyre passes over discrete obstacles can be investigated.
In the presented work passes over discrete obstacles with a single tyre are simulated with the Hohenheim Tyre Model. Different characteristics of the lateral force transmission are taken into account by varying the type of obstacle as well as tyre operating factors such as driving velocity and slip angle. The modelling approach is verified by comparing the simulation results to measurements on a single tyre during former research.
Keywords: Tyre modelling, Lateral forces, Driving dynamics, Driving comfort

Paper 19.

SEEDING EQUIPMENT DYNAMICS AT HIGH GROUND SPEED

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Abstract
Proper seed depth is a critical factor in successful crop development. As western Canadian farms continue to grow in size, seeding productivity demands follow closely. Increasing the working width of seeding equipment has been the favored approach. However, as the practical physical limitations of equipment size are approached, the need to increase operating speed is becoming increasingly important. Current seeding equipment technology can result in inconsistent seeding depth and poor plant emergence at higher speeds. Compared to relatively well-developed off-road vehicle dynamic applications, little research related to tillage and seeding implement system dynamics has been found. The present research combines off-road vehicle dynamics theory and soil-tool interaction research to further understand seeding implement motion during seeding operations. Equations of motion for a hoe-opener type seeding implement were developed, and efficient soil-tire and tillage-tool interaction models were adapted to represent soil contact. Additionally, operational data of the modelled implement were collected at a variety of operating conditions. The data provides both a means for model validation, and an opportunity for additional analysis once insights from the system model are further developed. By developing a dynamic model, the fundamental cause of shortfalls in current technology related to high speed seed placement can be better understood.

Keywords: Vehicle dynamics, soil-tire interaction, soil-tool interaction, vibration, seeding depth

Paper 18.

OF COMPUTATIONAL MODELS OF TRACKED TIMBER HARVESTING MACHINE TRANSMISSION LOADING DEPENDING ON MOVEMENT EXTERNAL CONDITIONS

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Abstract
Transmission of the tracked timber harvesting machine (TTHV) shall meet requirements of necessary travel movement speed at desired functioning reliability. The work is aimed at improving computational models of the tracked timber harvesting machine transmission loading and specifying methods of calculation of loading of the transmission elements depending on movement external conditions that justify selection and evaluation of the transmission elements' parameters at the stage of the TTHV designing and testing. The improved model to calculate loading of the tracked timber harvesting machine transmission at controlled curvilinear motion allows more reliable evaluation of loading of the transmission elements. The improved method to evaluate movement external condition influence on calculation of the TTHV transmission loading includes three main stages. The first stage consists in analysis of the transmission load mode at the TTHV moving at different speed under defined external conditions with a possibility to change

the movement curvature sign and vary the transmission parameters. The second stage consists in implementation of the TTHV calculation scheme in the form of local mathematical models allowing evaluation of the transmission element loading. A distinguishing feature of this technique is an employment of software application suites (SolidWorks, Universal Mechanism, Adams View, Adams Tracked Vehicles Toolkit) allowing reduction of the total time spent for development of the design and technical documentation at the designing stage, conduct of virtual tests, creation of the vehicle prototype. The third stage includes a method of bench and full-scale tests of the TTHV prototype dynamic response. This method provides for possible simulation of the TTHV movement along a curvilinear trajectory and a trajectory with a varied curvature sign, with maximum transmission loading.

Keywords: Transmission, Tracked vehicle, Curvilinear motion, Simulation

Oral Presentation 29

See PDF slides in the Conference Proceedings

POWER HOP: TRACTOR - DRIVELINE TORSIONAL COUPLED DYNAMICS

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Paper 32.

COMBINED CONTROL OF SEMI-ACTIVE AXLE AND CAB SUSPENSION

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Abstract

Farm tractor operators are exposed to a high level of whole body vibrations. In the past, a number of systems have been developed to reduce these vibrations using both active and semi-active suspension of the axle, the cab or the seat. With an axle suspension it is also possible to reduce wheel load fluctuations. This is important for driving safety, handling and – especially in the case of farm tractors – for tractive efficiency. The common control strategies of skyhook and groundhook control either focus on comfort or road holding. The conflict of objectives between a comfortable passive suspension design on the one hand and a safe passive suspension design on the other hand does also exist for semi-actively controlled suspensions. A gain in comfort results in increased wheel load fluctuation and vice versa. Therefore, a combined control strategy using a semi-active two stage suspension system consisting of an axle suspension and a cab suspension is proposed. Simulations of a quarter car model show the conflict of objectives for passive and single stage semi-active suspension systems. Possible control strategies for a two stage semi-active system are discussed and a combination of groundhook and skyhook control is proposed to solve the conflict. A modified tractor equipped with a semi-active hydro pneumatic front and rear axle suspension and a semi-active cab suspension system is used to test different combinations of passive and semi-active suspension settings on a hydraulic four-post-test-rig.

Results show that using a two stage suspension system can reduce dynamic tyre forces while at the same time improving the driver's comfort.
Keywords: farm tractor, semi-active suspension, driving comfort, driving safety, skyhook, groundhook

Oral Presentation 55.
See PDF slides in the Conference Proceedings

EVALUATION OF LOW INFLATION TIRE TECHNOLOGIES ON SOIL COMPACTION

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Abstract
Evaluation of recent advances in tire technologies such as advanced deflection agricultural tires (Firestone IF and VF) and precision tire inflation technologies on soil compaction, traction, fuel economy and crop yield responses are important. The purpose of the study was to investigate the effects of field and transport (road) tire inflation pressure settings of row-crop agricultural tractor and planter tires on soil compaction. A randomized complete block design experiment was conducted at Iowa State University farm in Boone, Iowa for two tire inflation pressure levels on Dual Front (Firestone IF 420/85R34) and Dual Rear (IF 480/80R50) tires on a John Deere 8310R MFWD tractor, and transport tires (Super single 445/50R22.5) on a John Deere DB60 planter. Soil compaction was measured using Stress State Transducers (SST) buried at 15-cm and 30-cm depths beneath the untrafficked soil surface. Cone index depth profile was measured at tire-centerline, tire-edge and 20 cm laterally outboard of the tire edge before and after tractor-planter tire passes. Peak Octahedral Normal Soil Stress (ONSS) and the corresponding Octahedral Shear Soil Stress (OSSS) values were calculated from the SST data. The peak ONSS and OSSS values from the road tire pressure settings were statistically higher (p-value < 0.01). The maximum ONSS was observed from the road tire inflation pressure setting at 15 cm from rear tires (179 kPa tire inflation pressure and 25 kN load per tire). The ONSS from the front tires (138 kPa tire inflation pressure and 17 kN load per tire) and planter transportation tires (620 kPa tire inflation pressure and 16.5 kN load per tire) were similar. Cone index data also showed significant differences, comparing before and after tires passes, at the tire-centerline. The peak cone index values were 1.3 MPa and 1.2 MPa from the road and field tire inflation pressure settings, respectively.
Keywords: Soil Stress State, Cone Index, Soil Compaction, Precision Tire Inflation

Paper 49.

UTOPUS: A NOVEL TRACTION MECHANISM TO MINIMIZE SOIL COMPACTION AND REDUCE ENERGY CONSUMPTION

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Abstract

Tractor tires on agricultural soil suffer from inherent limitations like energy loss due to slip and tire flexing and a need for considerable ballast to gain traction. These limitations contribute to soil compaction, make the agricultural tractor energy-inefficient and make it unviable to power a tractor with solar panels or by storing renewable energy in batteries.

To address these disadvantages as a whole, we introduce a novel traction mechanism that allows weeding and cultivation using only autarkic solar energy, based on the novel principle of retractable tines or crampons for traction.

The mechanism inserts relatively small crampons every few meters into the soil, and then uses a push-pull mechanism to pull tillage implements through the soil, without any additional ballast. The light weight of the resulting machine and the small contact area of crampons with the soil reduce soil compaction, while the static nature of the crampons minimizes energy loss and increases energy efficiency.

We report a range of successful proof-of-concept trials which show the practical feasibility of the basic concept for weeding and soil cultivation with solar energy, wind energy, and electric power supply under different conditions. We also provide calculations on the economic advantages compared to ballasted tires.

Keywords: Crampons, Push-Pull Locomotion, Inching Locomotion, Energy Efficiency, Tractive Efficiency, Soil Compaction

Paper 59.

RFT-BASED ANALYSIS OF VEHICLE-TERRAIN INTERACTION PROBLEMS

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Abstract

The traveling performance of off-road vehicles, such as space exploration rovers and construction machinery, depends significantly on the interaction between the ground and the running gear since

ground deformations are induced by the vehicle's movement. In the terramechanics community, several types of equipment able to travel on soft terrain have been developed in recent decades. In this study, we focused on numerical modeling of trafficability for rigid wheels with grousers under arbitrary slippage. In the analyses, we adopted resistive force theory (RFT), which is a relatively new theory developed from conventional terramechanics. In addition to RFT-based analysis, we conducted numerical analysis using the discrete element method (DEM). The qualitative applicability of the RFT to terramechanics analysis is discussed by comparing it to the results of DEM.

Keywords: RFT, vehicle-terrain interaction, DEM, grouser, trafficability

Paper 63.

THE EFFICIENCY OF AGRICULTURAL TRACTORS CARRYING OUT FIELD CULTIVATIONS

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Abstract

The general configuration of many agricultural tractor designs used today was widely established by the 1960's and 1970's. In the following decades continual design developments have taken place in chassis, transmissions, tyres and tracks, ergonomics, hydraulic and electric power and control, improved safety, electronic data collection, electronic control and data transmission. In most countries with high average personal incomes, the average size, weight and power of tractors has continually increased during this period, but tractors based on designs from these earlier decades are still available and are being introduced as part of the mechanization process from animal to tractor draught operations, making much of the research work carried out in earlier decades still highly relevant.

The aim of this paper is to consider and evaluate the mechanics and the performance of agricultural tractors carrying out field cultivations, including: implement forces, force transfer between tractors and implements, real and virtual hitch-points, traction prediction and the determination of tractive efficiency, using two wheel drive or four wheel drive, and how a control or field management strategy can be implemented to maximize tractive efficiency. Data and examples are presented that support the analysis and evaluation that is carried out in the context of agricultural tractors carrying out cultivations. There is poor availability of modern tractor field performance data in the public domain and aspects such as the dynamic variation of weight transfer and weight addition from ground working implements to tractors are not fully documented or evaluated in published research. Recent developments in field management, such as controlled traffic farming (CTF) and the system of rice intensification (SRI), which can improve the efficiency of energy use in field operations, are also briefly discussed.

Keywords: Tractor Mechanics, Implement Forces, Traction Prediction, Tractive Efficiency, Traction Control, Field Management

Paper 80.

MAPPING OF SOIL TRAFFICABILITY IN NSUKKA, NIGERIA USING GPS AND GIS

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Abstract

Variability in soil properties and conditions have often limited mobility of agricultural field vehicles, resulting in energy and time wastage and poor soil working. Trafficability refers to the capability of a terrain to provide mobility conditions for a vehicle such as an agricultural tractor. In this study, trafficability is identified as a function of soil shear strength and soil cone index which in turn depend on soil moisture content.

Soil moisture contents based on a randomized complete block design were determined by gravimetric method and corresponding cone index were determined using cone penetrometer. Using an experimentally determined trafficability criterion which states that soil is not trafficable above 8.29% (d.b) moisture content due to excessive wheel slip and sinkage; points on the soil surface are judged trafficable or not based on the measured soil moisture contents and corresponding cone index. A GPS hand held device was used to take location measurements while GIS version 10.3 was used to produce a map of land portions trafficable within the particular time duration under investigation. Result of this work also reveals the days in the study area available for tractor and other field machinery operations. Data obtained and maps developed can be used in decision support systems for machinery management and in planning autonomous navigation for agricultural field vehicles.

Keywords: Soil Trafficability, Vehicle Mobility, Mapping, GPS, GIS

Paper 95.

MULTI-BODY DYNAMICS MODEL OF AN AGRICULTURAL, TRACKED, SKID STEERED VEHICLE TOWING A HEAVY, PASSIVE LOAD

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Abstract

This paper proposes a generalized model for a skid-steered tracked vehicle towing a passive load. The model couples existing formulations in the literature for the powertrain components and the vehicle-terrain interaction to capture the salient features of terrain trafficability and predicts the vehicle's response. This coupling is essential for making realistic predictions of the vehicle's mobility capabilities due to the power-load relationship at the engine output. The objective of the model is to maintain adequate fidelity for autonomous vehicle control while maintaining real-time prediction capability. The modeling techniques shown are built on a previous single body dynamics study; however, the model presented includes multi-body dynamics intended to increase fidelity for turning maneuvers. The model derivation is presented using Lagrange's method with simulation results based on parameters from a Caterpillar and AGCO MT865 tractors. These results simulate a vehicle pair and motivate the development of feedback motion planning

algorithms in a leader-follower architecture where vehicles can evaluate a neighbor's mobility conditions and change course to minimize the risk of immobilization.
Keywords: Multi-Body Dynamics, Tracked Vehicle, Passive Towed Load, Motion Planning

Paper 88.

6X6 TERRAIN ARTICULATED TRUCK: DRIVELINE - SUSPENSION COUPLED DYNAMICS AND ENERGY EFFICIENCY EVALUATION

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Abstract

This paper presents an analytical study of energy efficiency of a 6x6 terrain articulated truck in stochastic terrain conditions with an emphasis on the influence of coupled dynamics of the driveline system and A-frame suspension. As shown, the tire normal reactions and circumferential wheel forces are mutually dependent through driveline, suspension and tire-soil characteristics. Such interdependence of the forces impacts the wheel power distribution between the drive axles and, thus, tire slippages and truck slip power losses.

Based on the accomplished understanding of the coupled dynamics, this paper considers optimum wheel power distributions to provide minimum slip power losses of the truck in various operational modes. Utilizing the optimum wheel power distribution field, optimum characteristics of the interaxle differential for the transfer cases were computed. Computational simulations of the truck with the optimum differential characteristics proved a considerable increase of the truck energy efficiency in different stochastic terrain conditions.

Keywords: Multi-wheel Terrain Truck, Coupled System Dynamics, Energy Efficiency

Paper 89.

ROPS DESIGNS TO PROTECT OPERATORS DURING TRACTOR ROLLOVERS

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Abstract

Although it is well known that properly used Rollover Protective Structures (ROPS) can virtually prevent tractor rollover fatalities, the US still has hundreds of these fatalities per year. An estimated 1.6 million tractors are not equipped with ROPS. Many of these tractors do not have ROPS commercially available although they were originally designed to support a ROPS. Some tractors have foldable ROPS that are not used properly. Other ROPS, although meet appropriate performance standards, are not effective at eliminating continuous rolls.

To meet this need, a Computer-based ROPS Design Program (CRDP) was developed to quickly generate ROPS designs based on tractor weights and dimensions. The final products from the program are the ROPS design drawings with specifications that can be used to construct the ROPS. The constructed ROPS would then need to be tested to assure it meet the appropriate ROPS standard. The ROPS designed with the CRDP for the Allis Chalmer 5040 tractor successfully passed the SAE J2194 static longitudinal, transverse and vertical tests.
Many ROPS being sold on new tractors use a foldable ROPS design. These ROPS are only effective when the ROPS is raised and locked in place. But raising and lowering ROPS is a tedious and difficult task, and many times ROPS are left down during tractor operations. Fatality reports are showing that operators are dying when tractor upsets are occurring with the mounted ROPS folded down. A simple foldable ROPS lift assist was designed and tested to ease in the raising and lowering of ROPS; decreasing the raising torque from 90 Nm to less than 50 Nm, while also lowering the resisting torque to lower the ROPS.
Continuous rolling of a tractor during an overturn can also cause additional harm to the tractor operator. Increasing the ROPS height to a critical ROPS height (CRH) will prevent continuous rollovers on slopes, providing additional operator protection. A model to determine CRH based on off-road vehicle dimensions and center of gravity (CG) height was developed and evaluated. Although low CG height increases the lateral tip over angle (making the tractor more stable), it also requires a high CRH to prevent a continuous roll.
Keywords: ROPS, tractor rollover, foldable ROPS

Paper 104.

EVALUATION OF 4 YEARS RUTTING EXPERIMENTS

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Abstract
We have during the last 4 years worked in the program on vehicle testing concerning rutting experiments from different types of forestry machines on a soft ground (peaty soil).
Rut depth when driving straight lane was measured after each travel and cone resistance in the ground was measured after 1-5-10 travels. In 2011 year also wheel pressure in the depth of ground was measured down to 50 cm depth. All machines were weighted with and without 75 % load before the tests.
Machines with wheels, tracks and bogie tracks were tested, but only forwarder types were tested because they cause the deepest ruts in operation.
The tracked machines caused very small rutting when driving straight forward compared to wheeled vehicles. The tests are used to be a basis for making a new types of formula to estimate ground pressures for evaluation of possible reduced disturbance of soil in the forest.
Based on all these studies 5 new formulas for forestry vehicles are proposed for further discussions.
Key words: forestry, wheels, tracks, models

Paper 93.

GOOD VIBRATIONS

Gunnar Bygdén, Lage Burström and Iwan Wästerlund

Abstract

A four-wheeled forestry machine are quite jumpy to ride on in uneven terrain. To overcome that problem Nordic forestry are often with 8 wheels and often the wheels are placed in a bogie construction, which means all wheels are powered. To improve traction bogie tracks has been used both to get better grip but also to minimize soil damage. These tracks are often made of steel and could mean a rather bumpy travelling. The question is it really so?

Four paths were used three times, going upwards and downhill, with the variables wheels, bogie tracks, ± 15 ton load, tested on an eight-wheeled 20 tons forwarder both on driver seat and cabin floor. The vibrations Decreased and most with load. Thus bogie tracks from Olofsfors improve traction, decrease fuel consumption on soft ground and decrease vibrations.

Paper 103.

ANALYSIS AND EXPERIMENT OF STEADY-STATE STEERING OF TRACKED VEHICLE UNDER CONCENTRATED LOAD DISTRIBUTION

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Abstract

In order to study the steady-state steering performances of tracked vehicle under concentrated load distribution and to improve the simulating accuracy of tracked vehicle steering model, a formula about load distribution of tracked vehicle is carried out which takes tracked tension into consideration in this paper, and the influence of load distribution caused by track tension is analyzed, What's more, a new dynamic steering model is established which considers the relationship between shear stress and shear displacement.

According to force and torque equilibrium theory, the steering dynamic equations are established and solved by iterative algorithm. Taking the width of track and track tension into consideration, the influence of kinematical and dynamic character parameters caused by the load distribution is analyzed. The theoretic calculated results show that width of track makes little differences of traction and barking force. Considering the track tension, the slippage ratio is 20% ~30% larger, while the steering resistance is about 10% smaller. Experiment for checking the analysis is carried out.

In order to get the accurate data of steering test, experiment method for steering parameters of tracked vehicle is proposed with the combination of GPS-based system, NI test system as well as memory revolving speed and torque tester. Finally the data is analyzed and compared with the theoretic calculated results. The results show that the theoretic calculated results and the data fit well. An important method for performances test and theoretical model foundation is provided in this paper for steady-state steering of tracked vehicle.

Key words: Tracked vehicle, Steady-state steering, Track tension, Concentrated load distribution

Track 4. Mobile robotics for ground applications, planet exploration and other environments

Paper 5.

COMPARISON OF MACHINE LEARNING APPROACHES FOR SOIL EMBEDDING DETECTION OF PLANETARY EXPLORATION ROVERS

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Abstract

This paper analyzes the advantages and limitations of known machine learning approaches to cope with the problem of incipient rover embedding detection based on propioceptive signals. In particular, two supervised learning approaches (Support Vector Machines and Feed-forward Neural Networks) are compared to two unsupervised learning approaches (K-means and Self-Organizing Maps) in order to identify various degrees of slip (e.g. low slip, moderate slip, high slip). A real dataset collected by a single-wheel testbed available at MIT has been used to validate each strategy. The SVM algorithm achieves the best performance (accuracy >95 %). However, the SOM algorithm represents a better solution in terms of accuracy and the need of hand-labeled data for training the classifier (accuracy >84 %).

Keywords: Support Vector Machine (SVM), Feed-forward Neural Network (FF-NN), K-means, Self-Organizing Map (SOM), Mars Science Laboratory (MSL) rover

Paper 7.

Measurement of the torque required to excavate the regolith and gravels on the lunar surface using a small scoop

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Abstract

Chinese missions to the moon are planned to sample the regolith and return it to the earth. Micro-scale excavators may be good candidates for these missions, as they would significantly reduce the launch mass. Thus, it is necessary to research the interaction between the scoop and the regolith being sampled. We present the development of a simple apparatus to measure excavation torque. All tests were conducted using TYII-2 regolith simulant with gravels. The test results show that, under loose regolith conditions, the penetrating angle and the bulk density had a great influence on the excavation torque, while the rotating speed had little effect. However, when the bulk density was compact, the rotating speed did influence the excavation torque. The excavation torque increased sharply when the scoop encountered the gravels; actually some parameters will influence the value of the torque such as the diameter, quantity, position, and inbuilt depth of the gravels.

When the excavation torque sharply increases, the operation should be immediately stopped and checked.
Keyword: excavation torque; lunar surface; gravels; small scoop; regolith

Paper 6.

RESEARCH ON VERTICAL IMPACT OF SPACE LANDER FOOTPAD

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Abstract
The interaction between footpad and planetary soil is of great importance due to the strong impact produced during the brief period of the space lander touchdown, which will affect the normal operation of the lander inner precision instrument. In this paper, the vertical impact tests of the space lander footpad were performed using a self-designed test system on six different soils (four types of planetary simulant regolith, a kind of Gobi sand and normal dry quartz sand) under two different bulk density condition (natural and compact), with different impact heights (600, 800, 1000 mm) and footpad diameters (60, 80, 100, 120, 140 mm), and the impact depth, the peak acceleration of the footpad were collected. Experimental results are shown with figures and tables, and analyzed to evaluate the impact characteristic of the test soils. The effect of impact height and footpad diameter on impact depth and the peak acceleration are analyzed under different soil. The experimental results and conclusions are useful for optimizing footpad–soil impact interaction mechanics model.
Keywords: Footpad, Impact depth, Peak acceleration, Planetary simulant regolith, Model test

Paper 33.

EXPERIMENTAL EVALUATION OF THE SCALE MODEL METHOD TO SIMULATE LUNAR VEHICLE DYNAMICS

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Abstract
As compared to driving on Earth, the presence of lower gravity and uneven terrain on planetary bodies makes high speed driving difficult. In order to maintain ground contact and control, vehicles need to be designed with special attention to dynamic response. The challenge of maintaining control on the Moon was evident during high speed operations of the Lunar Roving Vehicle (LRV) on Apollo 16, as at one point all four tires were off the ground; this event has been referred to as the "Lunar Grand Prix." Ultimately, computer simulation should be used to examine these phenomena during the vehicle design process; however, experimental techniques are required for validation and the elucidation of key issues. The objectives of this study were to evaluate the methodology for developing a scale model of a lunar vehicle using similitude relationships and to

test how vehicle configuration, six or eight wheel pods, and local tire compliance, soft or stiff, affect the vehicle's dynamic performance. Each wheel pod was a self-contained running gear attached to the chassis through suspension elements. The Lunar Electric Rover (LER), a human driven vehicle with a pressurized cabin, was selected as an example for which a scale model was built. The scaled vehicle was driven over an obstacle and the dynamic response was observed and then scaled to represent the full-size vehicle in lunar gravity. Loss of ground contact, in terms of vehicle travel distance with tires off the ground, was examined. As expected, local tire compliance allowed ground contact to be maintained over a greater distance. However, switching from a six-pod configuration to an eight-pod configuration, with reduced suspension stiffness, had a negative effect on ground contact. It is hypothesized that this was due to the increased number or frequency of impacts. The development and testing of this scale model provided practical lessons for future low-gravity vehicle development.

Keywords: Terrain Mobility, Moon, Scaling, Roving Vehicle, Mars, Low Gravity

Paper 38.

UTOPUS TRACTION TECHNOLOGY: A NEW METHOD FOR PLANETARY EXPLORATION OF STEEP AND DIFFICULT TERRAIN

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Abstract

After several successful missions to explore the surface of Mars with wheel-based rovers, the exploration of difficult and steep terrain has gained prominence in the field of planetary exploration, calling for new methods of vehicle locomotion which offer stability in steep and difficult terrain. UTOPUS traction technology offers a new method of locomotion which abandons the wheel paradigm for a two-phased anchoring and de-anchoring technique by driving removable crampons into the ground. In agriculture it minimizes soil compaction, reduces energy consumption, and produces a draft force similar to much heavier wheel-based tractors.

Here we investigate whether the inherent stability of locomotion based on removable crampons allows exploration of steep and difficult terrain. We present experimental results from climbing and descending a mound of heterogeneous dust, sand, and granular material at the critical angle of repose, at an inclination of 25–40 degrees. The UTOPUS vehicle repeatedly climbed and descended the mound safely. An initial problem when reaching the top of the mound was solved by rebalancing the vehicle. Occasional failure occurred when the vehicle had strong lateral inclination, or on patches of very loose ground, suggesting the need for some design changes to the current model.

Keywords: crampon-based traction, inching locomotion, push-pull locomotion, planetary exploration, steep terrain exploration

Paper 100.

INERTIA-BASED PROPELLED UNDERWATER ROBOTIC VEHICLES DYMANICS MODELING AND PERFORMANCE

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Abstract

The paper addresses dynamics modeling and performance of underwater inertia-based propelled robotic vehicles. They are both variable mass and configuration systems. They are energy efficient, since they consume only energy for controlling water amount in water tanks and motion of movable masses supporting their rotations. They may be thus cheap, durable and reliable vehicles for underwater missions. They serve for sea bottom exploration, military purposes or elimination of pollutions from sea waters. Variety of mission related control goals may be formulated in constraint equation forms, so the vehicles are constrained systems. There are other engineering systems which change their mass or configuration when they move, e.g. ground and space mobile robots and manipulators. The topic addressed in the paper is thus related to a quite wide class of constrained variable mass or configuration systems. The paper presents an analytical dynamics modeling framework for robotic systems whose novelty is that both holonomic and nonholonomic constraints can be merged into variable mass system dynamics and final motion equations are free of constraint reaction forces so they can be used directly to control design. An underwater inertia-based propelled robotic vehicle model dynamics and performance illustrate the theoretical development presented in the paper. The paper contribution is presentation of a unified approach to constrained variable mass or configuration systems modeling and enabling introducing analytical dynamics methods to nonlinear control problems.

Keywords: underwater robotic vehicles, variable mass system dynamics, constrained systems

Paper 75.

DEVELOPMENT OF AN UNMANNED GROUND VEHICLE FOR COASTAL MONITORING

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Abstract

The development of oil and gas resources of the Russian shelf is characterized by high degree of risk. Recently, one of the most efficient means for hydrodynamic measurements, determination of speed and sizes of drifting ice and evaluation of coastal hazards is remote sensing by means of radars. The purpose of the project is the creation of a new unmanned ground vehicle (UGV) for radar transportation. Consequently, the main objective of the project is creation of vehicle's chassis with high level of mobility in coastline conditions. Special modular structure with the possibility of re-equipping by different types of mover (wheeled, tracked, rotary-screw) has been chosen for

operating in severe coastline conditions. The parameters of the UGV have been determined on the base of vehicle-terrain interaction modeling and designing calculations: traction and speed calculation, evaluation of turnover, geometric trafficability, stability, amphibious properties. Currently, field testing mobility of an experimental prototype of the vehicle is conducted. Tests results will allow revealing the shortcomings of development and identifying ways of optimization of the structure and functioning modes of the UGV. The venue for practicing different variants of movement of the vehicle such as a remote control mode, autonomous bypass of obstacles, motion along a predetermined routes according to georeferencing will be the coast of Sakhalin Island. Thus, the paper reflects the approach to the creation of a new type of mobile systems for heavy duty of shorelines.

Keywords: Mobility, Unmanned Ground Vehicle, UGV, Environmental Monitoring, Coastline Conditions

Paper 64.

ONLINE ESTIMATION OF WHEEL SINKAGE AND SLIPPAGE USING A TOF CAMERA ON LOOSE SOIL

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Abstract

A prominent concern with wheeled mobile robots that travel on loose and rough terrain is that they may get stuck in soil and experience a sharp increase in wheel sinkage and slippage. Various analyses of wheel–soil interaction mechanics have been conducted to study this issue. Several studies have been carried out for the online estimation of wheel sinkage and slippage using image processing. However, these image-based online estimation methods are greatly affected by target environment conditions such as lighting and reflectance. In contrast, a ranging sensor that provides three-dimensional point cloud data performs better at estimation even in an uncertain environment. This study proposes an online sinkage/slippage estimation method using a time-of-flight (ToF) camera that can measure the distance from a target object. Sinkage/slippage estimation of the traveling wheel on loose soil is experimentally demonstrated by attaching the ToF camera on the side of the wheel. The experimental result showed that most of the wheel sinkage could be estimated to within ±*1 mm* absolute error using point cloud data; traveling velocity and slip ratio of the wheel could be estimated for a resolution of less than *1 mm/s* and less than *3.9%* absolute error, respectively.

Keywords: Online estimation, Sinkage, Slippage, Lunar/planetary exploration rover

Oral Presentation 14.

See PDF slides in the Conference Proceedings

NOVEL OBSERVATION METHOD OF THE UNMANNED GROUND VEHICLE WITH ARTICULATED SUSPENSION WHEEL FORCE BASED ON THE STRAIN MEASUREMENT OF THE ROCKER ARM

Zhang Xing,

Beijing Institute of Technology

Oral Presentation 53.
See PDF slides in the Conference Proceedings
HIGH WHEEL SLIP SINKAGE AND DRAWBAR PULL IN DEFORMABLE SOIL: MARS EXPLORATION ROVER WHEEL MOBILITY
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Paper 27.
EVALUATION AND OPTIMIZATION OF A 6X6 INDEPENDENT SUSPENSION VEHICLE FOR SMALL SCALE ROBOTIC DOZING
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Abstract
There is interest from industry in exploring alternatives to tracked vehicles for small scale dozing operations because of the limitations of the platform. One alternative is a six-wheeled vehicle with independent drives and active suspension. This alternative has higher mobility and controllability than tracked vehicles, but generally produces less traction. One way to close the gap in traction is to implement an adjustable suspension for all or some of the six wheels. This paper provides a study of implementing an adjustable suspension to a six-wheeled pivot-arm suspension robotic vehicle. First, a simplified version of the robot is constructed in CAD and imported into SimMechanics. Once in the SimMechanics interface, the user has full control over the vehicles properties, the operational environment, and can easily collect pertinent data. This study presents the results of adjustable suspension sensitivity analysis. The suspension properties of the vehicle are varied in the simulation and validated with physical testing. Following validation, an optimization program is written in MatLab, which easily interacts with SimMechanics, such that the optimal suspension properties are determined for different operational scenarios. Finally, case studies are presented where the optimal suspension properties are determined for the robotics platform performing dozing operations. This paper presents a suspension analysis and simulation for the vehicle and provides an overview of many ways which this simulation could be expanded.
Keywords: Vehicle Simulation, SimMechanics, Suspension, 6x6 Robotic Vehicle

Track 5. Military ground vehicle robotics

Paper 91.
THE NEXT GENERATION NATO REFERENCE MOBILITY MODEL DEVELOPMENT
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Abstract
The NATO Reference Mobility Model (NRMM) is a simulation tool aimed at predicting the capability of a vehicle to move over specified terrain conditions. NRMM was developed and validated by the U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC) and Engineer Research and Development Center (ERDC) in the 1960s and '70s, and has been revised and updated through the years, resulting in the most recent version, NRMM v2.8.2b. It was originally used to facilitate comparison between vehicle design candidates by assessing the mobility of existing vehicles under specific terrain scenarios, but has subsequently and most recently found expanded use in support of complex decision analyses associated with vehicle acquisition and operational planning support. This paper summarizes recent efforts initiated under a NATO Exploratory Team (ET) and its follow-on Research Technical Group (RTG) to upgrade this key modeling and simulation tool and the planned path forward toward implementing the recommendations of that team.
Keywords: NATO**,** NRMM, mobility model, operational planning, multibody dynamics

Paper 35.

Cooperative Teaming and Mobility in Autonomy-Enabled Convoys

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Abstract
This paper presents an overview of cooperative teaming and mobility as they pertain to military autonomy-enabled convoy operations. In particular, we discuss the "cooperative trust game" and its application cooperative coalition formation in centralized and decentralized convoys. We also discuss novel work in calculating support-surface mobility estimates and how they can be leveraged to improve overall convoy mobility. Finally, we provide an overview of the state-of-the-art in military autonomous convoy technology, and how teaming and mobility theories can drive the innovation for the next generation of unmanned ground vehicle systems.
Keywords: convoy; autonomy-enabled; teaming; mobility; trust; military; unmanned; all-terrain wheeled vehicles

Paper 61.

The Identification and Demonstration of Plausible Cyber Threats against Military Vehicle Operations from Software Defined Radio.

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Abstract
As automotive (vehicular) platforms develop and evolve to embed more software (for a variety of applications including sensing, control, infotainment, navigation, connectivity, diagnostics and vehicle health monitoring, passenger safety, and driver assistance), more interfaces to external components are introduced. This brings with it a heightened risk to security of such communications leading to deliberate manipulation (attacks) being launched to intercept,

manipulate and violate vehicular operations. Heavy vehicles, deployed for military and national security purposes, are increasingly connected, with autonomous control features, and with sensors on-board, and hence are at a particular risk of disruption and damage. Given both the sensitivity of missions that such vehicles embark on and the nature of malicious activity targeting them, cyber security threats can no longer be ignored.

The aim of this paper is to explore the security of wireless communication systems when exposed to threats generated by Software Defined Radios (SDR). The research is aimed at exploring this vulnerability due to the rapidly decreasing cost and the lowering of skill barriers to launch advanced Electronic Warfare (EW) attacks on wireless communication systems.

This paper draws on existing literature and threat modelling, and includes some early experimentation. Systematic threat characterisation provides for an appreciation of the design, development and modelling of Cyber security challenges for heavy vehicles in the military domain.

Keywords: Cyber Security, Military Vehicles, Communication Security, Threat Modelling, Software Defined Radio

Paper 90.

ANALYSIS OF VEHICLE PLATOON MOVEMENT DURING MILITARY EXERCISES

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Abstract

In this study a method that identifies off-road vehicle column movement was developed and evaluated. Previous studies have revealed that multiple vehicle passes produce detrimental soil and terrain impacts. Identifying the frequency and location of this type of multi-pass impact during military maneuvers is difficult. This method will aid in the assessment of environmental impacts of off-road military vehicles by allowing land managers to characterize vehicle movement patterns, especially column movement, at military training installations during maneuvers. Column movement is a type of platoon movement that occurs when vehicles are traveling one behind the other. GPS units mounted on military vehicles collected on and off-road tracking data during a reconnaissance maneuver at Fort Lewis Military Installation, Washington. A sample set of data utilizing a Stryker platoon of four vehicles was used to evaluate this method. The GPS coordinates, speed, and direction of travel of each vehicle was collected at each second. A criteria to identify platoon column movement was developed based on vehicle proximity, speed and direction of travel. Platoon column movement was correctly identified and documented. The results of this study show that the method can correctly identify off-road column movement for the purpose of evaluating the multi-pass impacts on the terrain. Using this approach the vehicle movement patterns associated with platoon movement (i.e. vehicle speeds and spacing) can be evaluated.

Keywords: Platoon, multi-pass, column, military vehicle, GPS, GIS

Written Only Paper 101.

STATISTICAL ANALYSIS ON LOADING OF TRACKED VEHICLE IN STEERING PROCESS

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Abstract

The paper describes a method for predicting the steering load of tracked vehicle in stochastic environment Steering condition is taken for example. On the basis of the relationship between kinematical and dynamic characteristic of tracked vehicles in steering process, A driving condition-vehicle-environment model and calculation process of the model are built. Statistic road environment and driving conditions of a certain vehicle are given in this paper. A superseded model of steering load is built by using response surface. Based on this superseded model , Effects of statistical vehicle velocity， friction coefficient and motion resistance efficient on traction and braking torques by means of Monte Carlo are analyzed. Testing systems are set up to test the load in steering process and load of a certain tracked vehicle is tested using the testing system. Finally, testing results are statistically analyzed. The accordance of the computing results and testing result indicates reasonability and validity of the method, which puts forward a new way to calculate the driving loading in complex uncertain environment.

Keywords: Tracked Vehicle, Statistical Characteristics, Steering Motion, Response Surface Model

Written Only Paper 102.

RESEARCH ON PARAMETERS MODIFICATION FOR HIGH MOBILITY TRACKED VEHICLE DYNAMIC MODEL BACED ON MULTI-OBJECTIVE GENETIC ALGORITHMS

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Abstract

A method of model parameters modification is researched to improve the accuracy of high mobility tracked vehicle dynamics model simulation results. Firstly, the dynamics model of high mobility tracked vehicle is established, and then the cement road and the gravel road are selected as the road surface conditions of model parameters modification, according to statistical regularity of the vehicle's driving conditions. The simulation results of dynamic model without parameter modification are compared and analyzed, with the corresponding real vehicle test results under the same driving conditions; in addition, the expression of model modification objective function is given. The modification parameters which influence objective function strongly are screened by using orthogonal experiment design method.

The radial basis function neural network approximation models of parameters to objective functions are built to solve the problem of the large calculation quantity and inefficiency of parameters modification. By analyzing the change rule between the objective functions with

parameters, the parameters modification is carried out simultaneously at two driving conditions by using the second Non-Dominated Sorting Genetic Algorithm (NSGA-Ⅱ), which is one type of multi-objective genetic algorithms, and the final results are obtained at last. The results show that the accuracy of high mobility tracked vehicle dynamic model simulation results is effectively improved and the availability of method of dynamic model parameters modification is validated.
Keywords: High mobility tracked vehicle, Parameters modification, Multi-objective genetic algorithms, Radial basis function neural network

Track 6. Innovative system designs for terrain and road vehicle applications

Paper 26.

MULTI-TRACK DRIVETRAIN AND SUSPENSION FOR HYBRID AND ELECTRIC ALL-TERRAIN VEHICLES

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Abstract
This paper is focused on the alternative multi-track drivetrain construction for the electric all-terrain vehicle and its performance investigation on a rough terrain. An extensive experience of electronic stability control technology for the wheeled vehicles could be applied to the innovative designs of multi-track off-the-road vehicle too. The advanced torque control algorithms implementation in a computer-based motion control system is a key factor to develop a new family of designs of electric-driven vehicles with non-steerable track modules driven by individual electric motors instead of rolling tires. The considerable growth of off-the-road performance could be achieved by increasing the effective diameter of the virtual wheel implemented by a track module of a certain shape. The terrain pressure reduction could be referred to as equivalent of the virtual tire pressure diminution. This paper attempts to investigate factors of suspension and drivetrain construction design for the said concept. The experimental study of the off-the-road performance of the prototype multi-track electric-driven amphibious all-terrain vehicle based on a "large diameter and low pressure virtual wheel" concept shows the practical effectiveness of the scheme.
Keywords: Multi-track, Tracked Vehicle, Off-road, Electric Vehicle

Paper 22.

ELECTRONIC STABILITY CONTROL TESTING OF MILITARY WHEELED VEHICLES

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Abstract
Electronic stability control (ESC) has recently been applied to several prototype military wheeled vehicles that underwent testing at the U.S. Army Aberdeen Test Center. Though not in production

on military vehicles yet, standardized test practices need to be established for the classes of military wheeled vehicles that would benefit from ESC in the future, including light, medium, and heavy vehicles. The Federal Motor Vehicle Safety Standard (FMVSS) 126, Electronic Stability Control Systems, was established as a standardized test of ESC effectiveness for passenger vehicles and light trucks, and utilizes a sine with dwell maneuver. Beginning in August 2017, all new 3-axle commercial truck tractors will be required to be equipped with ESC that includes roll and yaw stability functions. FMVSS 136, Electronic Stability Control Systems for Heavy Trucks, will be used to test ESC roll stability effectiveness, but not yaw stability effectiveness, using a J-turn maneuver. The challenge facing the military test and evaluation community is that the broad range of vehicle classes utilized by the military are susceptible to yaw and roll instability. This paper summarizes recent test findings of military vehicles and proposes guidance for future test methods.
Keywords: electronic stability control, tactical, military, test

Paper 31.

DESIGN AND SIMULATION OF A POD-BASED MOBILITY CONCEPT

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Abstract
This work presents a design and simulation-based validation of a pod-based mobility concept. The design of independent pods that can be attached to arbitrary heavy objects for movement and positioning is presented. The pods are free to rotate about a vertical axis and include two independently-driven wheels situated in an Active Split Offset Castor (ASOC) arrangement. The ASOC architecture allows the achievement of approximately omnidirectional motion with conventional wheels and minimal scrubbing, which makes the design suited to a range of terrains. Furthermore, each of the wheels in the design includes its own independent suspension, which also facilitates operation of the concept in unpaved environments. Once the pods are attached to their target, it is proposed that the object can then be tele-operated with minimal calibration. Specifically, feedback of pod speeds and angular displacements, as well as object heading and angular velocity, is employed to identify the orientation of the pods with respect to one another via a least-squares estimation technique. These feedback signals then also allow the object to be maneuvered by a remote driver, even in the presence of disturbances and wheel slip. The mobility concept is demonstrated via a dynamic simulation model that was constructed based on data from one instantiation of a vehicle that employs a similar pod-based architecture. The vehicle simulation is implemented in Simulink using the Simscape physical modeling extension.
Keywords: Terrain Mobility, Omnidirectional Mobility, Ground Robotics

Paper 54.

SOIL EMBEDDING AVOIDANCE FOR PLANETARY EXPLORATION ROVERS

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Abstract

This paper contributes a new and novel layer, embedding avoidance, to the traditional navigation control architecture of a planetary exploration rover. In particular, the aim of this new layer is to both maximize traction and minimize risk of entrapment. This layer is composed of a soil embedding detection algorithm (described in another paper published in this conference) and a traction control strategy. Simulation results demonstrate the suitability of the proposed embedding avoidance layer in realistic challenging conditions. Additionally, several traction control algorithms show the importance of considering both the slip compensation and the kinematic incompatibility problems within the same control strategy. After those experiments the following conclusions are drawn: (i) the proposed traction controllers mean simpler approaches than traditional torque-based optimal controllers, and they demonstrate a proper balance between slip-compensation (lowest mean slip) and reduction of wheels fighting effect (less aggressive control actions); (iii) when no traction control is considered (current solution in NASA's rovers), simulation results show the rover becomes stuck in one of the proposed scenarios.

Keywords: Traction control, kinematic incompatibility, slip, K-REX rover, ANVEL simulator

Paper 74.

TIRE TO TRACK TRASFORMIG SYSTEM (4TS)

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Abstract

Mattracks has designed and tested the *Tire to Track Transforming System (4TS)* enabling a vehicle to have both tracks and tires incorporated simultaneously. An operator switches between modes with the press of a button. Until the 4TS, Mattracks' conversion systems would require one to change the tires to tracks as one would change a tire; the 4TS is as simple as shifting from 2WD to 4WD. This technology enables a vehicle to have all of the advantages of wheels (durability, efficiency, high speeds) and tracks (flotation, traction, overall increased mobility) The initial prototype shows the 4TS transforms from tires to tracks in less than one minute, and transforms back from tracks to tires in less than one minute. Tests were performed on both the tire and track mode. The vehicle that was used as the test platform was a 2012 Polaris Ranger. Each test was also performed on the Ranger with stock tires as a base line for comparison. The data collected were drawbar power, rolling resistance, gradeability, side hill mobility, vertical step, double lane change stability, and top speed. The 4TS system exceeded the performance of the baseline stock vehicle in drawbar power and gradeability. The base-line vehicle did reach a higher speed, but this is in part due to the lighter overall weight of the stock unit as compared to the added weight the 4TS system adds. The difference in high speed would be lessened with further development into the 4TS to reduce the overall weight of the system. The goal of the 4TS is to scale up to larger

vehicles, and the added weight would become a lower percentage of the overall system weight and the top speed differences would be negligible. All other tests showed comparable results between the 4TS system and the baseline stock vehicle.
Keywords: Terrain Mobility, Tracked Vehicle

Paper 51.

HEAVY TRANSPORT SYSTEMS WITH ACTIVE TRANSMISSION

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Abstract

In most cases, transportation in areas with snowy and swampy terrain are possible only by road, due to the lack of railways, paved roads, sea routes, and so on. For the transportation of heavy loads over 20 tons requires a vehicle off-road and special vehicles. The aim is to design solutions to ensure the patency of multi heavy vehicles and road trains at the expense of all-wheel drive with power distribution organization for the driving axles and the use of special types of alternative propulsion.

The paper presents the Soviet, Russian and international developments in the field of off-road vehicles. For transportation are encouraged to apply active road train consisting of a tractor (AWD or not AWD) and trailer units with driving wheels. The advantages of the use of the active road trains are improving passability and average speeds of more than 30%, fuel-consumption reduction up to 20%, reduction of damaging effects on the soil to 40% by the off-road transportation of bulky heavy loads over 20 tons.

The example of development of the 14×14 active road train with the hydraulic drive of wheels of the trailer unit (a semitrailer) with a carrying capacity of 50 tons is presented.

The concept of heavy-load transport systems with the active drive of wheels with a carrying capacity from 20 to 58 tons is also provided.

Keywords: Active Road Train, Hydrostatic Transmission, Off-Road Vehicles, Passability

Paper 69.

MOBILITY VS. ENERGY EFFICIENCY OF A 4X4 HYBRID-ELECTRIC VEHICLE WITH AN ACTIVE DRIVELINE SYSTEM

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Abstract

This paper discusses an analysis of a 4x4 hybrid-electric off-road vehicle (HEV) with an active driveline system that is capable of controlling the power distribution between the front and rear wheels.

The paper presents a mathematical model of the 4x4 HEV vehicle and its active driveline system, including a hybrid-electric power transmitting unit (HE-PTU) that is functionally integrated in the vehicle HE powertrain. The HE-PTU's gear ratio is controllable and, thus, control of HE-PTU can

provide a different power split between the front and rear wheels. A detailed mathematical analysis of the power split between the wheels was conducted for the criteria of (i) vehicle energy efficiency and (ii) vehicle mobility in stochastic terrain conditions. As mathematically proven, the wheel power distribution should be different to either maximize vehicle mobility or minimize energy consumption.

Computational results illustrate the analytical findings by presenting a switching controller that can change the operational mode of the vehicle from the mobility mode to energy efficiency mode depending on a motion situation.

Keywords: Mobility, Energy Efficiency, Hybrid-Electric Power Transmitting Unit

Paper 73.

AN INTRODUCTION TO DROVE: DATABASE RECORDS FOR OFF-ROAD VEHICLE ENVIRONMENTS

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Abstract

This paper presents the results from a multi-year research program to create the Database Records for Off-road Vehicle Environments (DROVE), which is a consolidated database of test results conducted on coarse- and fine-grained soils. Published results were assembled from several technical reports for laboratory and field tests into a database (DROVE) and used to assess soil/tire interaction of off-road vehicles. The first edition of the database (DROVE 1.0) includes thousands of records from the existing archives of laboratory and field tests of wheels operating in loose sand and plastic clay, respectively. Sand and clay results were reduced from several technical reports. DROVE includes results from tests performed by wheels of different diameters, widths, heights, and inflation pressures, operating under varying loading conditions. The DROVE structure is assembled to include various traction performance parameters such as drawbar pull, torque, traction, motion resistance, sinkage, and wheel slip. DROVE is still under further development by combining test results obtained from other sources. DROVE provides the mobility community with a resource to evaluate existing soil mobility algorithms and also, to develop improved algorithms to assess performance of various wheel designs. The authors linked DROVE to the algorithms currently defined in the Vehicle Terrain Interface (VTI) for mobility modeling of wheeled vehicles. Comparison of the predicted versus measured performance parameters are presented for these varying soil types. This study provides insight into what published data exists, what are the bounds on the data, and how the data matches to the existing algorithms in models such as VTI.

Keywords: Off-Road Mobility; Database Records for Off-road Vehicle Environments (DROVE); Drawbar Pull; Motion Resistance; Sinkage; Vehicle Terrain Interaction (VTI)

Oral Presentation 76.
See PDF slides in the Conference Proceedings

LAB-BASED DEVELOPMENT AND VALIDATION OF ADAS

Kunal Patil
dSPACE Inc

Paper 87.

GROUND VEHICLE DYNAMIC STABILITY ANALYSIS WITH RANKING OF STABILIZING CONTROL LAWS USING THE SIGN STRUCTURE OF ITS STABILITY DERIVATIVES AND CLOSED LOOP DYNAMICS

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Abstract
This paper highlights the importance of the signs of the stability derivatives used in the linear vehicle dynamics models in automotive control applications. Using the recently introduced concept of Qualitative Alignment Image (QAI) of a matrix, the paper recalls the new conditions for Qualitative (Sign) Instability, Qualitative (Sign) Stability and Magnitude Dependent Stability/Instability of a real matrix. These conditions underscore the importance of the sign structure of a real matrix in its stability assessment. This paper then applies those conditions to the linear vehicle dynamic models in automotive control. This application results in valuable insight into the effect the stability derivatives have on the overall stability of the vehicle dynamics without resorting to complicated eigenvalue analysis thereby saving significant computational effort in the stability assessment of automobile dynamics. In addition, the proposed method can be used to rank various stabilizing feedback control laws from stability robustness point of view. This type of ranking has profound implications on the selection of different actuators based on their contributions to the overall stability of the closed loop dynamics of the vehicle. The proposed method is equally applicable to all types of vehicles including off-road and all-terrain vehicles.
Keywords: Real Parameter Variation; Structured Uncertainty; Vehicle Dynamics; All-Terrain Vehicles; Stability Derivatives

Paper 105.

AN ANALYSIS OF A WHEEL SPEED SENSOR SIGNAL FOR AGILE TIRE SLIPPAGE DYNAMICS

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Abstract
Cyber-physical systems integrate computational and physical components in control of physical, mechatronic systems.
These systems incorporate embedded control components which depend on sensor data to interface with the physical world. In this paper, an innovative design concept of a wheel rotational kinematics sensor is analyzed in application to vehicle agile dynamics. A cyber-functional model of the sensor includes its mechanical, electrical, and magnetic elements to produce a continuous signal of the wheel rotation speed. The magnetic field characteristic of the sensor is analyzed in regards to its agile signal generation.
The sensor, a new type of Hall-Effect sensor, is suitable for the fast measurement of wheel rotation speed needed for control of vehicle mobility through estimation of the tire slippage. A computer simulation of the sensor's performance demonstrates its fast response in providing wheel speed measurements. This is demonstrated in a one-corner model of a vehicle, providing awareness of the ground condition as the tire moves through changes in surface conditions.
Keywords: New Sensor, Cyber-signal, Agile Tire Slippage