ARC Cluster of Activities at University of Alabama at Birmingham

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The US Military is undergoing a rapid transformation, in response to changing global security environment and reemerging challenges from adversaries developing new cyber, electronic, and conventional capabilities. This creates a need for rapid modernization of key capabilities, including advanced autonomous systems. In particular, the development of military vehicles focused on radically enhanced mobility where ability to traverse diverse off-road terrain, with varied slopes and elevations under various adverse environmental conditions would enable future U.S. ground forces to tackle varied and unpredictable combat situations. The seven exploratory and translational projects that have begun at UAB as part of the newly established Autonomous Vehicle Mobility Institute (AVMI) development group are focused on research of novel methods, approaches, and enabling technologies to improve the state of the art in a number of areas directly related to autonomous vehicle mobility. Each of these projects were developed such that their work products complement or contribute each other and will together will form the basis of advanced technology demonstrations on AVMI's Simulator of Autonomous Mobility. These projects will be presented so as to inform new collaborative and synergistic opportunities with other ongoing and/or future ARC efforts.

A Hybrid Controller with Observation And Decision Making for Autonomous Mobility Control System (Thrust Area 1)

This research study develops fundamentals for an autonomous mobility control system (AMCS) with three components: a) an adjustable mobility control algorithm that is able to effectively operate in different severe terrains within an appropriate response time that is close to the tire-soil longitudinal relaxation time constant and, thus, to prevent the tire spinning, b) observation algorithms that are able to provide on-line states of the single-wheel module's normal, longitudinal, and rotational dynamics, and c) an Artificial Intelligence (AI) - based learning component that is able to learn from the observers' data in real-time and improve/mature the mobility control parameters. The autonomous mobility control system that functionally integrates the above-listed three components will be mathematically designed and demonstrated in computational simulations for a single-wheel module that is a simulation model of a quarter of a 4x4 vehicle with parameters of FED-Alpha including a single wheel-tire system, propulsion system (electric motor and driveline), brake, suspension, and steering.

Unique Approaches to Utilization of Proprioceptive and Exteroceptive Sensor Systems for Autonomous Agile Mobility (Thrust Area 1)

This project seeks to develop and define new fundamental approaches and provide recommendations for the utilization of proprioceptive and exteroceptive sensor system for autonomous agile mobility. In contrast to the existing modern electronic vehicle control systems with "reactive control", the response time in the proposed "agile control" is required to be less than the vehicle's tire relaxation time. To facilitate the development of this new vehicle mobility paradigm, a similar paradigm shift in wheel speed sensor technology is required to provide feedback to the vehicle's control system with an unprecedented level of temporal and spatial accuracy. Another challenge for autonomous vehicle mobility is the detection and classification of moving objects, where the data representation plays a critical role for better accuracy and performance. The innovative sensor fusion and in situ (i.e., edge) reservoir computing will enable faster computation, sensor information extraction, and intelligent decision making.

Instant Tire Slippage Characterization with Digital Image Correlation for Autonomous Mobility Applications (Thrust Area 3)

The project is aimed at conducting the basic research to uniquely define parameters ('cause') which are measurable in real-time and which lead to tire slippage ('effect'). Specifically, this project belongs to the (i) terra-mechanics area of detecting dynamic changes in the tire-soil interaction, and (ii) in-tire sensing for its use in AI-based algorithm design for autonomous vehicle control. Approach of this project is broken into the following four parts: (1) Creation of databases for traction characteristics, slippage, and instantaneous compression based rolling radius for different tires on different soils, (2) Digital image correlation of strain and deformation fields of tire outer surfaces in agile dynamic tire tests to wheel torque, the normal load and the road velocity, (3) Finite element simulation of agile dynamic tire tests, correlation of FE strain and deformation fields to those of measured in physical test, and (4) Establishment of a functional relationship between strain field on the internal surfaces of tire with slip behavior. Approaches (1) and (2) are continuation efforts of previous ARC project efforts.

Autonomous Vehicle Interactive Dynamics and Morphing with Mobility & Maneuver Self-Learning-and-Improvement (Thrust Area 1)

Dynamic couplings in vehicle systems require new approaches to de-couple and establish interactive dynamics of the systems. This project shall study two types of dynamical couplings: couplings of the physical components of vehicle cyber-physical systems and couplings of physical systems and information processes in hybrid and electric vehicles. A method will be designed to decouple dynamical actions of a vehicle's driveline from its steering to complement vehicle mobility and maneuver. The method will be applied to two vehicle configuration cases: a 4x4 FED-Alpha and an autonomous ground vehicle (AGV) composed of a flexible manipulator and rigid body. An optimization problem will be formulated and solved to determine the optimal split of the summation of the circumferential wheel forces among the 4x4's individual wheels in a way that maximize mobility and/or maneuver of the vehicle. For the AGV, the morphing of the configuration by dynamically reconfiguring the manipulator is proposed to manage instant magnitudes of the moments of inertia of the vehicle and, thus, control the tire-ground forces for the purpose of improving navigation, mobility, and maneuver. A system for autonomous mobility & maneuver self-learning and improvement will communicate with the vehicle's perception, navigation and planning system and an RL-based self-learning algorithm of the mobility and maneuver estimation/observation system to establish safe perimeters when moving along a given trajectory path.

Assessment and Virtualization of Tire-Soft Soil Interactions for Real-Time Evaluation and Control of Autonomous Vehicle Mobility (Thrust Area 3)

Current methods for modelling and simulating autonomous vehicle-terrain interactions are insufficient for Soldier training and mission rehearsal. The terramechanics approach is tedious and does not scale efficiently or effectively, leaving a time lag for vehicle response in simulation, which is noticeable to the human operators. Large geo-spatial databases exist for local network housing or updating from cloud servers, but the level of detail required for realistic physics-based interaction with an autonomous vehicle lacks in simulation. This project is addressing those deficits by identifying modeling methods, developing algorithms and requirements, and implementing the best toolchain for deducing autonomous vehicle-terrain interaction in a simulated environment for adequate functional and physical fidelity matched to operator mental models for enhanced training outcomes.

Maximizing Autonomous Mobility and Energy Efficiency On-the-Go Through Exteroceptive and Proprioceptive Self-Learning-and-Improvement (Thrust Area 4)

Mechanical driveline systems should be developed that are flexible enough to provide various power splits to the driving wheels for the purpose of either energy efficiency or mobility. In case of individual electric drives, new analytical fundamentals will be developed to coordinate the power delivering to the wheels, which lack mechanical connections in fully electric vehicles. To overcome these challenges, new vehicle dynamics fundamentals shall be developed to mathematically formulate and solve the problem of the wheel power distribution and to establish conditions for max terrain mobility. By correlating the new analytical accomplishments in mobility and energy efficiency management with the distinctive features and requirements to the autonomous vehicle models, research directions are identified and formulated for developing AI-based fundamentals to benefit the autonomous mobility and energy efficiency management. The overall goal of the project is to develop fundamentals and simulate an AI-based system to maximize mobility and energy efficiency of a 4x4 vehicle with e-motors in the wheels.

Technical Approaches and Analysis of Vehicle Conceptual Design for Mobility and Autonomous Mobility (Thrust Area 3)

The ultimate purpose of the project is to develop an advanced methodological foundation for vehicle conceptual design and vehicle major subsystem design for mobility and autonomous mobility. The work will begin with an analysis of technical approaches from eastern and western countries and will provide a comprehensive description and analysis of differences and similarities in analytical approaches to defining, modeling and assessing mobility, maneuver, and movability. A special attention will be on intelligent information management for mobility of autonomous ground vehicles (AGV), including approaches to modeling and simulation of AGV sub-systems, path planning and control, and observation and control of tire slippage and mobility. Parameters and characteristics of various types of wheeled and tracked, manned/unmanned vehicles will be gathered from reputable multiple open sources to build a comprehensive database for the purpose of establishing design metrics for mobility and related mobility metrics that are suitable in the eastern and western approaches. An express method will then be developed and applied to assess the eastern and western approaches to vehicle mobility or movability and to range the vehicles quantitatively and qualitatively.

Based on the above-described analysis, a method of conceptual vehicle design for mobility, which involves integrating vehicle dynamics with dynamics of sub-systems and intelligent decision-making and targets to identify the best combination(s) of the main vehicle parameters for mobility, will be developed further in the project. The approach will be based on inferring and analyzing regression models of the main vehicle conceptual parameters, which cover three clusters, including vehicle mass and overall geometry, vehicle powertrain, and chassis.

In collaboration with the NATO AVT-341 group, the integration of past, current, and future frameworks of vehicles and AGV design metrics in this project will provide a NATO STANREC (useful practices) on AGV mobility modeling, simulation and assessment.

These ARC projects support a collaborative Ground Vehicle Alliance around the ARC, which now includes the ARC, the Autonomous Vehicle Mobility Institute (AVMI) at the University of Alabama Birmingham, and the Virtual Prototyping of Ground Systems (VIPR-GS) Center at Clemson University.