DOCTOR
OF
PHILOSOPHY

INERTIAL AND MAGNETIC TRACKING OF LIMB SEGMENT ORIENTATION FOR INSERTING HUMANS INTO SYNTHETIC ENVIRONMENTS

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Current motion tracking technologies fail to provide accurate wide area tracking of multiple users without interference and occlusion problems. This research proposes to overcome current limitations using nine-axis magnetic/angular rate/gravity (MARG) sensors combined with a quaternion-based complementary filter algorithm capable of continuously correcting for drift and following angular motion through all orientations without singularities.

Primarily, this research involves the development of a prototype tracking system to demonstrate the feasibility of MARG sensor body motion tracking. Mathematical analysis and computer simulation are used to validate the correctness of the complementary filter algorithm. The implemented human body model utilizes the world-coordinate reference frame orientation data provided in quaternion form by the complementary filter and orients each limb segment independently. Calibration of the model and the inertial sensors is accomplished using simple but effective algorithms. Physical experiments demonstrate the utility of the proposed system by tracking of human limbs in real-time using multiple MARG sensors.

The system is "sourceless" and does not suffer from range restrictions and interference problems. This new technology overcomes the limitations of motion tracking technologies currently in use. It has the potential to provide wide area tracking of multiple users in virtual environment and augmented reality applications.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Human Systems Interface, Sensors, Modeling and Simulation

KEYWORDS: Micromachined Sensors, Complementary Filtering, Quaternions, Motion Capture, Networked Virtual Environments, Human Modeling, MARG Sensors, Inertial Sensors, Magnetic Sensors

OBSERVATION ADJOINT SENSITIVITY AND THE ADAPTIVE OBSERVATION-TARGETING PROBLEM

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This research introduces the adjoint of the data assimilation system, which together with the classical adjoint sensitivity problem, represents the two fundamental components of the complete forecast adjoint sensitivity problem. This adjoint of the data assimilation system is then used to investigate the sensitivity of

the forecast aspect J to the observations and background for idealized analysis problems, and finally a real-data case using the NAVDAS adjoint for a situation with unusually large 72-h forecast errors over the western United States during February 1999.

The observation sensitivity is largest when the observations are relatively isolated, assumed to be more accurate than the background, and the analysis sensitivity gradients are large in amplitude and have a spatial scale similar to the background error covariances. The observation sensitivity is considerably weaker for small-scale analysis sensitivity gradients. The large observation sensitivities suggest that adaptive observations near large-scale analysis sensitivity gradients have a greater potential to change the forecast aspect than observations near small-scale analysis sensitivity gradients. Therefore, targeting decisions based on the adjoint of the data assimilation system may be significantly different from targeting decisions based solely on the analysis sensitivity gradients. These results emphasize the importance of accounting for the data assimilation procedures in the adaptive observation-targeting problem.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Observation Sensitivity, Observation Adjoint Sensitivity, Adaptive Observations, Observation Targeting, Data Assimilation, Adjoint Methods

TROPICAL CYCLONE AND MID-LATITUDE CHARACTERISTICS AND PHYSICAL MECHANISMS CONTRIBUTING TO EXTRATROPICAL TRANSITION IN THE WESTERN NORTH PACIFIC

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This study of extratropical transition (ET) of tropical cyclones (TCs) in the western North Pacific examines 30 cases during 1 June through 31 October 1994-98 using Navy analyses, plus geostationary satellite visible, infrared, water vapor, and microwave imagery. Based on the similarity of all 30 ET cases in satellite imagery, a three-dimensional conceptual model of the *transformation* stage of ET is proposed to describe how these ET cases evolve into an incipient, baroclinic cyclone. A climatology of ET during the period studied is presented, and three levels of re-intensification (*little*, *moderate*, and *deep*) are defined based on storm intensity at the end of ET. The re-intensification stage in nine cases is studied via Navy Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) control forecasts, simulations with the initial TC vortex removed, and simulations in which the initial TC vortex is displaced. These COAMPS simulations demonstrate that deep or moderate re-intensification depends on *phasing* of the poleward translating TC remnants with a *critical region* in which cyclogenesis is favored in the mid-latitude circulation. The mid-latitude circulation and TC contributions to the re-intensification stage are identified via superposition with the critical region and modification of its location and diagnostic values, respectively, and the combination of these contributions determines the final storm intensity at the end of ET.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Command, Control, and Communications, Electronic, Electronic Warfare, Sensors, Modeling and Simulation, Other (Meteorological Support and Tactical Decision Aids)

KEYWORDS: Extratropical Transition of Tropical Cyclones, Transformation Stage, Re-intensification Stage, Critical Region, Petterssen Type-B Extratropical Cyclogenesis, Mid-latitude Circulation Contributions to Re-Intensification, Tropical Cyclone Contributions to Re-Intensification

EXPLOITING CONSECUTIVE ONES STRUCTURE IN THE SET PARTITIONING PROBLEM

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The Set Partitioning Problem (SPP) is one of the most extensively researched models in integer optimization, and is widely applied in operations research. SPP is used for crew scheduling, vehicle routing, stock cutting, production scheduling, and many other combinatorial problems. The power and generality of SPP come at a price: An SPP can be very difficult to solve. A real-world SPP often has columns, or rows, with long strings of consecutive ones. This is exploited this with a new preprocessing reduction that can eliminate some variables. A column-splitting technique is also introduced to render a model that can be solved directly or used to bound SPP with Lagrangian relaxation or an exterior penalty method. An SPP row-splitting method is developed that yields a special model that Bender's decomposition may then solve faster than the monolithic SPP. These techniques are demonstrated with well-known test problems from airlines and other researchers. A new U.S. Navy aircraft carrier long-term deployment scheduling model is contributed, using the new techniques to plan with weekly fidelity over a ten-year planning horizon. This improved time fidelity increases planned deployment coverage of areas of responsibility by about ten carrier weeks.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation, Computing and Software, Surface/Undersurface Vehicles-Ships and Watercraft

KEYWORDS: Set Partitioning, Consecutive Ones, Preprocessing, Problem Size Reduction, Set Packing, Lagrangian Relaxation, Subgradient Optimization, Penalty Method, Benders Decomposition, Aircraft Carrier, Optimization

FREE ELECTRON LASER DEVELOPMENT FOR DIRECTED ENERGY

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This dissertation investigates power requirements for a Free Electron Laser to burn through various missile radome materials. It also includes computer simulation results for several FEL system configurations designed to achieve maximum power while maintaining strict energy spread constraints.

The method used to determine power requirements to burn through materials was to use the Thomas Jefferson National Accelerator Facility's Free Electron Laser to conduct material damage experiments. As the laser was improved and increased in power, the laser spot sizes on the target materials were increased while maintaining a constant irradiance. The key results from these experiments included determining minimal spot sizes that can be used for future experiments, and validation that an irradiance level of 10 kW/cm^2 can burn through most missile radome materials in a few seconds.

The computer simulations involved changing various parameters of an FEL such as electron energy levels, pulse lengths, magnetic field strengths, desynchronism, as well as several other parameters, to determine the best possible configuration to achieve the desire power levels and energy spread requirements for development of a megawatt size FEL. The results indicate that for the proposed designs, both the required power and the required energy spread limit can be met.

DoD KEY TECHNOLOGY AREAS: Directed Energy Weapons, Materials, Processes, and Structures, Modeling and Simulation

KEYWORDS: Free Electron Laser, Laser Damage, Anti-Ship Cruise Missiles