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21-EPSCoR2021-0001

Adaptive and Scalable Data Compression for Deep Space Data Transfer Applications using Deep Learning

NASA WV Space Grant Consortium

Director/PI: Dr. Majid Jaridi

Data transfer has emerged as a fundamental and interdisciplinary challenge for NASA and its partners in space-based mission for sustained Earth and Solar observation, exploration of our solar system, and investigations of the cosmos. Advances in sensor technology and an increasing desire for a deeper understanding of the geospace environment (Sun to Earth and beyond) have resulted in an explosion of data volume in recent years (unprecedented spatial and/or temporal resolution as well as multispectral data) and requires new innovative data compression approaches. For example, the Atmospheric Imaging Assembly (AIA) onboard NASAs Solar Dynamics Observatory (SDO) launched in 2010 recently captured its 200 millionth image in 4K resolution (4096x4096 pixels), and its archive is over 10 PB of data products. While most missions prefer to have the cadence and resolution of the SDO imager (an image every 12 seconds at 4K resolution), the science goals of nearly all missions are limited by their data capabilities. The challenge is further emphasized by the use of data collected by deep-space spacecraft for real-time applications such as space weather forecasting, the subject of an Executive Order issued by former President Obama and supported by the current administration. For example, European Space Agencys (ESAs) plan to launch a dedicated spacecraft Lagrangeto the Sun-Earth L5 point for operational space weather forecasting will contain a suite of instruments that will collect a large volume of data that will all need to be transmitted to Earth in (near) real-time.

The design of science payloads involves trade-offs between sensor fidelity, onboard storage capacity, throughput and flexibility of the data handling systems, and the bandwidth and error characteristics of the communications channel. The basic requirements that heavily influence performance design trade-offs are size, power, weight, and complexity. The fifth requirement and always the decisive factor is mission risk. Data compression (to a manageable size before downlinking to Earth) serves as an enabling solution to avoiding data bottlenecks and fulfill the performance trade-offs and reliability requirements. Our research is motivated by the need for innovative and robust data compression techniques to mitigate the challenges of cost, volume, and latency for data transmission in space applications.

Our goal is to leverage new data science/machine learning extensions made possible by contemporary computational resources to develop new deep learning algorithms/technology for lossy compression of image data that has the promise of superior scientific performance while minimizing data loss. The proposed project is highly timely because of the contemporary computational resources (e.g., GPUs) available for deep learning, the large solar imaging data sets available from multiple NASA missions, and the unprecedented interest in the understanding of our Sun for its ability to significantly impact human life.

21-EPSCoR2021-0005

Synergistic Effects of Defects and Microstructure on Mechanical Behavior of LB-LBF Metallic Materials

University of Alabama in Huntsville

Director/PI: Dr. Lawrence Thomas

The overarching goal of the proposed research is to enable prediction of mechanical properties of additively manufactured (AM) metallic materials by considering the characteristics of defects and their surrounding microstructure. To achieve this goal, this project investigates the synergistic effects of defects and their surrounding microstructure on the mechanical properties of laser beam powder bed fused (LB-PBF) metallic materials, including IN718 and SS 316L. This research ad-dresses the main hindrance of adopting AM metallic materials in flight critical applications, i.e., their compromised and hard-to-predict mechanical behavior due to the presence of volumetric defects, including pores (gas-entrapped pores and key holes) and lack-of-fusions. Indeed, the mechanical performance (such as fatigue resistance and high strain rate response) is associated with significant scatter due to the stochastic nature of these defects and their surrounding microstructure. The central objectives of this research are to:

(1) Assess the effects of defect size/shape and microstructure on the fatigue behavior of AM IN718,

(2) Based on the fatigue data on AM IN718, incorporate the synergistic effects of defects and microstructure on fatigue performance into a predictive model,

(3) Validate this developed predictive model against the fatigue data of SS316L, and

(4) Assess the effects of defects/microstructure on the high strain rate behavior of AM IN718.

To achieve these objectives, a rigorous research program integrating AM fabrication, fatigue and high strain rate experiments, analysis, and numerical simulations both conventional linear elastic finite element method and crystal plasticitywill be carried out by a team of researchers at The National Center for Additive Manufacturing Excellence (NCAME) at Auburn University, University of Alabama-Tuscaloosa, and University of Alabama-Huntsville. The experimental effort serves to provide foundational data as well as initial knowledge on the defect-microstructure synergy. The design of experiments (DoE) is devised to achieve independent control of the AM alloys microstructural features and to evaluate the individual/synergistic effects of these features on the fatigue and high strain rate behaviors of AM alloys. The combined effect of defects/micro-structure on the high strain rate behavior of LB-PBF materials is currently not well understood, and the knowledge generated in this project serves to fill this gap. In addition to the experiments, a more complete picture regarding the defect/microstructure synergy on the fatigue behavior of these materials will be provided by parametric numerical simulations. The collective findings regarding the interrelationship between defect/microstructure and fatigue performance will then be cast into a predictive model. Such a model can enable the prediction of fatigue performance of LB-PBF components based on the most critical volumetric defect and the microstructure of the material. It can also be later extended to capture the stochastic effects of both volumetric and surface defects and/or other types of loading, such torsion and multiaxial.

Key components of this research not only align well with several of NASA interest areas under the 2020 NASA Taxonomy, but they also address many technical gaps identified in both the AMSC and NIST roadmaps. In fact, this research has already attracted significant interest from several NASA research centers as witness by the NASA support letters. In addition, this research led by NCAME is also highly aligned with the Alabama EPSCoR State Science & Technology Roadmap and the Strong Start, Strong Finishinitiative on advanced manufacturing, as noted by the support letter from Governor Ivey. Through this project, not only the teams relevant technical capabilities will be enhanced, but also the collaboration within the multi-university team will be strengthened, preparing the team for future opportunities.project will be enhanced, but also the collaboration within the multi-university team will be strengthened, preparing the team for future opportunities.

21-EPSCoR2021-0006

A Loci-based High-Order Production Solver for Aerothermochemical Modeling of Hypersonic Entry Systems on Modern Heterogeneous Supercomputers

The University of Mississippi

Director/PI: Dr. Nathan Murray

Background: NASAs stated goals include crewed missions to the Moon by 2024 and to Mars in the 2030s. This growth of mission complexity imposes new challenges on spacecraft design. The entry system, which is of direct relevance to the survival of spacecraft, must be designed with in-depth knowledge of the aerothermochemical environment of the spacecraft in flight. In reality, the entry environment cannot be replicated on the earth ground; hence, computer simulation techniques play a major role in modeling the entry environment and assisting with entry-system design.

A number of computer codes have been deployed in NASA for entry-system modeling (e.g DPLR, FUN3D and Loci-CHEM). These codes share one common characteristicthey are all based on the second-order finite-volume discretization of reactive-flow governing equations. The computer codes of such type struggle to provide high-accuracy and robust predictions of flow-field and heat-transfer at hypersonic speeds when a strong shock (typically above Mach 6) forms ahead of space vehicles. Specifically, the numerical solutions often exhibit deficiencies, including i) unreliable surface heating predictions due to the nonphysical post-shock entropy fluctuations; ii) extreme solution sensitivities to the choice of flux formulation and the setup of the computational grid; and iii) slow solution convergence, which hinders the timely delivery of useful results.

Goals: The proposed effort will address the limitations of NASAs current software and modeling tools and establish a prediction capability for aerothermochemical modeling of entry systems based on the high-order accurate discontinuous Galerkin (DG) scheme and the heterogeneous programming model. Recent studies showed that DG can offer superior accuracy when used for shock simulations, capable of providing oscillation-free shock profiles and highly-resolved thin thermal boundary layers. The DFEM method will address deficiencies i) and ii) mentioned above. Moreover, issue iii) will be addressed by enabling a Loci/CUDA or Loci/OpenCL hybrid programming model to fully utilize the computing resources on modern heterogeneous supercomputers.

This research will leverage our unique high-order DG solverLoci-THRUST, developed for chemically reacting flows and shock-capturing (Lv & Ihme, J. Comput. Phys., 2014, 2015; Lv et al., AIAA 2019-2168). A list of tasks will be implemented:

i) Develop efficient, robust and time-stable algorithms to incorporate the physical models of vibrational-energy relaxation, thermal radiation, and ionization reaction into the reactive-flow DG formulation.

ii) Extend the Loci-THRUST framework by hybridizing the Loci-programming model with OpenCL and CUDA languages to utilize the heterogeneous processors and complex memory hierarchy.

iii) Implement OpenCL and CUDA algorithmic kernels and enable proper interfacing with Loci.

iv) Carry out code verification and demonstrate the code speedup in classical test cases, such as hypersonic-flow-over-cylinder and double-cone configurations.

v) Benchmark the new solver against NASAs production code, DPLR, and provide best practice guidelines for using the new entry-system modeling capabilities.

Impacts: The proposed project aims to develop a robust entry modeling research program in the State of Mississippi. The impacts of the proposed research will include 1) establishment of a multi-institutional research program that can successfully compete for extramural funding, 2) enhancement of the research tracks of the involved researchers by producing high-quality conference papers and journal articles, 3) delivery of a upgraded version of Loci-Thrust solver with advanced aerothermochemical modeling capabilities to NASA, and 4) enhancing the STEM educational infrastructure through funding graduate students and helping train next generation of researchers and engineers in a timely research topic.

21-EPSCoR2021-0007

Autonomous Rover Operations for Planetary Surface Exploration using Machine Learning Algorithms

University of Hawaii at Manoa

Director/PI: Dr. Luke Flynn

Areas of Expertise: Dynamics, Estimation, Machine Learning

The research goal of this NASA EPSCoR proposal is to develop the learning algorithms for an autonomous rover with an application of prospecting ice in extraterrestrial terrain. Our secondary objectives are improving understanding of our unique geologic assets, our rover, and our students/workforce. UH Manoas Institute of Geophysics and Planetology retains the finest planetary scientists but lacks the technologists and facilities required to independently design, build, and operate planetary surface exploration rovers. Autonomous exploration of deep space celestial surfaces, specifically the moon for water ice, is NASAs second strategic goal (2.2) and fulfills advancement in NASA roadmaps technological area (TA04). Regarding state-of-the-art, current rover autonomy algorithms are rigid in model formulation and inflexible to adaptation. Current machine learning architectures are powerful and adaptive but not human interpretable and offer minimal safety guarantees. This research incorporates machine learning into autonomous rover operations for exploring an unknown terrain with a formalized science objective while addressing safety and interpretability.

The objectives of this proposal, led by Dr. Frankie Zhu, is to develop three algorithms that answer the following questions with the following contributions:

(i) Given an encoded scientific goal, like quantifying ice, how does a surface agent autonomously explore an unknown environment that offers goal convergence and minimizes distance traveled? The first contribution is a reinforcement learning algorithm that optimizes science information gain and roving distance to generate an exploration strategy whilst also offering convergence guarantees. The science objective is to characterize the distribution of ice on a planetary surface utilizing a payload provided by Dr. Shuai Li

(ii) What system identification method accurately learns a surface vehicles terramechanics model across various terrain whilst offering safe, interpretable, physics-informed predictions? A second contribution is to reveal the best terramechanics model structure for a reinforcement learning vehicle; models range from equations of motion derived from first principles, to a sparse set of fitted library functions, to neural networks, to symbolic regression.

(iii) How does a rover independently and precisely estimate its own global position? The final contribution is a precise global position estimator based upon celestial navigation onboard the planetary surface vehicle with sensor fusion and a sensitivity study on sensor characteristics.

With these three contributions, a robot imbued with a science objective can autonomously explore a planetary surface without orbiter or mission operations support. Our partners, NASA JPL and Astrobotic, can benefit from the ultimate research contributions of this body of work by taking the methodology as a whole or partitioning the algorithms selectively for full or partial autonomous operations.

This project enables our team to raise the technology of this autonomous rover system from TRL 2 to 4. In implementation, the autonomous learning algorithm development will span two different environments: (i) performance validation of the learning algorithms in a computer-simulated environment and (ii) field tests in planetary surface analogues, including harsh volcanic fields akin to Lunar landscapes. In the process of implementing this research, young faculty will lead research staff, train students, arrange new facilities, and organize partnerships with NASA JPL and Astrobotic.

21-EPSCoR2021-0008

Data assimilation and modeling to improve snow water equivalent assessment in Alaska

University Of Alaska Fairbanks

Director/PI: Dr. Denise Thorsen

This proposal is relevant to the strategic research of the NASA Terrestrial Hydrology Program (THP) and THP programs current priority to improve the ability to assess the seasonal snow component of the water cycle. The goal of this proposal is to contribute to the snow water equivalent (SWE) uncertainty analysis that lays the foundation for THPs snow-focused observing system simulation experiment. This goal can be achieved by providing high-resolution SWE maps produced by the SnowModel snow data-model fusion system while assimilating in-situ SWE measurements collected by University of Alaska Fairbanks (UAF) and other regional networks. SWE assessment is challenging in many areas of North America, but the situation is especially complicated in Alaska with the states sparseand diminishingsnow observation network, extreme topographic gradients, and a vast spatial extent. The advantage of our group is that we have collected, documented, and maintained consistent and repeated ground-based weather and SWE time series over a large region of northern Alaska. The scope of work is also coordinated with the upcoming NASAs SnowEx field campaign that will take place near Fairbanks and on the North Slope of Alaska in 20212023. While our long-term goal is to create accurate and reliable SWE maps for the entire state, this proposal focuses on the region north of 64N and continues the legacy of UAF snow research in the Arctic through collaboration with NASAs THP and the Goddard Space Flight Center.

NASA Mission Directorate/Center Alignment: This project directly aligns with Science Mission Directorate Terrestrial Hydrology Program and Goddard Space Flight Center Earth Science Division.

Area of Expertise: The proposed research requires expertise in snow water equivalent measurements and snow modeling in the Arctic.

Science PI: Svetlana Stuefer, Associate Professor, Department of Civil & Environmental Engineering, University of Alaska Fairbanks, Fairbanks, Alaska

21-EPSCoR2021-0009

On-Demand Manufacturing of Smart Systems for Structural Health Monitoring

Louisiana State University

Director/PI: Prof. Gregory Guzik

The objective of this collaborative proposal is to develop safe and high capacity batteries for NASAs future missions. To achieve this objective, we will develop a new solid-state electrolyte (SSE) capable of promoting uniform lithium plating that suppresses the formation of dendrite and prevents thermal runway. The proposed SSE possesses high conductivity and exhibits low reactivity against lithium-metal anode, a central component for high capacity battery. An experimentally-verified, physics-informed, theoretical framework will be developed for predicting the thermal and mechanical stability and long-term performance of the proposed batteries.

Future solar system exploration priorities identified by NASA seek to reach targets of broad scientific interest across the solar system. All of these missions must carry some form of energy storage. The extreme environments of planetary missions require considerable evaluation, adaptation and testing of the energy storage components and their subsystems, for planetary missions are far more demanding than the applications on Earth. Thus, the 2020 NASA Technology Taxonomy from the NASA Office of Chief Technologist has identified development of advanced energy storage as a transformational technology (TX03.2). The proposed research is also closely aligned with the Louisianas research priorities in materials science and advanced manufacturing.

In this project we will address the overarching challenges in developing high-performance and safe solid-state batteries, including: (1) what are the necessary chemistry and architecture for high-performance SSEs to enable a desirable electrochemical and mechanical property that can properly function in severe space environment in the presence of radiation and low temperatures; (2) how an interface can be created at the SSE, which can facilitate the Li ion-migration across this solid-solid junction while remaining stable against Li-metal anode and high-performance cathode; and (3) what is the thermodynamic origin for the formation of uniform Li-plating and Li-dendrites, and how this can be translated into developing cell materials and architecture to suppress dendrite formation. In this research, we expect to develop novel materials, electrolyte architecture, and theory for the safe and ultra-high capacity batteries.

The scientific effort of this project will be undertaken by an interdisciplinary team of researchers from University of Louisiana at Lafayette, Louisiana State University in Baton Rouge, and Louisiana Tech University. This team will collaborate with NASA partners at Glenn Research Center and Jet Propulsion Laboratory as well as industrial partners at General Motors and IBM on high-capacity anode development and testing, performance evaluation in a simulated space environment, and independent validations of the materials and batteries developed by the team.

This project, if funded, can place our team in a leading position in the area of energy storage, which is now a research priority in many federal agencies. The complementary expertise among Co-Investigators will lead to long-term collaboration at three Louisiana universities, multiple NASA centers as well as industrial partners to ensure a broad impacts for years to come.

21-EPSCoR2021-0010

Integrated Biofilm Control Strategies for Water Systems during Extended Space Flight

Montana Space Grant Consortium

Director/PI: Dr. Angela Des Jardins

Water supply and recycle systems on the International Space Station (ISS) and future extended space exploration missions are critical elements of the primary life support system. Microbes in the water can grow as biofilms on surfaces and this fouling has the potential to cause plugging and system failure. The overall goal of this project is to advance the development of biofilm control strategies for mitigating biofouling in water systems supporting crewed space exploration. This will be accomplished by integrating synergistic technologies: removal of key nutrients from water streams to reduce their ability to support microbial growth, addition of biocides to inhibit growth, deployment of antibiofilm materials or surface coatings, and incorporation of sensors to monitor and control system performance. Building on three NASA-funded seed projects in these areas, an interdisciplinary team has been assembled at the Center for Biofilm Engineering at MSU that merges engineering and microbiology, has active contacts with colleagues and managers at four NASA labs or centers, and decades of collective experience working on biofilm challenges. This EPSCoR Research Group proposal will integrate these efforts to create a specialized capability in Montana focused on biofilm control in water systems for extended space flight. An important driver of the research in the project is the future challenge of operating water systems in extended spaceflight or manned bases for long periods of time without resupply of parts or chemicals. In addition, NASA anticipates that some systems will experience significant periods of inactivity (termed dormancy) in which the potential for microbial growth and fouling is not well understood and microbial control strategies are therefore paramount. To address these needs, our workplan incorporates long-term experiments and periods of system dormancy. Research is organized in six technical objectives: 1) Evaluate long-term efficacy of targeted nutrient removal for preventing microbial growth and biofilm formation. 2) Evaluate long-term efficacy of preventing microbial growth and biofilm formation with biocides including those that can be electrolytically generated in-flight (e.g., halogens, hydrogen peroxide). 3) Evaluate long-term efficacy of preventing microbial growth and biofilm formation with coated or treated materials (as well as respective untreated materials). 4) Evaluate combinations of nutrient removal/material coatings/biocide control strategies. 5) Develop and fabricate a custom simulated microgravity microbial growth reactor that incorporates sensors, biofilm coupons, and continuous flow. 6) Develop and evaluate sensor technologies to monitor microbial growth and guide biocide control. Experimental work makes extensive use of CDC biofilm reactor systems, a model with which the team has a long track record of productivity. There are four salient features of innovation in this proposal: 1) A focus on electrolytic generation of biocides, a technical approach that affords high efficacy relative to mass, on-demand generation, and compatibility with electrochemical sensing. 2) A multi-sensor MEMS platform for water quality and biocide monitoring. 3) Likely synergies from integrating three mitigation strategies of nutrient removal, biocide addition, and antibiofilm coatings and materials. 4) A new simulated microgravity reactor system design. The project will rely heavily on reactor systems fabricated and supplied by a Montana small business, Biosurface Technologies (BST), the worlds lead supplier of biofilm reactors. This project and new NASA connections will strengthen BSTs presence in the marketplace. The project supports NASA-oriented workforce

development with participation of two graduate students, a post-doctoral level research engineer, four early career research faculty, and a junior faculty member.

21-EPSCoR2021-0011

Solar Activity And Space Weather

University of Kentucky

Director/PI: Dr. Alexandre Martin

TTITLE: SOLAR ACTIVITY AND SPACE WEATHER

ABSTRACT

The Kentucky NASA EPSCoR Programs mission is to enhance research and intellectual capacity of the state's universities and colleges through strategic investments in NASA-priority research areas and to increase researcher competitiveness for non-EPSCoR NASA funding. Motivated by this, and by the recent passage of the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, we propose to collaborate with two NASA Centers (MSFC and GSFC) to improve the identification, modeling, and near-real-time forecasting of solar flares. We propose three main research partnerships: (1) the use of machine learning techniques to analyze images and light curves in the extreme ultraviolet in order to detect patterns that are precursors to flare activity, (2) the development of techniques to produce high-throughput multi-layer optics for use in instrumentation designed to detect changes that indicate a solar flare is imminent, and (3) the modeling of the response of the solar atmosphere to the impulsive energy release in a solar flare.

These research partnerships combine multiple areas of expertise, including heliophysics, materials science, and computer science, and they involve researchers at Western Kentucky University, Eastern Kentucky University, and the University of Kentucky in collaborative efforts with two NASA Centers. Together this combination of basic and applied collaborative research efforts will serve to increase Kentuckys research capacity and reputation by establishing the Commonwealth as a major NASA partner in the national priority area of space weather forecasting. They will also build a competitive base of personnel and infrastructure, enabling researchers at Kentucky institutions of higher learning to develop sustained research endeavors with NASA and other Federal partners.

21-EPSCoR2021-0012

NASA EPSCoR: Design of Novel Polymeric Membranes and Responsive Molecules for CO2 Removal and Water Reclamation in Future Long-Term Missions: A Computational and Experimental Approach

University of Puerto Rico

Director/PI: Dr. Gerardo Morell

Water is an essential component aboard a spacecraft; it is important for consumption, adequate health, and sanitation of the crewmembers. During long-term space missions, the sources to reclaim water are humidity condensate, hygiene wastewater and human waste (mainly urine). Due to elevated costs of delivering supplies to space, the recovery of potable water from spacecraft wastewater is critical for life support of the crewmembers. On the other hand, excess carbon dioxide (CO2) exhaled from crewmembers is often considered a waste, that must be vented out of the cabin. Thus, water recovery and air revitalization systems are amongst the most massive and important sub-systems aboard spaceships. Therefore, finding ways to enhance the general performance of such systems is of utmost importance for the future of the space program.

This proposal is directly responsive to the goals of NASAs Human Exploration and Operations Mission Directorate (NASA Space Taxonomy Roadmap Area, TA06). In this research we explore on the development of integrated (i.e. dual-function) technologies for the purification of wastewater while removing the CO2 from the cabin during the same process. The general motivation for this project lies on reports from the NASA-Advanced Life Support Systems Division (NASA ALS) highlighting that the main objective to fulfill sustainability in future space missions is to develop fully regenerative integrated system technologies that provide air, water and resource recovery from wastes.

Efforts at the NASA Ames Research Center are currently geared towards the use of membrane-based water purification systems that are passive and thus provide for low-energy consumption, such as forward osmosis (FO). The driving force in the FO process is a gradient in osmotic potential generated by the presence of ionic species in the draw solution. The overall efficiency of the FO process is dictated by the selection of the membrane and the draw solute (ionic species capable of generate a high osmotic potential). As a strategy to enhance the FO process and complement NASAs efforts in these areas of water reclamation and CO2 removal, herein we propose a technology based on the purification of wastewater by means of a passive system (i.e. FO), while using a CO2-responsive switchable polarity solvent (SPS) as draw solute. This dual-function system of water purification integrated to CO2 removal technologies will provide the portability, reliability, and accuracy needed to achieve resource recovery during future space flight missions.

The main objective of the proposed project is to gain insights and to explore on the integration of wastewater reclamation and CO2 removal dual system in order to obtain potable water while removing a waste from the cabin environment. In general, the proposed project seeks to chemically synthesize a new class of CO2-responsive SPS and novel polymeric membranes that would account for an efficient SPS-FO integrated system. Our hypotheses are mainly under TRL 1 to 4 research work due the fundamental research questions that will be unveiled and tested via computational analyses and under laboratory environment.

This research is innovative as it will address efforts to couple functionalized polymeric membranes for the water purification process along with amine-based SPS that were not previously accounted for spacecrafts application. The results of this investigation will shed light on the development of integrated systems to address water recovery while minimizing the amount of released CO2. The broader impact of the current effort is supported on the disclosure of knowledge to both the scientific community and general public and commercialization.

21-EPSCoR2021-0014

Augmenting Physics-Based Design and Multi-Physics Based Manufacturing with Data Driven Models to Manufacture Advanced Composites Structures with Automated Fiber Placement

College of Charleston

Director/PI: Dr. Cassandra Runyon

Automated Fiber Placement (AFP) is one of the most complex manufacturing processes used to fabricate lightweight advanced air vehicle structures with superior qualities. Efficient manufacturing and new process planning techniques for AFP are needed for composite manufacturing of lightweight structures to support NASA programs such as the Advanced Air Transport Technology (AATT) project, Higher Aspect Ratio Optimal Wing activity, and the Hi-Rate Composites Aircraft Manufacturing (HiCAM) project to address current requirements for manufacturing aerospace vehicles. Today, to create structures with advanced composites, we carry out investigations in Mechanics (Design) to understand response in terms of strength and stiffness, and Multi-physics (Manufacturing) to understand the relationships between process parameters and their influence on mechanical properties. This proposal tests the scientific hypothesis that there exist capabilities to propose new composite structures incorporating a multitude of lifecycle attributes, such as design and manufacturing, based on a new framework that adds a data dependent dimension to physics-based ones. This will be accomplished through the following methods/techniques: (1) Assessment of Physics and Data-Driven Design Methods by surveying the literature and selecting adequate models, (2) Development of workflow platform to enable data-driven composites, and (3) Implementation and Validation through data collection, manufacturing, and testing of a selected design according to the developed framework. Outcomes of the project could have significant impact on composites fabrication at NASA and the aerospace industry here in South Carolina.

21-EPSCoR2021-0018

Advanced Soft-Magnetic Materials for Electrified Propulsion Systems

South Dakota School of Mines and Technology

Director/PI: Dr. Edward Duke

The performance of high-efficiency (HE) electronics, including those targeted in TX01: Propulsion Systems, is controlled through the electromagnetic behaviors of magnetically soft metal-amorphous nanocomposites (MANCs) that operate as filter inductors and transformers. These devices are integral to all-electric propulsion (TX01.3.8) systems and influence the cost, size, and weight of electronic filters and controller boards. The development of lightweight, high-power and HE filter inductors from tape-wound MANCs is the central goal of the proposed work, which is key to advancing the National Aeronautics and Space Administrations (NASAs) missions and fostering strategic plans. In our project, titled Advanced Soft-Magnetic Materials for Electrified Propulsion Systems (ASM-EPS), South Dakota (SD) NASA EPSCoR proposes to improve the mechanical and magnetic behaviors of low-cost Fe-based MANCs. Outcomes, including new stress-annealable compositions, thermomechanical processing conditions, materials properties data, and thermally efficient packaging will be

directly relevant to NASAs Aeronautics Research Mission Directorate (ARMD) through the Advanced Air Transport Technology project given its current focus in Strategic Thrust 4: Transition to Low-Carbon Propulsion. The work will also increase research capacity and economic growth in SD, particularly with respect to two key research thrusts [Energy and Environment and Materials and Advanced Manufacturing] in SDs 2020 Science and Technology Plan. ASM-EPS will establish a program that stimulates competitive research and strong partnerships between SD and NASA, particularly with regard to TX01.2 Electric Space Propulsion. ASM-EPS is poised to improve the current implementation of brittle MANCs and develop unprecedented manufacturing capabilities with subsequent benefits for the general U.S. population (i.e., improved efficiency of power transformers, electric cars, and spreading of high-voltage over large power grids). In particular, ASM-EPS, which includes the development of the necessary human capital in STEM, is expected to have a significant impact on the electronics industry valued over $1.5 trillion.

ASM-EPS is organized into four intertwined initiatives that coordinate activities to achieve our central goal, i.e., manufacture HE high-power inductor cores from Fe-based MANCs. The proposed initiatives include (1) alloy synthesis to develop novel MANCs, (2) stress-annealing and processing to tune their magnetic and mechanical behaviors, (3) materials and core characterization to understand MANC behaviors, and (4) packaging to improve thermal transfer between energized cores and their surroundings. HE high-power inductor cores will be manufactured from ground-uptechnology through the synergy between initiatives (1)-(4).

Supporting ASM-EPS are 8 faculty from South Dakota School of Mines and Technology (SDSM&T) and South Dakota State University (SDSU) and 4 NASA researchers at Glenn Research Center (GRC) and Jet Propulsion Laboratory (JPL). A minimum of 5 graduate students and 1 undergraduate will also be supported. ASM-EPS presents a well-defined plan that fosters close partnership between institutions and utilizes current NASA assets, including a commercial planar-casting system, custom core-loss measurement instrumentation, and expert personnel. Moreover, the project will develop research infrastructure in SD through the acquisition and implementation of a planar-casting system for synthesizing MANCs for the first time in the state. Progress in SDs education infrastructure will be made through collaborative efforts between faculty members, the Tiospaye Scholar Program (STEM retention for Native Americans at SDSM&T), and the implementation of findings in undergraduate and graduate curricula. Finally, in developing HE inductor cores, SD will be positioned for economic growth with CBMM, a niobium mining company, through the development of commercial electronics.

21-EPSCoR2021-0019

Diagnostics and Mitigation of Life Support System Biofilms Using Magnetic Nanoparticles

University of Vermont

Director/PI: Prof. Bernard Cole

We propose to investigate a novel nanoparticle-biofilm interaction paradigm via three integrated research directions, where the life support system biofilm mitigation in microgravity environment on the International Space Station (ISS) is essential for the both crew health and for system engineering. Two aspects of the potable water biofilms will be magnified during long duration space travel, where equipment must function properly for the entire time and where the immune system of the crew will not be fully functional. We aim to chart a groundbreaking new direction for the development of novel biofilm mitigation approaches that exploit both physical and chemical forces at the nanoscale simultaneously. Specifically, superparamagnetic and ferromagnetic iron oxide nanoparticles exhibit unconventional heating and catalytic-reactive oxygen species generation properties in the presence of alternating magnetic fields. We propose that their interactions with biofilms in microgravity can be effectively engineered in the presence of magnetic fields, leading to an effective, novel approach for biofilm disruption, dissolution, and dispersal. This research will result in revolutionary biofilm mitigation tools based on microbiological, fluid physics, and functional nanomaterials engineering.

In particular, we will examine interaction of bacterial biofilmsformed from single species or a mixture of bacterial species from the ISS potable water reclamation systemwith magnetic nanoparticles, which are frequently used in biofilm mitigation. The project will use magnetic nanoparticles controlled with a time- and space-varying magnetic field. The specific project objectives are as follows: (1) characterize biofilm response to oscillating nanoparticles, (2) simulate biofilm-particle system dynamics, and (3) mitigate biofilm growth using magnetic nanoparticles. Under the first objective, we will use the magnetic nanoparticles to characterize biofilm matrix response to particle motion, including (i) biofilm matrix permeability and particle capture rate for different particle sizes, (ii) biofilm matrix mechanical response to oscillatory particle motion with different frequencies, amplitudes and particle sizes, and (iii) biofilm species organization before and after treatment. Under the second objective, we will extend our hybrid agent-based biofilm growth model to include viscoelastic biofilm matrix response to oscillating nanoparticles, which couples with the first objective to enable iterative computational-experimental probing of biofilm response to magnetic nanoparticle motion. Under the third objective, we will use the magnetic nanoparticle system to examine different approaches for biofilm mitigation, including (i) biofilm matrix bulk removal, (ii) enhancement of chemical/heat biofilm treatment, and (iii) temporal bacterial community patterning and disruption.

This proposal is well aligned with the Space Life and Physical Sciences Research and Applications (SLPSRA) directorate. Within SLPSRA, our research plan spans across the Space Biology Program (microbiology), the Physical Science Research Program (complex fluids and fluid physics), and the Engineering Research Program (water recovery and management systems). With the full support of the NASA Jet Propulsion Laboratory (JPL), we aim to explore this new fundamental research direction in the area of interactions between biofilms and alternating magnetic field-driven nanoparticles in microgravity including novel physical, chemical, and biological phenomena at the interface of biofilms and nanoparticles research.

The research will be performed by a tightly integrated team of domain-specific experts in the fields of microbiology and bacterial genetics, complex fluids and fluid physics, water recovery and management systems, nanotechnology, and experimental design in microgravity who have a history of successful collaboration.

21-EPSCoR2021-0022

AR - Preventing immune system dysregulation during deep-space missions by Tocoflexol, a modified isomer of vitamin E

University of Arkansas at Little Rock

Director/PI: Dr. Mitchell Hudson

Background and Justification: At the inception of the Human Research Program in 2005, NASA identified immune dysregulation as a potential danger during long-term deep-space missions to the Moon and Mars (1-3 years beyond Earths magnetic field). Chronic irradiation (CIR, uninterrupted exposure to low-dose and low-doserate radiation) and microgravity (continuous experience of weightlessness) are 2 major space hazards that can induce immune dysregulation. Both of these enhance oxidative stress by increasing the generation of highly toxic reactive oxygen species (ROS), which can damage immune cells and result in inflammation. The compromised immune response may produce detrimental health effects for astronauts, impacting their quality of life as they age; such effects include increased risks for cancer, autoimmune conditions, cardiovascular disease, and cognitive dysfunction.

We and others showed that tocotrienolsa subgroup of vitamin Eare potent ROS scavengers and provide strong radio-protection with little to no serious side effects. Tocotrienols are also cardio-protective and have anti-cancer and anti-inflammatory properties. Unfortunately, tocotrienols have low bioavailability. Therefore, synthesizing a modified isomer of tocotrienol with greater bioavailability could be a valuable resource for protecting the immune system during and after deep-space missions. Better immune protection would reduce the risk of viral infection, inflammation, and genomic instability, which are the major risks of human space missions.

Approach and Novelty: We developed a ground-based facility at the University of Arkansas for Medical Sciences (UAMS) that is capable of exposing mice under simulated microgavity (SMG) to CIR concurrently. Very few similar facilities are operational in the US, and this is the first and only in Arkansas. In addition, we have successfully synthesized Tocoflexol, a modified

form of tocotrienol with higher bioavailability, and plan to test its efficacy in reducing spacefactor-induced immune dysregulation compared to the parent group of tocotrienols. Tocoflexol was developed by the Arkansas-based company Tocol Pharmaceuticals, LLC, in collaboration with UAMS and the University of Arkansas at Little Rock. We hypothesize that CIR and SMG will cause immune system dysfunction, and treatment with Tocoflexol will provide immune protection.

Objective 1: Characterize immune dysregulation after exposure to SMG or CIR alone and in combination. Mice will be exposed to SMG and/or CIR for 30 days at the approximate dose-rate encountered in space. To assess acute effects, tissues will be harvested on day 30 (day 30=completion of exposure). To assess late effects, tissues will be harvested on day 90 (60 days

after exposure). Immune dysregulation will be assessed as the change in the ratios of various immune cells and their functional activity in primary (bone marrow and thymus) and secondary (spleen and gut-associated lymphoid organ [GALT]) lymphoid organs.

Objective 2: Determine the efficacy of Tocoflexol in mitigating immune dysregulation after coexposure to SMG and CIR. Mice treated with either Tocoflexol or the parent compounds (3 times/week subcutaneously) will be exposed concurrently to SMG and CIR for 30 days. Immune dysregulation will be assessed in various primary and secondary lymphoid organs as in Aim 1 on day 30. Additionally, the efficacy Tocoflexol in reducing viral infection, inflammation, and genomic instability will be determined in mice subjected to 30 days coexposure. Opportunities for Collaboration: Our chronic irradiation facility will be made available to other research groups in Arkansas from academic or industrial areas to strengthen collaborations and optimize discoveries related to the adaptive and pathogenic mechanisms of deep-space travel. Such collaboration will allow us to explore potential therapeutics to improve the health outcome of astronauts engaged in space exploration.

21-EPSCoR2021-0023

Development and Testing of Recyclable Antimicrobial Materials for In-Space Manufacturing of Medical Devices

University of Nebraska at Omaha

Director/PI: Dr. Scott Tarry

Title: Development and Testing of Recyclable Antimicrobial Materials for In-Space Manufacturing of Medical Devices.

The mission directorate that closely related to the current project is the Space Technology Mission Directorate (STMD). This directorate highlights the need of methods for in-space manufacturing, as well as biological approaches to manufacturing as topics of particular interest.

The current proposal best aligns with the Marshall Space Flight Center (MSFC) EPSCoR Research Areas of interest including Modeling of Manufacturing Processes in Micro and Reduced Gravity Environments and Development of Process Pathways between In-Situ Resource Utilization (ISRU) and In-Space Manufacturing.

Areas of Expertise Required

3D Printing/Additive Manufacturing/Rapid Prototyping

Science Investigator (Science-I):

Jorge M. Zuniga Ph.D. UNO Department of Biomechanics jmzuniga@unomaha.edu

Technical Summary

The reported immune dysfunction of astronauts in space and the viral antibiotic resistance during spaceflights suggest the critical need of developing preventive countermeasures for the manufacturing of medical devices associated with high bacterial load. The objective of the current proposal is to develop new antimicrobial polymers compatible with the Additive Manufacturing Facility at the International Space Station (ISS) for in-space manufacturing of medical devices.

Two new antimicrobial materials will be developed, high-strength polylactic acid-based and a polyurethane-based material, and used during ground manufacturing of test coupons and medical devices using a replica of the ISSs Additive Manufacturing Facility. After ground manufacturing, antimicrobial and mechanical characterization testing will be performed on the ground manufactured objects. On-orbit manufacturing of test coupons and medical devices will be performed using a high-strength polylactic acid-based material at the original Additive Manufacturing Facility on the ISS. After on-orbit manufacturing at the ISS, antimicrobial and mechanical characterization of test coupons and medical devices manufactured on-orbit will be tested and compared to ground manufactured objects. A two-tailed student T-test will be performed to compare the differences between ground and on-orbit manufactured test coupons and medical on antimicrobial and mechanical characterization properties. An alpha value of 0.05 will be considered statistically significant for all comparisons.

Specific Aims:

Aim 1: Development of high-strength antimicrobial polylactic acid based- and polyurethane-based materials compatible with the additive manufacturing facility in the ISS.

Aim 2: Perform antimicrobial and mechanical characterization of new materials using a replica of the additive manufacturing facility on-ground.

Aim 3: Development and post-extrusion mechanical characterization of test coupons and the 3D printed medical devices manufactured on-orbit.

21-EPSCoR2021-0024

Low-Temperature Comparative Planetology: Pore-Scale Dynamics with Planetary Scale Implications

University of New Hampshire

Director/PI: Dr. Antoinette Galvin

Motivation: Current models of planetary ices exclude important microscale processes that dictate the ices biogeochemical and material properties. For ice-dominated worlds in our solar system neglecting microscale physics breeds uncertainty in their geophysical evolution and habitability. With upcoming missions targeting these high-priority bodies, constraining their characteristics and dynamics is vital to mission planning and data interpretation. An abundance of ice-rich terrestrial analog environments and a New Hampshire Earth science community with an extensive knowledge of such cryogenic systems provides the ideal opportunity to advance our understanding and representation of planetary ices as we enter a new era of ice-ocean world exploration. Here we outline our project plan, which leverages community knowledge of ice microstructural processes, to improve our understanding of planetary ice biogeochemistry, the dynamics of three phase ice-brine-sediment systems, and the interaction between spacecraft materials and planetary ices.

Methods: The project is centered around three interrelated topics. We will employ a multidisciplinary approach, combining the teams expertise in numerical modelling, analog field work, and laboratory experimentation with targeted collaborations with NASA centers (JPL) and existing NASA projects (OAST, VERNE, EELS) to accomplish these objectives.

Topic 1: Biogeochemistry of Planetary Ices: Constrain the biogeochemical dynamics that control the evolution and habitability of diverse terrestrial analog ice-brine systems and extend this knowledge to planetary ices. We will conduct biogeochemical assays of the ice-brine-sediment systems of British Columbias compositionally diverse hypersaline lakes and utilize these results to inform laboratory experiments of ice-brine system evolution and benchmark novel multiphase reactive transport models of planetary ices that include biogeochemical processes. Members of the team have conducted similar assays at these sites and in Arctic/Antarctic environments, others are experts in low-temperature laboratory experiments, and multiple team members have extensive experience in reactive transport modeling.

Topic 2: Multiphase Ice/Brine/Sediment Systems: Leverage terrestrial ice-brine-sediment systems to better understand the habitability and dynamics of Martian ice-brine-sediment systems. Utilizing the teams knowledge of terrestrial ice-brine-sediment systems and the assays of Topic T1 we will develop and benchmark numerical models of planetary ice-brine-sediment systems that accurately simulate their microstructural and geochemical evolution.

Topic 3: Ice Interactions with Spacecraft Materials: Quantify mission relevant properties and dynamics of the interaction between spacecraft materials and diverse planetary ices. Leveraging the team's low-temperature materials science expertise, and the results of Topic T1, we will identify a trade space of ice-brine systems that may be encountered by upcoming planetary missions. We will fabricate endmembers of these potential ices and test their thermochemical interactions with an array of prospective spacecraft materials.

Implications: Constraining the microscale processes that govern the material and transport properties of planetary ices has both astrobiological and geophysical implications. Coupled with investigations of the interactions between potential flight hardware and diverse planetary ices, our scientific program is directly relevant to the planning of future ice-ocean world missions, the Space Technologies Mission Directorate and has numerous applications to both the Earth and Planetary Science Divisions of the Science Mission Directorate. This proactive collaboration between the untapped terrestrial cryosphere community of New Hampshire and NASA promises to provide an ongoing partnership which expands the breadth and impact of both communitiesresearch.

21-EPSCoR2021-0027

Hanom Fresko yan Acho' Tasi: A cross-disciplinary study of coastal freshwater discharge hydrology and near-shore and coral reef ecology using geospatial analytical techniques

University of Guam

Director/PI: Dr. Leslie Aquino

Freshwater resources are the first priority for island communities, followed by coral reef ecosystems. Humans cannot live without water. Thus, it is imperative for inhabitants of small islands to understand how their freshwater is distributed, how much is available, and how best to develop, manage, and protect it. Studying the environmental, anthropogenic, and ecological effects on island groundwater and surface water can inform these questions. Coral reefs play a vital role in Guams economy and society. The role of freshwater discharge, particularly temperature control and the fate and transport of nutrients and contaminants, and its effects on coral reef ecosystem resilience is not well understood. This projects aims to model these freshwater relationships between island hydrology and coral reef ecology on Guam.

Understanding and mapping the distribution and properties of coastal freshwater discharge, such as volumetric flow rate, temperature, turbidity, nutrient content, presence or absence of suspected or possible contaminants, mixing/dilution rates, etc., is useful for water resource management as well as coastal zone management. A more complete picture of freshwater discharge involves detailing land coverage and environmental factors that impact watersheds and contribute to the occurrence of known stressors (e.g., nutrients, sediment) to these near-shore coastal waters and coral reef ecosystems. Guam is uniquely suited for such research as the northern half is an island karst aquifer drained entirely by coastal springs and seeps, and the southern half is a weathered volcanic upland drained entirely by surface runoff, providing two distinct hydrogeologic provinces for a comprehensive and comparative study.

Obtaining detailed knowledge of Guams coastal freshwater discharge is logistically and technically challenging, and therefore costly. In recent years, the use of geospatial data, such as satellite imagery and data acquired from unmanned aerial vehicles (UAVs), has proven very useful as a complementary source of information on various ecological and hydrologic processes, such as changes in land coverage, area of sediment plumes and freshwater plumes, and changes in coral reef cover. Examples of existing geospatial datasets or sources that cover Guam and near-shore coastal waters and would be applicable for this investigation include World View 2, 3, 4; IceSat-2, Sentinel 2, Landsat 8, UAV acquired thermal IR and multispectral imagery. Taking advantage of geospatial datasets of varying resolutions and traditional in situ field data would enable researchers to characterize and model different aspects of coastal freshwater discharge, from ridge to reef.

The intent of this project is therefore to integrate multiple disciplines and techniques, including:

1) analysis of geospatial datasets to identify geological features and changes in land coverages;

2) validation of the geospatial datasets with in situ field data (e.g., soil moisture, nutrient and sediment measurement, etc.) to reconcile multiple data sources of differing resolutions to create accurate models of freshwater discharge and sedimentation of coral reefs around Guam;

3) utilization of unmanned aerial vehicles (UAVs) and various sensors (e.g, thermal infrared, multi-spectral) for mapping and analyzing coastal freshwater discharge;

4) development of a three-dimensional computational fluid dynamics (CFDs) model to provide detailed physical understanding of the nutrient/sediment transport mechanism within shallow coastal areas that contain coral reefs; and

5) ecological investigation for characterizing and evaluating impacts on coral reef ecosystems around Guam.

Building upon previous NASA, NOAA, USGS, and USEPA work, results will provide insights to effective management of island freshwater resources and coral reefs that may be applied to other islands.