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An Overview of SBIR Phase 2 Physical Sciences and Biomedical Technologies in Space

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August 2015

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An Overview of SBIR Phase 2 Physical Sciences and Biomedical Technologies in Space

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Abstract

Technological innovation is the overall focus of NASA's Small Business Innovation Research (SBIR) program. The program invests in the development of innovative concepts and technologies to help NASA's mission directorates address critical research and development needs for agency projects.

This report highlights innovative SBIR Phase II projects from 2007-2012 specifically addressing areas in physical sciences and biomedical technologies in space, which is one of six core competencies at NASA Glenn Research Center. There are twenty two technologies featured with emphasis on a wide spectrum of applications such as reusable handheld electrolyte, sensor for bone markers, wideband single crystal transducer, mini treadmill for musculoskeletal, and much more. Each article in this report describes an innovation, technical objective, and highlights NASA commercial and industrial applications.

This report serves as an opportunity for NASA personnel including engineers, researchers, and program managers to learn of NASA SBIR's capabilities that might be crosscutting into this technology area. As the result, it would cause collaborations and partnerships between the small companies and NASA Programs and Projects resulting in benefit to both SBIR companies and NASA.

The Reusable Handheld Electrolyte and Lab Technology for Humans (rHEALTH) Sensor

Biomedical analysis sensor shrinks hospital lab to single point-of-care (POC) device

The DNA Medicine Institute has produced a reusable microfluidic device that performs rapid, low-cost cell counts and measurements of electrolytes, proteins, and other biomarkers. The rHEALTH sensor is compact and portable, and it employs cutting-edge fluorescence detection optics, innovative microfluidics, and nanostrip reagents to perform a suite of hematology, chemistry, and biomarker assays from a single drop of blood.

A handful of current portable POC devices provide generalized blood analysis, but they perform only a few tests at a time. These devices also rely on disposable components and depend on diverse detection technologies to complete routine tests—all ill-suited for space travelers on extended missions. In contrast, the rHEALTH sensor integrates sample introduction, processing, and detection with a compact, resource-conscious, and efficient design.

Developed to monitor astronaut health on the International Space Station and during long-term space flight, this microscale lab analysis tool also has terrestrial applications that include POC diagnostics conducted at a patient's bedside, in a doctor's office, and in a hospital.

Applications

NASA

- ▶ Real-time health monitoring and intervention
- ▶ Collecting electrolyte and complete blood count (CBC) measurements
- ▶ Measuring cardiac biomarkers for chest pain to test for myocardial infarction
- ▶ Monitoring astronaut renal function to assess kidney volume status
- ▶ Tracking bone biomarkers and calcium levels to assess bone loss and remodeling
- ▶ Measuring daily hematocrit for patients on anticoagulation therapy
- ▶ Detecting acute myocardial damage
- ▶ Tracking white blood cell counts throughout prolonged antibiotic courses
- ▶ Monitoring daily renal function of patients with kidney transplants or those with end-stage renal disease
- ▶ Measuring body fluid status of elite athletes to guard against dehydration
- ▶ Daily monitoring of electrolyte status for individuals taking diuretics

Commercial

- ▶ Real-time health monitoring and intervention



Phase II Objectives

- ▶ Complete prototype concept design and review
- ▶ Finalize subassembly optics testing, fluidics handling, electrical components, and software
- ▶ Establish micron chip prototyping, silica chip capabilities, and fingerstick blood collection device
- ▶ Determine accurate and repeatable CBC with differential for physiological samples
- ▶ Conduct blood electrolyte experiments to test system accuracy and precision
- ▶ Develop ratiometric mixing capabilities for the spiral vortexer
- ▶ Conduct reagent shelf-life tests
- ▶ Develop nanoliter reagent and flushing protocols for chip reuse

Benefits

- ▶ Allows rapid, low-cost analysis of a wide range of samples
- ▶ Reduces mass and volume of POC diagnostic technology
- ▶ Does not rely on single-use disposable components

Firm Contact

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Proposal Number: 07-2 X12.03-8958

Nanoscale Test Strips for Multiplexed Blood Analysis

Enables real-time, comprehensive health monitoring

A critical component of the DNA Medicine Institute's Reusable Handheld Electrolyte and Lab Technology for Humans (rHEALTH) sensor are nanoscale test strips, or nanostrips, that enable multiplexed blood analysis. Nanostrips are conceptually similar to the standard urinalysis test strip, but the strips are shrunk down a billionfold to the microscale. Each nanostrip can have several sensor pads that fluoresce in response to different targets in a sample. The strips carry identification tags that permit differentiation of a specific panel from hundreds of other nanostrip panels during a single measurement session.

In Phase I of the project, the company fabricated, tested, and demonstrated functional parathyroid hormone and vitamin D nanostrips for bone metabolism, and thrombin aptamer and immunoglobulin G antibody nanostrips. In Phase II, numerous nanostrips were developed to address key space flight-based medical needs: assessment of bone metabolism, immune response, cardiac status, liver metabolism, and lipid profiles. This unique approach holds genuine promise for space-based portable biodiagnostics and for point-of-care (POC) health monitoring and diagnostics here on Earth.

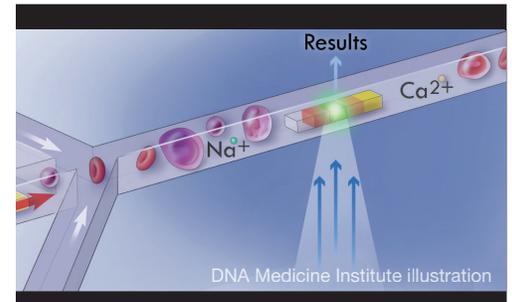
Applications

NASA

- ▶ Routine assessment of bone biomarkers
- ▶ Rapid assessment of altered immune response biomarkers
- ▶ Detection of infection, immunocompromised states, and hematological malignancies
- ▶ Measurement of cardiac biomarkers
- ▶ Liver function assessment
- ▶ Lipid measurements

Commercial

- ▶ Detection of acute myocardial damage
- ▶ POC monitoring of bisphosphonate therapy for patients with osteoporosis
- ▶ Diagnoses of acute cholecystitis
- ▶ Daily assessment of immune functions for patients with autoimmune disorders
- ▶ Study of bone remodeling for patients with Paget's disease
- ▶ Evaluation of effects of drugs and diet on liver function



Phase II Objectives

- ▶ Implement rapid nanostrip assay capability
- ▶ Develop mix-and-run assays
- ▶ Establish in-house aptamer production
- ▶ Develop lyophilized nanostrip technology with lyoprotectant:
 - Perform accelerated stability tests on lyophilized reagents
 - Perform extended testing on antibody and aptamer nanostrips
- ▶ Develop bone antibody, bone aptamer, immune antibody, and immune aptamer nanostrip panel
- ▶ Develop cardiac, liver, and lipid assay nanostrip panels

Benefits

- ▶ Enables massive multiplexing that has the potential to allow hundreds of measurements from a single session
- ▶ Facilitates home-based tests and measurements
- ▶ Contributes significantly to the evolving needs of space medicine, biomedical research, and POC diagnostics

Firm Contact

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Proposal Number: 08-2 X10.01-9385

Handheld Fluorescence Resonance Energy Transfer (FRET)-Aptamer Sensor for Bone Markers

Portable technology evaluates bone loss

Astronauts lose significant bone mass during lengthy space flights. NASA wishes to monitor this bone loss in order to develop nutritional and exercise countermeasures. Operational Technologies Corporation (OpTech) has developed a handheld device that quantifies bone loss in a spacecraft environment. The innovation works by adding fluorescent dyes and quenchers to aptamers to enable pushbutton, one-step bind-and-detect FRET assays that can be freeze-dried, rehydrated with body fluids, and used to quantify bone loss.

In Phase I, OpTech developed several 15-minute specific polyclonal FRET-aptamer assays with low nanogram/milliliter sensitivity. The company also cloned and sequenced 110 bone marker and calcidiol aptamers. During Phase II, OpTech freeze-dried and packaged optimized FRET-aptamer assays for use with a plastic cuvette and body fluid collection system. The assay system is coupled with a handheld, battery-operated fluorometer customized to detect bone markers and calcidiol in urine and serum. Sensitive and accurate (low ng/mL detection with correlation coefficients >0.95), the innovation produces results in 15–30 minutes.

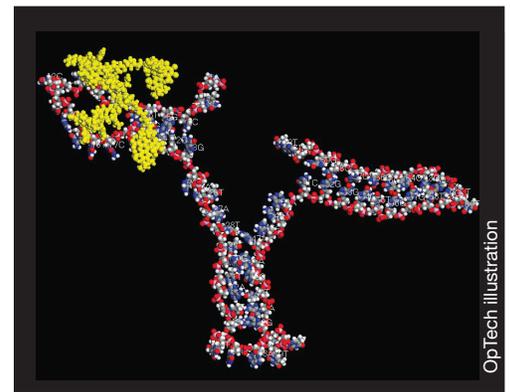
Applications

NASA

- ▶ Astronaut self-monitoring of bone loss and bone loss treatments (e.g., vitamin D augmentation)
- ▶ Monitoring other clinical analytes (e.g., glucose, environmental microbes in water) with development of appropriate FRET assays

Commercial

- ▶ Rapid point-of-care diagnostic system for osteoporosis and its treatment
- ▶ Monitoring system for bone repair following severe fractures and skeletal procedures



Phase II Objectives

- ▶ Synthesize red-region Black Hole Quencher® deoxyribonucleotide triphosphates (dNTPs)
- ▶ Screen all 110 Phase I aptamer sequences for best FRET with bone peptides, hydroxylysine, and 25-hydroxyvitamin D₃
- ▶ Complete three-dimensional modeling of selected aptamer targets
- ▶ Freeze-dry and retest FRET assays in serum and urine samples
- ▶ Coordinate optics and firmware changes for operation in red fluorescence window of serum and urine
- ▶ Develop software package
- ▶ Develop and produce plastic cuvette and body fluid sampling syringe system
- ▶ Integrate system components, including assays, handheld sensor, and laptop computer

Benefits

- ▶ Rapid (15–30 minutes)
- ▶ Easy to use aboard a spacecraft, in a physician's office, or at home with freeze-dried assay reagents
- ▶ Compact (handheld fluorometer)

Firm Contact

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Proposal Number: 07-2 X12.01-9625

Thioaptamer Diagnostic System (TDS)

Quickly identifies up to 32 biomarkers in a single sample

AM Biotechnologies, LLC, in partnership with Sandia National Laboratories, has developed a diagnostic device that quickly detects sampled biomarkers. The TDS quickly quantifies clinically relevant biomarkers using only microliters of a single sample. The system combines ambient-stable, long shelf-life affinity assays with handheld, microfluidic gel electrophoresis affinity assay quantification technology. The TDS is easy to use, operates in microgravity, and permits simultaneous quantification of 32 biomarkers.

In Phase I of the project, the partners demonstrated that a thioaptamer assay used in the microfluidic instrument could quantify a specific biomarker in serum in the low nanomolar range. The team also identified novel affinity agents to bone-specific alkaline phosphatase (BAP) and demonstrated their ability to detect BAP with the microfluidic instrument. In Phase II, AM Biotech expanded the number of ambient affinity agents and demonstrated a TDS prototype. In the long term, the clinical version of the TDS will provide a robust, flight-tested diagnostic capability for space exploration missions.

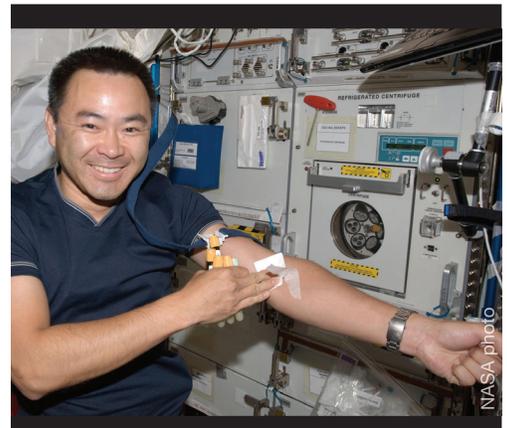
Applications

NASA

- ▶ In-flight diagnostics for health research and monitoring
- ▶ Opportunities for novel biomarker discovery
- ▶ Research on the International Space Station (ISS) regarding human adaptation to microgravity

Commercial

- ▶ Clinical research tool for novel biomarker discovery
- ▶ Handheld diagnostic system for remote, resource-poor locations
- ▶ Rapid diagnostic device for use by first responders and physician offices
- ▶ Affordable diagnostic system for university research laboratories and companies with limited budgets



Phase II Objectives

- ▶ Optimize binding agents demonstrated in Phase I of the project
- ▶ Select additional binding agents for next round of biomarkers
- ▶ Improve assay performance in serum
- ▶ Develop stand-alone prototype for NASA demonstrations

Benefits

- ▶ Eliminates the need to freeze samples on the ISS and return them to Earth for ground-based testing
- ▶ Operates in microgravity
- ▶ Is easy to use, self-contained, automated, and lightweight (<10 pounds)
- ▶ Requires minimal sample volumes (microliters)
- ▶ Is sensitive and rapid (<10 minutes)
- ▶ Permits simultaneous quantitation of 8–32 biomarkers
- ▶ Offers long-term reagent stability at ambient temperatures

Firm Contact

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Proposal Number: 08-2 X10.01-9543

Wideband Single Crystal Transducer for Bone Characterization

Quantifying bone degradation with high-resolution ultrasound

TRS Technologies, Inc., has developed a wideband ultrasound diagnostic tool for quantifying bone degradation of astronauts during long-duration space missions. The tool measures backscatter, attenuation, reflectivity, and other ultrasound parameters of bone in the spine and hip. These parameters have been correlated with physiological bone density, structure, and porosity through systems that provide high fidelity but are not space-capable.

In Phase I, TRS Technologies demonstrated that a compact ultrasound transducer with more than a 4-octave bandwidth could be produced using the special properties of single-crystal piezoelectrics and special processing techniques. (A 4-octave bandwidth is 175 percent larger than that of conventional transducers.) In Phase II, the company extended the capabilities of the Phase I transducer by providing more sensitivity and optimizing the frequency content relative to the acoustic field.

In addition to its use as a bone characterization tool, the technology can be used to examine space structures to evaluate microcrack progression over long-duration missions. The technology also could be useful in wideband medical imaging.

Applications

NASA

- ▶ Quantifying bone degradation
- ▶ Evaluating microcrack progression of space structures

Commercial

- ▶ Wideband medical imaging
- ▶ Cancer analysis
- ▶ Industrial and defense applications, with expansion to other frequency ranges



Phase II Objectives

- ▶ Optimize the Phase I transducer for sensitivity
- ▶ Test different transmit signals for optimum performance
- ▶ Demonstrate compatibility with electronics
- ▶ Confirm additional transducer capabilities over conventional systems by calibrating with other methods

Benefits

- ▶ Low cost
- ▶ Simple to use
- ▶ Launch-capable
- ▶ Robust
- ▶ Nonionizing modality

Firm Contact

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Proposal Number: 10-2 X12.02-9668

On-Orbit, Immuno-Based, Label-Free White Blood Cell Counting System with Microelectromechanical Sensor Technology (OILWBCS-MEMS)

For counting multiple cell types in space flight and terrestrial environments

Aurora Flight Sciences, in partnership with Draper Laboratory, has developed a miniaturized system to count white blood cells in microgravity environments. The system uses MEMS technology to simultaneously count total white blood cells, the five white blood cell differential subgroups, and various lymphocyte subtypes. The OILWBCS-MEMS detection technology works by immobilizing an array of white blood cell-specific antibodies on small, gold-coated membranes. When blood flows across the membranes, specific cells' surface protein antigens bind to their corresponding antibodies. This binding can be measured and correlated to cell counts.

In Phase I, the partners demonstrated surface chemistry sensitivity and specificity for total white blood cells and two lymphocyte subtypes. In Phase II, a functional prototype demonstrated end-to-end operation. This rugged, miniaturized device requires minimal blood sample preparation and will be useful for both space flight and terrestrial applications.

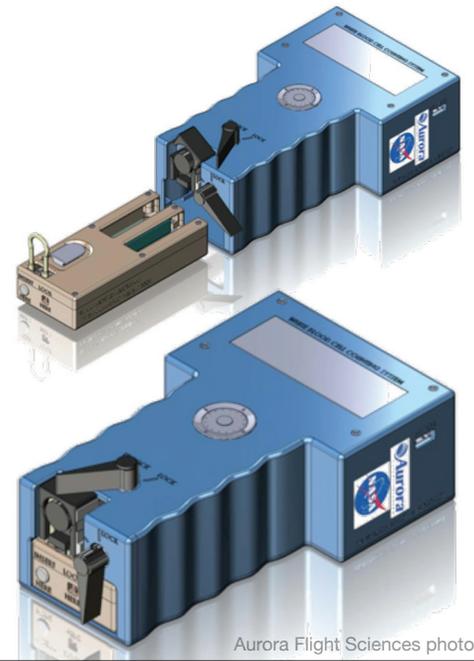
Applications

NASA

- ▶ On-orbit white blood cell counting
- ▶ Ground-based biomedical research and development

Commercial

- ▶ Immuno-based cell counting in biotechnology and medical industries
- ▶ Cell counting in remote locations:
 - Battlefield environments
 - Mobile triage units
 - Medical centers in the developing world



Aurora Flight Sciences photo

Phase II Objectives

- ▶ Refine surface chemistry design
- ▶ Continue long-term storage studies
- ▶ Transfer surface chemistry to nanohole array device
- ▶ Miniaturize subsystem prototype design and development
- ▶ Integrate, test, and verify functional prototype
- ▶ Report results

Benefits

- ▶ Simultaneous counting of multiple cell types
- ▶ High specificity and sensitivity
- ▶ Compact size
- ▶ Low power consumption
- ▶ Fully automated

Firm Contact

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Proposal Number: 08-2 X14.02-9864

Observation Platform for Dynamic Biomedical and Biotechnology Experiments Using the International Space Station (ISS) Light Microscopy Module (LMM)

Innovation will greatly accelerate ISS biomedical experiments

Techshot, Inc., has developed an observation platform for the LMM on the ISS that will enable biomedical and biotechnology experiments. The LMM Dynamic Stage consists of an electronics module and the first two of a planned suite of experiment modules. Specimens and reagent solutions can be injected into a small, hollow microscope slide—the heart of the innovation—via a combination of small reservoirs, pumps, and valves.

A life science experiment module allows investigators to load up to two different fluids for on-orbit, real-time image cytometry. Fluids can be changed to initiate a process, fix biological samples, or retrieve suspended cells. A colloid science experiment module conducts microparticle and nanoparticle tests for investigation of colloid self-assembly phenomena. This module includes a hollow glass slide and heating elements for the creation of a thermal gradient from one end of the slide to the other. The electronics module supports both experiment modules and contains a unique illuminator/condenser for bright and dark field and phase contrast illumination, power supplies for two piezoelectric pumps, and controller boards for pumps and valves. This observation platform safely contains internal fluids and will greatly accelerate the research and development (R&D) cycle of numerous experiments, products, and services aboard the ISS.

Applications

NASA

- ▶ On-orbit analysis of cultured cells from biotechnology experiments
- ▶ Cultivation and analysis of microbial samples
- ▶ On-orbit blood analysis
- ▶ Real-time observations of cell growth and differentiation
- ▶ Colloid physical self-assembly and crystallization experiments

Commercial

- ▶ Magnetic cell separation and analysis technologies



Techshot, Inc. photo

Phase II Objectives

- ▶ Develop detailed technical requirements document
- ▶ Design and build components to space flight specifications:
 - Electronics module to fit cold plate of LMM
 - Life science experiment module
 - Colloid science experiment module
- ▶ Develop the LMM Dynamic Stage observation platform verification plan
- ▶ Test the observation platform subsystems using the verification plan
- ▶ Complete laboratory testing via specific biology and physics microscopy observations and ground experiments

Benefits

- ▶ Enables more versatile biomedical experiments aboard the ISS
- ▶ Accelerates R&D cycles for numerous experiments, products, and services
- ▶ Creates novel uses and users of the LMM on the ISS

Firm Contact

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Proposal Number: 09-2 03.03-9290

Portable Cathode-Air Vapor-Feed Electrochemical Medical Oxygen Concentrator (OC)

A lightweight and robust alternative to conventional pressure-swing technology

Missions on the International Space Station and future space exploration will present significant challenges to crew health care capabilities, particularly in the efficient utilization of onboard oxygen resources. Exploration vehicles will require lightweight, compact, and portable oxygen concentrators that can provide medical-grade oxygen from the ambient cabin air. Current pressure-swing adsorption OCs are heavy and bulky, require significant start-up periods, operate in narrow temperature ranges, and require a liquid water feed. Lynntech, Inc., has developed an electrochemical OC that operates with a cathode-air vapor feed, eliminating the need for a bulky onboard water supply.

Lynntech's OC is smaller and lighter than conventional pressure-swing OCs, is capable of instant start-up, and operates over a temperature range of 5–80 °C. Accomplished through a unique nanocomposite proton exchange membrane and catalyst technology, the unit delivers 4 standard liters per minute of humidified oxygen at 60 percent concentration. The technology enables both ambient-pressure operating devices for portable applications and pressurized (up to 3,600 psi) OC devices for stationary applications.

Applications

NASA

- ▶ Portable unit for pre-extravehicular activities
- ▶ Portable unit (with additional inlet filters) in the event of atmosphere contamination events, such as fire
- ▶ Source of oxygen to refill high-pressure ISS tanks

Commercial

- ▶ Oxygen source for commercial and battlefield hospitals and for medical surgeons in deployed locations
- ▶ Home therapy patients that require supplemental oxygen as a primary treatment for chronic obstructive pulmonary disease (COPD) as well as other respiratory conditions such as asthma, chronic bronchitis, congestive heart disease, emphysema, and lung cancer
- ▶ Oxygen source for wound treatment
- ▶ Long-duration oxygen supply for ambulance use



Lynntech, Inc. photos

Phase II Objectives

- ▶ Optimize moisture adsorption at the cathode
- ▶ Optimize the anode flow-field expanded metal package
- ▶ Optimize the membrane electrolyte assembly compression in the OC stack
- ▶ Design and build a prototype OC stack
- ▶ Test, characterize, and deliver a prototype OC system to NASA
- ▶ Establish long-term operational and storage requirements for delivered system
- ▶ Complete a safety analysis, final report, and flight-ready analysis document

Benefits

- ▶ Provides on-demand and/or continuous medical-grade oxygen
- ▶ Delivers 60 percent humidified oxygen gas at pressures of 5 psi and above
- ▶ Enables both ambient-pressure and pressurized (up to 3,600 psi) OC devices

Firm Contact

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Proposal Number: 08-2 X10.01-9124

Electronic Procedures for Medical Operations

Improving comprehension and delivery of medical care

Electronic procedures are replacing text-based documents for recording the steps in performing medical operations aboard the International Space Station. S&K Aerospace, LLC, has developed a content-based electronic system—based on the Extensible Markup Language (XML) standard—that separates text from formatting standards and tags items contained in procedures so they can be recognized by other electronic systems. For example, to change a standard format, electronic procedures are changed in a single batch process, and the entire body of procedures will have the new format. Procedures can be quickly searched to determine which are affected by software and hardware changes. Similarly, procedures are easily shared with other electronic systems. The system also enables real-time data capture and automatic bookmarking of current procedure steps.

In Phase II of the project, S&K Aerospace developed a Procedure Representation Language (PRL) and tools to support the creation and maintenance of electronic procedures for medical operations. The goal is to develop these tools in such a way that new advances can be inserted easily, leading to an eventual medical decision support system.

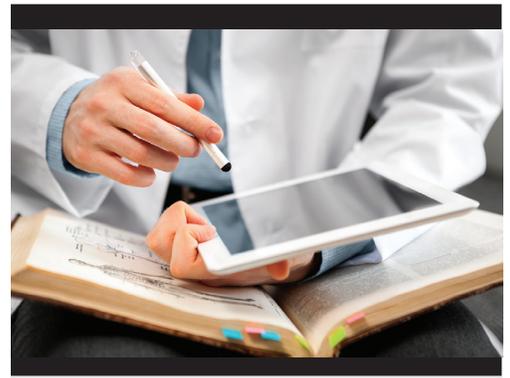
Applications

NASA

- ▶ International Space Station
- ▶ Space exploration vehicles

Commercial

- ▶ Hospitals
- ▶ Emergency medical technicians
- ▶ Firefighters
- ▶ Park rangers
- ▶ Pilots



Phase II Objectives

- ▶ Review medical operations workflow and existing medical procedures
- ▶ Review and update the PRL definition for the next-generation XML for medical procedures
- ▶ Design and prototype a medical equipment database
- ▶ Develop requirements for the procedure display
- ▶ Develop and use a test plan for evaluating the system editor
- ▶ Conduct an evaluation of the prototype
- ▶ Conduct market research for commercial applications

Benefits

- ▶ Improves the comprehension and delivery of medical procedures to flight medical officers and crew
- ▶ Enables a greater degree of coordination with flight surgeons and biomedical engineers on the ground
- ▶ Facilitates easier construction and maintenance of medical procedures

Firm Contact

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Proposal Number: 07-2 03.01-9652

Mini Treadmill for Musculoskeletal Health

For zero-gravity and terrestrial applications

Because NASA's approach to space exploration calls for long-term extended missions, there is a pressing need to equip astronauts with effective exercise regimens that will maintain musculoskeletal and cardiovascular health. ZIN Technologies, Inc., has developed an innovative miniature treadmill for use in both zero-gravity and terrestrial environments. The treadmill offers excellent periodic impact exercise to stimulate cardiovascular activity and bone remodeling as well as resistive capability to encourage full-body muscle maintenance. A novel speed-control algorithm allows users to modulate treadmill speed by adjusting stride, and a new subject load device provides a more Earth-like gravity replacement load.

This new and compact treadmill offers a unique approach to managing astronaut health while addressing the inherent and stringent challenges of space flight. The innovation also has the potential to offer numerous terrestrial applications, as a real-time daily load stimulus (DLS) measurement feature provides an effective mechanism to combat or manage osteoporosis, a major public health threat for 55 percent of Americans over the age of 50.

Applications

NASA

- ▶ Compact treadmill for use in zero-gravity environments

Commercial

- ▶ Mechanism to combat and/or manage osteoporosis



Phase II Objectives

- ▶ Build a technology demonstrator and engineering model
- ▶ Demonstrate that the model will satisfy the stringent volumetric, power, and performance requirements demanded by space missions
- ▶ Provide the active feedback necessary to control the model and display DLS
- ▶ Complete systems engineering and integration activities
- ▶ Prepare detailed mechanical and electrical data acquisition designs
- ▶ Finalize software design
- ▶ Complete component testbed and engineering model
- ▶ Demonstrate subject load device fractional gravity functionality

Benefits

- ▶ Maintains cardiovascular and musculoskeletal health
- ▶ Provides real-time DLS measurement feedback

Firm Contact

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Proposal Number: 06-2 X14.01-9514

Lightweight, Wearable, Metal Rubber™ Sensor

For autonomous health monitoring

NanoSonic, Inc., has developed comfortable garments with multiple integrated sensors designed to monitor astronaut health throughout long-duration space missions. The combined high electrical conductivity, low mechanical modulus, and environmental robustness of the sensors make them an effective, lightweight, and comfortable alternative to conventional use of metal wiring and cabling.

During Phase I of this project, NanoSonic demonstrated the feasibility of using its patented Metal Rubber sheet and fabric materials as sensor elements and highly flexible electrodes integrated into prototype instrumented garments. In feasibility tests, heart rate and electrocardiogram (EKG) data taken with the sensors were essentially identical to those obtained with standard biomedical instrumentation.

In Phase II, NanoSonic improved the sensor materials and integration methods by working with a large-volume U.S. textile manufacturer, the sensor and electronics design group of a major aerospace company, and a biomedical sensor and device laboratory of the U.S. Food and Drug Administration. Specific and notable accomplishments include:

- Designing, fabricating, and evaluating the performance of sensor jerseys
- Developing data acquisition electronics needed to interface with standard storage and communication modules
- Investigating requirements for scaled-up manufacturing

Applications

NASA

- ▶ Astronaut health monitoring
- ▶ Spacecraft instrumentation wiring
- ▶ Large-area radio frequency (RF) antennas, space-based radar, and photovoltaic arrays
- ▶ Ultralow-weight RF and electromagnetic interference shielding and ground planes for spacecraft and aircraft
- ▶ Highly flexible, conductive fairings and electrical interconnects in next-generation morphing air vehicles that change shape to optimize flight conditions
- ▶ Conformal “sensor skins” for unobtrusive measurement of aircraft skin friction and pressure

Commercial

- ▶ Physiological sensor garments for:
 - Emergency first responders
 - Athletes
 - Patients receiving home and institutional health care
 - Security personnel
- ▶ Electrical interconnects in flexible electronic displays
- ▶ Deployable photovoltaic fabrics for electrical power generation
- ▶ Low-weight RF shielding and ground planes for cell phones and other electronic instrumentation
- ▶ Low-weight, conformal RF phased-array antennas
- ▶ Air- and water-flow sensors for aircraft and ship systems
- ▶ Electrical interconnects in next-generation prostheses



NanoSonic, Inc. photo

Phase II Objectives

- ▶ Develop and demonstrate a low-weight, noninvasive, reliable, and comfortable autonomous health monitoring system for use by astronauts
- ▶ Develop an integrated smart sensor garment that can be worn comfortably to continuously monitor physiological status
- ▶ Use the patented Metal Rubber sheet and fabric as both electrical and mechanical sensor elements and flexible, low-weight electrical sensor interconnect materials

Benefits

- ▶ Monitors astronaut health through long-duration space missions
- ▶ Provides a lightweight and comfortable alternative to conventional monitoring systems composed of metal wiring and cables
- ▶ Offers high electrical conductivity and low mechanical modulus

Firm Contact

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Proposal Number: 06-2 X14.02-9306

Lunar Health Monitor (LHM)

A wearable sensor suite for continuous physiological monitoring

Orbital Research, Inc., has developed a low-profile, wearable sensor suite for monitoring astronaut health in both intravehicular and extravehicular activities. The Lunar Health Monitor measures respiration, body temperature, electrocardiogram (EKG) heart rate, and other cardiac functions. Orbital Research's dry recording electrode is central to the innovation and can be incorporated into garments, eliminating the need for conductive pastes, adhesives, or gels. The patented dry recording electrode has been approved by the U.S. Food and Drug Administration. The LHM is easily worn under flight gear or with civilian clothing, making the system completely versatile for applications where continuous physiological monitoring is needed.

During Phase II, Orbital Research developed a second-generation LHM that allows sensor customization for specific monitoring applications and anatomical constraints. Evaluations included graded exercise tests, lunar mission task simulations, functional battery tests, and resting measures. The LHM represents the successful integration of sensors into a wearable platform to capture long-duration and ambulatory physiological markers.

Applications

NASA

- ▶ Astronaut health and exercise monitoring
- ▶ Microgravity countermeasure assessment

Commercial

- ▶ Monitoring of emergency first responders
- ▶ Cardiac arrhythmia and mapping studies
- ▶ Monitoring during exercise and fitness activities
- ▶ Military health monitoring
- ▶ Patient rehabilitation and recovery tracking
- ▶ Pharmaceutical research and development



Orbital Research, Inc. photos

Phase II Objectives

- ▶ Complete design of the second-generation LHM
- ▶ Assemble a fully functioning prototype
- ▶ Demonstrate the performance of the prototype in a clinically and functionally relevant environment and protocol
- ▶ Complete a demonstration in a NASA test facility
- ▶ Review demonstration results and modify design accordingly

Benefits

- ▶ Provides continuous and comprehensive biomedical monitoring
- ▶ Eliminates skin irritation associated with extended exposure to conventional electrode adhesives
- ▶ Is comfortable to wear and quickly donned and doffed

Firm Contact

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Proposal Number: 06-2 X14.02-9443

Wearable Health Monitoring Systems

For use in extreme environments and conventional health care settings

The shrinking size and weight of electronic circuitry has given rise to a new generation of smart clothing that enables biological data to be measured and transmitted. As the variation in the number and type of deployable devices and sensors increases, technology must allow their seamless integration so they can be electrically powered, operated, and recharged over a digital pathway.

Nyx Illuminated Clothing Company has developed a lightweight health monitoring system that integrates medical sensors, electrodes, electrical connections, circuits, and a power supply into a single wearable assembly. The system is comfortable, bendable in three dimensions, durable, waterproof, and washable. The innovation will allow astronaut health monitoring in a variety of real-time scenarios, with data stored in digital memory for later use in a medical database. Potential commercial uses are numerous, as the technology enables medical personnel to noninvasively monitor patient vital signs in a multitude of health care settings and applications.

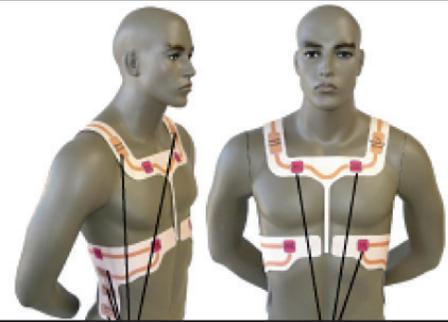
Applications

NASA

- ▶ Astronaut health monitoring:
 - Flight preparation and takeoff
 - Travel and landing
 - General mission activities
 - Health assessment in instances where astronauts cannot verbally communicate
 - Research for future missions

Commercial

- ▶ Medical researchers can noninvasively monitor daily vital signs of one of more patients participating in medical trials.
- ▶ Physicians can monitor patient health status during normal lifetime pursuits or after surgical procedures.
- ▶ Patients can set alarm triggers to warn of excessive risk activities.



Nyx Illuminated Clothing Co. photo

Phase II Objectives

- ▶ Build a working prototype that will demonstrate:
 - Integration of medical sensors, electrodes, electrical connections, circuits, and power supply into a single, wearable assembly
 - Distribution of electrical circuits to reduce bulk
 - Easy replacement of electrodes
 - Ability to measure biological sensor data and transmit it to an external computing device
 - Simplicity of adding medical sensors to the system through use of a digital data bus to reduce overall wiring needs
- ▶ Perform reliability testing and integrate electrocardiogram (EKG) functionality
- ▶ Introduce a specification to allow for snap-fit of new biosensors

Benefits

- ▶ Provides continuous and noninvasive health monitoring in extreme environments
- ▶ Integrates medical sensors and electronic circuitry into a single wearable assembly

Firm Contact

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Proposal Number: 06-2 X14.02-9549

Wearable Beat-to-Beat Blood Pressure Monitor

Provides continuous measurements in extreme environments

Linea Research Corporation has developed a wearable noninvasive monitor that provides continuous blood pressure and heart rate measurements in extreme environments. Designed to monitor the physiological effects of astronauts' prolonged exposure to reduced-gravity environments as well as the effectiveness of various countermeasures, the device offers wireless connectivity to allow transfer of both real-time and historical data. It can be modified to monitor the health status of astronaut crew members during extravehicular missions.

In Phase I of the project, Linea Research demonstrated the feasibility of the device. In Phase II, the company developed and fabricated a field-capable, low-power, lightweight monitor. In addition to supplying monitors to NASA, Linea Research plans to introduce the technology for use in ambulatory, high-acuity, and home-based blood pressure monitors.

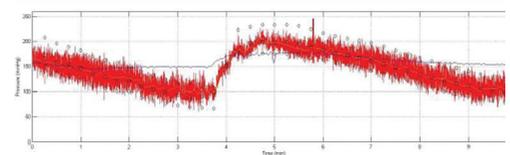
Applications

NASA

- ▶ Medical support for astronauts in reduced- and zero-gravity environments
- ▶ Evaluation of long-term physiological effects of hypogravity and the effects of various countermeasures
- ▶ Support for normal activities and medical emergencies

Commercial

- ▶ Ambulatory blood pressure monitors
- ▶ Home-based blood pressure devices
- ▶ High-acuity (e.g., arterial line replacement) devices



Linea Research Corp. illustration

Phase II Objectives

- ▶ Build a field-capable prototype that can be deployed in space missions:
 - Enhanced optical pulse detection
 - Model-based blood pressure estimation
 - Automated calibration
 - Optimization of algorithm for real-time implementation
 - Wireless connectivity
 - Human factors engineering, miniaturization, and system integration
 - Animal and human studies
 - Field testing of functional prototype

Benefits

- ▶ Enables continuous blood pressure measurement
- ▶ Requires cuff inflation only during calibration
- ▶ Eliminates the need for invasive procedures to obtain blood pressure via arterial lines

Firm Contact

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Proposal Number: 07-2 X12.01-9535

Individualized Behavioral Health Monitoring Tool

Detects warning signs of disorders and conditions

Behavioral health risks during long-duration space exploration missions are among the most difficult to predict, detect, and mitigate. Given the anticipated extended duration of future missions and their isolated, extreme, and confined environments, there is the possibility that behavior conditions and mental disorders will develop among astronaut crew.

Pulsar Informatics, Inc., has developed a health monitoring tool that provides a means to detect and address behavioral disorders and mental conditions at an early stage. The tool integrates all available behavioral measures collected during a mission to identify possible health indicator warning signs within the context of quantitatively tracked mission stressors. It is unobtrusive and requires minimal crew time and effort to train and utilize. The monitoring tool can be deployed in space analog environments for validation testing and ultimate deployment in long-duration space exploration missions.

Applications

NASA

- ▶ Long-duration space exploration missions
- ▶ Astronaut training
- ▶ Training of medical personnel to recognize signs of behavioral distress

Commercial

- ▶ Tracking behavioral health in occupations associated with high stress, high workload, and high danger factors:
 - Military personnel
 - Law enforcement
 - Emergency responders



Phase II Objectives

- ▶ Achieve an individualized behavioral health monitor software interface
- ▶ Develop a data integration system
- ▶ Construct a trend-and-change detection algorithm
- ▶ Complete a countermeasure selection aid

Benefits

- ▶ Detects behavioral disorders and mental conditions at an early stage when they can more easily be addressed
- ▶ Is unobtrusive
- ▶ Requires minimal time to learn and utilize

Firm Contact

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Proposal Number: 09-2 X12.02-9125

Exercise Sensing and Pose Recovery Inference Tool (ESPRIT)

A compact stereo-based motion capture solution for exercise monitoring

Crew exercise is important during long-duration space flight not only for maintaining health and fitness but also for preventing adverse health problems, such as losses in muscle strength and bone density. Monitoring crew exercise via motion capture and kinematic analysis aids understanding of the effects of microgravity on exercise and helps ensure that exercise prescriptions are effective. Intelligent Automation, Inc., has developed ESPRIT to monitor exercise activities, detect body markers, extract image features, and recover three-dimensional (3D) kinematic body poses.

The system relies on prior knowledge and modeling of the human body and on advanced statistical inference techniques to achieve robust and accurate motion capture. In Phase I, the company demonstrated motion capture of several exercises, including walking, curling, and dead lifting. Phase II efforts focused on enhancing algorithms and delivering an ESPRIT prototype for testing and demonstration.

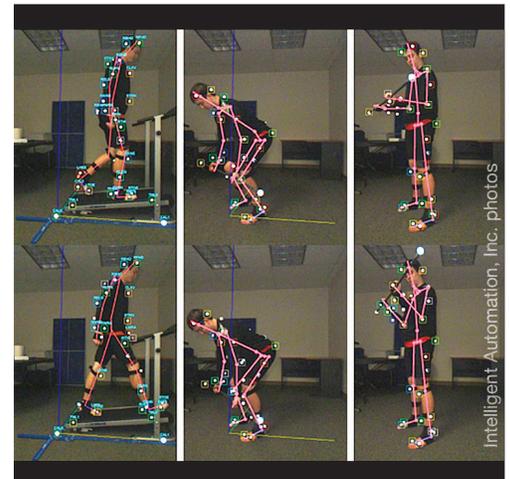
Applications

NASA

- ▶ Observing crew exercise activities
- ▶ Performing motion capture and kinematic analysis
- ▶ Contributing to the understanding of the effects on microgravity on exercise activities

Commercial

- ▶ Rehabilitation research:
 - Gait analysis
 - Orthopedics and skeletal movement monitoring
- ▶ Physiotherapy
- ▶ Human-robotics and human-computer interactions



Phase II Objectives

- ▶ Develop an ESPRIT prototype to perform 3D motion capture from stereo
- ▶ Conduct detailed performance evaluation with comparison of joint location estimation from commercial multicamera motion capture system
- ▶ Conduct technical demonstration in a representative environment

Benefits

- ▶ Compact and portable
- ▶ Fast set-up with minimal cabling
- ▶ Easy to use

Firm Contact

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Proposal Number: 10-2 X11.01-8378

Multimodal Neurodiagnostic Tool for Exploration Missions

For detecting stress markers and providing actionable feedback

Linea Research Corporation has developed a neurodiagnostic tool that detects behavioral stress markers for astronauts on long-duration space missions. Lightweight and compact, the device is unobtrusive and requires minimal time and effort for the crew to use. The system provides a real-time functional imaging of cortical activity during normal activities.

In Phase I of the project, Linea Research successfully monitored cortical activity using multiparameter sensor modules. Using electroencephalography (EEG) and functional near-infrared spectroscopy signals, the company obtained photoplethysmography and electrooculography signals to compute the heart rate and frequency of eye movement. The company also demonstrated the functionality of an algorithm that automatically classifies the varying degrees of cognitive loading based on physiological parameters.

In Phase II, Linea Research developed the flight-capable neurodiagnostic device. Worn unobtrusively on the head, the device detects and classifies neurophysiological markers associated with decrements in behavior state and cognition. An automated algorithm identifies key decrements and provides meaningful and actionable feedback to the crew and ground-based medical staff.

Applications

NASA

- ▶ Monitoring behavioral health of astronaut crew during long-duration space missions
- ▶ Training for the psychological challenges of extended space missions

Commercial

- ▶ Diagnoses and treatment of various neurologic diseases:
 - Multiple sclerosis
 - Epilepsy
 - Tumors
 - Brain abscesses
- ▶ Sleep monitoring
- ▶ Head injury and post-surgery evaluations
- ▶ Psychiatric illness evaluations
- ▶ Ambulatory, multimodality functional imaging of cortical activity



Phase II Objectives

- ▶ Design and fabricate an unobtrusive, flight-capable device that can be deployed for neurodiagnostic monitoring
- ▶ Develop algorithms that use the multimodality measurements to automatically classify neurophysiological markers associated with decrements in behavior
- ▶ Demonstrate and verify that the system provides feedback and automatically recommends countermeasures based on the neurophysiological data

Benefits

- ▶ Monitors behavioral health of astronaut crew during space missions
- ▶ Facilitates training for the challenges of extended space deployments
- ▶ Diagnoses various neurological diseases and psychiatric illnesses
- ▶ Permits autonomous operation
- ▶ Is unobtrusive and automated

Firm Contact

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Proposal Number: 10-2 X13.01-9606

Passive, Collapsible Contingency Urinal for Human Space Flight

Capillary-based fluid management system

Fluid transport systems for spacecraft face acute challenges because of the persistently unfamiliar and unforgiving low-gravity environment. IRPI, LLC, has developed a contingency wastewater collection and processing device that provides passive liquid collation, containment, bubble separation, and droplet coalescence functions. The lightweight, low-volume, low-cost, and potentially disposable device may be used for subsequent sampling, metering, storage, disposal, and/or reuse. The approach includes a fractal wetting design that incorporates smart capillary fluidics. This work could have a broad impact on capillary-based fluid management on spacecraft and on Earth.

Applications

NASA

- ▶ Backup waste collection device
- ▶ Urine sample metering and measuring to monitor crew health

Commercial

- ▶ Biomedical research
- ▶ Lab-on-a-chip technologies
- ▶ Fuel delivery systems
- ▶ Advanced heat pipe wick structures



IRPI, LLC photo

Phase II Objectives

- ▶ Identify, develop, and manufacture surfaces that establish micro- and mesoscale wetting for representative liquids
- ▶ Design a macrocapillary device utilizing micro/mesowetting material that encompasses a fractal wetting design that will provide passive functionality for fluids with variable wetting
- ▶ Incorporate design into an ergonomic and functional device that seamlessly merges mechanical, capillary, and standard interfacing
- ▶ Test each of the subcapillary components, including interfaces and bridges, in a high-rate drop to qualify individual components in low gravity
- ▶ Generate documentation and plans for International Space Station utilization of the developed device

Benefits

- ▶ Lightweight
- ▶ Low cost
- ▶ Low volume

Firm Contact

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