HRS: Rover Technologies

STATUS QUO

- Rich research and development community of terrestrial mobile robots
- Agency flagship Mars rover missions

PROBLEM/NEED BEING ADDRESSED

Low cost rover development that supports searching for volatiles as part of the resource prospector mission

QUANTITATIVE IMPACT

- Add active suspension up to 8 cm (compared to passive suspension in MER/MSL
- Pace of planning up to 4/hr (compared to 1/sol in MER/MSL)

NEW INSIGHTS

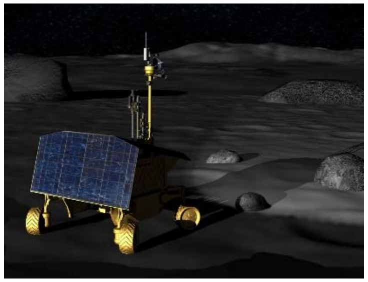
- NASA is developing a culture of Class D low cost, "high" risk missions (LRO, LADEE, small sat, etc). An opportunity exists to extend this into the rover regime that will be parallel to the existing flagship SMD Mars rover missions

PROJECT DESCRIPTION/APPROACH

- Develop and advance TRL of rover technologies, focusing on Resource Prospector mission
- Build and test prototype rover in FY15
- Advance TRL through test in FY16/17
- Develop new approaches to navigation, sensing and rover operations for high paced operations and short duration missions.

PROJECT GOAL

- Develop rover and rover technologies to be infused into Resource Prospector mission and future surface missions



HRS: Space Robotics Challenge

STATUS QUO

- Little autonomy in NASA robotics
- Humanoids that cannot fully function as assistants to crew
- Rovers are only robots prepared for pre-cursor missions

PROBLEM/NEED BEING ADDRESSED

NASA humanoid robots need more autonomy for Mars-mission type scenarios

PROJECT DESCRIPTION/APPROACH

- Redesign Valkyrie robot for sensing needs
- IHMC provides robust walking software
- Build 2 new Valkyrie robots
- Provide robots to US research teams through competitive bidding
- Administer Space Robotics Challenge as two-tiered, two-track competition
  - Virtual competition is tier 1, physical competition is tier 2
  - Robonaut 2 and Valkyrie will be competition platforms

QUANTITATIVE IMPACT

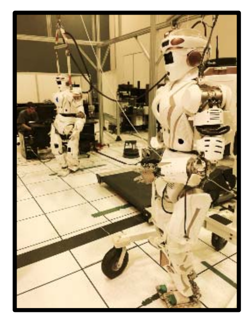
- More autonomous skill sets for mobile, dexterous robots
  - Dual-arm manipulation while walking or climbing
  - Handling of soft good items

NEW INSIGHTS

- How can we best integrate autonomous software from the greater robotics research community onto NASA robotic platforms?

PROJECT GOAL

- To provide a complex humanoid platform for US research teams to test their advanced autonomy software



NRI Grant:

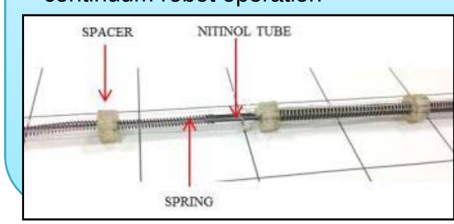
Long, Thin ‘Continuum’ Robots for Space Applications

STATUS QUO

- Nature – tails, trunks, tentacles
- Tendril – developed in a joint effort between Clemson University and NASA 2006
- Cottar Continuum Manipulator - Clemson
- CardioArm - Carnegie Mellon 2008

NEW INSIGHTS

- Key understanding gained in earlier collaborative work with NASA enables fundamentally new research directions
- Clemson continuum laboratory has been developed over the past 15 years under funding from NASA, DARPA, and the NSF
- Team has gained significant expertise in software environments for real-time continuum robot operation

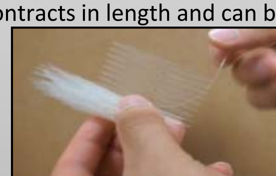


PROBLEM/NEED BEING ADDRESSED

NASA needs the ability to remotely inspect tight areas in space vehicles, such as behind racks on ISS, inside payload containers, and beneath thermal blankets, or to perform robust manipulation / exploration within inaccessible regions of extra-terrestrial bodies

PROJECT DESCRIPTION/APPROACH

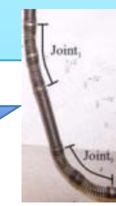
- Conduct R&D of long, thin, continuous backboned or “continuum” robots to solve problems of interest to NASA
- Collaborate with JSC, JPL, and GSFC
- The proposed research has two high-level objectives:
  - Develop long thin continuum robots featuring capabilities significantly beyond the state of the art
  - Demonstrate the ability of new capabilities to transform application scenarios of particular interest to NASA
- The research plan is structured in 3 thrusts:
  - Evaluate of a set of design alternatives, down-selecting through prototypes and testing to final robot hardware
  - Empirical investigation of the ability of new robots to penetrate and investigate tight, narrow spaces
  - Research in grasping & manipulation with long thin robots
- Preliminary findings in FY14 have lead to discovery of a new approach and prototyping of a scaly membrane that expands and contracts in length and can be locked into a shape



- Completing 2nd year of NRI research in FY14
- Cost/Schedule: $105K 2nd yr. / $545K total over 5 years

QUANTITATIVE IMPACT

- – Improved smoothness of motion
- – Improved ability to attain predicted amounts and locations of bending
- – Improved durability
- – Increased response speed
- – Improved ability to penetrate and maneuver within tight spaces
- – Improve / Develop algorithms to predict and control bending behavior



PROJECT GOAL

- Extend the state of the art to create robots with capabilities previously unattainable

Potential Applications:

- NASA – ISS, future exploration missions
- Homeland Security - safe inspection of tight spaces such as inside cars
- Agriculture & Env. Protection - nondestructive robotic access to more remote environments
- Medicine - sensing and surgery in complex parts of the body
- Industry - novel approaches to constraint and manipulation

NRI Grant:

A Novel Powered Leg Prosthesis Simulator for Sensing & Control Development

STATUS QUO

Current prosthetic leg devices have limited degrees of freedom or limited output capacity and can only be used for walking at low to moderate speeds

No leg prostheses yet match the performance of a living leg, but a few are making strides toward the goal

NEW INSIGHTS

- **New Sensing Technology :**

  Proprio Foot - quasi-passive ankle-foot device that uses sensors to determine the wearer's phase in the gait cycle

- **More Sophisticated Actuation :**

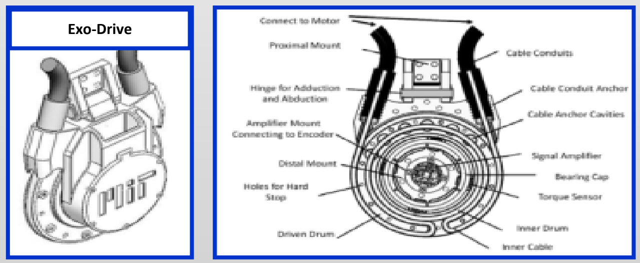
  PowerFoot - the 1st robotic ankle-foot prosthesis, uses inertial measurements & torque sensors to make informed decisions on the control of a series-elastic actuator that propels the user forward with each step

PROBLEM/NEED BEING ADDRESSED

Designers of powered prosthetic legs, exoskeleton legs, & robot legs lack the means to quickly search the design space hardware and control systems for optimal solutions

PROJECT DESCRIPTION/APPROACH

- Develop leg prosthesis simulator capable of applying specific model-predicted torques to both prosthetic & residual limbs of amputees and robot or exoskeleton legs
- Using a cable drive mechanism (Exo-Drive), the simulator will apply torque to both prosthetic and residual limb joints while an amputee or robot walks on a treadmill



- Collect kinematic, kinetic, elctromyographic, and metabolic data to develop a knowledge base that can be used to assess electromechanical prosthetic devices their control strategies
- Demonstrate that with the correct control scheme, the simulator can enable amputees to regain normal gait
- Phase 1 (FY13-15) – design/build Transtibial Prosthesis Simulator; program model-based control & sensing; evaluate on walking transtibial amputees or NASA Robonaut
- Collaborate with JSC Exoskeleton team on wearable robotics
- Completing 2nd year of NRI research in FY14
- Cost/Schedule: $246K 2nd yr. / $1.176 M total over 5 years

QUANTITATIVE IMPACT

The simulator will:

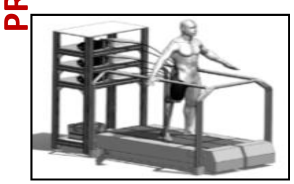
- Allow simulation of different prosthetic/ robotic hardware sensing & control schemes
- Provide useful test platform for NASA robotics
- Allow NASA to test Exo device and Robonaut legs with different control schemes
- Allow NASA to characterize human-machine performance

The Exo-Drive development will provide:

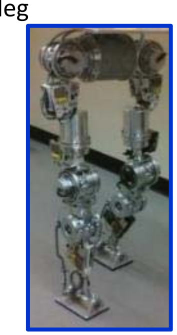
- Antagonistic control, cable termination, tendon-life, and torque/force sensing data relevant to NASA's new Exo design & Robonaut's hands
- Kinetic and kinematic data that will enable creation of new prosthetics that allow amputees to regain a normal gait, Improve ambulatory speed, and Improve stability

PROJECT GOAL

Provide prosthetics and robotics designers the simulation tools and data necessary to allow creation of prosthetics / robotic limbs that more closely imitate the motion of the human leg



Simulator with amputee volunteer & prosthetic leg



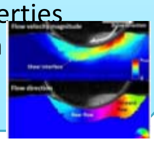
NRI Grant:
Long-range Prediction of Non-Geometric Terrain Hazards for Reliable Planetary Rover Traverse

STATUS QUO

- Stereo Cameras and LIDAR sensors excel at sensing geometric obstacles, but fail to detect hazards like weak or slippery terrain
- Mars Exploration Rover Spirit
- Honeybee Robotics percussive drive mounted on NASA K10 rover

NEW INSIGHTS

- Recent research into sensing of non-geometric terrain properties takes a “drive-by-feel” approach, where terrain properties are measured by driving over the terrain and comparing observed motion to actuation effort
- The measurements are correlated with terrain appearance to predict upcoming hazards
- While effective at short range, this approach is indirect and cannot measure terrain properties without wheel-terrain



PROBLEM/NEED BEING ADDRESSED

NASA needs better ways of detecting non-geometric terrain hazards such as soft soil, because they are mission-enders for autonomous ground vehicles on Earth and beyond - *Spirit* was mired in soft soil on Mars and *Lunokhod* got stuck in regolith on the Moon

PROJECT DESCRIPTION/APPROACH

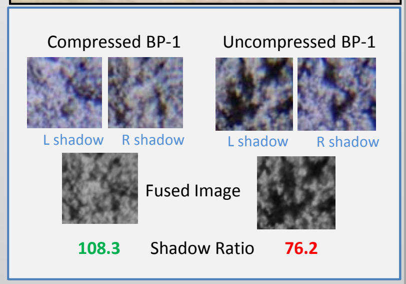
FY14

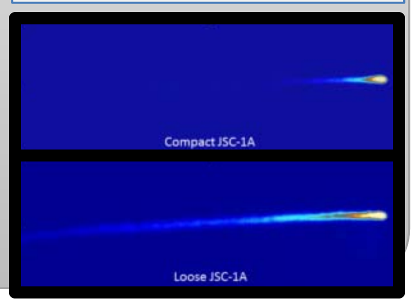
- Investigate use of multiple sensing modes for short & long range terrain property measurement
- Stereo visual odometry and wheel odometry to determine instantaneous slip on slopes
- Standoff microscopy to reveal surface structure and particle distribution to infer compaction
- Use laser to heat soil in front of rover and thermal imaging to view the heat pattern to infer the level of compaction

FY15

- Develop self-supervised learning software that can map multi-mode long-range sensor data to terrain properties
- Develop receding horizon contingency planning s/w that applies learned models of vehicle-terrain interaction to maintain stability and safety

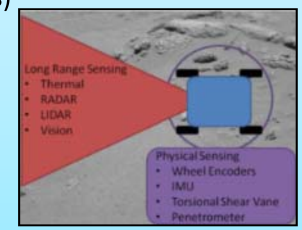
- Completing 2nd year of NRI research in FY14
- Cost/Schedule: \$249K 2nd yr. / \$761K total over 3 years





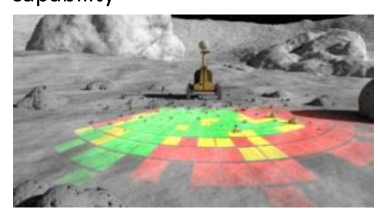
QUANTITATIVE IMPACT

- Improve ability to determine slippage on slopes utilizing high-fidelity high-frequency visual odometry (goal 97% accuracy)
- Develop methods of predicting loose soil at long range (previous methods = 0; goal = 2 to 3 methods)



PROJECT GOAL

- Develop method for robots to perceive and react to terrain hazards before engaging
- Overcome one of the major barriers to infusion of automated safety features in passenger cars - hazard assessment
- Fast, robust, predictive assessment of hazard will enable driving, working and exploring near the limits of machine capability



NRI Grant:

Active Skins for Simplified Tactile Feedback in Robotics

STATUS QUO

- Tactile sensing has been a topic in robotics for over 30 years
- Effective grasping of soft deformable objects, (including people in medical contexts) requires knowledge of the forces the robot is applying
- Inexpensive Force Sensitive Resistors (FSR) have been around for over a decade and have been used for tactile sensing, but no one has yet achieved highly integrated sensor *systems*

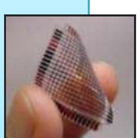
NEW INSIGHTS

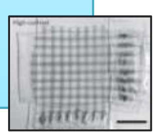
The fundamental breakthrough required to provide sense of touch is development of tactile sensing *systems* that address everything from the sensors to the manufacturing and cost to the integration (wiring, control, etc.)

Robotic hands have made significant progress over the last few years, but lack high- density tactile sensors

Build on existing successes in:

- Sensor development
- Micro-manufacturing
- Miniaturization of electronics
- More rigid polymers (a)
- Elastomers combined w/ metal (b)
- Highly stretchable elastomer and carbon nanotube networks (c)





PROBLEM/NEED BEING ADDRESSED

Robots working alongside people or interacting with us require a *sense of touch* to safely and effectively interact with us and to handle soft, fragile, or deformable objects (often designed only for human use)

PROJECT DESCRIPTION/APPROACH

The primary focus of this research is on development of a *tactile sensing system* for dexterous manipulation using:

- scalable micro-fabrication methods,
- reduced order modeling of elastomer deformations, and
- distributed computation in embedded CMOS

The goal is to produce soft, conformable, robotic skins with active embedded sensors and processing that will allow a robot to easily acquire and interpret tactile data

- Completing 2nd year of NRI research in FY14
- Cost/Schedule: \$232K 2nd yr. / \$697K total over 3 years

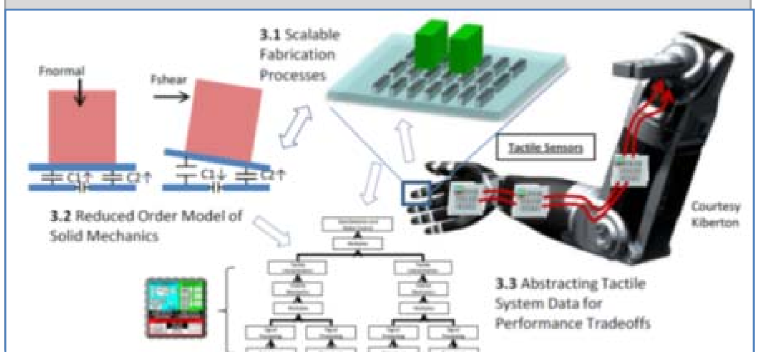


Figure 1. The proposed research plan begins with scalable fabrication processes to create all-elastomer tactile sensors, develops reduced order models to solve the inverse mechanics problem, and studies how to best partition computation for various performance tradeoffs.

QUANTITATIVE IMPACT

Target specifications:

- Force sensitivities in 3 axes of 1 mN to 1 N
- Dynamic range of 1000:1 to cover a wide range of manipulation tasks
- Thickness under 500 mm
- Bandwidth for a single tactile pixel of approximately 1 kHz
- Minimum spatial resolutions of 1 sensor per millimeter
- Power < 10 mW per fingertip

Tactile data will be especially important for 21st century robots that interact with soft, deformable objects, including people

PROJECT GOAL

- Goal is to create soft, conformable, robotic skin with active embedded sensors and processing and share the advances
- These active skins will be combined with future collaborations to integrate large array touch sensing on industrial, medical, and home-care robots
- Findings from this project will be periodically posted to iMechanica.org to expose the mechanics community to state-of-the-art tactile sensing for robotics
- Upon completion, the PIs will write a review article summarizing their findings
- Short videos will be posted to YouTube for broader public education as well

NRI Grant: Actuators for Safe, Strong, & Efficient Humanoid Robots

STATUS QUO

- Existing actuator knowledge has significant deficiencies
  - Commonly stated that electromechanical actuators have low power & low torque/mass ratios compared to hydraulics or pneumatics
  - Pneumatics often characterized as having a high torque density, but are more challenging to control
- Most actuator components have not been tailored for specific joint function
- Current approach is to select the equipment believed to best fit a balance of torque, speed, efficiency, & control requirements
- There has been little research on the optimization of an entire actuator electric drive (power converter, electric machine, and control)

NEW INSIGHTS

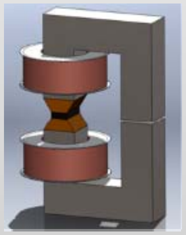
- New materials, new control strategies, and high-bandwidth power electronic converters make traditional machine design practices highly conservative
- This team has developed design tools for several classes of electric machine/power converter systems which are not based on traditional design practices, but are instead based on formal and rigorous multi-objective optimization techniques
- Purdue successfully optimized, constructed, and tested several machines using this approach, including a permanent magnet (PM) elbow actuator motor designed as a replacement for one on NASA's Robonaut 2

PROBLEM/NEED BEING ADDRESSED

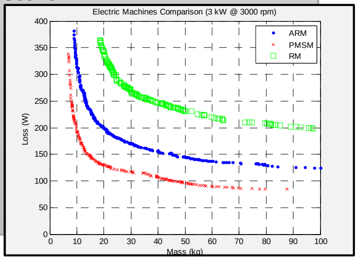
Current robotic actuators are not efficient enough to meet the requirements of future lightweight robots, exoskeletons, and prosthetics.

PROJECT DESCRIPTION/APPROACH

- Rigorously address technical issues associated with multi-objective optimization of actuators used in humanoid robots to provide means to design actuators that are on the boundary of theoretically achievable performance
  - Provide a rigorous approach to custom design of actuators tailored to specific joint function
  - Integrate the multi-domain models of power converters, controls, joint load profiles, and electric machines
  - Use formal multi-objective optimization to determine the boundaries of achievable performance for several existing and novel actuator drive topologies
  - Apply & experimentally validated results using the knee joint of NASA's Robonaut 2 as a primary design example



- In parallel, investigate new classes of electric machinery for actuators, including:
  - Reluctance & permanent magnet machines
  - Magnetic gearbox assemblies
  - Lundell (claw-pole) motors
- Finishing 2nd year of NRI research
- Cost/Schedule: \$165K 2nd yr. / \$497K total over 3 years



QUANTITATIVE IMPACT

- Actuators that are formally optimized for specific joint function will lead to significant improvements in the design of:
  - Humanoid Robots
  - Exoskeletons
  - Prosthetic Joints
- Potential benefits include:
  - Increased Strength
  - Increase Endurance
  - Mass Reduction

PROJECT GOAL

- Provide NASA with methods to custom-design robotic actuators that are on the boundary of theoretically achievable performance
- New projects based upon actuator design will be integrated into both undergraduate and graduate courses, effectively transferring the knowledge to many generations of students

NRI Grant:

Manipulating Flexible Materials

STATUS QUO

- Prior work by the PI has demonstrated that using force and tactile sensing to localize flexible materials is a feasible approach for small-scale manipulation problems
- However, it is difficult to scale the approach up to large problems because of the challenges involved in developing a haptic model of what the material is expected to "feel" like
- The problem is that it is hard to model flexible materials analytically and it can be difficult to gather a sufficiently large amount of training experience to train an accurate model

NEW INSIGHTS

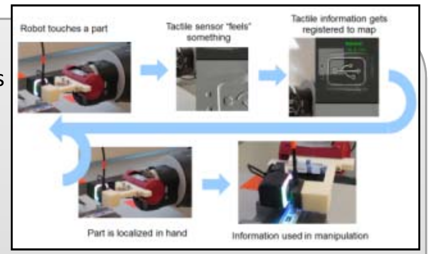
- Sparse coding has produced state-of-the-art results in speech, text, and image classification domains
- Similar results can be achieved in manipulation where it is important to learn from very few labeled examples
- PI lead dev of R2 control & autonomy and is uniquely qualified to develop these applications on R2
- In FY13 the team developed a novel sensor arrangement using the GelSight sensor

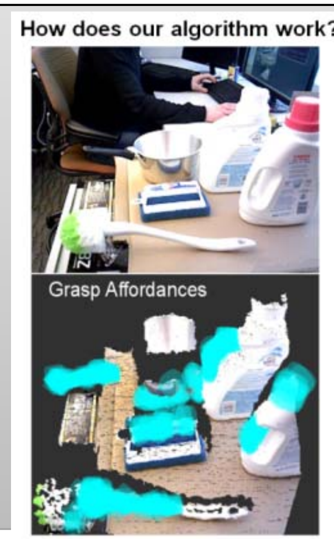
PROBLEM/NEED BEING ADDRESSED

Manipulating flexible/deformable objects is a key challenge in developing robots to work with humans in manufacturing & space (NASA EVA repair often requires manipulation of thermal blankets to access equipment

PROJECT DESCRIPTION/APPROACH

- Use force & tactile sensing to localize flexible materials
- Develop and test 2 ideas representative of NASA applications:
  - Use sparse coding to enable the robot to learn a set of haptic basis vectors that encode "micro-scale" haptic structure common to all objects from easy-to-obtain unlabeled data
  - Use techniques from robot localization & mapping to create haptic models of objects based on unstructured training data
- Develop applications on Barrett arm/hand system
- Aspects of the applications will also be tested using Robonaut 2 at GM
- Finishing 2nd year of NRI research
- Cost/Sched: $254K 2nd yr. / $756K total over 3 years





QUANTITATIVE IMPACT

- Enable dexterous robots to perform work that only humans can currently perform
  - Robots could perform dangerous EVA tasks with thermal blankets, cable routing, etc.
  - Potential of large impacts on manufacturing flexible materials & deformable parts, which are common in US manufacturing, but where there is no automated assembly as yet

PROJECT GOAL

- Make it easier & less expensive to create haptic models for use by robots
- Make data sets & software publicly available to the research community
- Disseminate tactile data sets that can be downloaded and used by robot manipulation researchers everywhere
- Plan to make ROS packages available that other researchers with access to a properly configured Barrett arm/hand system can use to replicate our results

NRI Grant:

Whole-Body Telemanipulation of the Dreamer Humanoid Robot on Rough Terrains Using a Hand Exoskeleton

STATUS QUO

Current manufacturing robots are expensive and limited to pre-programmed tasks. Most robots are designed and built for a specific task and can not perform the tasks of other robots. There are no manufacturing robots that are truly dexterous and capable of performing many dissimilar tasks

NEW INSIGHTS

Physical human-robot interaction (pHRI), an emerging technology, is the study of biological principles governing human motion and using them to realize mechatronic technologies for robotics. A general theoretical & computational framework to model & control pHRI systems has not yet been consolidated. The team recently developed & implemented a Whole-Body Compliant Control Architecture (WBC) in the *Dreamer* humanoid robot, the Willow Garage *PR2* robot and R5 demonstrating feasibility of endowing whole-body compliant skills to mobile dexterous robots.

PROBLEM/NEED BEING ADDRESSED

NASA currently lacks a robust method of remotely controlling (tele-operating) the whole body of a humanoid robot, especially over rough terrain

PROJECT DESCRIPTION/APPROACH

- Design an anthropomorphic hand exoskeleton, to be worn by a user, to provide natural control of a humanoid robot and force feedback to the user
- Integrate previous efforts in whole body manipulation and control with new efforts in pHRI to efficiently control mobile humanoid robots in manufacturing settings and on rough terrains as follows:
  - Develop a whole-body compliant control & modeling paradigm for the humanoid robot *Dreamer*
  - Design and build novel hand exoskeleton for telemanipulation of *Dreamer*
  - Develop a computational infrastructure for transferring the exoskeleton control skills to telemanipulation of Dreamer in complex & changing manufacturing environments
- Collaborate with JSC on whole-body tele-manipulation
- Completing 2nd year of research in FY14
- Cost/Schedule: \$345K 2nd yr. / \$1.38M total over 4 years

QUANTITATIVE IMPACT

- Provide cost effective, intuitive, natural means for people to control mobile dexterous robots
- Enable small & medium size manufacturing businesses to become competitive worldwide
- Revive and improve the state of manufacturing in the U.S.

PROJECT GOAL

- Develop a control framework for telemanipulation of low-cost mobile & dexterous robots, keeping humans at the center of the control loop by retargeting low-level exoskeleton gestures to sophisticated humanoid skills
- Provide NASA with a robust, natural method of tele-operating humanoid robots via an exoskeleton hand control Create interdisciplinary environment enabling:
  - Education, training, and co-advising of grad & undergrad students
  - Target outreach activities to underrepresented groups in science and engineering in Texas and Maine

NRI Grant:

Toward Humanoid Avatar Robots for Co-exploration of Hazardous Environments

STATUS QUO

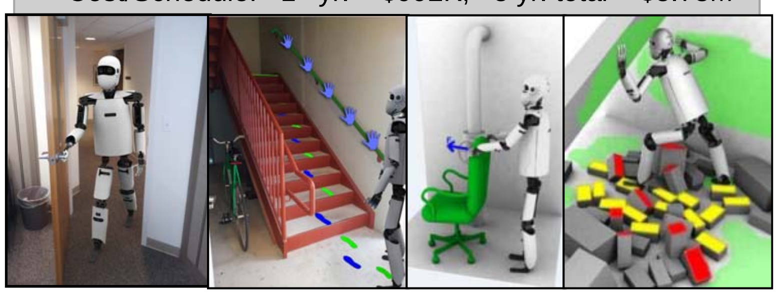
Today's robots are typically fully tele-operated, placing a large burden on the operator, or have autonomy that is opaque, leading to automation surprises. Today's best humanoids still fall over from slight pushes and cannot walk on even slightly rough ground without a high precision model of the surface

PROBLEM/NEED BEING ADDRESSED

Robots lack the mobility and reliability required to safety interact with humans and other robots, and lack the coordination required to ambulate to and do useful work in hazardous environments

PROJECT DESCRIPTION/APPROACH

- Existing open source robotics software libraries will be extended to make them more transparent, directable, and predictable in the avatar system.
- Demonstrate alternate approach to pure tele-operation or pure autonomy
- Demonstrate feasibility of using human-humanoid avatar robot teams for co-exploration of hazardous environments
- Improve humanoid motion planning in complex, dynamic, and unstructured environments
- Development will be focused on NASA's R5, which is available to the team through an existing cooperative agreement with NASA.
- Completing 2nd year of research in FY14
- Cost/Schedule: 1st yr. = $992K, 5 yr. total = $5.78M



NEW INSIGHTS

- Key understanding gained in earlier collaborative work with DARPA enables fundamentally new research directions

QUANTITATIVE IMPACT

– Improved balance algorithms
– Improved walking algorithms
– Ability to move over unstructured environments such as the scene of an accident or the surface of another planet or moon

PROJECT GOAL

Demonstrate feasibility of using human-humanoid avatar robot teams for co-exploration of hazardous environments using R5 as a testbed

NRI Grant:
Building the Robotic Commons

STATUS QUO

- Until recently, robotic software and hardware development has been an extremely expensive and time consuming effort to undertake
- NASA had to write all their own software from scratch for each new form of robot

NEW INSIGHTS

- Robot Operation System (ROS) – open source libraries and tools to help software developers create robot applications
- Gazebo Project - a 3D multi-robot simulator with dynamics. It is capable of simulating articulated robot in complex and realistic environments http://gazebosim.org/
- Willow Garage PR2 – developed PR2 robot, a robotics research and development platform that lets developers innovate right out of the box without building hardware and software from scratch

PROBLEM/NEED BEING ADDRESSED

Support the Open Source Robotics Foundation (OSRF) in continued development of ROS, Gazebo, and other open source robotics software utilized by NASA to reduce software development costs

PROJECT DESCRIPTION/APPROACH

- Continue development of Robot Operating System (ROS), currently used by a number of NASA robotics projects
- Continue development of Gazebo robot simulator
- Continued development, distribution, and adoption of open source software for use in robotics research, and education
- Work with JSC, JPL and ARC on robotic s/w –ROS has recently been integrated with R2 space legs, R5, Centaur 2
- Completing 2nd year of research in FY14
- Cost: 2nd yr. = $334K, 3 yr. total = $1M

QUANTITATIVE IMPACT

- Improve capabilities and performance of open source ROS software
- Improve Gazebo robotics simulator capabilities
- Gain new insights and capabilities for disaster response robots

PROJECT GOAL

- Advance the overall capabilities and performance of ROS and Gazebo for use by NASA's robotics projects
- Advance existing state of the art in robotics for disaster response

BAA Grant:

Representing and Exploiting Cumulative Experience with Objects for Autonomous Manipulation

STATUS QUO

- ***Fixed Automation*** **-** Most robots are designed and built for a specific task and can not perform the tasks of other robots
- ***Adaptive Controls***
  - Gain tuning
  - Self calibration
  - Dynamic identification
- ***Autonomous grasping***
  - RFID tags
  - Fixed jigs

NEW INSIGHTS

- Vast amounts of sensor data are now available on hands.
- Data includes motion, force, and other proprioceptive information
- Data also includes observation of external objects, tools and the environment.
- A control basis can be formulated with online experiences
- Grasping control can be associated with objects, used as a good start, and then further refined.
- Robots can share knowledge.

PROBLEM/NEED BEING ADDRESSED

Robots must currently be designed for and then programmed for each specific task.

PROJECT DESCRIPTION/APPROACH

- Develop and prove through testing a new approach to robot learning.
- The low level control basis approach allows simple skills to be put together for more complex actions.
- **Key Challenges**
  - Task generality, through fusion of many types of sensing
  - Robot generality, with object centric approach
- **Team**
  - PI is the leader in the field of autonomous manipulation
  - Small team, mainly with graduate students
- Infusion through the Robonaut system on ISS, taking ideas through software development to flight on a fast pace.
- NRC requested more autonomy for NASA's Robonaut system

QUANTITATIVE IMPACT

- ***Mission Impact***
  - ***Reduce operations costs by adding new tasks quickly.***
  - ***Provide a "caretaking robot" to be left behind on human tended spacecraft at NEAs, L2 or the moon.***
- ***Terrestrial Impact***
  - ***Direct connection to manufacturing***
  - ***Medicine, disaster response, DOD***

PROJECT GOAL

Advance the ability of robots to achieve the general ability to perform multiple tasks, get better through experience, develop new abilities, and share them with other robots.