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PI/PD Name: Christopher G Atkeson

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)

☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)

☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
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Race Definitions:
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PI/PD Name: Jessica Hodgins

Gender: ☐ Male ☒ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)

☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)

☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

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PI/PD Name: Patrick J Loughlin

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

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PI/PD Name: Arash Mahboobin

Gender: ☐ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☐ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Mark S Redfern

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 10-1		FOR NSF USE ONLY
NSF 10-596	11/08/10	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		
EFRI - EFRI RESEARCH PROJECTS		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				052184116	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
250969449		

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
Carnegie-Mellon University	5000 Forbes Avenue WH 405 PITTSBURGH, PA 15213-3890
AWARDEE ORGANIZATION CODE (IF KNOWN) 0001057000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)	☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION	☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS	☒ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **EFRI-M3C Preliminary Proposal: Models of forceful physical interaction in everyday life**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 1,498,066	48 months	10/01/11	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Robotics Institute & HCI Institute	5000 Forbes Avenue Pittsburgh, PA 15213 United States
PI/PD FAX NUMBER 412-268-6436	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Christopher G Atkeson	PhD	1986	412-681-8354	cga@cmu.edu
CO-PI/PD Jessica Hodgins	PhD	1989	412-268-6795	jkh@cs.cmu.edu
CO-PI/PD Patrick J Loughlin	PhD	1992	412-624-8002	loughlin@engr.pitt.edu
CO-PI/PD Arash Mahboobin	PhD	2007	412-624-7400	arm19@pitt.edu
CO-PI/PD Mark S Redfern	PhD	1988	412-647-7923	mredfern@pitt.edu

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, lobbying activities (see below), responsible conduct of research, nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 10-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The undersigned shall require that the language of this certification be included in any award documents for all subawards at all tiers.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

EFRI-M3C Preliminary Proposal: Models of Forceful Physical Interaction in Everyday Life

PI: Christopher G. Atkeson, Carnegie Mellon University, co-PIs: Jessica Hodgins, CMU, Pat Loughlin, Arash Mahboobin, and Mark Redfern, University of Pittsburgh.

The goal of our work is to understand how humans control their entire bodies to simultaneously balance, locomote, and manipulate, including the roles of attention and cognition. We will develop predictive mathematical models of whole body human sensory-motor performance. We will combine both human studies and experiments on a humanoid robot to develop and test our theories. We will use tasks from everyday life including work to develop a next generation ergonomics that models forceful physical interaction, movement, control, and mental state to reduce the cost of accidents such as falling and chronic injury by developing new ways to design and control our tools and environments at both hardware and software levels.

Intellectual Merit: One significant leap/paradigm shift in our work is developing and evaluating memory-based models. In terms of theories about the brain, memory-based models suggest that the brain uses its massive memory capacity to store particular experiences of forceful physical interaction, and recalls and combines these experiences to generate new behavior. In terms of engineering design and fundamental engineering knowledge, memory-based approaches focus on the use of nonparametric models in control. Memory-based approaches complement current parametric approaches to modeling and control, and provide a way to take advantage of the dramatic increase in memory capacity of computers. A memory-based approach transforms how learning is approached in biological studies and engineering design. It also allows easy customization of an assistive device to a user, and the development of new types of intelligent assistive devices. The proposed work directly addresses M3C elements. We will develop and experimentally validate theories of human-sensory motor control, and complementary predictive models to enable the design of machines for forceful physical interaction and cooperation with humans (M3C1). These models will lead to understanding and/or explanation of several important human sensory motor control functions (M3C3). We will apply our perceptual and cognitive science based approaches to explore the role of mental state in forceful physical interactions between humans, tools, and environments (M3C2). We will explore learning and skill acquisition, power transfer between humans, tools, and environments, and basic questions about human walking in our work on whole body behavior.

Broader Impacts: We expect our work to have several major impacts, particularly reducing accidents such as falling in the home, workplace accidents, and chronic injury. We will help lay the foundation for important medical/healthcare applications such as much more useful and intelligent assistive devices. Some of these devices will be autonomous, some of these devices will work with a user as another human would, and some of these devices will act more like an exoskeleton. A major issue is safety, particularly in consumer applications of these devices. In complementary work, we are developing soft inflatable devices to assist humans, greatly reducing the risk of injury and cost. The knowledge developed in the proposed work would tell us how to control this new type of assistive device. We have extensive experience in the area of improving workplace safety. A next generation ergonomics could transform our ability to improve safety and also job satisfaction in the workplace. It would also transform our ability to plan tasks, predict risk, and develop new assistive devices for work. Reducing the impact of accidents is an important national challenge. For example, falls are the leading cause of accidental death in persons 65 years or older. Based on the proposed work, we may be able to learn how to change environments and tools and train people to reduce the risk of falling and other accidents. Simulations based on our models, and actual test devices based on our humanoid robot work, can be used to evaluate risk in homes and workplaces and reduce it. We will develop the use of humanoid robots as real life “crash test dummies” to evaluate tools and environments in functional experiments outside the laboratory. A special emphasis of our work will be how motor and sensory performance and the underlying sensorimotor system change with age. We expect to gain an understanding of the changes that cause an increased risk of falling and injury in older adults, and the strategies that are used to compensate for these changes.

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Our vision is to understand forceful physical interaction by combining research efforts on humans and agile machines such as humanoid robots. Our approach is to study human behaviors, and implement the theories we develop in a physical model (i.e. a humanoid robot). We learn more about the implications of those theories using the physical model while extending the capabilities of humanoid robots. We believe this approach can lead to: a) greater understanding of human sensorimotor control of forceful physical interactions, and b) transformative shifts in engineering approaches to control of agile machines such as robots.

Vision and Goals: One goal of the proposed work is to understand how to generate a rapid and appropriate response to errors in forceful physical interactions, particularly during manipulation while standing or moving (mobile manipulation), in both humans and machines. Humans, even with relatively slow neural transmission and processing capabilities (communication and computational hardware), can detect, identify, and generate a response to a perturbation in a fraction of a second. A worker demolishing a structure when the part he is hammering unexpectedly gives way can choose to maintain his balance with just his ankles (ankle strategy), with his entire body (hip strategy), by taking a step (changing the base of support), by moving his arms and tool (righting reflex), or by reaching for and grasping a fixed support (grasp strategy). What the arms are holding, what can be dropped in an emergency, and what grasp or other support points are available are all taken into consideration. Internal prediction is used to evaluate the severity of the ongoing perturbation and the implications of potential response strategies, with large benefits for being able to predict the future as early as possible.

Robots and mobile machines in general are not yet capable of this robust behavior. Current humanoid robots such as Asimo, HRP2, Hubo, and our own robot (Figure 1) have relatively small limits to how hard they can be pushed or how much the terrain can deviate from a stiff flat floor before they fall. Their ability to apply forces or forcefully interact using tools is extremely limited.

Our human research has focused on understanding responses to perturbations while standing and slipping, tripping, and stumbling while walking (Figure 1-D). We have also been programming humanoid robots to be more robust during forceful physical interactions (Figure 1-A, B, and C). One goal of the proposed work is to cross fertilize between these two endeavors: Use understanding of human error response behavior to improve robot control, and use control schemes for robots to provide testable alternatives for human control. This cross fertilization approach will lead to experimentally verified, quantitative, mathematical theories of human sensorimotor control that can serve as predictive models for the design of machines for forceful physical interaction and cooperation with humans. Another goal is to address forceful physical interaction involving power flow between the human or robot and the environment. We will focus on manipulation while standing or moving, building on our previous work on legged locomotion with no manipulation.

We will also focus on the role of perceptual and cognitive factors, such as attention and anticipation, to connect physical human-machine interactions and theories about mental representations. How do humans allocate attentional resources during complex tasks? How do humans use anticipation of likely future behavior of the task or the environment to choose strategies and bias state estimation? We have recently been studying the role of attention in postural control in older adults, focusing on 1) determining attentional selectivity during standing, 2) investigating the temporal dynamics of attention during balance recovery, 3) investigating the influence of attention on motor responses during balance recovery, and 4) investigating the influence of attention during moving visual environments. We have modeled attentional effects using a postural prioritization model, discovered faster attentional dynamics than had been seen previously, and found perceptual inhibition in postural control. In the proposed work we will extend our research on perceptual and cognitive factors to mobile manipulation. We believe our work in this area will lead to understanding of how to allocate computational resources in multi-processor systems for improved anticipation and response.

Approach and Methodology: Our approach combines human studies of whole body control and experiments with a humanoid robot doing the same behaviors. This synergistic approach allows us to aggressively test our theories of how behaviors are controlled and coordinated. We have found that physical models of behavior are much more effective in exposing the flaws and gaps of our theories than simulations. We believe this approach and methodology can lead to: a) greater understanding of human sensorimotor control of forceful physical interactions, and b) transformative shifts in engineering approaches to control of agile

Figure 1: **A:** Our hydraulic humanoid robot standing on a moving platform used for clinical human balance testing. We compared the robot's perturbation responses to human perturbation responses. **B:** The humanoid responding to a push (stick with white padding on end). **C:** The humanoid collaborating with a human to lift a table. **D:** Human slipping experiments. This video image was shot with infrared illumination, because the experiment is done in darkness to conceal the slipping location from the subject. The subject's left foot has just slipped on a puddle of glycerin, and the right foot has come down from its swing and is pressing against the floor in an attempt to recover. **E:** An error response classifier for a simple optimal control model of standing balance. The axes are the ankle and hip velocities after an impulsive perturbation. For small perturbations, ankle torques are primarily used for the response. Larger perturbations in a particular direction are handled by recruiting hip muscles. Other large perturbations are handled by taking a step. **F:** A conceptual example of a continuous response generator based on storing trajectories. These are a set of optimized ankle responses to balance perturbations. The black dots are the initial state after the perturbation.

machines such as robots.

One basic question is whether humans learn behavior in terms of parametric models with small numbers of parameters, or non-parametric models represented using large numbers of adjustable synapses in the brain? We see the use of non-parametric models ("place coding" in the superior colliculus, for example) in many simple behaviors such as the control of eye movements. We see hints of similar coding in the motor cortex. A related question is whether robots and other machines *should* learn behavior using parametric or non-parametric models? The dramatic drop in the cost of memory favors the use of non-parametric models in engineering. We will use human experiments to try to tease out how *local* learning effects can be. Relatively broad learning effects favor low dimensional parametric models, and highly specific contextual effects suggest high dimensional non-parametric models. We will use comparative implementations of different forms of learning and control on our humanoid robot to experimentally measure their advantages and disadvantages. This is an example of how we will also explore learning in the proposed work.

A more specific hypothesis that we will explore is that the human error response system is a strategy classifier followed by individual modules to implement each strategy in a continuous fashion. The first stage of processing selects the type of response to be used. This selection occurs continuously, and the execution of one strategy can be interrupted by another. An alternative to the strategy classifier hypothesis is that there are no clear boundaries between strategies, and the entire response is generated as one unit. We will look for response discontinuities and errors in strategy selection to test the strategy classifier hypothesis in humans. We will use robot implementations of strategy classifiers to measure their performance and compare them with more monolithic control approaches.

Another hypothesis we will test is that information on how to generate detailed error responses is (for humans) and should be (for robots) represented in the form of example response trajectories. We will probe this hypothesis in humans by again looking at the structure of learning. If there are interference effects across time for learned responses to repeated initial conditions and perturbations, this supports the trajectory hypothesis. We will also look for evidence of an internal clock or internal model that guides the timing of the response. Can a response be interrupted? If a response is perturbed, does the system try to return to the original timing?

Our corresponding hypotheses for engineered systems are that selection of learned error responses is a good way to design complex behavioral systems, and that explicitly representing, learning, and precomputing specific responses (a memory-based approach) is also useful. Figure 1-F shows such a set of error recovery trajectories for a single link inverted pendulum balancer. The trajectories were generated using approximate dynamic programming (ADP) [7, 6, 11, 58, 9, 13, 12]. The control system uses the current state estimate to index this memory and figure out what to do next. Figure 1-E shows a more complex place coding, in which a discrete behavior or response strategy is selected [12]. Within each strategy a collection of trajectories similar to Figure 1-F is used to determine what to do next. We believe that a memory-based approach makes learning simpler and more effective, and that we can find ways to achieve appropriate levels of generalization during learning using a memory-based approach. We have been able to develop memory-based control and learning systems for simple robots. This proposal takes the next step in scaling up, making this approach work for systems with on the order of a hundred state variables. We have made great recent progress in relevant areas: using optimization and reinforcement learning to design nonlinear feedback control systems and reflexes for standing and walking, and using human movement data to create flexible behavior generators based on memory-based learning.

Strategy selection and implementation in standing postural control may require coordination among subsystems. For example, ankle, hip and stepping strategies probably require some temporal and spatial coordination. However, arm responses may or may not be independent of legged responses to perturbations. What are good coordination mechanisms between subsystems, and what influences coordination? We will extend our existing balance controller [12, 90, 89, 91, 92] to include arm responses and grasping. Are different joints controlled in a coordinated fashion, or are they controlled independently? Surprisingly, we know that in seemingly coordinated gaze shifts, the eyes and neck can be controlled largely independently [88]. We will use human subject experiments to detect if there is a particular onset of arm movements based on perturbation characteristics (i.e. profile and magnitude). Our current optimal control model predicts that arm movements are part of a generalized hip strategy, co-occurring with significant hip activation. We will test this prediction. We will also explore whether a simple parametric framework (perhaps even a linear framework) can model the human data. We will attempt to match human behavior on our humanoid robot, and compare results with controllers designed using optimal control.

We will develop models based upon the response behaviors we get from our human experiments. Standing balance responses to small perturbations can be modeled quite well with linear controllers. It has been proposed that gain scheduling of different linear controllers can fit responses to larger perturbations. We will extend the model of [67] to include arm motions and reproduce their experiments on the robot. We will explore whether a fixed nonlinear controller also fits the data. Park et al. [67] show that the gains of manually fit linear controllers decrease as the perturbation size increases. Another way to get the same effect is to have a "compressive" nonlinearity on position and velocity. We will explore a variety of structures for parametrized nonlinear controllers. We will use error minimization techniques similar to those used by [67] in the linear case to choose appropriate parameters in the nonlinear case. Similarly, we will explore using optimal control techniques to find appropriate parameters for nonlinear controllers, similar to what has been done to design linear quadratic regulator (LQR) controllers for standing balance [25, 38]. There have been several examples of finding a good match between optimal estimators and controllers and biological control systems [15, 17, 38, 37, 94, 14]. We will also explore using reinforcement learning techniques to design nonparametric nonlinear controllers, such as policy search and dynamic programming on reduced dimensional models [93].

Our current work on robots explores how forceful physical interaction and balance can be controlled using simple internal models [91, 92]. The state of the robot is mapped to the state of an internal model that takes into account balance such as a multi-link inverted pendulum. Desired motions are then generated for the internal model, and the corresponding contact forces (feet and hands, for example) are generated. This approach has been successful when applied to our humanoid robot (Figure 1-A, B, and C).

Understanding the transition to a stepping strategy is of particular interest to us. Stepping strategies have been described by Maki and colleagues [49, 48, 66], however, the decision process and sensory inputs that drive this strategy are unknown. We are especially interested in the decision to step: when is it made, can it be undone, and is the decision to step separate from the decision where to step? The limits to step initiation will be parametrized and initially will be based upon the data published by Maki and McIlroy [49, 48]. We note that from a theoretical point of view, the decision surface that determines when a perturbation is large enough to require stepping depends on the responses the subject will make. For example, a strategy that applies maximal ankle torque so that the center of pressure is at the edge of the foot leads to a decision surface where the center of mass velocity is related to the square root of the center of mass position, rather than a linear relationship as is commonly assumed. More complex strategies require numerical calculation of the decision surface. We will map the decision surface in human experiments in order to characterize the response strategy used by subjects, try to model the decision surface in terms of biomechanical variables, and test the model on the robot.

Once these individual behavior models have been implemented and explored, we will then attempt to unify these behaviors with a response selector. This approach will include components of sensory integration seen in many human experiments [32, 33, 35, 41, 69] and with the basic concept of adaptive motor strategies shown since the early work of Nashner [64]. This unified model will require significant experimental and developmental effort. We will bring our machine learning expertise to bear on the problem and explore techniques to select and/or blend behaviors, reduce dimensionality of complex problems, estimate parameters, and discover underlying structure.

The understanding of strategy selection in response to perturbations during manipulation while standing will be then extended to manipulation while locomoting. There are similarities (and presumably differences) between standing and locomotion recovery strategies. Forceful interactions during locomotion may emphasize predominantly step trajectory alterations (analogous to stepping strategies) and arm responses (similar to righting reflexes and grasping strategies). We will explore locomotor recovery response strategy choice and implementation in an iterative way similar to our standing approach. While many researchers have modeled gait in terms of optimizing metabolic energy expenditure [5], recovery from perturbations is very different. We believe that recovery strategies optimize criteria that reflect minimizing risk of falling or injury, force limits, and potential for internal injury due to force magnitudes, rapidly changing forces, and rapidly changing force derivatives. However, similar questions exist as in our standing postural experiments: How are all these strategies implemented? Are they linked to distinct sensory inputs? Are strategies altered online as the perturbation progresses? Do higher cognitive processes, such as attention, play a role in response generation? Does manual manipulation or concurrent upper extremity task execution alter responses? Again, we will explore these questions for locomotion using human experimentation to examine behaviors and then incorporating proposed strategies in our humanoid robot physical model. Model development will be a major effort in our locomotion studies. We will develop search algorithms that select appropriate terms and appropriate weightings for the terms in optimization criteria. Terms that will be tried include quantities that can be sensed (though proprioception, vision or vestibular) and potentially processed by the brain, such as joint velocities, accelerations, jerks (the derivative of acceleration), higher derivatives of joint angle, joint torques, support forces and torques, rates of change of forces and torques, higher force and torque derivatives, and nearness to obstacles. We will also consider motor system errors in force and torque production, such the standard deviation or variance of muscle force being related to desired muscle force. Models of muscle activation error will allow us to calculate the risk of further perturbation, such as slipping, hitting another obstacle, and self collisions, and include these terms in the optimization.

Impact: This proposal brings together experts in human motor control and bioengineering (Redfern, Loughlin, and Mahboobin) and experts in robotics (Atkeson and Hodgins). This synergy of experts from different disciplines supports our combination of human studies and experiments with a humanoid robot. We expect to achieve significant advancements in fundamental engineering knowledge based on our exploration of forceful physical interactions based on memory-based approaches. We see a strong potential for a long term impact on the national need to reduce health costs due to accidents such as falling.

What is transformative? One transformative element of our proposed research is to emphasize memory-based control approaches. In engineered systems memory has become very cheap, and the brain has a huge memory capacity. We will explore memory-based control using human and robot models. Focusing on memory-based approaches will transform how engineering approaches prediction and control. For example, the emphasis on obtaining and using simple idealized parametric models will be reduced, and there will be greater use of learned models. We will also borrow ideas from biology to build better robots. Our models will guide the design of more robust robot controllers based on insight from the human control system, and provide insight into robust engineering control system design in general. Another transformative element for neuroscience and biomechanics will be the emphasis on specific quantitative control systems for complex behaviors. Computational models of whole body control have the scientific benefit of guiding neuroscience research and helping us understand an important behavior and its disorders. We believe our work will lead to substantial progress towards understanding learning in the brain. We believe we can replicate brain-like creativity in developing new error responses to anticipated and unanticipated situations. Our difficult technology benchmark, testbed, and challenge will be getting a humanoid robot to exhibit human-level competence in forceful physical interactions during standing balance and gait. We believe that our work will lead to more capable machines and assistive technology that can operate in human environments, more robust robot controllers based on insight from the human control system, and provide insight into robust engineering control system design in general.

Human health impact and next generation ergonomics: Success in this endeavor will lead to improved systems for falling and other accident prediction and prevention systems. Falling is an important problem with significant health and economic consequences. Because we will implement the models in a physical robot, we will be able to evaluate the models' interaction with actual human environments, providing much more sophisticated evaluations of accident risk and guiding accident prevention. Humanoid robots also make useful experimental subjects for real life safety and ergonomics experiments ("active crash test dummies"). Actually walking on a slippery floor is a much better predictor of what will happen than even a very detailed dynamic computer simulation. We also believe that by using software filters we can make motors more like muscles (add additional dynamics and delay) and sensors more biological (modify dynamics and add delay).

How can robotics advance computational neuroscience? As a concrete example of how implementing models on a robot reveals issues for computational neuroscience, we describe implementing integral control for our robot standing on two feet. Integral control is useful for compensating for "calibration" errors, offsets, and relatively constant disturbances. There is evidence that humans use integral control during standing [34, 68]. A key issue is whether there are two integrators, one for each leg, or just one for the entire body. If there is just one integrator, the loads on the two feet cannot be equalized. If there are two integrators, difficult coordination issues arise that surprised us. When we implemented current models of human standing balance on our robot, we discovered that they did not correctly account for the interaction of integral control for each foot. For integral control to be stable, contralateral feedback gains needed to be a factor of 10 greater and of opposite sign when compared to ipsilateral gains [2]. Current biological models use purely ipsilateral feedback. We will explore this and other issues involving coordination between the two legs in the implementation of posture, walking, and error handling models. We expect similar surprises from a quantitative examination of error responses from a control point of view.

Education and outreach: We will create an environment for training of undergraduates and graduate students by: 1) involving them in the research, 2) developing and requiring an appropriate curriculum, and 3) disseminating educational and research materials. In addition to his undergraduate teaching of a course on humans and humanoid robots, Atkeson will create a graduate course on "Optimizing Behavior" based on our and other's work in this area. Mahboobin will help develop and co-teach a graduate course on "Biomechanical Modeling of Movement, Posture, and Gait". In addition to our normal teaching responsibilities, Redfern is the Vice Chairman of the Undergraduate Program in Pitt's Bioengineering Department. An additional activity that would be made possible by this funding is to make our simulations publicly available and maintained. The CMU Robotics Institute already has an aggressive outreach program at the K-12 level [23], and we will participate in that program.

Diversity: One of the co-investigators is female. We will make sure to include women and minority students. CMU is fortunate in being successful in attracting an unusually high percentage of female undergraduates in Computer Science. The Bioengineering Department at Pitt has 40% female undergraduates, and a similar fraction of female graduate students. In terms of graduate students, we have had success working with each of our respective graduate admissions programs. For example, out of 7 graduate students, Hodgins has 1 minority and 5 female students. In the latest American Society for Engineering Education (ASEE) report, Pitt Engineering was second in the nation in percentage of PhD engineering degrees awarded to women.

Coordination plan: Although this proposal involves two universities, it will not be particularly difficult to manage, as the two institutions involved are within an easy 10 minute walk of each other. The situation is not too different from a collaboration between a computer science department and a medical school within one institution.

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[91] * B. Stephens. Modeling and control of periodic humanoid balance using the linear biped model. In *International Conference on Humanoid Robots*, 2009.

[92] * B. Stephens. Dynamic balance force control for compliant humanoid robots. In *International Conference on Intelligent Robots and Systems (IROS)*, 2010.

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[96] * Katsu Yamane, Yuka Ariki, and Jessica Hodgins. Animating non-humanoid characters with human motion data. *The ACM SIGGRAPH / Eurographics Symposium on Computer Animation (SCA 2010)*, 2010.

[97] * V. B. Zordan and J. K Hodgins. Tracking and modifying upper-body human motion data with dynamic simulation. In *Eurographics: Computer Animation and Simulation Workshop*, 1999.

CHRISTOPHER GRANGER ATKESON

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Education

Ph.D.	1986	MIT	Brain and Cognitive Sciences
S.M.	1981	Harvard	Applied Mathematics (Computer Science)
A.B.	1981	Harvard	Biochemistry, summa cum laude

Employment

Professor	RI & HCII, CMU	2004–present
Associate Professor	RI & HCII, CMU	2000–2004
Associate Professor	College of Computing, Georgia Tech	1994–2000
Associate Professor	Brain and Cognitive Sciences, MIT	1990–1993
Assistant Professor	Brain and Cognitive Sciences, MIT	1986–1990

Honors and Awards

- National Science Foundation Engineering Initiation Award, 1987-1988.
- National Science Foundation Presidential Young Investigator Award, 1988-1993.
- W. M. Keck Foundation Assistant Professorship in Biomedical Engineering, 1988-1990.
- Alfred P. Sloan Research Fellow, 1989-1991.
- W. M. Keck Foundation Associate Professorship in Biomedical Engineering, 1990-1991.
- Teaching Award from the MIT Graduate Student Council, 1990.
- Edenfield Faculty Fellowship Award, 1995.
- Elected by faculty to College of Computing Dean's Advisory Committee, 1995–1996, 1996–1997.
- Finalist, Best Paper Award, ICRA 2000.

External Service

- Program Committee for ICRA 89, *Neural Networks for Computing,* 1990-1994, IJCNN 91, IROS 91, IROS 95, NIPS 93, Machine Learning 95, Machine Learning 96, ICRA 05.
- Editorial Board, *Machine Learning Journal,* 1997-2001.
- US Program Committee Chair, *Humanoids 2003,* 2003.
- General Chair, *Humanoids 2004,* 2004.
- Associate Editor, IEEE RAS Conference Editorial Board, ICRA 07.
- US Program Committee Chair, *Humanoids 2008,* 2008.
- Scientific Board, *Dynamic Walking Conference,* 2005-present.
- Consulting and part time appointment, Advanced Telecommunications Research Laboratory (ATR), Japan, 1993-present.

Five Related Publications

1. "Control of Instantaneously Coupled Systems Applied to Humanoid Walking", E. Whitman and C. G. Atkeson, *IEEE-RAS International Conference on Humanoid Robots,* 2010
2. "Multiple Balance Strategies From One Optimization Criterion", C. G. Atkeson and B. Stephens, *IEEE-RAS International Conference on Humanoid Robots,* 2007.
3. "A Mechanism For Sensory Re-weighting in Postural Control", A. Mahboobin, P. Loughlin, C. G. Atkeson, and M. Redfern, *Medical and Biological Engineering and Computing,* 47(9):921–929, 2009.
4. "Sensory Adaptation in Human Balance Control: Lessons for Biomimetic Robotic Bipeds", A. Mahboobin, P. J. Loughlin, M. S. Redfern, S. O. Anderson, C. G. Atkeson, and J. K. Hodgins, *Neural Networks,* 21(4):621-627, 2008.
5. "Random Sampling of States in Dynamic Programming", C. G. Atkeson and B. Stephens, *IEEE Transactions on Systems, Man, and Cybernetics, Part B,* 38(4):924–929, 2008.

Five Other Relevant Publications

1. "Nonparametric Representation of an Approximated Poincaré Map For Learning Biped Locomotion", J. Morimoto and C. G. Atkeson, *Autonomous Robots,* 27(2), 131–144, 2009.
2. "Powered Bipeds Based on Passive Dynamic Principles", S. O. Anderson, M. Wisse, C. G. Atkeson, J. K. Hodgins, G. J. Zeglin, and B. Moyer, *IEEE-RAS International Conference on Humanoid Robots,* 110-116, 2005.
3. Morimoto, J. and C. G. Atkeson, "Minimax Differential Dynamic Programming: An Application to Robust Biped Walking" *NIPS,* 2002.
4. "Using Humanoid Robots to Study Human Behavior", C. G. Atkeson, J. Hale, M. Kawato, S. Kotosaka, F. Pollick, M. Riley, S. Schaal, T. Shibata, G. Tevatia, A. Ude, and S. Vijayakumar, *IEEE Intelligent Systems,* 15(4):46–55, 2000.
5. *Model-Based Control of a Robot Manipulator,* MIT Press, C. H. An, C. G. Atkeson, and J. M. Hollerbach, Cambridge, Massachusetts, 1988.

Collaborators (outside CMU): R. Cham, U. Pitt; R. Cooper, U. Pitt; M. Kawato, ATR; P. Loughlin, U. Pitt; M. Redfern, U. Pitt; S. Schaal, USC; A. Ude, ATR;

Graduate Advisor: E. Bizzi, MIT.

Students and Postdocs (16 PhD and 2 postdocs total). current students: B. Stephens, S. Sanan, E. Whitman, C. Dellin, B. Xinjilefu, J. Wang, M. Dogar, and A. Dragan.

Jessica Hodgins

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A Education

School	Degree	Date
Yale University	B. A.	1981
Carnegie Mellon University	Ph. D.	1989

B Appointments

Employer	Position	Beginning	End
Disney Research, Pittsburgh	Director	2008	present
Carnegie Mellon University	Professor	2004	present
Carnegie Mellon University	Associate Professor	2001	2004
Georgia Institute of Technology	Assistant Dean	1999	2001
Georgia Institute of Technology	Assistant, Associate Professor	1992	2001
International Business Machines	Postdoctoral researcher	1990	1992
MIT Artificial Intelligence Lab	Postdoctoral associate	1989	1990

C Publications

Five Related Publications:

- Anderson, S.O., Wisse, M, Atkeson, C.G.,Hodgins, J. K., Zeglin, G. J., and Moyer, B., 2005. Powered bipeds based on passive dynamic principles. Proceedings of the 5th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2005).
- Anderson, S.O., Atkeson, C.G. and Hodgins, J.K., 2006. Coordinating Feet in Bipedal Balance, Proceedings of the 6th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2006).
- Anderson, S. O., Hodgins, J. K. and Atkeson, C. G., 2007. Approximate Policy Transfer applied to Simulated Bongo Board Balance, IEEE-RAS International Conference on Humanoid Robots (Humanoids).
- Safonova, A., Hodgins, J. K. 2007. Construction and Optimal Search of Interpolated Motion Graphs. ACM Transactions on Graphics 26(3), Proceedings of SIGGRAPH 2007.
- Safonova, A., Hodgins, J. K., Pollard, N. S., 2004. Synthesizing Physically Realistic Human Motion in Low-Dimensional, Behavior-Specific Spaces. ACM Transactions on Graphics 23(3) (Proceedings of SIGGRAPH 2004).

Five Other Significant Publications:

- Yamane, K., Kuffner, J., Hodgins, J. K. Synthesizing Animations of Human Manipulation. ACM Transactions on Graphics 23(3) (Proceedings of SIGGRAPH 2004).

- Park, S.I., Hodgins, J. K., 2006. Capturing and Animating Skin Deformation in Human Motion. ACM Transactions on Graphics 25(3), Special Issue of the Proceedings of ACM SIGGRAPH.
- Chai, J. and Hodgins, J. 2005. "Performance Animation from Low-Dimensional Control Signals." ACM Transactions on Graphics 24(3), Special Issue of the Proceedings of ACM SIGGRAPH.
- Lee, J., Chai, J., Reitsma, P.S.A., Hodgins, J. K., Pollard, N. S. 2002. Interactive Control of Avatars Animated With Human Motion Data. ACM Transactions on Graphics 21(3) (Proceedings of SIGGRAPH 2002).
- Zordan, V. B., Hodgins, J. K. 1999. Tracking and Modifying Upper-body Human Motion Data with Dynamic Simulation. *Eurographics: Computer Animation and Simulation Workshop*.

D **Synergistic Activities**

- Papers Chair for ACM SIGGRAPH 2003
- Editor-in-Chief of ACM Transactions on Graphics. 1999-2002
- Freely available motion capture database (mocap.cs.cmu.edu)

E **Awards Received**

- Impact Award at SIGGRAPH 99 for "Graphical Modeling and Animation of Brittle Fracture." With James O'Brien.
- Alfred P. Sloan Research Fellowship, 1995.
- David and Lucille Packard Foundation Fellowship in Science and Engineering, 1994.
- National Science Foundation Young Investigator Award, 1994.

F **Collaborators:**

- **Collaborators outside of Carnegie Mellon University and Disney Research**

  HansPeter Pfister (Harvard), Paul Viola (Microsoft), Steve Seitz (Washington), Amy Bruckman (Georgia Tech.), Stefan Schaal (University of Southern California), Gregory Shakhnarovich (Brown University), James Rehg (Georgia Tech), Simon Baker (Microsoft), Zoran Popovic (Washington), Greg Turk (Georgia Tech), Pamela Hinds (Stanford), Carol O'Sullivan (Trinity College Dublin), Thierry Chaminade (Institut de Neurosciences Cognitives de la Mediterranee), Mitsuo Kawato (ATR, Japan), Gordon Cheng (Munich), Mark Redfern (University of Pittsburgh), Rakie Cham (University of Pittsburgh), Markus Gross (ETH).
- **Graduate Advisor and Postdoctoral Sponsors** Marc Raibert (Boston Dynamics), Alan Norton (Colorado School of Mines).
- **Thesis Advisor and Postgraduate-Scholar Sponsor**

  Thesis Advisor: 10, Postdocs: 5

  Wayne Wooten (Pixar), James O'Brien (Berkeley), Victor Zordan (University of California, Riverside), David Brogan, Ron Metoyer (Oregon State), Nancy Pollard (CMU), Bobby Bodenheimer (Vanderbilt), Kiran Bhat (ILM), German Cheung (Google), Katsu Yamane (Disney), Jinxiang Chai (Texas A&M), Sang Il Park (Sejong University), Liu Ren (Bosch), Alla Safonova (U Pennsylvania), Bilge Mutlu (Wisconsin).

Patrick J. Loughlin
University of Pittsburgh

Professional Preparation

Undergraduate Institution: Boston University
Major: Biomedical Engineering
Degree & Year: BS, 1985

Graduate Institution: University of Utah
Major: Bioengineering
Degree & Year: MS, 1988

Graduate Institution: University of Washington
Major: Electrical Engineering
Degree & Year: PhD, 1992

Appointments

2002-present	*William Kepler Whiteford Professor*, Departments of Bioengineering, and Electrical & Computer Engineering, University of Pittsburgh, Pittsburgh, PA.
2001-2002	*Professor*, Departments of Bioengineering, and Electrical & Computer Engineering, University of Pittsburgh, Pittsburgh, PA.
1998-2001	*Associate Professor*, Departments of Bioengineering, and Electrical & Computer Engineering, University of Pittsburgh, Pittsburgh, PA.
1993-1998	*Assistant Professor*, Department of Electrical & Computer Engineering, University of Pittsburgh, Pittsburgh, PA.

Publications

Five most closely related to the proposed research

R. Peterka and P. Loughlin, “Dynamic regulation of sensorimotor integration in human postural control,” *J. Neurophysiol*., vol. 91, pp. 410-423, 2004.

A. Mahboobin, P. Loughlin, M. Redfern, P. Sparto, “Sensory re-weighting in human postural control during moving-scene perturbations,” *Exp Brain Res*, vol. 167, pp. 260-267, 2005.

A. Mahboobin, P. Loughlin, M. Redfern, ``A model-based approach to attention and sensory integration in postural control of older adults.,’’ *Neuroscience Letters*, vol. 429, pp. 147-151, 2007.

A. Mahboobin, P. Loughlin, M. Redfern, S. Anderson, C. Atkeson, J. Hodgins, “Sensory adaptation in human balance control: Lessons for biomimetic robotic bipeds,” *Neural Networks*, vol. 21, no. 4, pp. 621-627, 2008.

A. Mahboobin, P. Loughlin, C. Atkeson, M. Redfern, ``A mechanism for sensory re-weighting in postural control,’’ *Med Biolog Eng Comput*, vol. 47, pp. 921-929, 2009.

Five other significant contributions

P. Loughlin, M. Redfern and J. Furman, "Time-varying characteristics of visually-induced postural sway," *IEEE Trans. Rehab. Engr*., vol. 4, no. 4, pp. 416-424, 1996.

P. Loughlin and M. Redfern, "Spectral characteristics of visually-induced postural sway in healthy elderly and healthy young subjects," *IEEE Trans. Rehab. Engr.,* vol. 9, no. 1, pp. 24-30, 2001.

P. Loughlin, M. Redfern and J. Furman, "Nonstationarities of postural sway: The utility of time-frequency analysis in studying human balance," *IEEE Engineering in Medicine and Biology Magazine*, vol. 22, no. 2, pp. 69-75, 2003.

P. Sparto, J. Jasko, P. Loughlin, "Detecting postural responses to sinusoidal sensory inputs: a statistical approach," *IEEE Trans. Neural Syst. And Rehab.* Engr., vol. 12, no. 3, pp. 360-366, 2004.

M. Cenciarini, P. Loughlin, P. Sparto and M. Redfern, ``Stiffness and damping in postural control increases with age,'' IEEE Trans. Biomed. Engr., vol. 57, no. 2, pp. 267-275, 2010.

Synergistic Activities

- Teaching: *Human Postural Control* (special topics course), *Time-Frequency Signal Analysis* course, Depts of Bioengineering, and Electrical & Computer Engineering, University of Pittsburgh.
- Associate Editor, IEEE Trans. Biomedical Engineering
- Professional society memberships: Acoust. Soc. Amer. (Fellow); American Inst. Med. and Biol. Engineering (Fellow); BMES; IEEE (Sr. Member); SPIE

Collaborators & Other Affiliations

- Chris Atkeson, PhD, Carnegie Mellon University
- Leon Cohen, PhD, Hunter College, CUNY
- Joseph M. Furman, MD, PhD, University of Pittsburgh Medical Center
- Jessica Hodgins, PhD, Carnegie Mellon University
- J. Richard Jennings, PhD, University of Pittsburgh
- Mark S. Redfern, PhD, University of Pittsburgh
- Patrick Sparto, PhD, University of Pittsburgh

Graduate and Postdoctoral Advisors

Ph.D. Advisor:
Les Atlas, University of Washington

Thesis Advisor and Postgraduate-Scholar Sponsor

- Have supervised over 15 MS/PhD students since 1993.

Arash Mahboobin
University of Pittsburgh

Professional Preparation

Undergraduate Institution: Azad University, Tehran, Iran
Major: Biomedical Engineering
Degree & Year: BS, 1998

Graduate Institution: University of Illinois, Urbana-Champaign, IL
Major: General Engineering
Degree & Year: MSE, 2002

Graduate Institution: University of Pittsburgh
Major: Electrical Engineering
Degree & Year: PhD, 2007

Appointments

2010-present	*Research Assistant* Professor, Department of Bioengineering, University of Pittsburgh
2008-2010	*Postdoctoral Research Associate*, Department of Bioengineering, University of Pittsburgh
2002-2007	*Research Assistant*, Department of Electrical and Computer Engineering, University of Pittsburgh, Pittsburgh, PA.
2000-2002	*Research Assistant*, University of Illinois at Urbana-Champaign, Department of General Engineering.
2000-2001	*Teaching Assistant*, University of Illinois at Urbana-Champaign, College of Business

Publications

Mahboobin A, Loughlin PJ, Redfern, MS, Sparto PJ: Sensory re-weighting in human postural control during moving-scene perturbations. *Experimental Brain Research* 167(2):260-267, 2005.

Mahboobin A, Loughlin PJ, Redfern MS: A model-based approach to attention and sensory integration in postural control of older adults. *Neuroscience Letters* 429:147-151, 2007.

Mahboobin A, Loughlin PJ, Redfern MS, Anderson SO, Atkeson CG, Hodgins JK. *Neural Networks* 21(4):621-627, 2008.

Mahboobin A, Loughlin P Atkeson C, Redfern M: A mechanism for sensory re-weighting in postural control. *Med Biolog Eng Comput* 47:921-929, 2009.

Mahboobin A, Cham R, Piazza SJ: The impact of a systematic reduction in shoe-floor friction on heel contact walking kinematics – A gait simulation approach. *Journal of Biomechanics* 43:1532-1539, 2010.

Synergistic Activities

- Teaching: *Biomechanics* II (Lecturer), *Biomedical Applications of Signal* Processing (Assistant Instructor).
- Publications in postural control and robotics.

Collaborators & Other Affiliations

- Christopher Atkeson, Carnegie Mellon University

- Mark S. Redfern, PhD, University of Pittsburgh
- Patrick J. Loughlin, PhD, University of Pittsburgh
- Rakié Cham, PhD, University of Pittsburgh
- Stephen J. Piazza, PhD, Penn State University

Graduate and Postdoctoral Advisors

Ph.D. Advisor:
Patrick J. Loughlin, University of Michigan

Postdoctoral Advisor**:**
Rakié Cham, University of Pittsburgh

Mark S. Redfern
University of Pittsburgh

Professional Preparation

Undergraduate Institution: University of Michigan
Major: Engineering Science
Degree & Year: BSE, 1978

Graduate Institution: University of Michigan
Major: Bioengineering
Degree & Year: MSE, 1982

Graduate Institution: University of Michigan
Major: Bioengineering
Degree & Year: PhD, 1988

Appointments

2008-present	*Associate Dean for Research*, Swanson School of Engineering, University of Pittsburgh
2001-present	*William Kepler Whiteford Professor*, Department of Bioengineering; University of Pittsburgh, Pittsburgh, PA.
2001-present	*Professor*, Departments of Bioengineering, Otolaryngology, Industrial Engineering, Physical Therapy, and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA.
2000-2001	*Associate Professor*, Departments of Bioengineering, Otolaryngology, Industrial Engineering, Physical Therapy, and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA.
1995-2001	*Associate Professor*, Departments of Otolaryngology, Industrial Engineering, Physical Therapy, and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA.
1993-present	*Director*, Human Movement and Balance Laboratory, University of Pittsburgh
1988-1995	*Assistant Professor*, Departments of Otolaryngology, Industrial Engineering, and Physical Therapy, University of Pittsburgh, Pittsburgh, PA.
1988	*Post Doctoral Fellow*, University of Michigan, Center for Ergonomics, funded by NIOSH.
1978-1981	*Clinical Prosthetist*, Metropolitan Prosthetics and Orthotics, Berkeley, Michigan

Publications

Five most closely related to the proposed research

Redfern MS, Muller M, Jennings JR, Furman JM: Attentional dynamics in postural control during perturbations in young and older adults. *Journal of Gerontology: BIOLOGICAL SCIENCES* 57A(8):B298-B303, 2002.

Loughlin PJ, Redfern MS: Analysis and modeling of human postural control. *IEEE EMB Magazine* 22(2):18, 2003.

Redfern MS, Talkowski ME, Jennings JR, Furman JM: Cognitive influences in postural control of patients with unilateral vestibular loss. *Gait & Posture* 19(2):105-114, 2004.

Mahboobin A, Loughlin PJ, Redfern MS: A model-based approach to attention and sensory integration in postural control of older adults. *Neuroscience Letters* 429:147-151, 2007.

Mahboobin A, Loughlin P Atkeson C, Redfern M: A mechanism for sensory re-weighting in postural control. *Med Biolog Eng Comput* 47:921-929, 2009.

Five other significant contributions

Redfern MS, Jennings JR, Martin C, Furman JM: Attention influences sensory integration for postural control in older adults. *Gait and Posture*, 14:211-216, 2001.

Redfern MS, Cham R, Gielo-Perczak KG, Gronqvist R, Hirvonen M, Lanshammar H, Marpet M, Pai CYC, Powers C: Biomechanics of slips. *Ergonomics* 44(13):1038-1166, 2001.

Mahboobin A, Loughlin PJ, Redfern, MS, Sparto PJ: Sensory re-weighting in human postural control during moving-scene perturbations. *Experimental Brain Research* 167(2):260-267, 2005.

Muller MLTM, Jennings JR, Redfern MS: Postural prioritization defines the interaction between a reaction time task and postural perturbations. *Experimental Brain Research* 183(4):447-456, 2007.

Redfern MS, Jennings JR, Mendelson DN Nebes RD: Perceptual inhibition is associated with sensory integration in standing postural control among older adults. *J Gerontol B Psychol Sci Soc Sci* 64(5):569-576, 2009.

Synergistic Activities

- Teaching: *Biodynamics of Movement* course, Department of Bioengineering, University of Pittsburgh.
- Have published a number of articles regarding human postural control and movement.
- Patent: "Apparatus and Method for Postural Assessment While Performing Cognitive Tasks," issued September 19, 2006. U.S. Patent No. 10/840,791 (Carey D. Balaban and Mark S. Redfern)

Collaborators & Other Affiliations

- Carey D. Balaban, PhD, University of Pittsburgh
- Adolpho Bronstein, MD, PhD; Div of Neurosciences, Imperial College, London, UK
- Donald B. Chaffin, PhD, University of Michigan
- Joseph M. Furman, MD, PhD, University of Pittsburgh Medical Center
- J. Richard Jennings, PhD, Department of Psychology, University of Pittsburgh
- Patrick J. Loughlin, PhD, University of Pittsburgh

Graduate and Postdoctoral Advisors

Ph.D. Advisors:
Donald Chaffin, University of Michigan
David Anderson, University of Michigan

Postdoctoral Advisor:
Donald B. Chaffin, University of Michigan

Thesis Advisor and Postgraduate-Scholar Sponsor

- Have supervised more than 20 MS/PhD students since 1990.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION: Carnegie-Mellon University			FOR NSF USE ONLY		
			PROPOSAL NO.	DURATION (months)	
				Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Christopher G Atkeson			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Christopher G Atkeson - Professor/ PI	0.00	0.00	1.00	$ 14,875	$
2. Jessica Hodgins - Professor / Co-PI	0.00	0.00	1.00	15,485	
3. Patrick J Loughlin - Co-PI	0.00	0.00	0.00	0	
4. Arash Mahboobin - Co-PI	0.00	0.00	0.00	0	
5. Mark S Redfern - Co-PI	0.00	0.00	0.00	0	
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	30,360	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL SCHOLARS	9.00	0.00	0.00	37,827	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				29,213	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				38,724	
TOTAL SALARIES AND WAGES (A + B)				136,124	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				15,752	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				151,876	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,800	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				7,244	
5. SUBAWARDS				250,000	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				262,244	
H. TOTAL DIRECT COSTS (A THROUGH G)				422,920	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 56.7000, Base: 134196)					
TOTAL INDIRECT COSTS (F&A)				76,089	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				499,009	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 499,009	$

M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $

PI/PD NAME: Christopher G Atkeson	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Carnegie-Mellon University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Christopher G Atkeson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Christopher G Atkeson - Professor / PI	0.00	0.00	1.00	$ 15,396	$
2. Jessica Hodgins - Professor / Co-PI	0.00	0.00	1.00	16,027	
3. Patrick J Loughlin - Co-PI	0.00	0.00	0.00	0	
4. Arash Mahboobin - Co-PI	0.00	0.00	0.00	0	
5. Mark S Redfern - Co-PI	0.00	0.00	0.00	0	
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	31,423	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL SCHOLARS	7.80	0.00	0.00	33,930	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				30,671	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				96,024	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				15,092	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				111,116	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,064	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				6,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				7,240	
5. SUBAWARDS				250,000	
6. OTHER				40,656	
TOTAL OTHER DIRECT COSTS				303,896	
H. TOTAL DIRECT COSTS (A THROUGH G)				424,076	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 56.7000, Base: 133420)					
TOTAL INDIRECT COSTS (F&A)				75,649	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				499,725	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 499,725	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Christopher G Atkeson

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **Carnegie-Mellon University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Christopher G Atkeson**				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Christopher G Atkeson - Professor/ PI**	0.00	0.00	1.00	$ 15,935	$
2. **Jessica Hodgins - Professor / Co-PI**	0.00	0.00	1.00	16,588	
3. **Patrick J Loughlin - Co-PI**	0.00	0.00	0.00	0	
4. **Arash Mahboobin - Co-PI**	0.00	0.00	0.00	0	
5. **Mark S Redfern - Co-PI**	0.00	0.00	0.00	0	
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	32,523	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL SCHOLARS	7.20	0.00	0.00	32,418	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				32,206	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				97,147	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				15,003	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				112,150	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,336	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				3,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				7,384	
5. SUBAWARDS				250,000	
6. OTHER				42,692	
TOTAL OTHER DIRECT COSTS				303,076	
H. TOTAL DIRECT COSTS (A THROUGH G)				424,562	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 56.7000, Base: 131870)**					
TOTAL INDIRECT COSTS (F&A)				74,770	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				499,332	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 499,332	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				
PI/PD NAME **Christopher G Atkeson**				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. NAME*				Date Checked / Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 4

ORGANIZATION	FOR NSF USE ONLY		
Carnegie-Mellon University	PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Christopher G Atkeson	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Christopher G Atkeson - none	0.00	0.00	0.00	$ 0	$
2. Jessica Hodgins - none	0.00	0.00	0.00	0	
3. Patrick J Loughlin - none	0.00	0.00	0.00	0	
4. Arash Mahboobin - none	0.00	0.00	0.00	0	
5. Mark S Redfern - none	0.00	0.00	0.00	0	
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.00	0	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL SCHOLARS					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				0	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				0	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 2. TRAVEL 3. SUBSISTENCE 4. OTHER					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES					
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER SERVICES					
5. SUBAWARDS					
6. OTHER					
TOTAL OTHER DIRECT COSTS				0	
H. TOTAL DIRECT COSTS (A THROUGH G)				0	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) (Rate: , Base:)					
TOTAL INDIRECT COSTS (F&A)				0	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				0	
K. RESIDUAL FUNDS					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 0	$

M. COST SHARING PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME Christopher G Atkeson	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Carnegie-Mellon University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Christopher G Atkeson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Christopher G Atkeson - none	0.00	0.00	3.00	$ 46,206	$
2. Jessica Hodgins - none	0.00	0.00	3.00	48,100	
3. Patrick J Loughlin - none	0.00	0.00	0.00	0	
4. Arash Mahboobin - none	0.00	0.00	0.00	0	
5. Mark S Redfern - none	0.00	0.00	0.00	0	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (5) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	94,306	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (3) POST DOCTORAL SCHOLARS	24.00	0.00	0.00	104,175	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				92,090	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				38,724	
TOTAL SALARIES AND WAGES (A + B)				329,295	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				45,847	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				375,142	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				27,200	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				14,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				21,868	
5. SUBAWARDS				750,000	
6. OTHER				83,348	
TOTAL OTHER DIRECT COSTS				869,216	
H. TOTAL DIRECT COSTS (A THROUGH G)				1,271,558	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				226,508	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,498,066	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 1,498,066	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Christopher G Atkeson

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Patrick J. Loughlin**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Modeling Sensory Integration and Attention in Postural Control of Older Adults

Source of Support: NIH/NIA

Total Award Amount: $492K (direct costs) Total Award Period Covered: 07/01/07-06/30/11

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 3.0 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Nonstationary signal processing methods for channel characterization and sonar signal

Source of Support: ONR

Total Award Amount: $329.6K (total) Total Award Period Covered: 10/01/09–09/30/12

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 1.5 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Sonar Signal Analysis and Waveform Design for Enhanced Target Detection and Classifi-

Source of Support: ONR

Total Award Amount: $300.3K (total) Total Award Period Covered: 01/01/09-12/31/11

Location of Project: University of Pittsurgh

Person-Months Per Year Committed to the Project. Cal: 1.0 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Other agencies (including NSF) to which this proposal has been/will be submitted.

Investigator: **Arash Mahboobin**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Modeling Shoe-Floor Interface Properties to Predict Slips and Falls

Source of Support: NIOSH

Total Award Amount: $910,739 Total Award Period Covered: 08/01/10-07/31/13

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 6.0 Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Mark S. Redfern**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Modeling Shoe-Floor Interface Properties to Predict Slips and Falls

Source of Support: NIOSH

Total Award Amount: $910,739 Total Award Period Covered: 08/01/10-07/31/13

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 3.0 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Claude D. Pepper Older Americans Independence Center (M. Redfern: Core Leader, Technology Core)

Source of Support: NIH/NIA

Total Award Amount: $6,037,066 (total) Total Award Period Covered: 10/01/09–09/30/14

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 1.2 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: RI: Medium Collaborative Research: Trajectory Libraries for Locomotion on Rough Terrain

Source of Support: NSF

Total Award Amount: $102,831(Pitt portion) Total Award Period Covered: 07/01/10-8/31/13

Location of Project: Carnegie Mellon University

Person-Months Per Year Committed to the Project. Cal: 1.0 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: CPS Medium Collaborative Research: Monitoring Human Performance with Wearable Accelerometers

Source of Support: NSF

Total Award Amount: $290,092 (Pitt portion) Total Award Period Covered: 9/01/09-8/31/12

Location of Project: Carnegie Mellon University

Person-Months Per Year Committed to the Project. Cal: 1.0 Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Mark S. Redfern**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: ERC: Revolutionizing Metallic Biomaterials

Source of Support: NSF

Total Award Amount: $6,842,000 Total Award Period Covered: 09/01/08-08/31/13

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 2.0 Acad: Sumr:

Support: ☒ Current Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Influence of White Matter Damage on Step Initiation

Source of Support: NIH/NIA

Total Award Amount: $1,475,000 Total Award Period Covered 10/01/08–09/30/12

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: 1.0 Acad: Sumr:

Support: ☐Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: Total Award Period Covered:

Location of Project: University of Pittsburgh

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Mentoring of Postdoctoral Fellows

We expect to have one postdoctoral fellow involved in the project. Our philosophy for mentoring postdoctoral fellows (and graduate students), which has worked very well in the past and started many on successful academic careers, is to emphasize learning by doing with extensive feedback from supervising faculty. Career counseling and discussion of professional practices are provided in many informal settings, as well as in formal one-on-one review meetings. The postdoc will work closely with the faculty at Carnegie Mellon and the University of Pittsburgh. We will have weekly meetings to discuss the progress on the project, which is one venue to focus on improving all our abilities to collaborate with colleagues with diverse backgrounds and disciplines. The postdoc will have special training in topics related to machine learning, control, and acquisition and processing of human motion data. A critical role we faculty play is to introduce postdoctoral fellows to more senior colleagues at conferences and during seminar visits. These colleagues not only may hire the postdoc as faculty in the future, but also provide useful examples of career paths and choices. We encourage and help postdocs to write proposals. We co-write papers with postdocs, as well as encourage them to take the lead in writing their own papers. As faculty we spend a great deal of time editing and commenting on draft proposals and papers. We require practice presentations before any conference presentation, as well as regular presentations at lab meeting. Critiquing such presentations often takes significantly longer than the presentation itself. We encourage postdoctoral fellows to co-teach with us, so we can provide feedback on their teaching. We also encourage postdoctoral fellows to co-mentor or mentor graduate students and undergraduates, gaining experience in mentoring. We provide guidance on how to collaborate with researchers from diverse backgrounds through informal advice as well as by example. We will work with the postdoc to develop expectations of the skills to be achieved during their stay, and will track the goals.

Key Personnel

This proposal brings together experts in motor control neuroscience, human balance and gait, motor disorders, biomechanics, bioengineering, and humanoid robotics. All the co-PIs have been collaborating on human and humanoid balance for four years [45, 44, 85]. Experiments and data collection on human subjects will be conducted at the Human Movement and Balance Laboratories (HMBL) at the University of Pittsburgh led by Dr. Redfern. This laboratory has extensive experience in studying standing postural control, locomotion, and specifically slips, trips and falls. Experiments on humanoid robots will occur at the CMU Robotics Institute and be directed by Dr. Atkeson.

Chris Atkeson (Professor, RI (Robotics Institute) and HCII, CMU, www.cs.cmu.edu/∼cga) will serve as the Principal Investigator. Dr. Atkeson brings an expertise in optimal control, reinforcement learning, and approximate dynamic programming. He has over 25 years of experience with humanoid robotics and robot learning including both mobility [4, 2, 12, 36, 53, 56, 57, 54, 51, 50, 55, 52] and manipulation [1, 8, 73, 81, 82]. He also has experience with human movement psychophysics [10, 45, 44].

Jessica Hodgins (Professor, RI and CS, CMU, www.cs.cmu.edu/∼jkh) brings expertise in behavior generation, behavior capture, and large scale simulation. She has extensive experience in humanoid robotics and legged locomotion [30, 26, 16, 27, 28, 4, 2, 3, 36], behavior capture for computer animation and robotics and whole body simulation [95, 31, 39, 96]. Hodgins has extensive experience with behavior libraries [40, 84, 83, 29, 71, 65, 72, 97]. She has recently been working on capturing and modeling human error responses [85] and developing behavior capture techniques for use outside the lab [18, 87, 86]. Hodgins has also constructed several motion capture databases and made them freely available on the web for the use of other researchers (mocap.cs.cmu.edu, kitchen.cs.cmu.edu). Hodgins runs the CMU Graphics Lab and Disney Research Pittsburgh.

Mark Redfern (Professor, Bioengineering, University of Pittsburgh, www.engr.pitt.edu/bioengineering/main/people/faculty/redfern_mark.html) brings expertise in balance and gait biomechanics and neuroscience and associated disorders. Pat Loughlin (Professor, Bioengineering, Pitt) is an expert in human postural control, control systems, and signal analysis. Arash Mahboobin (Research Assistant Professor, Bioengineering, Pitt) brings expertise in sensory re-weighting models of human postural control. Redfern and Loughlin have been conducting NIH funded research in postural control for 15 years. Funded research that is directly related to this proposal includes: *Postural Control in the Elderly: The Role of Attention* R01 AG14116 (PI: Redfern, coI: Loughlin) This study investigates the influence of higher cognitive function in postural control in young and older adults. Properties of sensory integration are explored during dual-task paradigms to probe the influence of attention. Our basic concepts of sensory integration have been developed partially through this work. *Time-Varying Characteristics of Human Postural Sway* R01 DC04435 (PI: Loughin, coI: Redfern) This recently completed project investigated changes in sway during various visual and proprioceptive conditions. This project has also helped to form our conceptual model of postural control, particularly regarding sensory integration. *Biomechanics of Slips in Older Adults* R01 OH07592-01 (PI: Cham, coI: Redfern) This study investigates the biomechanics of slips and falls, both kinematics and kinetic responses during recovery attempts are studied. Biomechanical modeling, similar to that being proposed in Specific Aim 3, is used to analyze the data. *Balance and Instability: A Multidisciplinary Approach: Claude D Pepper Older Americans Independence Center* P30 AG024827AG: The NIH-funded Pepper Center is dedicated to the understanding of balance disorders in older adults, and improvement of balance in these populations. Redfern, and Loughlin are associated with this Center. The resources of this Center (statistical support, recruitment, data management, and technical support) will be available to support our effort in this study. Relevant papers by the investigators include [19, 21, 20, 22, 24, 42, 43, 46, 47, 59, 61, 62, 60, 63, 75, 77, 76, 78, 79, 74, 80, 70].

Conflicts

Anderson, David, University of Michigan, advisor
Atkeson, Christopher Granger, CMU, PI
Atlas, Les, University of Washington, advisor
Baker, Simon, Microsoft, collaborator
Beschomer, Kurt, University of Wisconsin (Madison), collaborator
Bhat, Kiran, ILM, advisee
Bizzi, Emilio, MIT, advisor
Bodenheimer, Bobby, Vanderbilt, advisee
Brogan, David, Virginia, advisee
Bronstein, Adolfo, Imperial College, UK, collaborator
Bruckman, Amy, Georgia Tech., collaborator
Chaffin, Donald B., University of Michigan, advisor
Chai, Jinxiang, Texas A&M, advisee
Cham, Rakie, Pitt, collaborator
Cheng, Gordon, ATR, collaborator
Cheung, German, Neven Vision, advisee
Cohen, Leon, Hunter College, CUNY
Dean, Paul, University of Sheffield, UK, collaborator
Donelan, J. Maxwell, Simon Fraser University, collaborator
He, Jiping, Arizona State University, advisor
Hinds, Pamela, Stanford, collaborator
Hodgins, Jessica, CMU, coPI
Kawato, Mitsuo, ATR, collaborator
Keller, Edward L., Smith-Kettlewell Eye Research Institute, advisor
Loughlin, Pat, Pitt, co-PI
Mahboobin, Arash, Pitt, co-PI
Marks, Joe, Disney, collaborator
McCrory, Jean, West Virginia University, collaborator
Metoyer, Ron, Oregon State, advisee
Moran, Daniel, Washington University in St. Louis, collaborator
Morimoto, Jun, ATR, collaborator
Muller, Martijn, University of Michigan, collaborator
Norton, Alan, Colorado School of Mines, advisor
OBrien, James, Berkeley, advisee
OSullivan, Carol, Trinity College Dublin, collaborator
Park, Sang Il, DHRC, advisee
Pfister, HansPeter, Harvard, collaborator
Piazza, Steve, Penn State, collaborator
Pollard, Nancy, CMU, advisee
Popovic, Zoran, Washington, collaborator
Prochazka, Arthur, University of Alberta, collaborator
Raibert, Marc, BDI, advisor
Redfern, Mark, Pitt, coPI
Rehg, James, Georgia Tech, collaborator
Ren, Liu, Bosch, advisee
Safonova, Alla, U Pennsylvania, advisee

Schaal, Stefan, USC, collaborator
Seitz, Steve, Washington, collaborator
Shakhnarovich, Gregory, Brown University, collaborator
Stilman, Michael, Georgia Tech, advisee
Turk, Greg, Georgia Tech, collaborator
Viola, Paul, Microsoft, advisee
Walton, Mark M. G., University of Rochester, advisee
Wisse, Martijn, Delft, collaborator
Wooten, Wayne, Pixar, advisee
Yamane, Katsu, Disney Reseach Pittsburgh, advisee
Zordan, Victor, University of California, Riverside, advisee