Basic Details Of Applicant

Co-applicant details

Details of authorised representative in lead institution /Co-applicant's Institution

Note: (An authorized representative is considered to be one of the following superiors: Dean, Vice Dean, Dept. Head, VP Research or an authorized senior official from the Research Office)

I. Name of authorised representative (if available other than the lead applicant) in lead institution & Authorised signatory to sign the grant agreement.

Name :
Designation :

Details of Team Members

Details of Team Members:

Name	Designation	Name Of Institution	Mailing address	Telephone	Mobile E-mail
			2500		

Shastri Indo-Canadian Institute Awards and Other Awards (If applicable)

Please list any awards previously received from Shastri Indo-Canadian Institute : NaN
Any other award : NaN
Please list any awards previously received from Shastri Indo-Canadian Institute by Co-host/Co-applicant : NaN
Any other award by Co-host/Co-applicant : NaN

Association with SICI member institution (If applicable)

Please indicate whether you are associated with a SICI member institution : Yes
Please indicate whether co-applicant is associated with a SICI member institution : Yes

Details of Project/Program/Abstract/Ethics

Project Title: [redacted]

Abstract of Project/Program(250 words):
Driven by the end goal of developing enhanced humanoid robots for both defense as well as humanitarian aid purposes (including Urban Search & Rescue) [redacted] (Canada) and [redacted] (India) with the participation of the members of their corresponding research groups have formed a team to undertake the problem of developing suitable humanoid robot control mechanisms for: • High-speed maneuvering control of highly articulated humanoid robots to enhance the robot's walking/motion speeds by using its arms, hands, torso, etc. to enhance support during maneuvering tasks in confined spaces. The ultimate goal is to enable the robot's abilities to navigate in unstructured terrains with the aid of all of the robot's physical characteristics (e.g., arms, knees) to increase stability despite navigation uncertainties that the robot might experience. By doing this it is envisioned that the walking speed of the robot will naturally increase while simultaneously increasing the robot's safer operation and minimizing any potential fall/unbalance of the robot. The goal of the collaboration between Canada and India is targeted to enhance the robot's maneuvering and stabilization mechanisms to enable improved human-robot interactions and their use within complex structured or unstructured environments. The project will tackle a complex problem associated with humanoid robots that when solved will have the capability to be deployed in structured indoor and unstructured outdoor environments and be used in diverse defense and humanitarian applications, such as rescue operations and surveillance and reconnaissance applications. The project has a maximum anticipated time duration of 24 months.

Objectives of Project/Program: Biological walking systems, including humans, can adaptively use their interlimb (legs, arms, and hands) coordination for locomotion to deal with different situations. Neurophysiological studies have revealed that the adaptive coordination emerges from dynamical interactions of neural activities, plasticity, musculoskeletal systems, and the environment. Achieving this on legged robots remains a grand challenge. Driven by the end goal of developing enhanced faster humanoid robots for efficient response in defence and humanitarian aid operations (e.g., urban search and rescue), the [redacted] and the [redacted] have joined forces to develop suitable humanoids control mechanisms to enhance the robot's locomotion abilities. The proposed collaborative project on "High speed walking gait control of a life-size humanoid robot" will use bio-inspired knowledge and control of legged robots to enable adaptive interlimb coordination in humanoid robots for enhanced speed and stability. Our developments will target speed-dependent, environment-dependent, body-dependent, and task-dependent adaptations to enable humanoid robots to effectively move within cluttered structured as well as unstructured environments. This will be achieved by using the full humanoid robot's available resources (i.e., hands, arms, and legs) and its motion characteristics (kinematics and dynamics) to maximize the robot's stability in all phases of its walking. The project will not look into the selection of which maneuvering scheme the robot should use (walk, climb, jump, crawl, etc.) to traverse the given terrain. The project will look into extending the bipedal characteristics of humanoid robots and extending such abilities to include the use of the robot's arms to aid in the walking/maneuvering phases. The goal is to increase the maneuvering speed of current humanoid robots without the need to modify their mechanical characteristics and design. The work will comprise numerous experimental tests using a state-of-the-art 5-foot tall humanoid robot having 29 joints in its entire body. The mechanisms to be developed will target complex confined spaces including moving at high speeds on moving surfaces (e.g., tilting platforms) and increasing the speed at which current humanoid robots are able to perform simple tasks, such as going up and down typical stairs and going through doors.

Background and Rationale of Project/Program(300 words): The humanoid form provides an anthropomorphic context of interaction between robots and people. Practically, humanoids can be well suited to be integrated into people's everyday life environments and settings. At least, in theory, humanoids could use the same spaces and the same tools that people do since their form and function are defined by the human one. However, control and interaction with humanoids pose a less expected and quite intriguing social challenge: should humanoids attempt to behave like people do when they interact with us? Should humanoids demonstrate intelligence, agency, and intent? Should they present what people will perceive as an emotional reaction during interaction? These control and Human-Robot-Interaction questions are fundamental to the design, control, and implementation of humanoids that can be effectively integrated into defence, humanitarian aid, and manufacturing environments and thus assist in complex and challenging tasks (some dangerous while others having a humanistic nature). In 2010, an ambitious team undertook groundbreaking trials at the Alberta Children's Hospital using a Humanoid Robot to distract children during medical procedures. Such work has the first of its kind worldwide. The results of such Research and Developmental work were very positive. Although the obtained results were very promising the study also revealed a set of challenges that need to be further developed before humanoid robots can effectively be used in defence and complex environments. In general terms (without describing in detail the technical aspects) the identified aspects that previous work revealed need to be further developed include: • Better human-robot interactions to enable humanoid robots to self-adapt to people's unexpected behaviors. • Enhanced humanoid safety mechanisms to maximize their interaction with humans in a very safe fashion. • Enhanced robot maneuvering and stabilization mechanisms to enable improved human-robot interactions and their use within complex structured (e.g., buildings) or unstructured (e.g., outdoor) environments.

Project Description :(Please provide full proposal on activity proposed for the grant like scope, objectives, and relevance/significance/ contribution in development or expansion of knowledge about India/Canada or development/sharing/building of idea and intended outcome) :

Through diverse research projects over the past few years [redacted]s team in collaboration with a number of summer internship students from India (i.e., [redacted] (2017), [redacted]sh (2016), [redacted] & [redacted] (2014) and [redacted]) have been working on diverse aspects of humanoid robots [e.g., 4, 7, 15, 16, 17, 22] and collectively have placed the [redacted] ([redacted]) at the forefront of humanoid robotics Research and Development (R&D) in Canada.

While the accomplishments of affordable modern day commercial humanoid robots are nothing short of amazing, they often fall short of providing true deployment capabilities. By combining the applicants' (India and Canada) proven R&D abilities with their research into robot manipulators, humanoid control, walking/mobility, Human-Robot Interaction (HRI), etc. the team will push the boundaries of their work using a state of the art humanoid robotic system.

HRI is the study of the ways in which people and robotic technology influence each other [1]. Humanoid robots are an essential element in HRI studies and in the design of future robotic hardware and interfaces including work on artificial intelligence (AI) and formal control methodologies, modeling, programming, movement (navigation), sensory perception capabilities and other aspects with applications to diverse areas. This is becoming more acute given the near-term emergence of affordable and prevalent robotic technology, for example in the form of driverless cars, of health care and domestic robots. Within the large HRI, robot design and control research within [redacted] lead by [redacted] (Mechanical Engineering) and [redacted].

E. Sharlin (Computer Science) are leading the way in Canada in the use of humanoid robots within their corresponding research programs. Dr. s team is using humanoids to learn more about the social aspects of interaction with robots, and in order to design better social robotic interfaces. Serrano's team and collaborators are developing enhance control and motion capabilities to enable humanoid robots to effectively work in human-centered as well in complex non-engineered environments. Drs. Dr. and Dr. ( ) are leading the way in walking locomotion [14,19,25], gait transition between diverse indoor and outdoor terrains [20,26,27,28], and robot walking energy consumption [29]. The team has also worked on the dynamic running of bipedal machines [e.g.,18,15,21].

In past projects, the team lead by Dr. has used small humanoids. Dr. 's team has used a static industrial humanoid, Rethink Robotics' Baxter, to investigate social HRI research challenges. This robot has been used to learn more about how people react to the integration of a humanoid robot as a quality inspector in a production line [2]. The same robot has been also used to explore questions of trust in the interaction between people and robots, with Baxter playing the trust-based interactive "investment game" with people [3], following different behaviors patterns and allowing us to probe people's reaction and assessment of the humanoid's trustworthiness. in collaboration with 's Faculty of Medicine and the Alberta Children's Hospital (ACH) have used small and somewhat fragile humanoids such as Aldebaran's NAO robots to investigate robotics in pediatric health care [5-8] and children perception of robotics [9]. Research has investigated how children understand robots and the use of humanoids in reducing the stress and pain children experience while undergoing medical procedures such as vaccinations and phlebotomy [7]. Drs. and have investigated robot leg behaviors in bipedal locomotion [14, 16, 19] while Drs. and have developed control algorithms for bipedal running and hopping of robots [17, 21-22, 24].

The results obtained by the team in robotics are encouraging and unique, for example, humanoid robots have been used as distracting tools to significantly reduce children's stress and the time nurses and doctors take to apply a given procedure in some cases by more than 50%. This has significantly enhanced the operation and treatment of patients in children hospitals [7], who have identified the high value of adopting humanoid robots.

The Thormang 3.0 humanoid robot (to be used in the proposed R&D work between India and Canada) has also demonstrated that the methodologies developed by the teams in Canada ( ) and India (I) in walking can be enhanced and be applied for the use of humanoid robots in defence and humanitarian aid events that occur after natural (e.g., earthquakes, and tsunamis) or accidental events (e.g., explosions). However, in order to effectively apply humanoid robots in such applications (e.g., rescue victims trapped inside collapsed buildings after an industrial accident) better humanoid-robot stability and faster robot navigation is needed to enable them to move at fast speeds inside a priori unknown structured or unstructured environments.

Driven by the end goal of developing enhanced humanoid robots for both defense as well as humanitarian aid purposes Dr.) (C a) and Dr. r (India) with the participation of two graduate students, one from the (Ms.) and one from the r (Mr.), have formed a team to undertake the next phase of the developmental work.

The goal of this collaboration is targeted to enhance the robot's walking and stabilization mechanisms to enable improved human-robot interactions and their use within complex structured (e.g., offices and clinics) or unstructured (e.g., outdoor) environments. The focus, however, will be on increasing navigation speeds by using enhanced maneuvering abilities. Specifically, the project will have as a two-year term goal to enable:

- High-speed *walking/motion gait control of a life-size humanoid robot having 29 DOF for enhancing the robot's walking/motion speeds by using its arms and hands to enhance support during the walking maneuvers. The ultimate goal is to enable the robot's abilities to navigate in unstructured terrains with the aid of the robot's arms to increase stability despite navigation uncertainties that the robot might experience. By doing this it is envisioned that the walking speed of the robot will naturally increase while simultaneously increasing the robot's safer operation.*

The research aspects that the above short-term (2 years) goal will support in the long term (5-7 years) will focus on three main areas: biology, robotics and software/control methods. The following five areas are sectors in which the above mentioned short-term project's goal will significantly enhance in future R&D activities. Thus we anticipate this initial collaboration to go beyond the collaborative work described in this proposal:

***Human Motor Primitives*:** The work within this subject will aim at grounding the development of novel robot architectures on the human motor control and cognitive architecture and at providing new fundamental and theoretical insights into its organization.

***Compliant Systems*:** Design, realization, and testing of a new generation of robotic platforms actuated by compliant electromechanical movers. Mechatronic actuation designed with stiffness close to those found in biological systems will enable the development of appropriate joint level control strategies that will allow the effective control of the joint motion and stiffness for improved and safer HRI.

***Morphological Computation*:** In robotics, the term "morphological computation" indicates the employment of the body as an active component in signal processing and in achieving a set of desired behaviors which are thought to enable the control of complex systems easily. The proposed R&D activities will foster development to build formal description of a broad variety of humanoid robotic structures, to identify "extended" motor primitives in non-compliant and compliant systems that in addition to neural circuitry take into account the morphology of the body, and to analyze its effects on stability and the ability to adapt to new variants of system requirements

***Adaptive Modules*:** The proposed developments will enable to design the building blocks of a complete hierarchical control architecture. More specifically, the proposed work will provide the means to explore the various options for designing adaptive modules using dynamical systems, to provide mathematical tools to analyze stability and to provide adaptive modules as building blocks for the complete architecture and demonstrate simple locomotion and reaching skills based on a minimal system.

***Learning*:** The enhanced motion and navigation to be developed with this Canada/India collaboration will provide the ability to develop novel learning algorithms which arise from the context of rich motor skills and the hard learning problems encountered when humanoid artifacts interact with people and in real outdoor environments.

In this project, we will particularly focus on having a compliant robot (the ability to tolerate and compensate for misaligned parts potentially caused by human-robot interaction) for people to interact and use safely, and on the Morphological Computation aspects. Such technical and robot motion control design features will be developed during this project at both academic institutions. In , the work will focus on the high-speed walking/motion gait control aspects operating on rough and dynamic surfaces. India, on the other hand, will focus on the modeling and stability motion analysis of the robot's path planning aspects. Such work will use the robot's arms and hands to enhance support during the walking maneuvers.

The work at both institutions will be integrated into the Thormang robot's Robot Operating System environment and tested in diverse test environments inside a laboratory space.

The work will be carried out in such a way to find ways to join the modules and mechanisms into comprehensive motor behavior control architectures. This will be facilitated with the use of the Thormang 3.0 humanoid robot available at where experimental tests will be performed.

A number of fundamental questions will be resolved concerning the nature of top-down vs. bottom-up interactions between modules; the representations within modules and the communication/transformations between modules of world and body features, goals, rewards and control actions; interactions between learning mechanisms and more.

The project is being structured such that the short and long-term research is performed by progressing through an evolutionary sequence of architectures, each of which lends itself to the design of complete robots, rising in level of cognitive autonomy and flexibility that can exist in a dynamic world, completely autonomously for long periods of time while becoming effective tools.

In the long-term, the envisioned developments are to enable us to transfer the scientific innovations from diverse subjects into a hardware and software architecture facilitating research on rich motor skills both within the research programs at and India as well as the scientific community at large.

The mechanisms to be developed within this project will provide feedback to the different subjects from an architecture engineering and robotic experimentation viewpoint and apply diverse experimental evaluation methods not possible by each on the individual universities collaborating in this project.

The team is a transdisciplinary research team that represents an intersection of expertise in key fields. Our team members have a blend of pure and applied research expertise, leadership roles, and relationships necessary for this work. The team has a solid background in conducting research to improve the use of robots in a number of settings including clinical care of ill and injured children and operations associated with Urban Search & Rescue and humanitarian aid. Our team brings the core and complementary expertise in robot engineering, computer science, and Artificial Intelligence.

The collaborative work will significantly enhance the R&D work at both institutions with a high impact in humanoid robotics, bio-inspired intelligence and design & control as the main scientific areas. The project will considerably foster teams of researchers within and 's ecosystem as well as with external organizations. Cooperation with related projects among diverse faculty members within and outside and will also amplify. The project will initially support the training of 2 students but it is envisioned that future collaborative work between and in the area of humanoid robotics will train a large number (8-12 estimated) of highly qualified people/students per year (including visiting summer students).

The project will establish and reinforce long-lasting collaborations and train high profile researchers with multidisciplinary expertise. Students will be trained in the general areas of mechanical and electrical engineering, as well as other areas (e.g., computer science) as our research groups have done previously.

Activities that you hope will occur in the 18-24 months following the completion of your project as a result of the work that you do? (Maximum 300 words) :

The proposed project will enable a number of R&D activities beyond the proposed project. After two years the work will shift to tacking the following three aspects: i) Adaptive Modules, ii) Learning, and iii) robot design, aspects. These three activities are envisioned to continue being performed in collaboration between 1) Adaptive Modules: The initial collaborative results will facilitate developing building blocks, the motor primitives, as dynamical systems that would result in a set of ground-breaking paradigms such as the ability to produce discrete and periodic motions, suitable for being combined in multiple ways in order to generate more complex robot movements in real time not possible today. 2) Learning: The results will also enable the redesign and development of new and existing learning algorithms such as recurrent neural networks, as well as the integration of different learning algorithms in complex modular control architectures into humanoid robots. The above two aspects of the future work will be tested in different environmental conditions where the humanoid robot will be deployed to analyze its operation under a priori unknown situations. The last activity envisioned to be performed within the 24 months after the completion of the initial project is: 3) Enhanced Robot Design: Due to the high cost of current humanoid robots the goal of this aspect of the future work will be to • Drastically reduce the cost of the humanoid robots to make them more affordable and foster their use in diverse sectors. For this we envision to develop new robot hardware systems using 3D printing methodologies to design a potentially customizable robot system that children and organizations find appealing, is safe, robust, and easy to maintain (eliminating the deficiencies observed of commercially available humanoid robots). • Introduce analytics (to greatly reduce programming time).

Details of Ethics

Does your project require ethics approval due to research on human subjects, input on the environment, bio hazards etc.?

Note: Shastri Institute cannot release funds without a "Certificate of Ethics Approval" from your home institution
no

If yes, have you initiated the ethics approval process at your home institution?
no

Budget Details

Note: A detailed balanced budget that describes and justifies anticipated expenditures and indicates other funding sources, particularly those from the institution itself.

Budget Details:

A total of **$17,890 CDN** (INR 10,00,000) is being requested to the SHASTRI Research grant program to conduct the proposed research work during a proposed 24 month period. The PI of this application will also be using his current Discovery grant resources ($29K/yr.) as needed to support the research in addition to a supplemental research grant application that has been submitted to the DND IDEaS program which will provide funds for related work. The total supplemental funds (in addition to the funds requested from the Shastri Indo-Canadian Institute) is estimated to be $40K CDN over the two-year project.

Salaries and Travel ($9,600 CDN):

a) Two graduate students will be supported during this project. When at the (e.g., summer internship visits) these students will receive a stipend of $1,000/month using Dr. C R&D grants. Mr. currently a Ph.D. student at will be applying for a post-doctoral fellowship that will enable him to continue working on this project after completing his Ph.D. degree. Ms. will continue being financially supported at via teaching Assistant activities and available R&D funds. Other students participating in the project (e.g., 2 summer students) will receive a financial stipend of $1K/yr. for a total project cost of **$4,000 CDN**. Supplemental financial support for the students will be provided by a Discovery Grant fund as well as the IDEaS project grant (which was submitted on November 30, 2018).

b) Additional financial support of **$3,600 CDN** will be required to cover travel expenses between India and Canada for one member of the team. This funding is to be provided by the Shastri Research program grant. Both students participating in this project will be co-supervised by Dr. and Dr.

c) Technical/professional consulting fees. This cost, estimated at **$2K** ($1K/yr.) from previous projects, include technical services from the University technical staff to help integrate electronic equipment such as sensors and embedded systems into the robot for experimental testing. The technical staff will be used during the equipment/robot set up and implementation aspects of the robot testbed.

Equipment ($5,050 CDN): will be purchased to assist in the analysis, design & testing phases of the work.

d) Two Intel NUC Computers will be acquired and used in running the methodologies being developed. Each participating team (Canada and IIT) will require a computer for development activities, analysis, simulations as well as experimental tests. Two computers, having a total retail cost of **$700 CDN** ($400 each), will be used to develop the needed algorithms using diverse software tools readily available at and (e.g., V-Rep, Matlab and Simulink where algorithms will be simulated before being experimentally tested in the robot)

e) A Lidar (Hokuyo) and camera sensor with a retail cost of $6,200 CDN will be acquired. This sensor will be acquired at a reduced educational discount (30%) cost of **$4,350 CDN**. This sensor is the minimally viable item to be used to prove the validity of the humanoid robot navigation control methodologies to be developed. This sensor will be used at and at different times during the project. Other needed sensors (e.g., GPS and stereo vision) are readily available in the PI's lab and will be shared with India, if and when needed.

Facility usage fees ($0.0):

f) Based on past experience with similar projects, we are considering expenses for 3D printing some of the robot's sensor brackets to be used to test the developments. Here we will use the machine shop facilities at the academic institutions taking advantage of the free use of the equipment offered to faculty members. We anticipate that approximately 20-30 hours of 3D printing time will be used during the life of this project.

Materials and Supplies ($2,600):

g) Diverse materials and supplies will be acquired during the entire life of the project. These items (e.g., 3D printing materials, Rechargeable batteries to power the robot(s), cables/wires, etc. will be used to manufacture sensor mounting brackets, repair the robots when if needed, etc. The total yearly expenditures are estimated to be: $1,300 in yr 1; and $1,300 in yr.

Communications Activities ($400):

h) A minimum of eight group workshops (4/year) between and and the students participating in the project will be performed. The associated costs include diverse forms of communication between the academic organizations/members, and the students (e.g., progress reports, faxes, and mailing packages/letters). The associated communication costs will be partially supported by popular technologies such as Skype. However, mailing packages will require an estimated **$400 CDN** for the duration of the project. The requested budget for communication includes the costs for paper, printer toner cartridges, and memory sticks used to deliver and share the developments and results in print form as well as electronically.

Field Tests ($240):

i) Work for testing/operating the proposed humanoid robot during a two year period has an estimated cost of **$240 CDN** as the associated expenses will use facilities already available within the campus area. However, based on previous projects expenditures will be required to repair the robot if and when needed during/after tests, and replace the rechargeable LiPo batteries when needed (see Materials and Supplies section).

Technology Transfer (component and system design) ($0.0):

All software tools (e.g., Matlab) to be used in the project are readily available in the academic's institutions and research labs. Thus, no costs will be incurred in software. All Matlab code, as well as other electronic generated tools will be shared between the academic faculty members as part of the technology transfer and collaborative efforts.

Evaluation Criteria

- Academic merit (includes research abilities i.e. clarity of objectives, scopes and methodology and innovativeness of proposal (10 points)
- The coherence and importance of proposed activities to achieve anticipated outcomes in the given timeline (10 points)
- Evidence of bi-national (Indian and Canadian) dimension (10 points)
- Scholarship of the researchers and involvement of young scholars (10 points)
- Clarity of expected outcomes and relevance of the project i.e. the likelihood that the project findings will be of use to students, researchers, policy makers at the grass root level and the public (10 points)
- Justified Budget (10points)