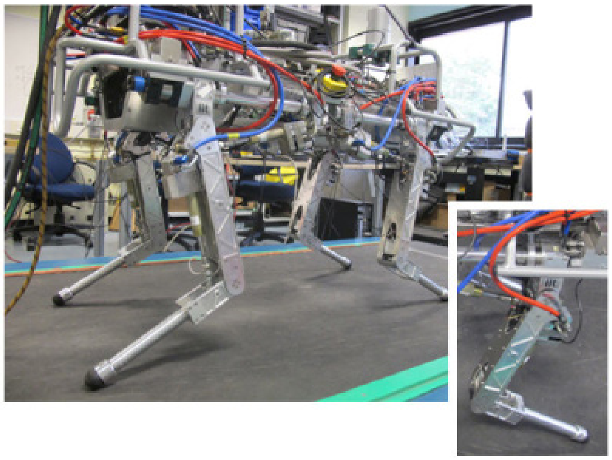
Case Study:
Italian Institute of Technology (IIT)

Accurately Simulating a Four-Legged Walking Robot with Adams

Overview

Today, when a building collapses in an earthquake or explosion, when a mine accident occurs, in a nuclear power plant and in other disaster scenarios, search and rescue teams walk or crawl through difficult terrain in an effort to locate survivors. This task requires highly skilled men and women who are in such short supply that there may not be enough of them to rapidly survey the scene of the catastrophe. Search and rescue is extremely hazardous work and there are some areas which cannot be reached by humans because the danger is too great. A new generation of robots is being designed to address these challenges. While there are a number of different potential search and rescue robot designs, one of the most interesting is a four legged robot being designed by the Dynamic Legged Systems Lab led by Dr. Claudio Semini (Italian Institute of Technology) to perform dynamic tasks such as walking in rugged terrain, carrying heavy loads, climbing hills and even jumping and running. The advantages of rescue robots include the fact that they can supplement scarce human searchers in order to locate victims faster and that they can enter areas that are too dangerous or inaccessible by humans [1].



Four legged robot prototype

“Now that we have succeeded in accurately modeling the robot’s leg, we are half-way towards our immediate aim of simulating the performance of the complete robot in tasks such as walking or running over different types of terrain.”

Ferdinando Cannella, Head of IIT’s Advanced Industrial Automation Lab

Challenge

One of the critical design challenges faced by IIT engineers designing the new robot is the selection of the bearings and beams used in the legs which is important because the stiffness of the bearings and beams governs the value of the forces on the hip and knee. The link flexibility problem can be solved analytically with equations, but this approach requires a high level of mathematical skills and also a considerable amount of time. The complexity of the analytical method increases exponentially as the degrees of freedom and geometric complexity of the robot increase [2].

Solution/Validation

Advanced Industrial Automation Lab engineers instead used Adams and MSC Nastran to simulate the performance of the robot in a fraction of the time that would have been required for the analytical approach. Each robot leg contains about 450 parts. IIT engineers merged these components into just a few rigid bodies, one for each moving part of the structure. These included the slider, upper leg, lower leg, hip cylinder, hip beam, knee cylinder and knee beam as shown in the diagram above. The position of each rigid body was characterized by three reference points, two on the ends of each body and one in the center of mass. The actuators’ movement was modeled with spring-damping elements.

Two different models were built from these elements with the difference being the method of connecting the rigid elements. The first model, called the Rigid Connected Prototype (RCP), uses rigid connections with infinite stiffness at the joints between the elements. The second model, called the Flexible Connected Prototype (FCP), uses flexible joints created with Adams bushing elements.

The accuracy of the two models was evaluated with a drop test. At the beginning of the test the leg was standing in its equilibrium position. A vertical guide was used to maintain vertical alignment during the test. Then the leg was raised to a fixed elevation, dropped and left free to oscillate from the impact. During the test the slider position was measured with an absolute encoder and the forces on the knee and hip joints were measured with load cells. The experiment was repeated three times so that its repeatability could be gauged.

The experimental results were compared to Adams simulation results. In the RCP simulation, the slider displacement shows good correlation with the experimental results. However, the hip and knee forces predicted by simulation were considerably higher than those seen in the physical experiment. This is explained by the unrealistically high stiffness in the joints of the RCP model. Two variations of the FCP simulation were performed. One variation used four Adams bushing elements corresponding to joints 1, 2, 4 and 6 in the diagram. The second variation used six Adams bushing elements at all six joints in the diagram. The FCP simulation provides results that correlate well with the physical test results for both forces and displacement. The FCP simulation with four bushings shows excellent correlation

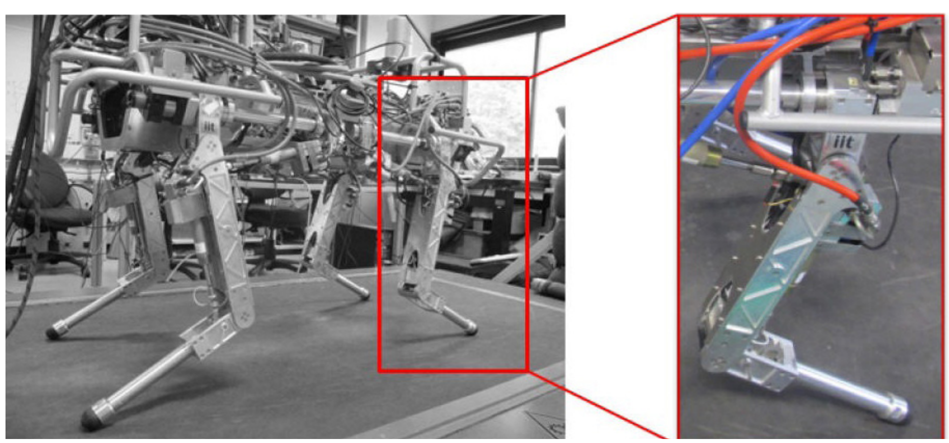
Key Highlights:

Product: Adams

Industry: Robotics/Machinery

Benefits:

- Up to 80% time savings using Adams and MSC Nastran compared to the traditional analytical approach
- The model built with realistic flexibility correlates well with the physical measurements for slider displacement, knee force and hip force
- Accurate modeling of the robot’s leg enables the engineers to investigate the performance of the complete robot in tasks such as walking or running over different types of terrain as a next step



Prototype of Robot being designed by IIT

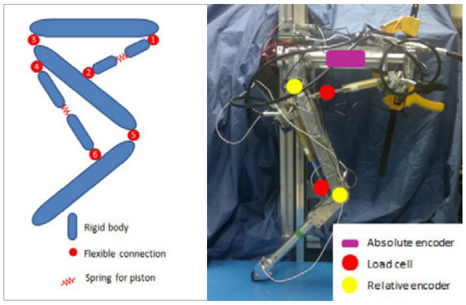
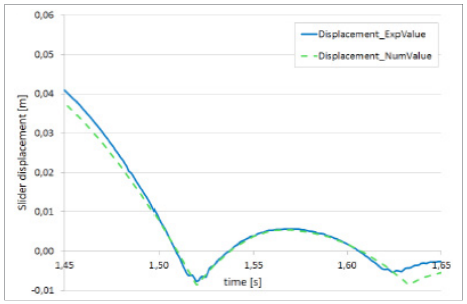
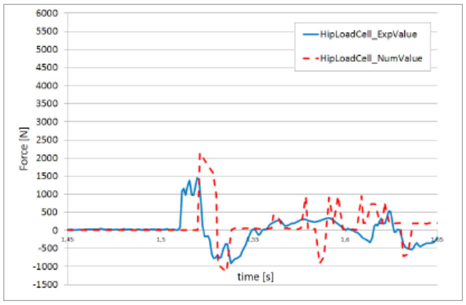


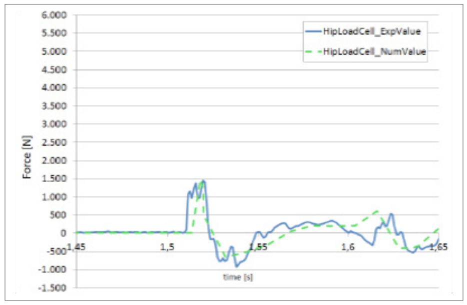
Figure 2. Diagram of rigid multibody model and Drop test



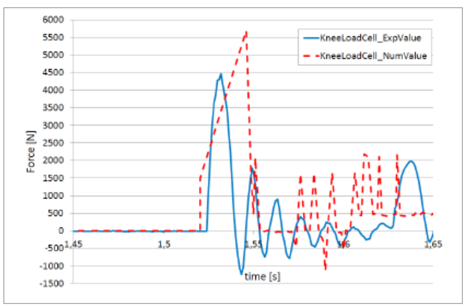
RCP simulation slider displacement vs experimental results



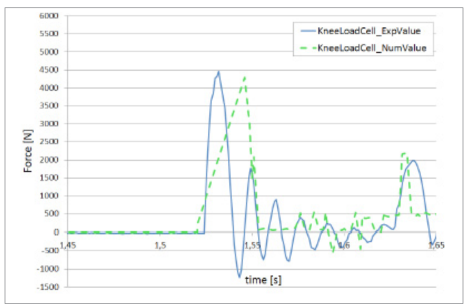
RCP simulation hip force vs experimental results



FCP four bushing simulation hip force vs experimental results



FCP four bushing simulation knee force vs experimental results



FCP six bushing simulation knee force vs experimental results

with physical testing for slider displacement and hip force but the knee forces do not match up well. This is explained by the fact that the knee force predictions depend largely on the stiffness of joints 4 and 5. The model built with 6 bushings correlates well with the physical measurements for slider displacement, knee force and hip force [3].

Results

"Now that we have succeeded in accurately modeling the robot's leg, we are half-way towards our immediate aim of simulating the performance of the complete robot in tasks such as walking or running over different types of terrain," said Ferdinando Cannella, Head of IIT's Advanced Industrial Automation Lab. "We are currently working on developing a simulation model of the complete prototype. Once that model has been validated, then engineers will begin evaluating a wide range of design alternatives in order to improve the performance of the robot. When the design has been optimized in the simulation world, then a new prototype will be constructed to validate these improvements in the real world. I like to highlight that this work will last 3 years and it is carried out by Mariapaola D'Imperio as PhD project and supported by MSC Software Senior Project Manager. Daniele Catelani; the good results demonstrate the goodness of this collaboration [4]."

About the Italian Institute of Technology

The Italian Institute of Technology is a foundation established jointly by the Italian Ministry of Education, Universities and Research and the Ministry of Economy and Finance to promote excellence in basic and applied research and to contribute to the economic development of Italy. The primary goals of the IIT are the creation and dissemination of scientific knowledge as well as the strengthening of Italy's technological competitiveness. To achieve these two goals, the IIT will cooperate with both academic institutions and private organizations, fostering through these partnerships scientific development, technological advances and training in high technology. The Dynamic Legged Systems (DLS) lab is performing research and development for the design and control of high-performance, versatile legged robots, including planning and perception. The torque-controlled hydraulic quadruped robot HyQ is our flagship platform.

For more information on Adams and for additional Case Studies, please visit **www.mscsoftware.com/case-studies**

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