Case Study: **Shanghai Jiao Tong University**

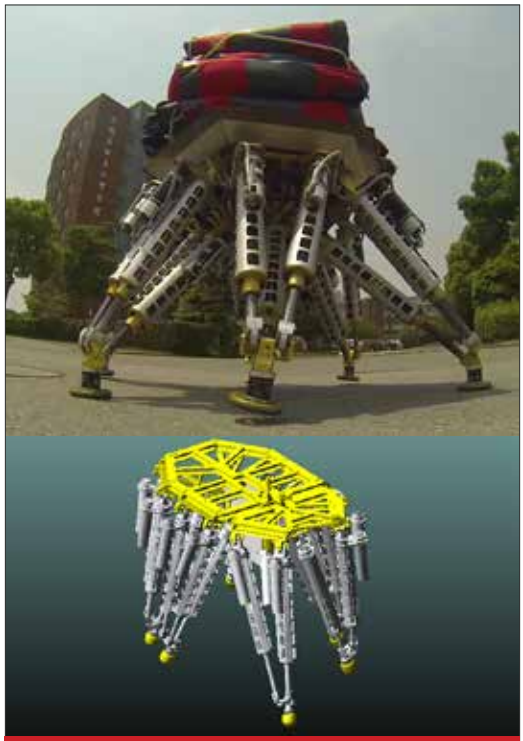
Chinese University Develops Legged Robot for Rescue Operations in Nuclear Plants

Overview

Shanghai Jiao Tong University researchers including Dr. Gao Feng, Director of the Chinese National Laboratory of Mechanical System and Vibration at SJTU and Dr. Yang Pan, Postdoctoral Research Fellow at SJTU, have designed the Octopus III six-legged robot for moving, searching, detecting, repairing and rescuing in extreme environments such as nuclear radiation, fires, and underwater. The six-legged Octopus III robot takes advantage of the unusual capabilities of legged robots such as traversing uneven terrain, overcoming obstacles, performing vertical climbs, and righting themselves after turning over.

Legged robots are substantially more difficult to design than wheeled robots because they require complex mechanics and control strategies to maintain their equilibrium, orientation, efficiency and speed. The Octopus III's six legs each have an identical drive mechanism consisting a parallel mechanism with three limbs. Each leg has one UP limb with a universal joint and a prismatic joint connected in series and two UPS limbs with a universal joint, a prismatic joint and spherical joint connected in series.

The robot is controlled by an onboard computer running the Linux operating system that communicates wirelessly with a remote computer running the Windows operating system. Orders such as move forward or turn left can be issued to the robot through a human machine interface (HMI) on the Windows computer. The onboard computer contains optimized kinematics and dynamic models of the robot and controls the robot's 180 servo motors. The robot weighs about 270 kg, can climb a 20 degree slope and walks at 1.08 km/hr.



Adams simulation of robot walking

"If we had not used Adams to optimize the design prior to building the prototype, we would probably have needed five additional prototypes at a cost of $100,000 each to get the design right. With Adams, the first prototype worked exactly as intended so we did not have to make a single change."

Dr. Yang Pan, Postdoctoral Research Fellow, Shanghai Jiao Tong University

Challenges

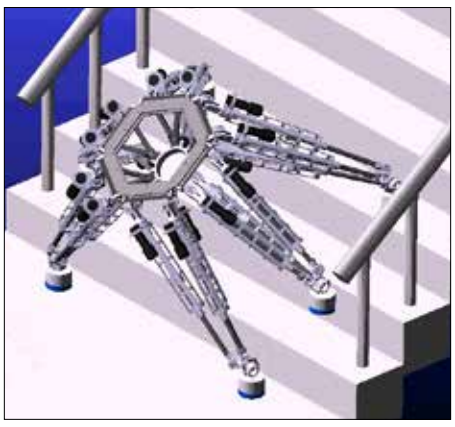
The SJTU researchers faced the challenge of delivering a high level of speed, payload, durability and other parameters in the new robot at the lowest possible cost. Traditional methods of designing robots such as using equations or software to model kinematics and simple dynamics are losing their effectiveness as robots become lighter and operate under higher loads, because complex dynamic effects play an increasing role. The designers needed to know how much load each of their proposed designs would be capable of carrying, how they would perform in a variety of tasks and the magnitude of the forces that would be applied to the various joints of the robot in order to optimize the design and deliver a competitive product.

Solution/Validation

Pan used Adams multibody dynamics software to create a complete working prototype of the robot and the task that it is performing, such as carrying a heavy load or turning a valve. Pan developed the geometry for proposed robot designs in SolidWorks computer aided design (CAD) software and wrote Adams/View command language scripts to convert the geometry into an Adams model such as by adding joints, bearings and motors. "The Adams/View command language works well for parametric modeling of robots because I can write create a single file to produce the robot design and then produce new design variants simply by changing numbers in the command language file," Pan said. Many actions performed with the Adams interface have equivalents in Adams/View command language. The commands can be stored in a file and imported as needed.

Pan evaluated many alternate robot parallel and serial mechanisms including 1UP, 2UPS, 3UPS and 3PRS. Adams made it possible to evaluate the dynamic performance of the design concepts as an entire system in the early stages of the design process. With Adams, Pan was able to evaluate the transient dynamic behavior of many different proposed designs in much less time, at a lower cost and at an earlier stage in the design process than would have been required to obtain the same information from prototype testing. He was able to increase the speed and load of the robot while ensuring that the robot was able to traverse a wide range of different surfaces.

After determining the UP and UPS combination used in the Octopus III provided the best results, Pan tried many different joint dimensions simply by changing variables in Adams/View command language scripts. He evaluated the ability of the robot to perform isotropically, in other words to be able to move a given payload at the same speed in any desired direction. He also used simulation to evaluate proposed designs for the presence of singular conditions that would cause the robot to stop moving. After running a considerable number of design iterations, the researchers settled on a design that met all of their objectives. At this point, the team commissioned the construction of a prototype at the cost of about $100,000.



Adams simulation of robot climbing stairs

Adams simulation of Octopus robot closing a valve

Key Highlights:

Product: Adams

Industry: Machinery/Robotics

Benefits:

- The Adams/View command language works well for parametric modeling of robots
- The performance of the prototype closely matched the Adams predictions
- Applying Adams simulation early in their robot design saved five additional prototypes at a cost of $100,000 each

Results

The SJTU researchers tested the prototype under a wide range of conditions such as turning valves and switches and carrying loads of up to 500 kilograms in order to evaluate its fitness for proposed missions. The physical experiments showed that the performance of the prototype closely matched the Adams predictions. "If we had not used Adams to optimize the design prior to building the prototype, we would probably have needed five additional prototypes at a cost of $100,000 each to get the design right," Pan said. "With Adams, the first prototype worked exactly as intended so we did not have to make a single change."

About Shanghai Jiao Tong University

Shanghai Jiao Tong University is a public research university located in Shanghai, China. Established in 1896 by an imperial edict issued by the Guangxu Emperor, the university is renowned as

Octopus robot walking

Load carrying experiment with robot prototype

Robot balances itself after being pushed

one of the oldest and most prestigious and selective universities in China. It's total enrollment of 42,881 students includes 16,099 domestic undergraduates, 19,632 domestic postgraduate students and 1,721 international students. In 2015, SJTU led China for the sixth consecutive year in number of projects and research grants issued by the Chinese government. The number of papers published by SJTU researchers in 2014 at 5,398 was second among Chinese universities.

About Dr. Gao Feng

Dr. Gao Feng is a professor of Mechanical Engineering, Shanghai Jiao Tong University. He is the chief scientist of the national "973" project "Basic Problems Research on Nuclear Power Plant Emergency Rescue Robot", the winner of the National Science Foundation for Distinguished Young Scholars of China and Director of the Chinese National Laboratory of Mechanical Systems and Vibration. His research team has been issued more than 100 Chinese patents. In the past 3 years, the team obtained over 75 million RMB in research funding.

About Dr. Yang Pan

Dr. Yang Pan is a postdoctoral research fellow at the Mechanical Engineering school of Shanghai Jiao Tong University. He is the youngest main member of the national "973" research project "Basic Research on a Nuclear Power Plant Emergency Rescue Robot". He designed 4 prototypes of 6 legged rescue robots with 3 different parallel mechanisms and all of them have shown very good capabilities in terms of payload, velocity and autonomous control. Dr. Yang Pan has published more than 15 research papers in international journals and conferences and has obtained 5 Chinese patents.

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