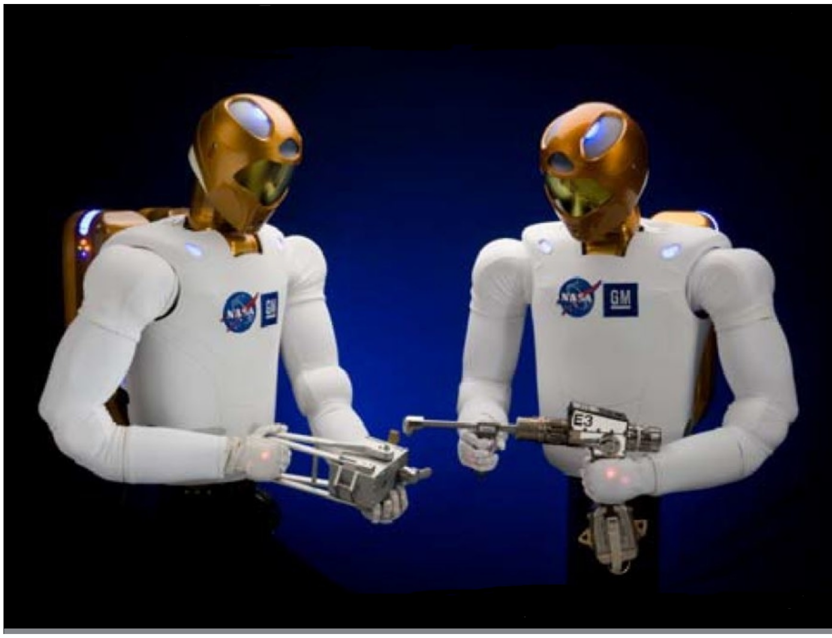


National Aeronautics and
Space Administration

TECHNOLOGY SOLUTION

Robotics, Automation and Control

Advanced Humanoid Robotic Arm Technologies

Cutting-edge systems for humanoid robotics

NASA and General Motors, two organizations at the forefront of robotics, have developed the Robonaut 2 (R2) – a state-of-the-art, dexterous, humanoid robot capable of performing tasks in an automated fashion (or via teleoperation). The technology developed throughout the project represents the cutting edge of autonomous, humanoid robotics. These technologies are available for licensing, both in a modular framework or as an integrated system, to enhance your robotic products.

R2's 5 Degrees of Freedom (DoF) arms, the topic of this flyer, use series elastic actuation to provide improved shock tolerance, accurate and stable force control, and beneficial energy storage capacity. An impedance controller limits the stiffness of the arms, ensuring workspace safety in scenarios where humans and robots are working in the same environment.

BENEFITS

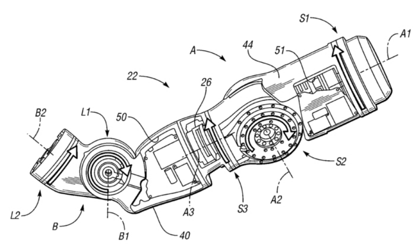
- Automates simple tasks: R2 can take over simple, repetitive, or dangerous tasks in locations such as the ISS, hazardous areas, manufacturing facilities, etc.
- Series elastic actuator technology: SEAs are integrated into the R2 robotic arms, which provide high shock tolerance and energy storage capacity, as well as accurate and stable force control.
- Workspace safety: R2's impedance controller limits the stiffness of the arms. Thus, in situations when the robot is inhibited by the environment, it only exhibits a reasonable amount of torque.
- Fine torque sensing: The R2 SEAs enable fine torque sensing without sacrificing strength or payload capacity.
- Advanced FPGA-based torque controller: Combining all of the necessary hardware elements into one physical printed circuit board resulted in decreased volume and increased noise immunity. Additionally, the controller uses a multi-drop high speed communication bus to decrease latency.

THE TECHNOLOGY

R2 uses brushless DC motors, harmonic drive gear reductions, and electromagnetic failsafe brakes as the building blocks for the powerful, torque-dense actuators in its human-scale, 5 DoF upper arms. Moreover, the use of series elastic actuators and novel tension sensing & control systems represent some of the most innovative technologies present in the humanoid robotic arms of R2.

Series Elastic Actuators (SEAs): R2's SEAs achieve fine torque sensing at each of its joints without sacrificing strength or payload capacity. Such capabilities are enabled through the development of several advanced technologies. Specifically, novel planar torsion springs (U.S. Patent No. 8,176,809) are integrated into each rotary series elastic actuator (U.S. Patent No. 8,291,788), while two absolute angular position sensors, calibrated using a novel technique (U.S. Patent No 8,250,901), measure the deflection of each spring. Force and Impedance Control Systems (U.S. Patent No. 8,525,460): These systems use position sensor signals for sending position data to an embedded processor that determines the positional orientation of the load relative to a motor shaft and its related torque on a string. A FPGA-based controller (U.S. Patent No. 8,442,684) provides a high-speed (10 KHz) control loop for the electric motor and gear reduction assembly present in R2 joints.

Tension Sensing & Control of Tendon-Based Robotic Manipulators: NASA has also developed technologies to provide tension sensing & control of humanoid robotic arms. First, a tendon tension sensor (U.S. Patent No. 8,371,177) measures strain on tendons (strings) employed in robotic arms. A novel calibration system (U.S. Patent No. 8,412,378) calibrates the tendon tension sensors. Finally, joint space impedance control systems (U.S. Patent Nos. 8,170,718 & 8,060,250) provide closed-loop control of joint torques or joint impedances without inducing dynamic coupling between joints, as well as programmable Cartesian arm stiffness.



A depiction of R2's rotary series elastic actuators (U.S. Patent No. 8,291,788).

Custom torsion springs (U.S. Patent No. 8,176,809) from the R2 series elastic actuators.

APPLICATIONS

The technology has several potential applications:

- Industrial manufacturing & maintenance
- Space exploration
- Personal assistance & caregiving
- Emergency services & operations in hazardous environments
- Repetitive task automation

PUBLICATIONS

Patent No: 8,291,788; 8,525,460; 8,442,684; 8,250,901; 8176809; 8371177; 8060250; 8,291,788; 8170718; 8,511,964; 8,443,693; 8,443,694; 8,919,842; 8483877; D628,609

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NASA's Technology Transfer Program pursues the widest possible applications of agency technology to benefit US citizens. Through partnerships and licensing agreements with industry, the program ensures that NASA's investments in pioneering research find secondary uses that benefit the economy, create jobs, and improve quality of life.

MSC-24736-1, MSC-24755-1, MSC-24742-1, MSC-24743-1, MSC-24569-1, MSC-24571-1, MSC-24686-1, MSC-24736-1, MSC-24687-1, MSC-24739-1, MSC-TOPS-101

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NP-2022-04-3051-HQ