Robot vision: Muscle-like action allows camera to mimic human eye movement

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Using piezoelectric materials, researchers have replicated the muscle motion of the human eye to control camera systems in a way designed to improve the operation of robots. This new muscle-like action could help make robotic tools safer and more effective for MRI-guided surgery and robotic rehabilitation.

Key to the new control system is a piezoelectric cellular actuator that uses a novel biologically inspired technology that will allow a robot eye to move more like a real eye. This will be useful for research studies on human eye movement as well as making video feeds from robots more intuitive. The research is being conducted by Ph.D. candidate Joshua Schultz under the direction of assistant professor Jun Ueda, both from the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology.

"For a robot to be truly bio-inspired, it should possess actuation, or motion generators, with properties in common with the musculature of biological organisms," said Schultz. "The actuators developed in our lab embody many properties in common with biological muscle, especially a cellular structure. Essentially, in the human eye muscles are controlled by neural impulses. Eventually, the actuators we are developing will be used to capture the kinematics and performance of the human eye."

Details of the research were presented June 25, 2012, at the IEEE International Conference on Biomedical Robotics and Biomechatronics in Rome, Italy. The research is funded by National Science Foundation. Schultz also receives partial support from the Achievement Rewards for College Scientists (ARCS) Foundation.

Ueda, who leads the Georgia Tech Bio-Robotics and Human Modeling Laboratory in the School of Mechanical Engineering, said this novel technology will lay the groundwork for investigating research questions in systems that possess a large number of active units operating together. The application ranges from industrial robots, medical and rehabilitation robots to intelligent assistive robots.

Robustness against uncertainty of model and environment is crucial for robots physically interacting with humans and environments," said Ueda. "Successful integration relies on the coordinated design of control, structure, actuators and sensors by considering the dynamic interaction among them."

Piezoelectric materials expand or contract when electricity is applied to them, providing a way to transform input signals into motion. This principle is the basis for piezoelectric actuators that have been used in numerous applications, but use in robotics applications has been limited due to piezoelectric ceramic's minuscule displacement.

The cellular actuator concept developed by the research team was inspired by biological muscle structure that connects many small actuator units in series or in parallel.

The Georgia Tech team has developed a lightweight, high speed approach that includes a single-degree of freedom camera positioner that can be used to illustrate and understand the performance and control of biologically inspired actuator technology. This new technology uses less energy than traditional camera positioning mechanisms and is compliant for more flexibility.

"Each muscle-like actuator has a piezoelectric material and a nested hierarchical set of strain amplifying mechanisms," said Ueda. "We are presenting a mathematical concept that can be used to predict the performance as well as select the required geometry of nested structures. We use the design of the camera positioning mechanism's actuators to demonstrate the concepts."

The scientists' research shows mechanisms that can scale up the displacement of piezoelectric stacks to the range of the ocular positioning system. In the past, the piezoelectric stacks available for this purpose have been too small.

"Our research shows a two-port network model that describes compliant strain amplification mechanisms that increase the stroke length of the stacks," said Schultz. "Our findings make a contribution to the use of piezoelectric stack devices in robotics, modeling, design and simulation of compliant mechanisms. It also advances the control of systems using a large number of motor units for a given degree of freedom and control of robotic actuators."

In the study, the scientists sought to resolve a previous conundrum. A cable-driven eye could produce the eye's kinematics, but rigid servomotors would not allow researchers to test the hypothesis for the neurological basis for eye motion.

Some measure of flexibility could be used in software with traditional actuators, but it depended largely on having a continuously variable control signal and it could not show how flexibility could be maintained with quantized actuation corresponding to neural recruitment phenomena.

"Each muscle-like actuator consists of a piezoelectric material and a nested hierarchical set of strain amplifying mechanisms," said Ueda. "Unlike traditional actuators, piezoelectric cellular actuators are governed by the working principles of muscles - namely, motion results by discretely activating, or recruiting, sets of active fibers, called motor units.

"Motor units are linked by flexible tissue, which serves a two-fold function," said Ueda. "It combines the action potential of each motor unit, and presents a compliant interface with the world, which is critical in unstructured environments."

The Georgia Tech team has presented a camera positioner driven by a novel cellular actuator technology, using a contractile ceramic to generate motion. The team used 16 amplified piezoelectric stacks per side.

The use of multiple stacks addressed the need for more layers of amplification. The units were placed inside a rhomboidal mechanism. The work offers an analysis of the force-displacement tradeoffs involved in the actuator design and shows how to find geometry that meets the requirement of the camera positioner, said Schultz.

"The goal of scaling up piezoelectric ceramic stacks holds great potential to more accurately replicate human eye motion than previous actuators," noted Schultz. "Future work in this area will involve implantation of this technology on a multi-degree of freedom device, applying open and closed loop control algorithms for positioning and analysis of co-contraction phenomena."

Future research by his team will continue to focus on the development of a design framework for highly integrated robotic systems. This ranges from industrial robots to medical and rehabilitation robots to intelligent assistive robots.

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