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Multiplexed Force and Deflection Sensing Shell Membranes for Robotic Manipulators

This technology can be used to enhance precision in robotic surgery.

Lyndon B. Johnson Space Center, Houston, Texas

Force sensing is an essential requirement for dexterous robot manipulation, e.g., for extravehicular robots making vehicle repairs. Although strain gauges have been widely used, a new sensing approach is desirable for applications that require greater robustness, design flexibility including a high degree of multiplexibility, and immunity to electromagnetic noise.

This invention is a force and deflection sensor — a flexible shell formed with an elastomer having passageways formed by apertures in the shell, with an optical fiber having one or more Bragg gratings positioned in the passageways for the measurement of force and deflection.

One object of the invention is lightweight, rugged appendages for a robot that feature embedded sensors so that the robot can be more "aware" of loads in real time. A particular class of optical sensors, fiber Bragg grating (FBG) sensors, is promising for space robotics and other applications where high sensitivity, multiplexing capability, immunity to electromagnetic noise, small size, and resistance to harsh environments are particularly desirable. In addition, the biosafe and inert nature of optical fibers makes them attractive for medical robotics. FBGs reflect light with a peak wavelength that shifts in proportion to the strain to which they are subjected. Multiple FBG sensors can be placed along a single fiber and optically multiplexed. FBG sensors have previously been surface-attached to or embedded in metal parts and composites to monitor stresses.

An exoskeletal force sensing robot finger was developed by embedding FBG sensors into a polymer-based structure. Multiple FBG sensors were embedded into the structure to allow the manipulator to sense and measure both contact forces and grasping forces. In order to fabricate a three-dimensional structure, a new shape deposition manufacturing (SDM) process was developed. The sensorized SDM-fabricated finger was then characterized using an FBG interrogator. A force localization scheme was also developed.

A sensor is formed from a thin shell of flexible material such as elastomer to form an attachment region, a sensing region, and a tip region. In one embodiment, the sensing region is a substantially cylindrical flexible shell, and has a plurality of apertures forming passageways between the apertures. Optical fiber is routed through the passageways, with sensors located in the passageways prior to the application of the elastomeric material forming the flexible shell. Deflection of the sensor, such as by a force applied to the contact region, causes an incremental strain in one or more passageways where the optical fiber is located. The incremental strain results in a change of optical wavelength of reflection or transmittance at the sensor, thereby allowing the measurement of force or displacement.

The ability to route a single optical fiber through the passageways of the outer shell of the sensor, combined with the freedom to place Bragg grating-based sensors in desired locations of the shell, provides tremendous flexibility in sensing force in three axes, as well as the possibility of providing a large number of sensors for more sophisticated measurement modalities, such as torque and shell deflection in response to multipoint pressure application.

This work was done by Yong-Lae Park, Richard Black, Behzad Moslehi, Mark Cutkosky, and Kelvin Chau of Intelligent Fiber Optic Systems Corp. for Johnson Space Center. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to MSC-24501-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Whispering Gallery Mode Optomechanical Resonator

These devices can be used for remote and inertial sensing, and mass detection.

NASA's Jet Propulsion Laboratory, Pasadena, California

Great progress has been made in both micromechanical resonators and micro-optical resonators over the past decade, and a new field has recently emerged combining these mechanical and optical systems. In such optomechanical systems, the two resonators are strongly coupled with one influencing the other, and their interaction can yield detectable optical signals that are highly sensitive to the mechanical motion. A particularly high-Q optical system is the whispering gallery mode (WGM) resonator, which has many applications ranging from stable oscillators to inertial sensor devices. There is, however, limited coupling between the optical mode and the resonator's external environment. In order to overcome this limitation, a novel type of optomechanical sensor has been developed, offering great potential for measurements of displacement, acceleration, and mass sensitivity.

The proposed hybrid device combines the advantages of all-solid optical WGM resonators with high-quality micro-machined cantilevers. For direct access to the WGM inside the resonator, the idea is to radially cut precise gaps into the perimeter, fabricating a mechanical resonator within the WGM. Also, a strategy to reduce losses has been developed with optimized design of the cantilever geometry and positions of gap surfaces.

The cantilever is machined by making fine cuts in a high-Q crystalline WGM resonator using focused ion-beam (FIB) technology. Such cuts can be much smaller than the optical wavelength, which should preserve the quality of the optical resonator. At the same time, reflection from the cantilever surfaces will result in coupling between the degenerate clockwise and counterclockwise propagating WGM. Therefore, a well-established technique of position-sensitive, dual-resonator coupling will be implemented in a novel system with optical and mechanical resonators' high quality factors. This technique allows for optical cooling, as well as heating, of the mechanical oscillator.

This innovative hybrid system combines the advantages of both WGM and Fabry-Perot (FP) cavity resonators by utilizing the WGM resonator with the aforementioned cuts in the crystal to create an independent micromechanical resonator, residing directly in the middle of the optical WGM as an integral structure of the disk. This feature allows the direct coupling of the mechanical motion to the optical modes, much like a membrane inside an FP cavity. In this configuration, the single-mode optomechanical interaction can be selectively accessed as with a standard WGM resonator, or the coupled optical mode interaction as in that of a membrane-FP cavity.

The challenge of this approach is to maintain the optical finesse in the presence of the air gaps and the corresponding interfaces. The partially reflecting surfaces result in standing waves (SWs) in the resonators, and the mode coupling between them. These interfaces can also introduce scattering and diffraction losses. The estimates and previous WGM experiments suggest that a combination of appropriate microfabrication processes, such as FIB, and strategic use of SW modes, can reduce the losses and yield an optical resonator $Q \approx 10^8$, higher than any cavity Q of optomechanical systems at the time of this reporting.

This work was done by David C. Aveline, Dmitry V. Strekalov, Nan Yu, and Karl Y. Yee of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47114

Vision-Aided Autonomous Landing and Ingress of Micro Aerial Vehicles

This technology enables a micro aerial vehicle to transition autonomously between indoor and outdoor environments via windows and doors based on monocular vision.

NASA's Jet Propulsion Laboratory, Pasadena, California

Micro aerial vehicles have limited sensor suites and computational power. For reconnaissance tasks and to conserve energy, these systems need the ability to autonomously land at vantage points or enter buildings (ingress). But for autonomous navigation, information is needed to identify and guide the vehicle to the target. Vision algorithms can provide egomotion estimation and target detection using input from cameras that are easy to include in miniature systems.

Target detection based on visual feature tracking and planar homography decomposition is used to identify a target for automated landing or building ingress, and to produce 3D waypoints to locate the navigation target. The vehicle control algorithm collects these waypoints and estimates the accurate target position to perform automated maneuvers for autonomous landing or building ingress.

Systems that are deployed outdoors can overcome this issue by using GPS data for pose recovery, but this is not an option for systems operating in deep space or indoors. To cope with this issue, a system was developed on a small unmanned aerial vehicle (UAV) platform with a minimal sensor suite that can operate using only onboard resources to autonomously achieve basic navigation tasks. As a first step towards this goal, a navigation approach was developed that visually detects and reconstructs the position of navigation targets, but depends on an external VICON tracking system to regain scale and for closed-loop control.

A method was demonstrated of vision-aided autonomous navigation of a micro aerial vehicle with a single monocular camera, considering two different example applications in urban environments: autonomous landing on an elevated surface and automated building ingress. The method requires no special preparation (labels or markers) of the landing or ingress locations. Rather, leveraging the planar character of urban structure, the vision system uses a planar homography decomposition to detect navigation targets and produce approach waypoints as an input to the vehicle control algorithm. Scale recovery is achieved using motion capture data. A real-time implementation running onboard a micro aerial vehicle was demonstrated in experimental runs.

The system is able to generate highly accurate target waypoints. Using a three-stage control scheme, one is able to autonomously detect, approach, and land on an elevated landing surface that is only slightly larger than the footprint of the aerial vehicles, and gather navigation target waypoints for building ingress. All algorithms run onboard the vehicles.

This work was done by Roland Brockers, Jeremy C. Ma, and Larry H. Matthies of Caltech; and Patrick Bouffard of the University of California, Berkeley for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47841