

fering 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.

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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.

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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