Direct optical measurement of force and torque in optical tweezers

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A key contribution of optical tweezers to biology and biophysics, recognized by the award of the 2018 Nobel Prize in Physics to Arthur Ashkin, who invented optical tweezers in 1986 [1], has been the measurement of forces on the order of piconewtons in biological systems. There are two main routes to the measurement of forces. First, since the force depends on the position of the trapped particle, the force can be inferred from the position if this dependence is known. Especially in the case of small displacements such that the trap can be treated as a linear spring characterized by a spring constant, this dependence can be found. However, this requires a calibration for each type and size of particle, and needs to be repeated if the properties of the trap change.

The optical force results from the change in momentum of the trapping beam as it is scattered by the trapped particle. Therefore, measurement of the angular distribution of the scattered light allows the direct optical measurement of the force [2]. Most implementations of this make use of a per-particle calibration, but it is possible to calibrate a suitable detector once, and measure the force acting on arbitrary particles, even if the properties of the trap are changed.

In this talk we review the direct optical measurement of forces, including recent developments in calibrate-once methods. Noting that it is generally not possible to capture all of the scattered light, we discuss why, and to what extent, the forces can be accurately measured. We also consider the direct optical measurement of torque, which is straightforward in some cases [3], and a challenge that has yet to be overcome in other cases.

References

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