Diffusion of gold nanoparticles measured by single particle tracking

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Single particle tracking by optical microscopy has been of interest to fields ranging from nano-engineering to molecular biology. This method enables one to determine not only the position of a particular molecule or nanoparticle but also to characterize the motion of individual particles. It is therefore possible to reveal the dynamics of nanoparticles or biological molecules like proteins in complex environments such as, for example, a cellular membrane. The dynamics are in general expressed by evaluating the diffusion coefficient D. Here, we investigated the dynamics of gold nanoparticles in media of different viscosity using wide field optical microscopy, which yields time resolution of up to 30 ms and areas of 82 μm x 82 μm. The positions of the nanoparticles were determined by fitting the signal of each particle to a two-dimensional Gaussian curve. We then calculated the mean square displacement and performed a linear fitting to determine the diffusion coefficient. We found that the number of optimal fitting points for the linear fitting is important and compared our experimental results with simulations and a published theoretical analysis.

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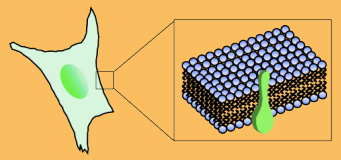
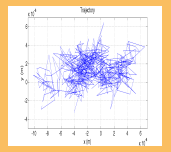
Motivation

The dynamics of cellular membranes and proteins are expressed as a diffusion coefficient.



Cell

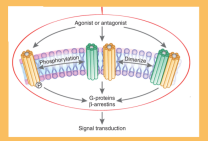
Cellular membrane and protein



Simulation of diffusion of the protein

The diffusion coefficient is important for…

Membrane protein



→ Signal transduction

Lunn et.al. Nat. Bio. Tech (2011)

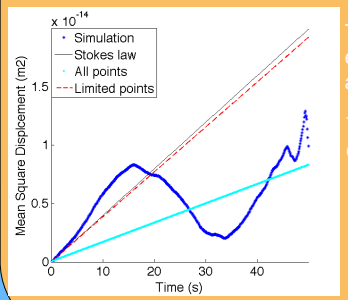
Motor protein

→ Cellular kinetics

Ishijima et.al. Cell. (1998)

Objective

The objective is to establish an analysis method to deduce the diffusion coefficient.



The diffusion coefficient is expressed as linear function and deduced by linear fitting.

The number of fitting points changes diffusion coefficient.

Modified Mean Square Displacement (MMSD)

Method

Theory: Modified Mean Square Displacement (MMSD)

The theory describes the standard deviation and is function of x.

$$x = \frac{\sigma^2}{\tilde{D}\triangle t}$$

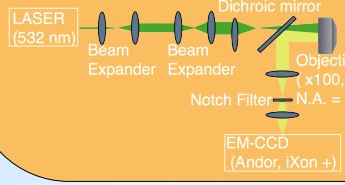
σ Localization error
$\tilde{D}$ Diffusion constant
$\triangle t$ Time interval

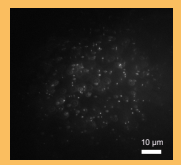
Michalet Phys.Lett.E (2010)

Simulation: Trajectories and Mean Square Displacement

The movement of the particle follows the random process and the Stokes-Einstein law.

Optical Setup: Total Internal Reflection Fluorescence Microscopy

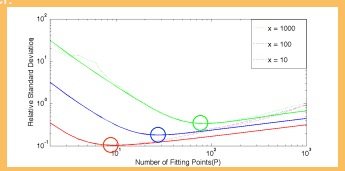




Fluorescence image

Results

There is a number of fitting point making relative standard deviation of each trajectory smaller.

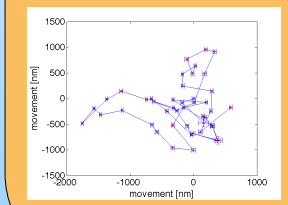


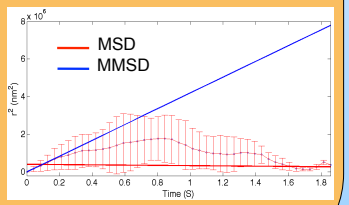
○ Fitting points of MMSD

Theory

Simulation

Experimental trajectory and mean square displacement



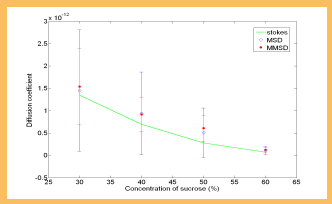


Since the MSD uses all fitting points, the diffusion coefficient calculated by MSD fluctuates.

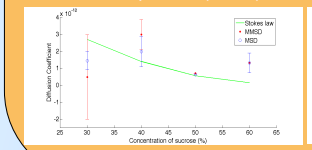
Results cont.

At every point, the error of MMSD is smaller than that of MSD.

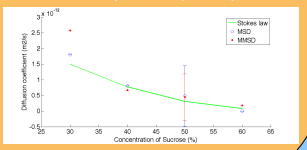
Fluorescence Beads



Au nanoparticle (50nm)



Au nanoparticle (90nm)



Discussion & Summary

- The best fitting numbers was predicted by the theory and confirmed by simulation and experiment.
- The data points are not enough because the photoluminescence of Au nanoparticles is much weaker than fluorescence beads.
- This method will be very useful for the molecular biology and nano-engineering field.

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