Magnetic Propulsion of Magnetoelastic Sentinels

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Magnetoelastic sentinels are a bioinspired method of seeking out bacteria in a liquid. A magnetoelastic sentinel is constructed of a freestanding magnetoelastic resonator (transducer platform) coated with a biorecognition layer targeting a specific pathogen. Just as white blood cells seek out and capture specific invading pathogens within the human body, magnetoelastic sentinels will move through a liquid, seeking out and capturing specific bacterial pathogens. A sentinel's resonant frequency decreases as its mass increases due to the capture of bacteria. The resonant frequency is detected wirelessly by the affect of its self-generated magnetic field on a nearby induction pickup coil.

To capture bacteria, however, the sentinels must encounter the bacteria. This becomes less likely as the bacterial concentration decreases. There are several approaches to improve the odds of encounter when the concentration of bacteria is low including flow cells and stirring. These are dynamic fluid environments that can be problematic due to fluid shear or separation because of density differences. The approach outlined here is to provide locomotion to the sentinels in a static liquid (1). The sentinels can be programmed to move, either continuously or intermittently, in a predetermined pattern such as a spiral or randomly throughout the liquid to expose the sensor to more parts of the liquid and more potential bacterial targets.

Providing locomotion ability to the sentinels, propelling them through a liquid sample, increasing exposure to bacterial target, effectively lowers the limit of detection. Locomotion of the sentinels is the result of forces ($\boldsymbol{F}$) and torques ($\boldsymbol{\tau}$) that are experienced by the sentinel that arise in the presence of an external magnetic field ($\boldsymbol{B}$) (2). The forces and torques are given in terms of vector quantities by

$$\boldsymbol{F} = V(\boldsymbol{M} \cdot \boldsymbol{\nabla})\boldsymbol{B} \qquad [1]$$

$$\boldsymbol{\tau} = V(\boldsymbol{M} \times \boldsymbol{B}) \qquad [2]$$

where V is the volume of the sentinel and $\boldsymbol{M}$ is magnetic moment of the sentinel.

The torque on the sentinel is the result of the misalignment of its magnetic moment ($\boldsymbol{M}$) with an external magnetic field ($\boldsymbol{B}$) as shown in Equation 2. The torque on the sentinel causes it to align with the magnetic field as shown in Figure 1. Torque alone will cause the sentinel to rotate about its center of mass. To cause translation of the sentinel, an additional force is required. The force for translation arises from gradients in the external magnetic field as given by Equation 1. Both the forces generated and the torque produced are directly proportional to the volume of the sentinel however, less of each are required as the dimensions of the sentinel decreases.

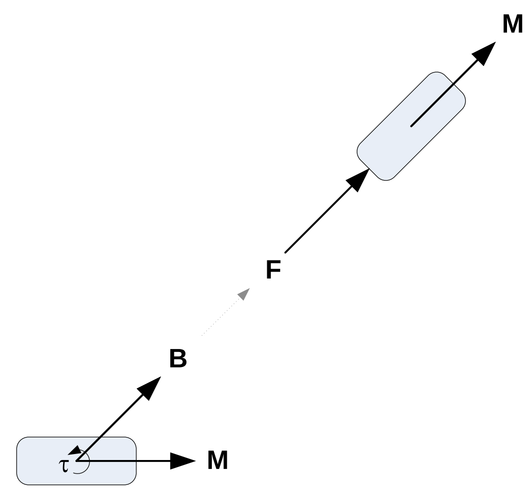

Figure 1. The misalignment of the sentinel's magnetic moment ($\boldsymbol{M}$) with an external magnetic field ($\boldsymbol{B}$) generates a torque which will cause the sentinel to align with the external field. A field gradient will generate a force ($\boldsymbol{F}$) on the sentinel, causing it to translate position.

A variety of electromagnetic coil arrangements are possible to manipulate the sentinels using magnetic fields (3). Different combinations and configurations of Helmholtz, Maxwell, and Golay coils have been proposed to provide magnetic manipulation, with the most recognizable implementation being Magnetic Resonance Imaging (MRI) systems. A system based on Helmholtz and Maxwell coils is under development for magnetoelastic sentinels.

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