Instituto Tecnológico y de Estudios Superiores de Monterrey

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School of Engineering and Sciences

Induced Rotation of Ratchets in Passive Environments

A thesis presented by

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The commitee members, hereby, certify that have read the thesis presented by **Yeray Cruz Ruiz** and that it is fully adequate in scope and quality as a partial requirement for the degree of Master in Nanotechnology.

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Declaration of Authorship

I, Yeray Cruz Ruiz (student), declare that this thesis titled, “Induced Rotation of Ratchets in Passive Environments” and the work presented in it are my own. I confirm that:

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- Where I have consulted the published work of others, this is always clearly stated.
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- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Yeray Cruz Ruiz (Student)
Monterrey, Nuevo León, México, May 2025

Dedication

To my parents for their unwavering support, to my friends for making this journey easier, and especially to Dr. Antonio, who always believed in me and was an incredible mentor.

Acknowledgements

For those who come after.

Induced Rotation of Ratchets in Passive Environments

by

Yeray Cruz Ruiz

Abstract

Swimming at the mesoscale has been a topic of interest for the past two decades because of the complexity of motion at a low Reynolds number, a regime where the viscous forces dominate over the inertial ones. The scallop theorem is a principle that follows these complex ideas and states that a scallop, which has only one degree of freedom, must be unable to have net displacement in this regime due to the lack of time-reversal symmetry of the Navier-Stokes equations. Indifferent to our mathematical understanding, nature was capable of creating biological beings that are able to displace under these circumstances by developing what we call nonreciprocal motion. The esquerichia coli, for example, has a flagellum that rotates in one direction, pushing the fluid backwards and therefore moving the bacteria forwards. Inspired by these ideas, researcher have taken interest in generating motion at those scales. One example are bacterial micromotors, where a dented ratchet is immersed into a bacterial bath where they convert energy from their surroundings into movement. This movement normally follows a ballistic trajectory and in time some of them, will collide into the ratchet transferring their kinetic energy, and therefore making the motor spin thanks to the geometry of the ratchet. Unfortunately, the nutrients they absorb will end and in time the system's medium will need to be replaced, stopping the whole process, therfore being an inneficient process. This is a type of active matter that gets energy from its medium. But, Can we do the same with passive matter?

In this work, we analsze paramagnetic colloids, manipulated by an external precessing magnetic field. The system is confined betwen the z axis and presents periodic boundary conditions in x, and y axis. When multiple particles are present, dipole-dipole interactions arise, leading to either attraction or repulsion depending on their head-to-tail alignment. The particles' internal fields also rotate, dynamically altering their interactions over time. We observe that from 0Hz to 3Hz, the colloids form pairs and start rotating with a shared center of mass, whereas from 3.25 to 7Hz particles have a moment of replsion, creating a neighbor exchange between different pairs, obtaining a ballistic trajectorWe observe that from 0Hz to 3Hz, the colloids form pairs and start rotating with a shared center of mass, whereas from 3.25 to 7Hz particles have a moment of replsion, creating a neighbor exchange between different pairs, obtaining a ballistic trajectory. To investigate whether this motion can perform work, we place a ratchet-like object with different parameters amidst the particles.

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Introduction

Here goes the intro

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Background

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Swimming at the mesoscale

2.1 Low Renolds number

At the mesoscale, where objects such as bacteria and colloidal particles operate, the physical world is governed by a regime in which viscous forces dominate over inertial ones. This regime is characterized by a small Reynolds number (Re), a dimensionless quantity that compares inertial to viscous effects. Therefore, the force applied at that moment will describe the movement or displacement performed, not deppending on any past force, this is a characteristic of an overdamped system. In his seminal lecture, Life at Low Reynolds Number, Purcell highlighted the surprising and often counterintuitive behaviors that emerge in such environments [1]. For instance, time-reversible motion — common at macroscopic scales — is ineffective for propulsion at low Re, necessitating non-reciprocal strategies like flagellar rotation or body undulation.

This physical constraint fundamentally shapes how microorganisms swim and how artificial microswimmers must be designed. Subsequent work by Lauga and Powers [Lauga Powers, 2009] expanded on Purcell's insights by examining the fluid dynamics of various propulsion mechanisms, including bacterial run-and-tumble behavior and the synchronization of flagella. These concepts are directly relevant to systems explored in this thesis, where both biological and magnetically driven entities are used to induce motion in passive structures at the microscale.

La detección y diagnostico de fallas en procesos automáticos es un tema de gran importancia, debido a los altos requisitos de calidad en los productos que se comercializan hoy en día, a la seguridad de operación de las plantas de los diferentes procesos industriales y a la previsión de catástofres aéreos, terrestres y espaciales. Problemas como desgaste de actuadores, fallas en los sensores, mantenimientos inapropiados de los elementos de control y medición son factores que propician fallas frecuentes en los sistemas de control y monitoreo que cada vez se vuelven más complejos y grandes.La falta o un mal diseño de sistemas de detección y diagnóstico de fallas en los sensores y actuadores han causado inumerables accidentes aeréos en diferentes lugares del mundo. Por ejemplo en el ámbito industrial se puede recordar la cátastrofe sufrida en Chernóbil donde un aumento rápido de potencia en el reactor 4 produjo el sobrecalentamiento del núcleo del reactor nuclear, provocando la explosión del hidrógeno acumulado en su interior. En el áera automotriz diariamente se esta expuesto a fallas en sensores y actuadores provocando un funcionamiento anormal en el vehículo, si la falla no se detecta y diagnóstica oportunamente habrá mayores gastos en la reparación y perdida tiempo del propietario. Debido a la gran parte de la seguridad que se requiere en diferentes áreas es de gran interés desarrollar mejores sistemas para una buena detección y diagnóstico y es por eso que se han estado desarrollando en estos últimos años diversas propuestas para afrontar las necesidades de cada aplicación y así tener sistemas automáticos más confiables. Este documento hace una revisión de diferentes métodos empleados para la detección y diagnóstico de fallas en diversas áreas.

Chapter 3

Name of Appendix

Uso de referencias [**?**] and [**?**]

Chapter 4

Diagnosis in Dynamic Systems

4.1 Definitions

Some important definitions in dynamic systems are:

1. *Static versus dynamic systems.*
   A system is

2. *Linear versus non-linear models.*
   A linear model,

4.2 The Qualitative Model Representation

Bibliography

[1] Edward M Purcell. Life at low reynolds number. In *Physics and our world: reissue of the proceedings of a symposium in honor of Victor F Weisskopf*, pages 47–67. World Scientific, 2014.

Curriculum Vitae

Yeray Cruz Ruiz was born in Tlalnepantla, Estado de México, México. He received a Bachelor of Science degree in Mechatronics (2021) from Tecnológico de Monterrey, Campus Monterrey, México, where he is currently a full-time master's student in Nanotechnology, focusing on computational studies of soft matter systems out of thermodynamic equilibrium. His research interests include Soft Matter Physics, Colloidal Models, Spin Systems, Non-Equilibrium Statistical Mechanics, Active Matter, Glassy Systems, and Computational Physics. A passionate advocate for Free and Open Source Software (FOSS), he actively engages in FOSS communities, promoting collaboration and accessibility in scientific research.