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Assessment of Geometry and Gaits for Optimal Displacement and Efficiency

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Abstract

This paper studies the displacement and efficiency of a Purcell's three-link microswimmer in low Reynolds number regime, capable of moving by the implementation of a motion primitive or gait. An optimization is accomplished getting to the geometry of the swimmer and therefore the motion primitives, considering the form of the gait and its amplitude. The target is to seek out the geometry of the swimmer, amplitude and shape of the gaits which make optimal the displacement and efficiency, in both a private way and combined (the last case are going to be mentioned as multiobjective optimization). Three traditional gaits are compared with two primitives proposed by the authors and other three gaits recently defined within the literature. Results demonstrate that the very best displacement is obtained by the Tam and Hosoi optimal velocity gait, which also achieves the simplest efficiency in terms of energy consumption. The rectilinear and Tam and Hosoi optimal efficiency gaits are the second optimum primitives. Regarding the multiobjective optimization and considering the 2 criteria with an equivalent weight, the optimum gaits end up to be the rectilinear and Tam and Hosoi optimal efficiency gaits. Thus, the conclusions of this study can help designers to pick, on the one hand, the simplest swimmer geometry for a desired motion primitive and, on the opposite, the optimal method of motion for trajectory tracking for such a sort of Purcell's swimmers counting on the specified control objective.

Keywords: Low Reynolds Number • Non-Reciprocal Motion • Displacement • Efficiency • Optimal • Design • Multiobjective Optimization • Gaits • Purcell's Microswimmer

Introduction

Advances in micro- and nanotechnology have promoted the manufacturing of latest miniature biomimetic artificial devices inspired by biological systems. New applications emerge thanks to their ability to access to small spaces at the microscale, like perform medical procedures during a minimally invasive way, deliver drugs with high precision, and sensing towards diagnosis and monitoring. During this sense, understanding hydrodynamics at the microscale is crucial, which means navigating in low Reynolds number regime where viscous forces predominate over inertial ones. during this regime, the study of microswimmer dynamics acquires a crucial role on understanding the motion and finding new ways to propel these swimmers.

Mainly, two ways of propulsion at low Re regime are often distinguished. On the one hand, the movement are often obtained by performing a unidirectional body motion, deployed by a rotating corkscrew and supported the movement of prokaryotic cells or bacteria. On the opposite hand, flexible flagellums of eucaryotic cells have inspired the movement through planar waveforms, resulting in the study of various waveforms for propulsion and style of prototypes. During this respect, Purcell introduced the so-called Purcell's three-link swimmer, composed of three links attached by one degree-of-freedom joints and defined because the simplest swimmer that would implement a gait or motion primitive within a coffee Re flow and manage to maneuver a particular distance. It must be said that there are other sorts of Purcell's swimmers counting on the amount of links that they're made from (widely called N-link swimmers).

Concerning the Purcell's three-link swimmer, several authors already studied its dynamics comparing the displacement obtained through the implementation of traditional primitives and estimating a coefficient of efficiency supported the energy consumption of the joints, Other works study the dynamics of a 3D model and supply new gaits, while others analyze the dynamics of the generalized case of N-link and check out to approximate it to a sperm swimmer. Regarding the motion primitives, methods for designing new motion primitives are reported in, providing the definition and implementation of various gaits, while other works analyze the symmetries of the Purcell's three-link swimmers and their effect on generating gaits with particular symmetries so as to realize a desired net motion. These symmetries allowed to define other stroke sequences, represented as a Fourier series , which give optimal efficiency and velocity of the swimmer. Finally, the controllability of the Purcell's swimmers was studied in and experimental trajectory tracking was addressed in. Although considerable work has been wiped out this field, the defined gaits haven't been compared among them, nor any study involving the displacement and efficiency has been administered with all the motion primitives. additionally, the parameters that influence the movement of Purcell's swimmer have barely been analyzed.

This work aims to unravel these research gaps offering a completely unique comparative study between gaits in terms of displacement and efficiency towards doing optimal both the geometric design and therefore the trajectory tracking in future works.

This work aims to unravel this research gaps offering a completely unique comparative study between gaits with the target of optimizing the displacement and efficiency towards the implementation of an optimal trajectory tracking and therefore the design of a prototype in future works. The study focuses on three aspects: the form and amplitude of the motion primitives, and therefore the swimmer geometry. With the aim of analyzing the performance from different viewpoints, displacement and efficiency of the Purcell's three-link microswimmer are reported here in two alternative ways , namely separately and altogether, this last case by a multiobjective optimization. Regarding the motion primitives, this work proposes two new gaits and compares them with three traditional ones, already studied within the references and other three gaits defined by other authors. The results of this study will provide the optimal primitive along side its best amplitude and geometry of the swimmer for

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achieving optimal displacement, optimal efficiency and minimizing a multiobjective function. A preliminary work are often found in where the displacement and efficiency were calculated for various primitives, amplitudes and geometries, although these variables weren't analyzed together.

The document is organized as follows. Section 2 recalls the environment properties and therefore the hydrodynamics associated with low Re regime, supported the Navier–Stokes equations, also because the basis of the resistive force.

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