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Examination of the manuscript entitled « Micromanipulation Using Dielectrophoresis: Modeling and Real-Time Optimization-Based Control» presented by Mr Tomas Michalek

10 November 2020

To whom it may concern,

My name is Stéphane Régnier and I am a reviewer for the Ph.D. thesis of Mr Tomas Michalek on "Micromanipulation Using Dielectrophoresis: Modeling and Real-Time Optimization-Based Control". My research is mainly dedicated to micro/nano robotics i.e. on the same field as this thesis.

The aim of the work described in this thesis is to create a computational framework and experimental system for noncontact micromanipulation using dieletrophoresis for mainly biological applications. The designed system should be able to control position and/or orientation of micro-objects with various shapes.

The thesis is divided into six chapters including an introduction chapter and a conclusion chapter and a bibliography for each chapter.

The first chapter is dedicated to an introduction with an overview of micromanipulation methods and dielectrophoresis. Finally the key contributions are summarized chapter by chapter with the contributions for every chapter.

This second chapter deals with mathematical models of dielectrophoresis. Firstly Mr Tomas Michalek test the accuracy of existing models of DEP (dipolar, quadrupolar, octupolar) with a refinement by multipole approximations. All the simulations and experiments use a spherical particle above a parallel electrode array with comparable sizes. The model based on Maxwell stress tensor (MST) provides the reference value of the force. Experiments reveals that the models predict the force with an error that cannot be eliminated but can be used for some purposes such as a model-based control system design. The calculation duration is obtained between 0.42 ms for the dipolar model and 1.8 ms for the octopular model.

The effective multipole (EM) method approximates the polarization induced charge distribution in an object by a set of multipolar moments. The Coulombic interactions of these moments with the external polarizing electric field then gives the DEP forces and torque forces acting on the objects. The multipolar moments are only known for spherical objects. The third chapter introduces an original approach for real-time computation of multipolar moments for objects of arbitrary shapes having even arbitrary internal composition. The proposed model is validated using Maxwell stress tensor. The model can be used for control of position and orientation of non-spherical objects.

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The next chapter deals with the electrorotational behavior of non-spherical micro-objects. The control-oriented model of general electrophoresis is extended with the hydrodynamics. The resulting model can compute the translational and angular velocities of micro-objects under generalized dielectrophoresis (gDEP) in fractions of second. The comparisons of the simulations with experimental results show that the model is able to reflect the complex behavior of a Tetris-shaped micro-object. This model can be used in a controller achieving a steady angular velocity of the arbitrary shaped objects.

Finally the model is used in the last chapter for the non-contact manipulation of arbitrarily-shaped micro-objects using dielectrophoresis. A visual feedback control based on a real-time optimization-based inversion of a mathematical model is used. The experimental demonstration is carried out using Tetris-shaped SU-8 micro-objects on a chip with quadrupolar electrode array. The analysis of manipulation accuracy show that the mean error in position is around 5 μm while the error in orientation is around 0.01 rad. This chapter is very impressive. The presented method really opens up new possibilities in simultaneously manipulating objects of arbitrary shapes even with smaller objects.

Finally a chapter dedicated to the conclusions and future work concludes the manuscript.

The contributions of the work reported in the manuscripts are excellent with clear descriptions of the state of the art, theoretical models and non-contact micromanipulations using dielectropheresis. Experimental results on micromanipulation are very impressive with a lot of perspectives.

In summary, I strongly recommend to accept Tomas Michalek's thesis for the degree of doctor of the Czech Technical University in Prague and my personal evaluation is in the top 5% of the phd student of the faculty of Sciences and Engineering of Sorbonne University.

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