



Prof. Dr. Antonio Ramos,  
Depto. Electrónica y  
Electromagnetismo,  
Facultad de Física,  
Universidad de Sevilla,  
Avda. Reina Mercedes s/n,  
41012-Sevilla. Spain.

CTU in Prague, Faculty of Electrical Engineering  
Office for Science and Research  
Technicka 2  
166 27 Prague 6  
Czech Republic

September 24, 2020

Dear Prof. Ing. Milan Polívka,

This letter reports on my opinion about the dissertation thesis submitted by Ing. Tomáš Michálek in the field "Control Engineering and Robotics" at the Faculty of Electrical Engineering, Czech Technical University in Prague.

**Review on the dissertation thesis "Micromanipulation Using Dielectrophoresis: Modeling and Real-Time Optimization-Based Control" submitted by Ing. Tomáš Michálek .**

This dissertation thesis is about the positioning and orientation control of microscopic objects using dielectrophoresis (DEP). The dissertation presents a novel computational model capable of obtaining, in real time, the dielectrophoretic and hydrodynamic forces and torques actuating on arbitrarily-shaped microscopic objects. These computations are employed in experiments together with visual feedback control to perform the micromanipulation of arbitrarily-shaped objects. The whole procedure is demonstrated in a video of experiments with Tetris-shaped objects.

The high quality of this thesis is proven by the number of research articles that has been published in international journals as a result of the research of the PhD candidate, Tomáš Michálek. In the list of publications presented, there are 5 published papers in the most prestigious journals in subject areas such as Automation and Control Systems, Mechanical Engineering, Analytical Chemistry, and/or Mathematical Physics. Another publication is in preparation. In addition, Tomas Michálek has presented his work in nine international conferences. Therefore, the scientific community has already validated the results obtained by the PhD candidate.

The previous paragraph was about "objective numbers". I now detail the achievements, which in my opinion, has been obtained by the PhD candidate in the development of his thesis. Tomáš Michálek has implemented a novel modelling scheme that allows the dielectrophoretic manipulation of microparticles with arbitrary shape. Until now, most

of the research on DEP micro-manipulation was dedicated to spherical or spheroidal microparticles. To obtain the DEP forces and torques, Tomáš Michálek has employed the effective multipolar method (EM). This EM method provides approximated results and the thesis validated it versus the more rigorous Maxwell stress tensor (MST) method. The EM method is used in this thesis because it can be computed rapidly, and with sufficient accuracy, in order to perform the required real time control of the particles. The thesis teaches us how to compute the electrical multipoles of an arbitrarily shaped object by using finite element calculations of the fields of the polarized object. Having the multipolar moments and the electric field of a certain array of electrodes, the calculation of dielectrophoretic forces and torques can be obtained in fractions of a second. In order to provide real-time prediction of the translational and rotational velocity of the object in a liquid medium, the thesis supplemented the EM method with a hydrodynamical model valid for low Reynolds numbers. Finally, the last experiments presented in the dissertation show control of position and orientation of non-spherical objects using dielectrophoresis for the first time. The object's position and orientation are determined continuously by using image processing of video taken by a microscope. The difference with the desired position and orientation determine the needed translational and angular velocities that, thanks to the hydrodynamic model, are translated to the required DEP force and torque. By using optimization-based inversion of the EM model, the required signal voltages are then obtained and applied to the electrodes. The recorded video of these experiments clearly shows that the PhD candidate, Tomáš Michálek, has fulfilled the main goals of his thesis.

In summary, the PhD candidate, Tomáš Michálek proved to have a creative and inventive ability to perform research and to achieve scientific results. I strongly recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

Yours Sincerely,