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Open loop control of dielectrophoresis non contact manipulation

Michaël Gauthier¹, Mohamed Kharboutly¹, Nicolas Chaillet¹,

Abstract—The framework of this paper is the study of “No Weight Robots-NWR” that use non-contact transmission of movement (e.g. dielectrophoresis) to manipulate micro-objects enabling significant throughput (1Hz). Dielectrophoresis (DEP) is currently used to separate, manipulate and detect micro particles in several domains with high speed and precision, such as in biological cell or Carbon Nano-Tubes (CNTs) manipulations. A dielectrophoresis system can also be considered as a robotic system whose inputs are the voltages of the electrodes and output is the object trajectory. This “No Weight Robots” enables the positioning of the manipulated object in a 3D space. This paper is summarized the modeling principle of this new type of robots and some first results on trajectory control in 2D space.

I. INTRODUCTION

The first industrial robot “UNIMATE” based on standard joints was commercialized in 1961 (see figure 1). Nowadays more than one million of robots are in use all over the world. In the 1980’s the use of compliant structures in robotics was started to enable high precision positioning making them, at present, the most widely used structure for microscale robots. However, transmission of movement in such robots is obtained via the movements of mechanical parts which largely limits throughput due to inertial effects. In the 2000’s, LightWeight Robots (LWR) have been developed to reduce robot inertia. However, the impact of inertia is still important.

Recently a new generation of robots that use non-contact transmission of movement to manipulate micro-objects is emerging. Besides eliminating the inertia of a robotic structure, this approach also eliminates friction and adhesion (between the tweezer and the component) which are highly detrimental to a robot performance and life time.

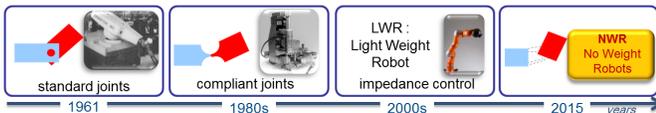


Fig. 1. History of the emergence of motion transmission in robotics: No Weight Robots - NWR is a new generation of robots based on non-contact motion transmission.

Current dielectrophoresis devices [1] are only open-loop controlled, such as the manipulation of particles [2], continuous separation and analysis of micro particles like biological cells and bacteria [3], dielectrophoretic fieldflow

fractionation (DEP-FFF) separation [4], motion of carbon nanotubes [5]. Because of this open loop control, the objects trajectory and final position are not guaranteed. This paper summarizes our recent works on open loop control of micro-object trajectory in a dielectrophoresis system.

II. DIRECT DYNAMIC MODEL OF A DIELECTROPHORESIS-BASED SYSTEM

Usually, the inertia of micro-objects is negligible and the dynamic behavior of a micro-objet in a dielectrophoresis system is characterized by [6]:

$$\vec{\dot{X}} = (\vec{F}_{DEP}(X, U) + \vec{P}) / (6\pi\mu R), \quad (1)$$

where:

$$\vec{F}_{DEP}(X, U) = 2\pi\epsilon_m r^3 Re[K(\omega)] \nabla(\vec{E}^2(X, U)), \quad (2)$$

where $K(\omega)$ is the Claussis-Mosoti factor, ϵ_m is the electrical permittivity fo the medium, $\vec{E}(X, U)$ the electric field and ω is the angular velocity of the electric field and μ the dynamic viscosity of the liquid. In order to compute this trajectory, a numerical simulator is needed. It must be able to compute the dielectrophoretic force generated by very complex geometries in function of the electrical tension U on the electrodes. On the right hand, corresponding analytic equations are very complex and hard to establish. On the left hand, the finite element modeling (FEM) solution is limited by a long computation time and specially when electric voltage changes frequently. Thus, we propose to use the hybrid numeric simulator based on additive laws [6] combining the ability of the FEM solution to simulate complex electrode geometry and short computation time of analytical equations.

The diagram in figure 2 illustrates the 3D direct dynamic modeling. Having the applied electric voltages and the electrodes geometry as input, the direct modeling simulator computes the micro-bead’s corresponding trajectory. Generally,

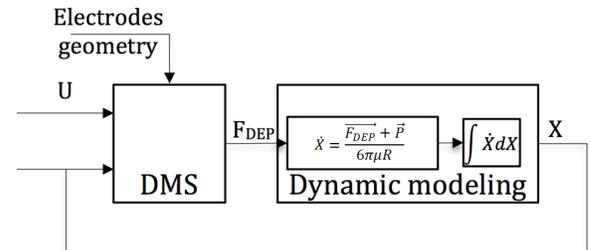


Fig. 2. A dynamic modeling and DMS are used to compute the micro-bead’s 3D trajectory.

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the micro-bead's behavior in dielectrophoretic force field is characterized by its high dynamics and nonlinearity. This numeric simulator is experimentally validated in [6], [7] where we have shown that the dynamics are very high and the time response of the micro-bead is less than $3ms$. Moreover the behavior of the micro-bead is subject to high nonlinearity and especially when the micro-bead approaches the electrodes.

III. TRAJECTORY TRACKING

To control the micro-bead's trajectory, an elementary control law for trajectories tracking has been established. The behavior of a micro-bead in a dielectrophoretic system is characterized by its high dynamics as presented in [6] and the nonlinearity with respect to the applied voltages as shown in the equation (1). This elementary control law must take into consideration this two problematics. Consequently a simple proportional integrator control is not sufficient especially when the micro-bead approaches the electrodes where the nonlinearity becomes very high. One way to solve this problem is to use the Newton-Raphson numeric method which is able to find the values of the control variables, u_x and u_y to follow a reference trajectory. By sampling the dynamic model (1) and knowing the trajectory $[\hat{x}(t), \hat{y}(t)]$ with respect to the time we are able to compute the appropriate control variable $u_x(t)$ and $u_y(t)$ using the Newton-Raphson method as illustrated in the figure 3.

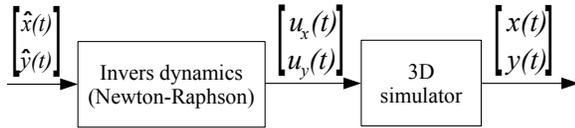


Fig. 3. The Newton-Raphson method is used to find the control variables u_x and u_y

We have tracked a square reference trajectory with $1s$ period, presented in the figure 4. Applying the Newton-Raphson method, a series of u_x and u_y control variables are computed and transmitted to a digital-analogic convertor to be applied to the electrodes (see figure 4). The position of the micro-bead ($100\mu m$ diameter) is captured by a high speed camera acquisition at 300 images per seconds.

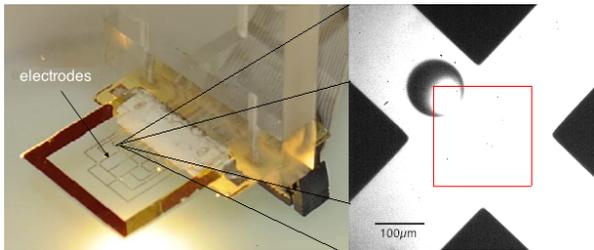


Fig. 4. Experimental electrode used to apply the dielectrophoretic motion. The square presents the reference trajectory.

The figure 5 shows the real trajectory of the micro-bead when applying the u_x and u_y series already computed. The

relative error between the real trajectory and the reference is less than 8%. This results shows the ability to control the trajectory of a micro-bead in dielectrophoretic system using open loop control strategy in a 2D space[8].

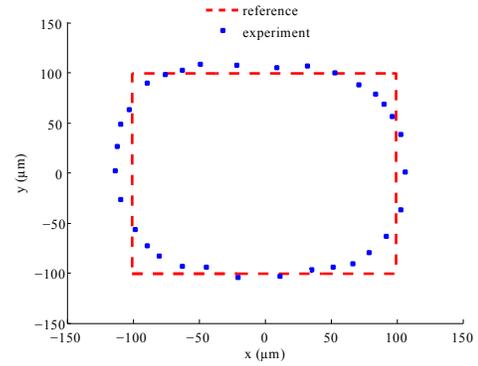


Fig. 5. The real trajectory of the micro-bead when applying the computed u_x and u_y . The square is done in 1s.

IV. CONCLUSION

In order to control the trajectory of a micro-object for long distance and high speed, an elementary open-loop positioning control for a micro-bead is presented using dielectrophoresis. A 3D dielectrophoretic force simulator has been firstly presented. We have synthetised an 2D open loop control based on the non-linear inversion of the model. The approach has been validated experimentally. This article shows the potentiality of non contact movement transmission in micro-nano-robotics using dielectrophoresis. Future works will focused on 3D control and closed loop control.

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