Precise Motion Control of Metallic Miniaturized Grippers in Dynamic and Cluttered Environments

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***Abstract*— We demonstrate precise closed-loop control of metallic miniaturized grippers under the influence of the magnetic fields. A challenging Pac-Man-like scenario, composed of virtual dynamic and static obstacles, is used to evaluate the proposed approach. The combination of path planning algorithms and closed-loop control allows to precisely move the metallic miniaturized grippers and perform accurate and fast manipulation and transportation tasks. The controlled grippers safely navigate the environment at an average speed of 219 μm/s and maximal speed of 706 μm/s.**

I. INTRODUCTION

Miniaturized grippers have the potential to radically reduce the risk and invasiveness of clinical interventions such as biopsies, cytoreductions, endarterectomies, and cardiac surgeries. In particular, miniaturized grippers have the potential to advance the functionality of currently tethered medical devices for targeted and personalized therapy. In order to perform such tasks, it is of utmost importance to control the motion of the miniaturized agents accurately and robustly.

In this study, we demonstrate precise motion control of metallic miniaturized grippers. They are biocompatible and can be actuated in a temperature dependent manner, by the intrinsic stress developed in a chromium/gold bilayer. The proposed study offers the potential to accurately control metallic miniaturized grippers, which are as small as 100 μm in size, in cluttered and dynamic scenarios using magnetic fields.

II. EXPERIMENTAL VALIDATION

The electromagnetic setup and the Pac-Man-like scenario used to validate the proposed approach are depicted in Fig. 1. The behavior of the dynamic obstacles is modeled based on the attitude of the Pac-Man ghosts. In order to precisely control the miniaturized agent along collision-free paths, we design a motion control algorithm based on the prescribed performance method [2]. The prescribed performance method ensures the convergence of the control error to a predefined and arbitrarily small set. We utilize the prescribed performance concept to generate magnetic control forces to steer the miniaturized gripper along the desired path. The control forces use a combination of position and velocity errors.

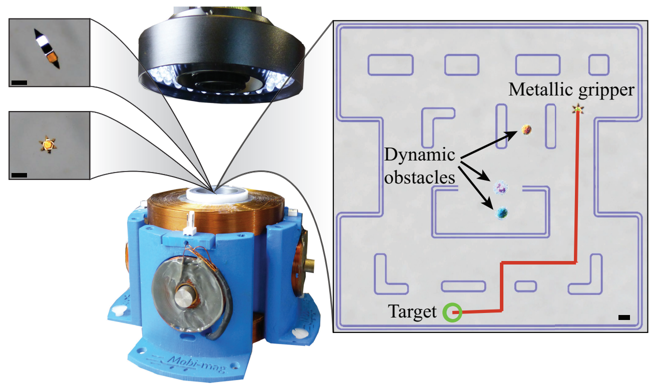

Fig. 1. The electromagnetic system is composed of six coils (four on the sides, one on the top, and one on the bottom) fixed in a frame around a reservoir with the liquid (water). The microscope objective is positioned above the reservoir. A Pac-Man-like scenario is used to validate the accuracy and robustness of the proposed motion control method. A metallic miniaturized gripper has to move through the maze in order to reach the target area (green), while avoiding collisions with virtual static (violet) and dynamic obstacles. The A* path planning algorithm is used to generate collision-free paths (red). Magnetic forces are exerted on the miniaturized metallic gripper to control its position. Several different grippers are tested, ranging in size from 100 μm to 980 μm with 2 and 6 fingers. The scale bar is 250 μm.

We validate the proposed approach using several metallic miniaturized grippers having different shapes (2 and 6 fingers) and sizes (100 μm, 250 μm, 750μm, and 980 μm). Each gripper performs 5 trials. In each trial the gripper moves from its actual position toward the first target area. Once the gripper reaches the first target area, it has to move toward the second target, and so on. Four different targets are considered. Results demonstrate that metallic miniaturized grippers can be controlled to move at an average speed of 219 $\pm$ 135 μm/s and maximal velocity of 706 μm/s.

Additional experiments are performed in order to assess the grasping capabilities of the grippers. Results revealed that 91% of the grippers did not lose their grasp when a strong magnetic field was applied. Moreover, such fields caused about 30% of the grippers to pluck the segment of tissue they were attached to.

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