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Non-contact Manipulation for Automated Protein Crystal Harvesting Using a Rolling Microrobot

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***Abstract*— In this work, a magnetic visual control system for automated protein crystal harvesting is proposed. The system consists of a rod-shaped microrobot, a magnetic actuation system and a visual control system. A rotating magnetic field induces the microrobot to roll on the supporting surface, thereby creating a vortex in a liquid environment. This vortex enables the robot to trap and transport even delicate objects in a non-contact manner to a pre-defined position. We present the micro-agent, the actuation system and the visual control system to achieve this automated procedure.**

I. INTRODUCTION

X-ray crystallography is the predominant method used to determine the spatial structure of macromolecules at atomic resolution. Due to the small scale and delicate nature of protein crystals they are usually harvested from their growth solutions or cryoprotectant buffers manually, causing this step to be the major bottleneck of high-throughput crystallography. Possible solutions for the automation of the crystal harvesting process, including using a six-axis robotic arm for manipulation [1], have been proposed, but all these methods have significant disadvantages.

Our proposed method uses a rotating magnetic field to induce a rolling motion of a microrobot. The crystals are trapped in the vortex created by this motion, allowing them to be manipulated gently.

II. EXPERIMENTAL SYSTEM

Motion control of untethered microrobots via magnetic fields is an effective actuation method as no physical connection is required between the controlling system and the microrobot [2]. Nevertheless, automation at the micro-scale is challenging because of the scale-differences in sensing and actuation compared to the macro-scale [3].

A. The RodBot

Our microrobot, which we call the RodBot, is a wireless mobile device with a typical size of $300-600 \times 60 \times 50$ $[\mu m]$ [4]. The polymer body of the RodBot contains several transverse soft-magnetic posts which align with an external magnetic field. When the field direction changes, the RodBot realigns with it, and if a rotating field is applied the RodBot rolls over a substrate around its long axis (typical frequencies and linear speeds: 1–10 Hz, and 0.2–2 mm/s, respectively). In a low Reynolds number liquid environment a rolling RodBot generates a rising flow in front of it and a cylindrical vortex parallel to and above it. Protein crystals ranging from a few microns to sub-millimeter size can be lifted off the substrate by the flow, trapped in the vortex, and transported to and deposited onto an extraction-loop. The RodBot technique generates forces up to $\sim$100 nN, sufficient to move most protein crystals, yet not damage them, setting the RodBot apart from other micromanipulation systems.

B. The Magnetic, Visual Control Systems

Magnetic control is based on the MiniMag system [2]. It consists of eight coils to generate a magnetic field of variable amplitude and direction. The signal from a top-view camera allows image processing software to detect the position and orientation of the RodBot, providing the feedback for the visual control system. Based on the initial state of the robot, obstacles to be avoided, and the location and the orientation of the final goal, a smooth trajectory is generated. This control approach (trajectory tracking) incorporates the kinematic and non-holonomic constraints of the robot and enables a straight-forward design of motion. The control inputs to the system are the forward velocity and yaw angle of the RodBot (rotation frequency and the orientation of the field, respectively).

III. RESULTS AND DISCUSSION

In the video we demonstrate the effectiveness of actuating the RodBot, and its ability to trap and transport micro-objects (polystyrene beads or crystals) to a desired location. We also show preliminary results for automated protein crystal harvesting via a magnetic/visual control system. The gentle, non-contact extraction of crystals from their growth solutions or cryoprotectant buffers minimizes damage often encountered with other crystal harvesting techniques.

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