A MULTI-RATE STATE OBSERVER FOR VISUAL TRACKING OF MAGNETIC MICRO-AGENTS USING SLOW MEDICAL IMAGING MODALITIES

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Kolff program: Restoring organ function by means of regenerative medicine (REGENERATE), Bioadhesion, biocompatibility and infection (BIOBI)

Introduction
Minimally invasive surgery can benefit greatly from utilizing micro-robotic agents. A successful medical intervention by an operator using micro-agents requires clear visualization, accurate sensing and precise feedback control. But, medical imaging modalities suffer from low acquisition rate. An appealing remedy for this drawback is multi-rate state estimation. This method provides estimates of the system states for intermediate time instants where measurements are not available. In this study, we propose to apply multi-rate state estimators for the visual tracking outputs of micro-agents in order to have intermediate position data between two consecutive frames. The significant contribution of this study is that the multi-rate state estimation is first applied to the field of micro-robotic interventions to virtually increase the sampling rate of position data for control using low-rate visual feedback.

Methods
The micro-agents are tracked using sum of squared differences and normalized cross correlation based visual tracking methods. Further, the outputs of the two methods are fused to minimize the tracking error and prevent tracking failures. In order to increase the convergence rate and robustness of tracking, a pyramidal implementation of the proposed template-based tracking method is applied. During the tracking, the template images are updated with a drift correction strategy to minimize the registration error and prevent template drifts. These tracking outputs serve as a measurement to the multi-rate state estimators. Then, intersample states of micro-agents are estimated using multi-rate Luenberger and Kalman state estimators for visual tracking of micro-agents.

Results
In the experiments, four iron-core coils placed on the same plane are used for the planar manipulation of the microagents. During the experiments, magnetic hydrogel grippers, spherical and elliptical shaped micro-agents are used. All of the agents are imaged using a microscope and a 2D ultrasound probe. In total, 120652 images are acquired. The proposed method is implemented in both MATLAB and C++ using OpenCV library. The average execution times are measured as 69.68 [ms] in MATLAB and 13.22 [ms] in C++, respectively. The tracking performance is quantitatively evaluated by computing both normalized cross correlation (NCC) and a combination of Forward-Backward error and NCC (FB+NCC) values. NCC+FB value is calculated by computing NCC value between the backward and the template images. NCC and FB+NCC values are computed as 0.9943 ± 0.0117 and 0.9970 ± 0.0082, respectively. The multi-rate state estimation accuracy is measured using a high-speed camera. Maximum absolute error in x and y axes are 2.273 and 2.432 pixels for an 8-fold increase of the sample rate (25 frame per second), respectively.

Conclusions
Experimental results demonstrate that the proposed method can accurately track micro-agents with different shapes in images obtained from slow medical imaging modalities while providing intersample estimates in real-time. We envision that this method could be readily utilized with clinical instrumentation to accelerate translation of the use of microrobots in realistic minimally invasive operations. In the future work, the proposed multi-rate sampling method will be applied to the field of robotic biopsies to virtually increasing the sampling rate of position data using low-rate visual feedback.