An Integrated Approach to Dexterity Enhancement in Human-Machine Collaborative Systems

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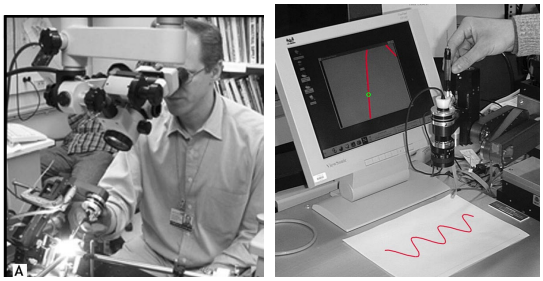

Figure 1: Our experimental system for cooperative manipulation.

We are developing systems aimed at surmounting human physical limitations when performing tasks that combine learned skills, judgement and high dexterity. We refer to these systems as Human-Machine Collaborative Systems (HMCS), as they generally seek to seamlessly integrate human judgement and experience with robotic and sensory augmentations. The HMCS concept is initially aimed at micro-manipulation (e.g. microsurgery or microassembly), but ultimately will be applied to larger-scale remote operation (e.g. manipulation or disassembly of hazardous objects or assembly in outer space), and dexterous exploration (e.g. a remote system for medical palpation). We are currently developing a demonstration system that focuses specifically on micro-surgical applications within the human retina and on micro-assembly.

Our long-term research objective is to develop a canonical HMCS system substrate with a "design methodology" that integrates: 1) qualitative analysis of tasks to produce a skeleton augmentation structure, 2) quantitative modeling to validate and further refine the augmentation model, and 3) computational support for synthesis and validation of complete augmentation systems. To date, we have reported on the following specific projects:

Control Techniques A general family of control techniques creates anisotropic compliances (generating a specific type of "virtual fixture") that can be used to enhance the speed and accuracy of fine manipulation. An implemented version of these algorithms operating in a closed-loop fashion in conjunction with visual tracking is presented in [2, 3] (Figure 1).

Task Segmentation We are modeling surgical manipulation tasks using a small set of action primitives embedded within a Hidden Markov Model (HMM) framework. We have successfully used HMMs for online segmentation of human actions, and generated appropriate assistance based on segmentation results [4, 5].

Human Factors We have undertaken human-machine performance studies to measure the effectiveness of different types and levels of augmentation on manipulation performance. The results of these studies for cooperative and virtual systems are presented in [6, 7]. The effectiveness of assistance in telemanipulation systems depends on virtual fixture type and location (on the master or slave), and on the underlying control system [1].

Our future goals are to 1) extend these concepts to a complete system for surgical augmentation, 2) to apply the same concepts to related micro-assembly problem, and 3) to extend the concepts to remote operation.

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References

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