Paper Critical Review

CS 446 Computer Integrated Surgery II

April 27, 2012

Robert Eisinger

Mentor: Marcin Balicki

Included is a critical review of the paper *Performance of Robotic Augmentation in Microsurgery – Scale Motions* by Rajesh Kumar et al. for MICCAI 1999 [1]. I will first discuss the relevance of the chosen paper. The paper discusses results of a basic experiment intended to gauge the usefulness of scale motions in microsurgery. The paper conveys the basic experimental apparatus and results, but leaves the reader in the dark about why certain aspects of the experiment were chosen as opposed to others, for instance. While the advantage of scale motions is conspicuous, a few concerns arise as to the applicability of this research.

Introduction

With the help of the advancement of microscopes and precision tools, microsurgery has become a popular field of research. More generally, micro precision is a highly useful technology with applications outside of Medical Robotics, such as biochemical synthesis or small-organism dissection and implantation. Often, however, these tasks are performed outside of human dexterity abilities, such as the inherent hand tremor of the hand and the inability to move the hand less than about 10 microns [1] at a time. Kumar's conference paper details an experimental procedure for assessing the usefulness of a cooperative control system for obtaining better motion precision.

Our project is titled *Telemanipulation and Telestration for Microsurgery*. Simply put, our project is comprised of integrating the Phantom Omni haptic device into a Telemanipulation system capable of driving the Steady Hand Eye Robot (also known as Eye Robot 2). By *system*, we refer to a number of features, including, but not limited to, (1) telemanipulation, (2) telestration, (3) bilateral telemanipulation, and (4) bimanual telemanipulation. All four of these features integrate the concept of cooperative control, which is why I selected Kumar's paper for my seminar paper. Assessing the success of our system, especially with respect to cooperative control and the advantages acquired from such, is not straightforward; this paper helps provide ideas for these efforts.

Paper Summary

This paper first begins by introducing the conceptualization that cooperative control systems offer significant advantages in microsurgery. A cooperative assistant system is a machine-human interaction that allows the human's intelligence to be maintained without the machine taking away from it. An example of a cooperative control robot is what was at the time called the Steady Hand Robot, whereby the surgeon and the robot both hold the tool. Essentially, the robot and the surgeon work together cooperatively. More importantly, the authors note, is that this system in no way should hinder the surgeon's already-existing intelligence and skillset. A cooperative system should only help, not hinder.

One way in particular, of helping, is reduction of hand tremor. Hand tremor becomes

problematic in demandingly precise surgeries such as retinal surgery. The paper focuses on quantifying the effect of cooperative control specifically in the reduction of hand tremor. An experiment is developed to test precision with and without the tremor reduction (with and without a cooperative robot), and the accuracy's are compared.

A number of attempts at cooperative control systems have been previously investigated, as well as methods for evaluation (for example, [2]). Lengthy procedures that require fine resolution motions are good candidates for robotic assistance, and many of these procedures have associated conceptualized cooperative systems thought out. The paper mentions some of these, such as neurosurgery and Master-slave systems, but does not delve deeper into the results or general successes or failures of such systems.

Technical Apparatus

The authors decided to test the advantage of tremor cancellation on two robots: the new Steady Hand robot and the LARS robot.

The Steady Hand robot is a 7-degree-of-freedom manipulator with XYZ translation, two rotational degrees of freedom, and two instrument degrees of freedom. A force sensor is built into the end effector, and the robot comes equipped with a remote center of motion. Its resolution is about 10 microns.

The LARS robot is designed for laparoscopic surgery and has 7 degrees of freedom. The degrees of freedom are identical to the Steady Hand robot. It also has a remote center of motion, and has a resolution of about 50 microns. Notice that the Steady Hand robot has a more precise resolution than the LARS robot. This distinction is also quite clear from the results of the experiment, as we will see.

These two robots were chosen because they both have tremor cancellation and they are both well-tested robots with working cooperative control systems. For both robots, the surgeon and the robot hold the tool.

Technical Approach

The authors performed an experiment using six subjects, each of which were graduate students. They compared the accuracy and reliability of performing a precise task. Subjects placed a microsurgical needle into holes that were either 250 micrometers, 200 micrometers, or 150 micrometers under magnified vision at 40-fold magnification.

Subjects performed the experiment with and without the aid of the robots. The experimenters recorded time to completion and number of errors per unit time as well as absolute number of mistakes.

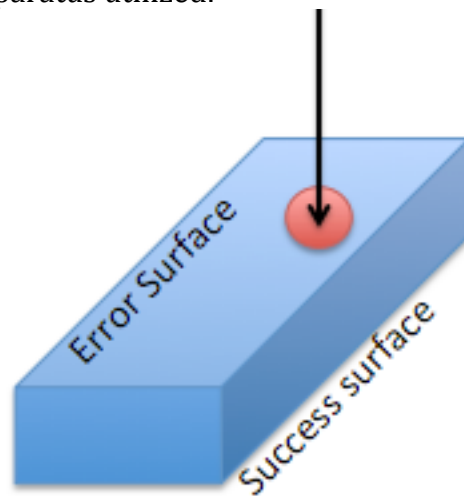**Figure 1** indicates the experimental apparatus utilized:

Figure 1. Experimental apparatus.

A sandwich of two metallic plates was used as the workspace. The various holes as aforementioned were scattered throughout. In between the two metallic plates is insulating material. Subjects placed microsurgical needles inside holes of specified size. Both plates were connected to the robot, and any contact with the needle and a plate closed a circuit. If the needle made contact with the top plate (the error surface), the trial was considered incorrect, because this implied the subject missed the target hole. On the other hand, if a subject placed the needle through a hole, then the needle reached the bottom surface (the success surface), and the closed circuit was considered an accurate trial.

Three versions of this pick-and-place task were performed: (1) Unassisted Series, (2) Hand Held Series, and (3) Autonomous Series. In the

Unassisted Series, no robot assistance is used. In the Hand Held Series, the subject holds the tool, which is attached to a robot (the Steady Hand robot or the LARS robot). Lastly, in the Autonomous Series, the robot is registered to the eight corner holes of the pattern and interpolated thereon, thus performing the task autonomously. Results for all three series and for all three-hole sizes were recorded for each subject.

Summary of Results

Table 1 indicates the performance of the three pick-and-place tasks split up by hole size. Regardless of the hole size, the trend is the same: Hand-held pick-and-place leads to better performance than unassisted pick-and-place, and the Steady Hand Robot leads to better performance than the LARS Robot.

The authors also provide values for the average number of erroneous attempts for each experiment (which decreases on the hand held series), as well as the total number of attempts used in a 10-minute time lapse (which also decreases on the hand held series). In both cases, the Steady Hand Robot gives better results than the LARS Robot. Lastly, a table is included that gives values for the average time between attempts, which is about 4 seconds in the hand held series for both robots, and about 3 seconds in the unassisted series.

The take home message the authors gave, as a consequence of this data, is that a robot can indeed extend human capabilities by assisting with microsurgical tasks at a greater spatial resolution than humanly possible. Further, as a consequence, the robots may improve the safety of microsurgical procedures at high magnification, whereby the human orientation of space is lost.

In addition, the authors noted that the Steady Hand robot significantly increases the pick-and-place accuracy, even more so than the LARS robot does. This may be attributed to the higher resolution of the Steady Hand robot, although the authors did not attempt to explicate why results for the Steady Hand robot were better than the LARS robot (see **Table 1** for an example of this distinction). Finally, the authors briefly mention that there might be other factors that influence the difficulty in positioning a needle, but do not mention any specifically. They conclude that further experiments are needed to evaluate these parameters.

Critique

The authors of this paper did a satisfactory job of providing empirical evidence to the usefulness of a cooperative approach to microsurgical manipulation. It was the first paper to design an experiment for these purposes. As an overall impression, it is clear to the audience that Robots that are fine-tuned for precise scale motions enhance human ability in microsurgical tasks.

Nonetheless, the analysis of results as well as the careful control of confounding variables is not thorough by any means. There are a number of questionable areas of the experiment that may or may not have an effect on the end result of the claim. I suspect that these concerns would not discredit this research; however, the claim may have been *stronger* had the authors retained a few considerations throughout the experimental design and analysis of results.

The paper itself had a few shortcomings. Firstly, the title is somewhat misleading. Upon reading the title, I assumed the paper investigated the interplay between normal human hand motion and the scaling of that motion through robotics. But, the paper is more so about the advantages of tremor cancelation rather than motion scaling. While this is a somewhat minor consideration, it contributes to

Size of Holes	Unassisted	LARS Robot		Steady Hand Robot	
		Hand-held	Autonomous	Hand-held	Autonomous
250um	48.8%	56.0%	53.0%	77.8%	98.4%
200um	46.3%	50.8%	50.0%	76.7%	97.7%
150um	43.0%	46.0%	48.0%	79.0%	96.5%

Table 1. Comparison of performance in the three modes. Success rates are included.

an initial confusion throughout the duration of reading the Introduction of the paper.

The first section of the Introduction is titled *Previous Work*, and this subsection is especially useful. While the manner in which the information is presented is blunt (with such a title as *Previous Work*), the message that previous research has not evaluated the usefulness of cooperative control is clear. On the other hand, this is one section in which an elaboration of material would have been useful. The authors cited about 30 papers related to this research in only a single paragraph, and in doing so, very quickly brushed through the majority of them without stating any details about the research other than the most broad point possible. After scanning through this section in the paper, it leaves the reader with a number of questions with regard to the efficacy of each of these previous experiments. For example, the paper cites the design of a passive robotic arm to provide guidance with dynamic constraints [3], but does not indicate if the design was considered successful and useful, for example. So in truth, the reader is uncertain if experiments to assess cooperative control have actually not been performed before, because the authors do not explicitly state that these previous papers did not discuss assessment of their respective systems.

With respect to the overall format and content of the paper, the experimental apparatus was unclear, and a figure of the sandwich of metallic plates would have been useful. Also, there are lots of dimensions that are introduced to the reader (the size of the holes, the thickness of the metallic plates, the tool size, etc), but it is not easy to keep track of these things without an image. It is also hard to gain a sense of understanding for the size of all the experimental materials relative to everything else. For example, how much larger were the holes than the tooltip when keeping in mind the resolution of the LARS robot? Clarifying these questionable items would have been useful.

Lastly, the connection of this research to clinical relevance was somewhat absent. There was only one mention of a medically relevant application of this system (anastomosis), and it would have been useful to gain more motivation

for the research by indicating multiple applications of this research to Medicine.

In addition to these general paper imperfections, there exist a number of analytical dilemmas that most likely impacted the final results the authors reported in the tables.

The authors selected to measure the accuracy, the number of errors, and time of the pick-and-place experiment as ways to measure the usefulness of the cooperative control system of tremor reduction in the LARS and the Steady Hand Robot. Firstly, the authors did not indicate why these dimensions were chosen. Were there previous studies that showed that these are trusted measures of usefulness? Were other dimensions used but turned out to be unsuccessful? This aspect of the paper is weak, and it diminishes the degree to which is this research is substantial due to the fact that it is unknown if these actual values (such as the number of seconds for a pick-and-place hand-held task) are impressive or not.

Generally speaking, the analysis of results is incomplete. It is especially clear with a quick glance that the Steady Hand Robot leads to much better results than the LARS Robot, and that the LARS Robot's results are almost not even highly impressive when compared to the Unassisted series. Whether this is due to the micro resolution of the Steady Hand Robot, or due to some other variable is unknown to the reader and could have meaningful implications for the author's claims about cooperative control. The ANOVA that was run on the data was useful in showing the significant effect of the LARS and the Steady Hand Robot.

While it makes sense that the authors used an Unassisted series and compared it to the Hand-held series (in other words, with and without the aid of Robots), the authors did not elaborate as the purpose of the Autonomous series. While it might be assumed that the purpose of this series was to gauge the precision of the robot as a type of normalization, the authors do not explicitly state this.

On a positive note, the authors certainly presented enough evidence for the readers to generate their own ideas about the usefulness of cooperative control. It seems repetitive to include both accuracy percentages as well as absolute errors, but this does indeed help

enforce the fact that the hand-held series aids in the pick-and-place task. The organization of the results section as a whole is good. The presentation of results is straightforward and easy to follow. Furthermore, the authors described what the data was before presenting it, so that by the time the reader reviewed the results, it was clear what the numbers meant.

The conclusions the authors draw are a bit speculative. The results from the experiment only partially provide evidence for these claims. The authors rightly state that a robot can extend human capabilities with microsurgical tasks by providing greater spatial resolution. But then they proceed to state that as a consequence, robots may improve the safety of delicate microsurgical procedures. Firstly, the use of the word *may* sounds speculative and non-conclusive. Secondly, to make such a claim seems to be a stretch based on the data from the experiment. While it is true that usefulness of a system and ease in surgery may be related to safety, but whether it is directly related is another field of research, and the authors make this assumption too casually.

The experiment had six subjects, which were mostly computer graduate students with no microsurgical training. This helps alleviate the bias of the subjects. But, as before, the authors use this information to make another long-shot conclusion: "Their unfamiliarity with motions at this scale suggests that performance would improve with skilled and trained users." This statement is confusing. The subjects were not trained, so how is it that this research can so easily be applied to trained individuals (i.e. surgeons)?

In the closing of the paper, the authors write:

"…other factors such as mistakes made in positioning the needle are difficult to evaluate… Further experiments in evaluating these and other parameters are planned."

This is shocking to read at the end of the paper. It plays a role in insinuating that there are other confounding variables that may have been at play in this experiment that could have effected the results. It leaves the reader at a mysterious point at the end of the paper. However, it is sensible that the authors mentioned that they plan to pursue further studies on these variables. But until then, should we trust these results? This and many other questions are remained unanswered by the end of the paper.

Conclusion

Kumar's *Performance of Robotic Augmentation in Microsurgery – Scale Motions* provides a usable and repeatable way of measuring the advantage that a cooperative control system confers to a surgical task. The analysis of the results of the experiment, while perhaps non-thorough, is outweighed by the simplicity of the experimental apparatus and the clarity of the results. It is obvious that a cooperative control system is advantageous in precise surgical motions.

This finding is useful for our Computer Integrated Surgery II project. Our project revolves around the idea of a cooperative control system. In fact, generally speaking, our project is the advancement of an already existing cooperative control system (Steady Hand Eye Robot) by adding even more cooperative control features (Telemanipulation, Telestration, etc). It is beneficial for us to have data, such as that presented in this paper, to support our ideas that a cooperative control system is useful in surgery.

Furthermore, we now have an example of a way of validating a cooperative control system. In our project, we are using an Omni device to control the Steady Hand Eye Robot. Perhaps we will be able to assess the success of this system by repeating the experiment from this paper, except adding a new series (the Omni) and further comparing the results.

References

1. Kumar R., Goradia T. M., Barnes A. C., Jensen P., Whitcomb L. L., Stoianovici D., Auer L. M., Taylor R. H., Performance of Robotic Augmentation in Microsurgery – Scale Motions, MICCAI 1999.

2. Krapohl B. D., Zins J .E., Siemionow M., Computer Assisted Microsurgery: Introduction of a new robotic arm, 4th

International Symposium on Computer Assisted Orthopedic Surgery, Davos, Switzerland,March 1999.

3. Delnondedieu Y, Troccaz J, PADyC: a passive arm with dynamic constraints. A proto- type with two degrees of freedom, MRCAS'95, Baltimore, USA, pp173-180.