

Design considerations for Micro-surgical Tools

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Abstract-Micro-surgery is a clinical practice where the clinician is working at or beyond the threshold of human dexterity. The tools available to surgeons are conventional in their design, and this provides a limit to what can be achieved. This paper describes considerations and possible methods for applying new technologies to assist in practice.

I. INTRODUCTION

Microsurgery describes a category of clinical tool processes where the operator is working at, or just beyond, the threshold of human dexterity and sensory feedback needed for satisfactory tool control. This occurs in a wide range of clinical disciplines. Existing tools are available that are especially designed to increase sensory feedback for control. These are microscopes, mechanical tools and sensors.

Binocular microscopes enhance visual perception of the working site and require that the clinicians field of view is uninterrupted by distractors that would require refocus and refreshment of perception. This has implications on tool design: Mechanical tools, such as those illustrated in figure 1, are multi-functional to minimise the number of changes and distractions from the field of view during the procedure. Many of the mechanical tools shown are spring loaded to give tactile perception of the movement of the tool actuation points. Thus forceps are actuated by progressively applying greater force across the handle and movements imparted by the finger-tips are miniaturised at the tool point. The surgeon has no perception of applied forces at the tool point. These force levels are insignificant compared with the forces applied to actuate the tool and are so small that they cannot be perceived by normal human tactile sensation, and certainly not following transmission through tools and surgical gloves. Surgery is traditionally a practical skill with response to both tactile and visual stimulus, thus at present micro-surgery requires quite different skills, and therefore can only be practised successfully by a few who have developed new

skills that lead to satisfactory results albeit with varying strengths and consistency.



Figure 1 A range of tools for micro-surgery

II. Needs

Tools are needed that enable clinicians to utilise both visual and force feedback whilst working at such small scales. There is a need to design such that the benefits of precision of motion of the machine and the decision capability of the clinician are harnessed in an integrated system. Tools need to extend perception by the clinician from the tool point and need to be actuated by inputs require to adopt as natural a posture as possible. Ideally, to the clinician they need to appear to be an extension to their own sensing and actuation system.

Master-slave surgical tool systems have been investigated and some systems implemented for assisting with complex tool actions have been reported for minimal access surgery [1], and some guided systems working within simulated constraints, such as that of Davies[2]. There are similarities with micro-surgery where the clinician is accessing the working site through difficult access and with reduced sensory feedback of the state at the working site.

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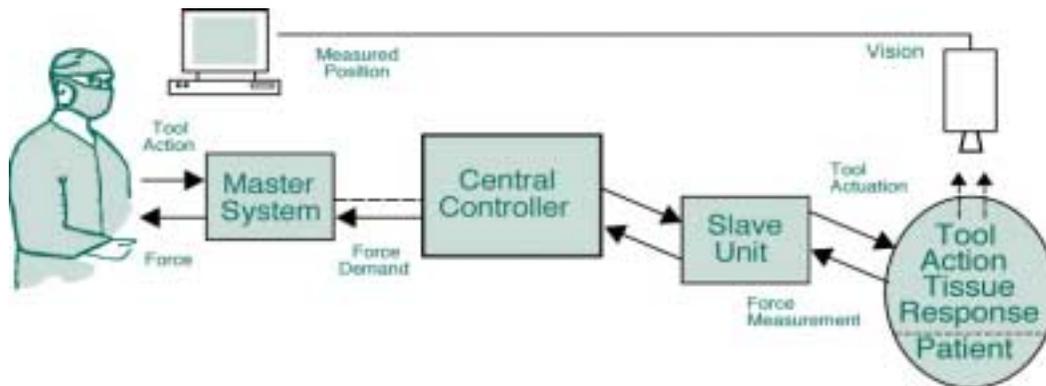


Figure2 A function diagram of a Master-slave system for Microsurgery

A simplified schematic illustrating the principal functions of a master-slave system are shown in figure 2. Forces at the tool point are sensed and transmitted to the user via servo force controllers. The demand for tool motion is sensed from the motion imparted by the surgeon and is transmitted to servo motion controllers at the tool point. There are many challenges to such a system for surgery that are exacerbated by the impact of scale for micro-surgery. Working through the principal functions, the following can be identified:

- Tool: Small mechanisms, sensors to measure motion, contact and state of the tissue/tool interaction, actuators and versatile tool action.
- Delivery mechanism: To provide a stable platform for tool mechanism deployment at the working site should be manoeuvrable, stiff when required, carry all services to the tool point and minimise visual obstruction.
- Controllers: To transform input demanded motion from the master-unit at the surgeon to the motion required at the tool point through the delivery and tool mechanisms. To transform the measured forces at the slave-tool unit to

actuators at the clinician/machine interface that represent tactile signals of the tactile phenomena at the tool/tissue interface.

- Master-unit: To be as 'natural' an interface with the clinician as possible to enhance input motion rather than to impede and to provide suitable tactile signals and information to the user with respect to tool contact and motion.
- Visual feedback system: To provide perception of depth in the field of view and to minimise on distractive actions in order to maintain the surgeons view on the working site.
- Ergonomics: Generally, the surgeon must be maintained in a relaxed state to maximise concentration and control at the tool point.

III. THE IMPACT OF DYNAMIC RESPONSE ON DESIGN REQUIREMENTS.

The dynamic response of the system is to deal with accurate tool action with respect to moving tissue interfaces, which under certain circumstances may require fast reaction to changes in sensory data, and will need to communicate with suitable tactile response to the surgeon in order to provoke a response. The human operator can deal with a range of tactile information, but will not be able to sense certain disturbances or indeed to respond to them.

Therefore there is an upper limit to the bandwidth of the master-unit, and this needs to be determined. Too high a bandwidth will increase the magnitude of actuators to an unnecessary level to transmit accurate disturbance data. Smaller actuators will be less massive and will not produce as cumbersome a master-unit in practice.

The response to a user to tactile stimuli has been measured for specific poise and gesture in the subject. For controlling tools, the requirements are specific: machines will be guided by finger movements, the clinician should be in a relaxed gesture, preferably seated with supported arm and hand to maximise perception of tactile stimuli. Preliminary investigations reveal that for the response to tactile disturbances with visual stimuli there is a break frequency at nearly 2Hz for unexpected events. For events that could be anticipated the threshold increased to a value above 4Hz. These values for digit excitation and response are of the same order to that measured by Brookes[3]. A typical measured digit response to maintain contact force level with a step change in stiffness of a surface is shown in figure 3. This response is compatible the above frequency threshold values.

This information is an indicator of the performance required of an actuated master-slave system controlled by a human operator. Other tactile information can be gathered at higher frequencies to indicate events such as slip and impact, for which accurate phase is not required.

Where human response is not sufficient to tackle a critical process, then automatic machine action offers advantage. Machines can react more rapidly to changes in state than human response. This could include the detection of tissue interfaces say to avoid penetration, or to penetrate a flexible tissue without overshoot into the underlying layer, by applying techniques such as those described by Brett[4] to deal with accurate physical tool-tissue interaction. Such action does require swift and accurate determination of state, and it would not be appropriate to override master-slave action to deal with circumstances that were not expected.

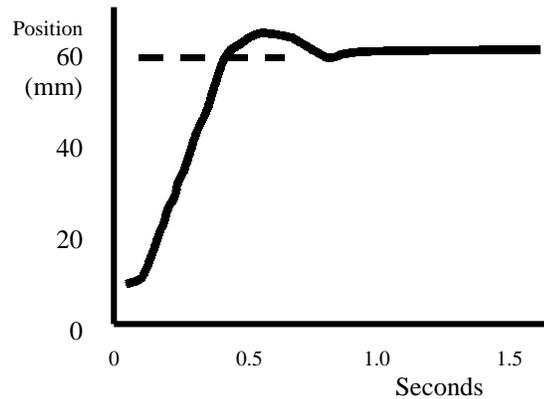


Figure 3 Typical digit response to tactile stimulus

IV. CONCLUSIONS

This paper describes baseline considerations for the design of tools for micro-surgery. The discussion suggests principal needs for systems combining the benefits of automated tool systems to enhance the performance of a clinician, and deduces typical minimum system response to deal with surgeon demand signals to control tool action.

V. REFERENCES

- [1] Dario,P., Carrozza,M.C., Marcacci,M., D'Attanasio,S., Magnani,B., Tonet,O. and Megali,G., 'A novel mechatronic tool for computer assisted arthroscopy.', IEEE Trans on Information Technology in Biomedicine, Vol 4, No1, March 2000, pp15-29.
- [2] Davies B.L. , 'Hands-on Robots for surgery.', Seminar on Surgical Robotics and Computer assisted surgery., IMechE, London, 14th November 2000.
- [3] Brooks,T.L., 'Telerobotics response requirements., IEEE Int Conf on Systems, Man and Cybernetics, 1990, pp113-150.
- [4] Brett,P.N., Baker,D., Griffiths,M.V. and Reyes,L., 'A mechatronic drilling tool for ear surgery: A case study of design characteristics', Int J of Mechatronics, vol 6 No 4, June 1996.