Ergonomic Interface Concepts for Minimally Invasive, Remote, and Virtual Surgical Systems

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Abstract. Traditional open surgical techniques require a surgeon to assume a posture of leaning over the patient with a direct eye-to-hand perspective. As new minimally invasive and remote surgical procedures evolve, the surgeon is not required to maintain the same posture as in open techniques. While more ergonomic postures may be facilitated, some current remote systems have maintained surgeon configurations that are small variants of legacy postures (e.g., maintaining the eye to hand perspective). While the legacy configuration may be more familiar with some surgeons, studies have indicated that it can result in excessive fatigue. Robotics and human factors researchers have determined that fatigue due to inefficiencies in operator interfaces lead to longer completion times and increased task execution errors. This paper discusses operator interface design issues and guidelines that are relevant to remote and minimally invasive surgery, and presents one possible operator interface solution based on the compact remote console deployed for environmental restoration and remote handling of hazardous nuclear waste.

1. Background/Problem

The ergonomic structure of some current minimally invasive, remote, and virtual surgical systems are based on postures inspired by traditional open procedures. While tradition and familiarity may be a reasonable justification, these posture configurations are not optimal with respect to fatigue (and hence, distraction and errors) for extended operation. This paper outlines some specific ergonomic findings and a particular implementation of the concepts for remote environmental restoration and teleoperated tasks.

2. Method/Tools

Historic studies [1] and ongoing studies at Oak Ridge National Laboratory (ORNL) directed at human factors and ergonomic operator interface designs for remote environmental restoration efforts have resulted in guidelines for the size, distance, and angle of video viewing capabilities in order to minimize eye strain and back and neck fatigue while providing a maximum amount of data to the operator. For example, for viewing National Television Standards Committee video it has been determined that the distance between the operator's eye and the center of the viewing monitor should be 2 to 2.5 times the diagonal size of the monitor. At closer distances, the operator sees the pixels instead of the image; at further distances, the operator loses image detail. To minimize fatigue, the height of the center of the viewing screen should be 0 to –5 degrees from horizontal to the operator's eye level. The optimum viewing cone is considered to be 30 degrees around the operator's –5 degree line of sight. Video monitors and graphical user interfaces may be placed outside of this region without causing operator fatigue if they are only intermittently used. In current research [2], a control chair has been determined to be an efficient method to maintain operator orientation for viewing video. The control chair-based approach also facilitates positioning the operator with respect to the position and orientation of the tool interface.

Several research studies target the tradeoffs of stereoscopic vs. mono-image viewing and necessary design constraints for stereo if it is to be used effectively [3], [4]. When presented with both technologies, operators are initially attracted to the stereo display due to its novelty but then transition to the mono-image display when prolonged work sessions (continuous 8 hour days for several weeks) are required. The authors of [3] also provide evidence (i.e., the weak binocular vision capabilities of humans, ability of humans to accurately determine depth information from alternate visual queues) that questions the justification for stereovision. Typically, multiple mono-image views that provide differing perspectives, tool end close-ups, and overview and zoom capabilities are better received. Ongoing development indicates that three primary views (with additional views available on an as-needed basis via video switching) is optimum for the mono-image display configuration in the sense that three views allow for a combination of several close-up views and a "distant" perspective, and operators reports that more than three views begins to be cumbersome/confusing to manage. For surgical use, multiple single camera views can be placed with multiple laparoscopic/arthroscopic ports and on the surgical tooling itself (especially for endoscopic procedures).

The design and configuration of the master controller/tool interface is also a significant human factors issue (e.g., the interface may require significant bracing by the operator to steady the hands and limit fatigue). However, experience indicates that generic tool interfaces were ill-suited for many tasks due to a lack of adequately matched articulation capabilities. Hence, in each remote system implementation customized implementations were pursued.

To address the aforementioned human factors and ergonomic issues, a compact console (see Figure 1) has been developed at ORNL [2] for operators performing remote, robotic-based environmental restoration efforts. It has been used for multiple deployments requiring extended operator use that resulted in greater attention capabilities, reduced fatigue, and improved acceptance by the user. While the chair, video monitor/viewing, and associated graphical user interface have been standardized, each field implementation was retrofitted with a different master controller concept based on the types of tooling involved, the type of remote system being controlled, and the degree of support that the operator needs to execute those tasks with minimal fatigue. From Figure 1 the tool interface support arms can be implemented from any of the four corners of the compact console. An emphasis on flexibility to support divergent tool interface concepts needs to be maintained. The chair and the height and distance of the monitor array can be adjusted for optimum viewing; the master controller support arms are likewise adjustable.

3. Results

Prior use of the operator interface guidelines presented in this paper have been used extensively in the remote systems community with exceptional acceptance by operators that are required to operate for extended periods of time. These same design techniques are now being investigated for implementation in minimally invasive, remote, and virtual surgical systems to reduce fatigue in a single session, to provide for more extended operations while managing fatigue, and to permit more surgeries sequentially due to reduced operator (surgeon) fatigue. The compact console has been presented as an example of a system based on these guidelines that has a proven track record.

Figure 1. Commercial generic version (before task-specific master has been installed) of compact console.

4. Conclusions

Use of a chair-based operator interface with proper alignment to mono-image flat panel displays is a cost effective ergonomic solution that facilitates low fatigue for minimally invasive, remote, and virtual procedures that require extended periods of concentration. Modularity of the system with regard to the tool interface, control chair, and video displays provide more flexibility to adhere to human factors design guidelines. The ORNL compact console is the first example of a remote operator station designed around these guidelines.

5. Novelty/Discussion

The compact console approach has been used in many applications in the hazardous waste remote systems user community and has been proven to improve concentration, reduce fatigue, and improve acceptability by the user. Current development is focused on leveraging lessons learned and research insights from environmental restoration tasks towards next-generation remote surgical interfaces.

References

[1] H. P. Van Cott and R. G. Kinkade, eds., *Human Engineering Guide to Equipment Design*, American Institute for Research: Washington DC (1972).

[2] M. W. Noakes and W. D. Willis, "Compact Remote Operator Console Development, Deployments, and Technology Transfer," *American Nuclear Society Spectrum*, Reno, Nevada, August 4–8, 2002.

[3] J. V. Draper, et al., "Three Experiments with Stereoscopic Television: When It Works and Why," *Proc. of the IEEE International Conference on Systems, Man, and Cybernetics*, Richmond, VA, 1991, pp. 105-110.

[4] A. M. Ariyaeeinia, "Analysis and Design of Stereoscopic Television Systems," *Signal Processing: Image Communication*, 13(3): pp. 201-208 (1998).