

Usability in Surgical Technology: Finding Research Questions in Practical Problems

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Abstract—Intuitive design may become an integral component of medical technology, much like it has in the consumer space, as a number of undercurrents converge. These include increasing burdens on clinical practitioners, growing demands on health systems, and the advancing complexities of technology. Surgical systems serve highly trained experts performing mission-critical tasks, so improving usability in this context will require novel user interfaces and design practices. In support of care providers, this paper explores the cognitive aspects of exemplary surgical tasks, outlining methods that promote intuitive operation, efficient workflows, and clinician well-being. Solutions to these practical yet nuanced problems may inevitably prompt new research questions.

I. THE FOURTH AIM

In 2008, Berwick et al. [3] proposed a measure of health-care performance around improving population health, supported by the contributing aims of patient satisfaction and operational efficiency. Documentation requirements increased, patient expectations grew, and healthcare systems faced increasing cost pressures. The burden of improving performance was ultimately placed on clinicians, whose needs were overlooked leading to the deterioration of provider experience and subsequent declines in all three performance criteria. The fundamental role of personnel in the delivery of healthcare was acknowledged as an added dimension in the Quadruple Aim [4], upon which emerging technologies will be increasingly evaluated against.

Healthcare technologies have grown in complexity alongside broader innovation, as evident in history of bronchoscopy [5]. With its 1964 invention, the 1992 introduction of endobronchial ultrasound, the 2006 integration of electromagnetic (EM) tracking, and the 2018 regulatory approval of robotic bronchoscopy, pulmonologists learned to use a new device, interpret ultrasound images, register devices to medical images, and operate robots—all while practicing complex medical specialties.

Numerous reports highlight the burdens of technology borne by clinicians. Primary care physicians, for example, dedicate 25–50% of their attention to a computer, even while tending to patients [6]. Data entry, while ultimately beneficial, disrupts the workflow of care and diminishes practitioner satisfaction [7]. Electronic health record systems are widely regarded as a costly technological failure, leaving its potential unfulfilled while creating an epidemic of burnout [8]. Similar usability shortcomings can be found in surgical

systems, yet further advances are projected due to engineering platform commoditization, industry consolidation, and the influence of consumer technology. Usability is thus of paramount importance in the next generation of surgery.

II. USABILITY IN SURGICAL TECHNOLOGY

The Food and Drug Administration (FDA) offers advice on medical device usability based on general-purpose standards, including human factors (AAMI/ANSI HE 75) and usability engineering (ANSI/AAMI/IEC 62366). These recommendations emphasize the prevention of user error through mechanisms such as warnings, disambiguation, and design controls. Such rudimentary guidance assumes a baseline of cognitive ability to use a device, without regard to any cognitive strain incurred by its use. A broader definition of usability [9], [10] consists of the following attributes:

- 1) Learnability: The amount of training needed
- 2) Efficiency: The fluidity of task performance
- 3) Memorability: Retention of the initial training
- 4) Errors
- 5) Satisfaction

Surgical workflows consist of highly trained tasks performed regularly, making errors and efficiency the most applicable usability traits; learnability and memorability effects can be amortized over time. This paper builds on the FDA error prevention guidance and extends the concept of usability towards efficiency. In particular, we focus on *cognitive efficiency*, as surgical tasks often involve fine motor control in response to rapid judgment. Alleviating cognitive load thus has the potential to improve overall efficiency, reduce mental fatigue, reduce judgment errors, and ultimately improve clinician satisfaction, an essential component of the Quadruple Aim. The following section discusses possible approaches to these practical problems as well as the corresponding research questions that may arise.

III. COGNITIVE EFFORT IN SURGICAL TASKS

Surgery is both a physically and mentally demanding undertaking, so developers should strive to reduce the cognitive footprint of prospective surgical technologies. In this regard, inspiration on usability may be drawn from design techniques commonly used in the consumer product domain. At the same time, it is important to note that surgery is distinguished from everyday experience in fundamental ways, including the highly trained nature of tasks and the critical role of expert judgment.

Note: This paper contains excerpts of themes and examples from authors' previous works [1], [2] as a basis for the present content.

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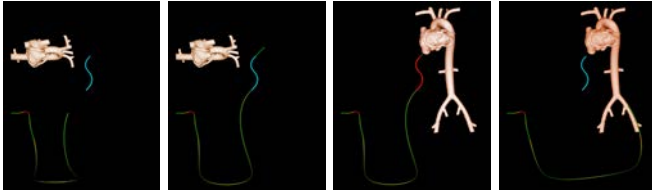


Fig. 1. One-swipe registration sequence from left to right: (1) A tracked catheter device and an anatomical model are initially unregistered. (2) Surgeon guides device through a special registration fixture. (3) Model becomes instantly registered to device. (4) Surgeon can navigate device using model as a roadmap.

A. Cognitive Friction

Cognitive friction includes the intermediate steps that ostensibly lead to a goal, yet detract from it at the same time; this property can nudge one to avoid the task or its tools. For the critical task of surgery, cognitive friction can increase cognitive load, impairing both judgment and motor skills [11]. One example is the registration of navigated devices, which is widely regarded as cumbersome [12]. Canonically, the user touches a tracked device to multiple ordered fiducials. They then hope that the sequence was performed satisfactorily, lest they have to repeat the seemingly arbitrary ritual. In [1], the generic registration task is streamlined to a single swipe in an effort to reduce cognitive load, as shown in Fig. 1; it can furthermore make re-registration a less burdensome process, affording clinicians more freedom in setup and workflow.

Beyond efficiency and convenience, reducing friction offers immediacy as a cognitive benefit. A natural user tendency is to correlate the activation of a task with its eventual outcome in a bid to improve future results. Reducing the latency of task execution allows one to infer cause-effect relationships more precisely, leading to improved performance and problem identification.

Reducing the number of steps to perform a task, especially one as well defined as registration, can initiate research questions on the division of labor between humans and machines. A shared responsibility scenario requires an intimate understanding of the task, a high level recognition of its progress, and interaction between users and systems. Further experiments can then evaluate the efficacy of various configuration options.

B. Natural Vision

Medical images can be rendered in naturally interpretable ways. Fig. 2 (left) shows a B-mode ultrasound image of a mitral valve. Standard 3D imaging (Fig. 2, center) helps reduce the cognitive load needed for mental 3D reconstruction. Then thanks to natural lighting and shadows, a photo-realistic rendering (Fig. 2, right) improves depth perception and visualization of 3D spatial relationships, thereby reducing the cognitive effort of interpreting the arbitrary color shading commonly applied in 3D ultrasound today. Natural visualizations may also reduce the need for robots designed to resolve hand-eye coordination challenges (e.g., [13]).

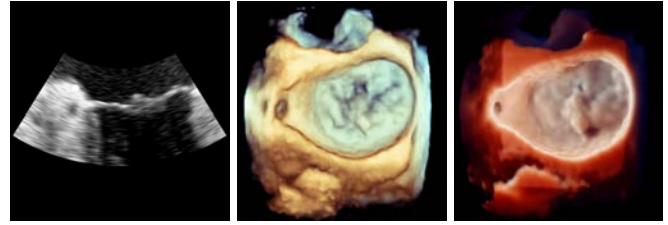


Fig. 2. Comparison of ultrasound image renderings of a mitral valve. (Left) Conventional B-mode. (Center) Standard 3D. (Right) Photo-realistic image that evokes natural vision, making interpretation of the scene more fluid.



Fig. 3. An augmented reality solution provides flexibility in the workspace.

Artificially representing data for compatibility with human vision evokes broader questions on the validity of such an approach, as well as specific questions on the fidelity of the reconstructions. Further research can be conducted to ascertain the viability and performance of photorealistic rendering in different clinical applications.

C. Ergonomics

As technology is added to already crowded interventional labs, physicians strain to work around equipment. Augmented reality (AR) enables a paradigm shift in room design in which the tools revolve around physicians, providing them with the right content at right location and time, as illustrated in Fig. 3. Immersing physicians in a tailored AR environment allows them to see the real world superimposed with the live imaging and data needed to guide precision therapy. Voice recognition, eye tracking, and gestures allow for easy interaction with interventional systems, keeping physicians' focus on patients rather than on technology. There is a vast solution space in augmenting a surgeon's reality, calling for studies into the effective use of the technology.

D. Spatial Context

A robot can navigate a workspace given a point on its end effector—this singular point is often regarded as synonymous to the physical end effector itself. A clinician can likewise navigate a device in this manner, e.g., an EM tracked catheter [14]. However, visualization of the entire device can make this task more intuitive, as pictured in Fig. 4. One possible explanation is that peripheral cues inform a mental model of the device, allowing for closure between

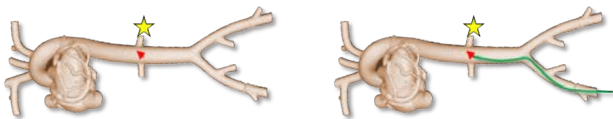


Fig. 4. Navigating a catheter to the renal artery (stars). (Left) With a tip-only visual (red arrows), navigation is possible, but strenuous. (Right) When more device is visible (green line), hand-eye coordination is more fluid.

expected and actual behavior. Small field-of-view imaging (e.g., ultrasound, endoscopy) provides further insight into the challenges of navigating with limited spatial context. Novel technologies will need to be developed to enlarge perspectives that would otherwise be hidden.

E. Linearity

As linearizing complex problems affords practical, if imperfect, solutions, linearizing the behavior of a technology can help users calibrate to its imperfections. For example, a user can gainfully teleoperate a robot with low absolute accuracy provided the relationship between control input and actuation output is proportional and predictable. People excel at estimating linear trends [15], which opens the possibility of relaxing technical requirements. Considerable effort may be needed to recast system errors onto a linear scale.

IV. DISCUSSION

The experience of clinical practitioners is vital to improving care delivery, especially as the demands on healthcare systems continue to grow. The usability of supporting technologies will thus increase in prominence in the next generation of surgery. In examining various surgical technologies, a recurring observation is that an intimate understanding of users and workflows is a prerequisite to applying suitable usability enhancements. This paper lists examples showing how usability problems in surgery can generate fundamental questions on a broader scale. Moreover, the nuanced nature of these problems calls for both thorough technical underpinnings and creative problem solving.

REFERENCES

- [1] P. Thienphrapa, P. Vagdari, A. Chen, and D. Stanton, "User centric device registration for streamlined workflows in surgical navigation systems," in *IEEE Int. Conf. on Robotics and Automation (ICRA)*. IEEE, May 2019.
- [2] P. Thienphrapa, B. Mory, A. Panse, V. Pai Raikar, A. Torjesen, D. Schulman, M. Flexman, and A. Popovic, "Basic principles for integrating next generation technologies into surgical workflows," in *ICRA Workshop on Next Generation Surgery*, May 2019.
- [3] D. M. Berwick, T. W. Nolan, and J. Whittington, "The triple aim: care, health, and cost," *Health Affairs*, vol. 27, no. 3, pp. 759–769, May 2008.
- [4] T. Bodenheimer and C. Sinsky, "From triple to quadruple aim: care of the patient requires care of the provider," *Annals of Family Medicine*, vol. 12, no. 6, pp. 573–6, Nov. 2014.
- [5] T. S. Panchabhai and A. C. Mehta, "Historical perspectives of bronchoscopy: Connecting the dots," *Annals of the American Thoracic Society*, vol. 12, no. 5, pp. 631–641, 2015.
- [6] O. Asan and E. Montague, "Physician interactions with electronic health records in primary care," *Health Systems*, vol. 1, no. 2, pp. 96–103, Dec. 2012.
- [7] M. W. Friedberg, P. G. Chen, K. R. Van Busum, F. Aunon, C. Pham, J. Caloyeras, S. Mattke, E. Pitchforth, D. D. Quigley, R. H. Brook, F. J. Crosson, and M. Tutty, "Factors affecting physician professional satisfaction and their implications for patient care, health systems, and health policy," *Rand Health Quarterly*, vol. 3, no. 4, p. 1, 2014.
- [8] E. Fry and F. Schulte, "Death by a thousand clicks: Where electronic health records went wrong," 2019. [Online]. Available: <http://fortune.com/longform/medical-records/>
- [9] J. Nielsen, *Usability engineering*. San Francisco, CA: Academic Press, 1993.
- [10] B. Shneiderman, *Designing the user interface: Strategies for effective human-computer interaction*, 3rd ed. Boston, MA: Addison Wesley Longman, 1998.
- [11] C. M. Carswell, D. Clarke, and W. B. Seales, "Assessing mental workload during laparoscopic surgery," *Surgical Innovation*, vol. 12, no. 1, pp. 80–90, Mar. 2005.
- [12] D. P. Perrin, N. V. Vasilyev, P. Novotny, J. Stoll, R. D. Howe, P. E. Dupont, I. S. Salgo, and P. J. del Nido, "Image guided surgical interventions," *Current Problems in Surgery*, vol. 46, no. 9, pp. 730–766, Sept. 2009.
- [13] P. Thienphrapa, A. Popovic, and R. H. Taylor, "Guidance of a high dexterity robot under 3D ultrasound for minimally invasive retrieval of foreign bodies from a beating heart," in *IEEE Int. Conf. on Robotics and Automation (ICRA)*. IEEE, May 2014, pp. 4869–4874.
- [14] A. M. Franz, T. Haidegger, W. Birkfellner, K. Cleary, T. M. Peters, and L. Maier-Hein, "Electromagnetic tracking in medicine—A review of technology, validation, and applications," *IEEE Transactions on Medical Imaging*, vol. 33, no. 8, pp. 1702–1725, Aug. 2014.
- [15] D. Kahneman, *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux, 2011.