Basic Principles for Integrating Next-Generation Technologies into Surgical Workflows

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Abstract— **Emerging technologies for the operating room are subject to evaluation against the Quadruple Aim, which describes healthcare performance as a union of: patient satisfaction, clinical outcomes, provider satisfaction, and operational efficiency. Consequently, new developments will be expected to fulfill multiple aims simultaneously. This paper outlines basic principles for increasing the usability of prospective surgical innovations. As technologies become more sophisticated, system designers can incorporate these concepts to ensure intuitive operation and efficient workflows. Such investments address the experience of clinical professionals, who are already subject to physically, cognitively, and emotionally taxing responsibilities. As the dimensions of the Quadruple Aim are coupled, improved user experience has the potential to impact patient satisfaction, outcomes, and efficiency as well.**

I. Introduction

In 2008, Berwick et al. [1] proposed a measure of healthcare 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 [2], upon which emerging technologies will be increasingly evaluated against.

Healthcare technologies have grown in complexity alongside broader innovation, as evident in history of bronchoscopy [3]. 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 [4]. Data entry, while ultimately beneficial, disrupts the workflow of care and diminishes practitioner satisfaction [5]. Electronic health record systems are widely regarded as a costly technological failure, leaving its potential unfulfilled while creating an epidemic of burnout [6]. 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.

The Food and Drug Administration describes the usability of medical devices in terms of human factors (AAMI/ANSI HE75) and usability engineering (ANSI/AAMI/IEC 62366), which consider safe usage given a baseline cognitive ability. In this paper, we use examples to extend the concept of usability towards cognitive efficiency to ultimately support user performance and satisfaction.

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II. Basic Principles, by Example

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 [7]. One example is the registration of navigated devices, which is widely regarded as cumbersome [8]. 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 [9], the generic registration task is streamlined to a single swipe in an effort to reduce cognitive load; 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.

B. Natural Vision

Medical images can be rendered in naturally interpretable ways. Fig. 1 (*left*) shows a B-mode ultrasound image of a mitral valve. Standard 3D imaging (Fig. 1, *center*) helps reduce the cognitive load needed for mental 3D reconstruction. Then thanks to natural lighting and shadows, a photo-realistic rendering (Fig. 1, *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

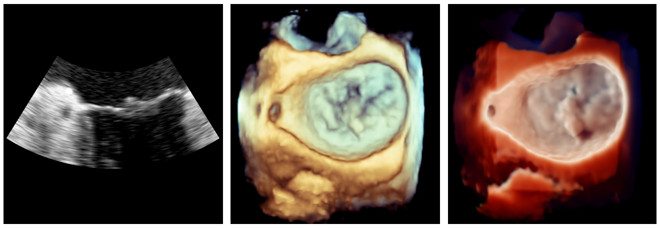

Fig. 1. Comparison of ultrasound image renderings of a mitral valve. (*Left*) Conventional B-mode. (*Center*) Standard 3D. (*Right*) Photo-realistic image that evokes natural vision, making interpretation of the scene more fluid.

Fig. 2. An augmented reality solution provides flexibility in the workspace.

visualizations may also reduce the need for robots designed to resolve hand-eye coordination challenges (e.g, [10]).

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. 2. 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.

D. Additional Considerations

1) 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. However, visualization of the entire device can make this task more intuitive, as pictured in Fig. 3. One possible explanation is that peripheral cues inform a mental model of the device, allowing for closure between 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.

2) 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

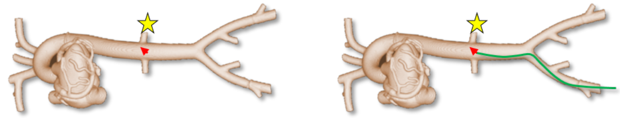

Fig. 3. Navigating a catheter to the renal artery (stars). (*Left*) With a tip-only visual (red arrows), navigation is possible, but strenuous. (*Right*) When more device is visible (green line), hand-eye coordination is more fluid.

absolute accuracy provided the relationship between control input and actuation output is proportional and predictable. People excel at estimating linear trends [11], which opens the possibility of relaxing technical requirements.

III. 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 become a key characteristic in the next generation of surgery. This paper lists illustrative examples on how complex systems may use intuitive interfaces to ease technological burdens on clinicians. While described independently, these concepts are often related; for example, augmented reality headsets may improve both data representation and ergonomics simultaneously. An intimate understanding of users and workflows is a prerequisite to applying suitable usability enhancements, and more generalized approaches may emerge through experience.

References

[1] 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.

[2] 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.

[3] 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.

[4] 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.

[5] 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.

[6] 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/

[7] 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.

[8] 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.

[9] P. Thienphrapa, P. Vagdargi, 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.

[10] 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.

[11] D. Kahneman, *Thinking, fast and slow*. New York: Farrar, Straus and Giroux, 2011.