Discussing Facets of Hybrid User Interfaces for the Medical Domain

Katja Krug * †
Interactive Media Lab Dresden,
TU Dresden, Germany

Ricardo Langner‡
Interactive Media Lab Dresden,
TU Dresden, Germany

Konstantin Klamka§
Interactive Media Lab Dresden,
TU Dresden, Germany

Figure 1: We discuss six facets of hybrid UIs in a medical context. For this purpose, we present three research projects (RP1-RP3) in which we have been involved and discuss how their characteristics contribute to hybridity: **RP1:** A laparoscopic liver navigation pipeline with *in-situ visualization overlays [3, 4]* (left), **RP2:** point cloud alignment through mid-air gestures on a *stereoscopic display [13]* (middle), **RP3:** and the exploration of interacting with transparent tablets in *Augmented Reality [12]* (right).

Abstract

Hybrid user interfaces are commonly discussed in the context of integrating conventional displays into Mixed Reality environments, as well as multi-modality and cross-device interaction. We believe that the consideration of these overarching categories does not suffice to inform the development of these interfaces in very distinct application domains, such as medicine. Instead, we argue that the medical domain comprises of various further aspects that influence the design of hybrid user interfaces. With this work, we want to discuss additional facets that emerge from the specific constraints and challenges of this particular field. To do this, we first introduce three selected research projects, in which we have been involved, showcasing the range of possible tasks and application areas in the context of medicine. As a result, we identify and discuss the following facets: Physical Location, Visualization Placement, Display Capabilities, Interaction Style, Enhancement Target, and Task Concurrency.

1 Introduction and Background

Many processes in the medical domain follow long-established patterns and are often barely digitized. Well-tried procedures come with the advantage of practiced experts, foreseeable outcomes and proven training methods, but they also neglect possible optimizations brought by recent technological advancements. For example, interdisciplinary research projects like Medivis [14] show how Augmented Reality (AR) and Computer Vision can help to improve surgical care for patients. Furthermore, a series of research has been conducted focusing on touchless human-computer interaction in operating rooms and interventional radiology suites that discusses drawbacks of current solutions and highlights promising research directions (for an overview, see Mewes et al.'s literature review [15]). However, the employment of such novel user interfaces in the medical context stagnates. The reasons for this are manifold and can be explained along various aspects: the long-winded bureaucratic processes needed to approve novel medical devices, the need for adaptation of current medical education and training, the uncertainty that comes with novel techniques and technologies, and the hesitation by experts to overturn one's own training in favor of new approaches. Therefore, when designing novel interfaces for the medical domain, it is necessary to consider a phase of transition *between* conventional methods and future user interfaces.

Hybrid User Interfaces (hybrid UIs), according to Feiner and Shamash [6], combine "heterogeneous display and interaction device technologies." Particularly interesting in the context of this work is that hybrid UIs allow for the prioritization of enhancement over replacement, for example, through introducing diverse additional input and output modalities into conventional settings (e.g., foot input [8], gaze interaction [9], voice commands [17], or multimodal variations [7, 10, 15, 18]). However, we think that discussing the design of hybrid UIs should also include aspects beyond input and output channels. Due to the uniqueness of medical requirements, hybridity can encompass contextual factors that impact design rationales. For example, staff with different expertise and roles have to work together and involved processes come with specific and diverse complexities (e.g., comparing diagnostics and surgery).

With this work, we want to present our perspective on further facets that can inform the design of hybrid UIs in the medical domain. We describe three exemplary research projects (Fig. 1) in which we have been involved and examine how their characteristics contribute to hybridity.

2 Example Research Projects

In the following, we briefly present three research projects (Fig. 1), each leveraging different visualization and interaction concepts as well as assisting specific medical activities.

RP1 In-situ Visualization Overlays [3, 4]
Docea et al. [3, 4] investigated in-situ overlays of important anatomical structures for endoscopic video streams during minimally invasive surgery (MIS). MIS is performed through small incisions serving as entrance points for an endoscope and laparoscopic instruments. The surgeon navigates within the body solely based on the output of the endoscope which is usually streamed to a monitor close to the operating table. This cognitively challenging process needs a lot of training to be mastered.

In this project, to facilitate this process during laparoscopic liver surgery, an image guidance system supports the navigation during MIS [3, 4], aiming to overlay in-situ 3D augmentations onto the en-

*Also with the Centre for Tactile Internet with Human-in-the-Loop (CeTI), TU Dresden
†e-mail: katjakrug@acm.org
‡e-mail: langner@acm.org
§e-mail: klamka@acm.org

doscopic video output, such as vessels, tumors and other important anatomical structures (Fig. 1 left). Here, the stereo-endoscope is used to create a 3D point cloud of the inner body [16] for subsequent manual registration of the aforementioned 3D models, using a region-based point cloud registration algorithm [2]. The in-situ overlays aim to facilitate the navigation within the inner body, by accentuating regions of interest and offering visual landmarks. Individual visualization parameters, such as the transparency or visibility of augmentations, can be adjusted via mouse and keyboard.

RP2 Mid-air Point Cloud Registration [13]
Krug et al. [13] explored an alternative to conventional manual point cloud registration interfaces by introducing a system consisting of a stereoscopic display and an external hand tracker for mid-air gesture interaction. RP1 incorporates the manual registration of preoperatively captured organ models to the 3D point cloud of the inner body, performed on a 2D desktop setup using mouse and keyboard. This interaction results in the user's dominant hand becoming non-sterile, which would either necessitate subsequent sterilization, to precautionarily wear a second layer of gloves, or have an assistant performing the interaction. While systems employing Mixed Reality (MR) head-mounted displays (HMDs) allow for stereoscopic vision and mid-air interaction, today's devices aren't very convenient for the operating room (OR) environment which demands strong environmental attentiveness. Additional discomfort for the surgeon should also be avoided. To ease the registration process and support depth perception and intuitive, sterile interaction, this research project introduces a point cloud registration system consisting of a stereoscopic display and an external hand tracker for mid-air gesture interaction [13] (Fig. 1 middle). With this setup, during surgery, the process of manual point cloud registration can not only be seamlessly integrated into the MIS navigation pipeline of RP1, but can also be facilitated through the integration of stereoscopic perception of inherently spatial data, as well as intuitive gestural interaction.

RP3 Transparent Interaction Panel for AR [12]
Krug et al. [12] introduced the usage of a transparent interaction panel for volumetric data exploration in Augmented Reality (AR).

Conventional medical imaging techniques, such as magnetic resonance imaging (MRI) scans, produce inherently spatial results, which suggest immersive exploration in 3D space. Since these explorations usually take place in less restrictive settings where sterility is not an issue, the possibilities are much broader, e.g. wearing an HMD to view immersive visualizations, or taking up more physical space for body gestures or the movement of tangible artifacts.

Prior work has already explored the potential for using tangible artifacts or handheld devices [11] to slice into volumetric anatomical data (cf. slicing techniques [1]). With CleAR Sight [12] (Fig. 1 right), the authors further broaden the interaction spectrum using a transparent interaction panel for AR environments. Here, the transparent touch-enabled device can be utilized in different ways to explore an anatomical volumetric data set: (i) As a tangible prop to pick the data up and fix it to the surface of the panel for further inspection or relocation; (ii) As a slicing plane with the possibility to attach alternative data representations to the surface of the panel; (iii) As a see-through window for selection and transformation from afar; (iv) As a transparent canvas for direct and indirect virtual annotations in 3D space. This way, the flexibility of the immersive environment can be combined with the convenience of touch input and haptic feedback for more complex or precise interactions.

3 Discussing Facets of Medical Hybrid UIs

Hybrid UIs are often classified within the scope of multi-modality or cross-device interaction. As an application area, the medical domain is defined by many unique characteristics which necessitate the consideration of many other facets that can influence the design of these UIs. Many of these characteristics stem from the restrictive conditions of the OR, since the inherent challenges that emerge from this application area differ greatly from common usage contexts within hybrid UI research. Therefore, we want to put greater weight on the discussion in regards to the OR compared to more general settings. In the following, we want to discuss selected facets in relation to the research projects introduced in section 2.

Physical Location
Locations in the medical domain can be characterized by different properties, including, among others: need for sterility, presence of patients, presence of machinery, amount of people and available space. Among possible locations are the operating room, laboratories, patient accommodations, or more flexible settings such as staff offices and conference rooms. Out of these possible places, the OR is a the most restrictive setting. It is a fast-paced and crowded environment with highly sensitive machinery and complex, high-risk tasks. Respective user interfaces are often supposed to alleviate this overwhelming situation, or at least not contribute to further stress. They are therefore mostly minimalistic and consist of familiar input and output modalities, in order to seamlessly blend in with the established processes and the given environment. Interfaces such as RP1 would need to operate within the constraints of the OR environment, e.g., by adding a second monitor to display the augmented video stream alongside of the conventional endoscopic video output. In comparison, RP3 is an example for a system which is mostly decoupled from environmental restrictions, besides sufficient space for spatial interaction and the limitation of lacking sterility, which makes it unsuitable for the OR. It could be, for example, employed in staff offices for collaborative data explorations or in patient accommodations for educational purposes. Applications such as RP2 can be employed more flexibly. Even though the mid-air gesture interaction was initially motivated by the need for sterility in the OR, it can facilitate the process of manual point cloud registration regardless of the environmental context, especially if combined with the enhanced depth perception offered by the stereoscopic display. Therefore, it can transition between these distinct physical locations, even though they are fundamentally different. We see potential in this specific setup as a dynamic extension of conventional setups which are employed across different locations in the medical domain.

The OR is an environment characterized by many constraints which can also be transferred to other medical settings, such as laboratories or intensive care units. To support transitions, hybrid UI designs for these locations should bear a strong focus on enhancing current setups instead of replacing them.

Visualization Placement
The possibilities for visualization placement in hybrid UIs are very diverse, as discussed, for example, by Ens et al. in regards to spatial analytic interfaces [5]. We want to categorize common placement strategies, taking into account the different physical locations of the medical domain and their accompanying restrictions: Visualizations can be placed *in-situ* over a region of interest, in *spatial relation* to a region of interest, or *spatially decoupled* from it. In the OR, most of the visualizations are decoupled from the physical location of actual regions of interests. This is partly due to the rareness of MR HMDs in these environments, a detail which will be further elaborated on in the *Display Capabilities* section. Instead, visualizations are mostly shown on monitors and their proximity to the region of interest, which is usually the operating table, strongly depends on the importance to the task. For instance, during MIS, the endoscope video output is crucial to the surgical process and therefore displayed on a monitor close to the surgeon. As presented in RP1, in-situ overlays over video streams shown on these monitors can be a feasible step towards enhancing these setups and therefore forming

the basis for hybrid UIs. Since these virtual overlays cover parts of the image, the augmented video stream should be offered in addition, not instead of the raw camera output. RP2 shows another example for decoupled visualizations in the OR. The point cloud and organ model are displayed on the stereoscopic display with no spatial relation to the data source. As established in the *Physical Location* section, this interface could be employed in multiple places, allowing for additional placement of visualizations in spatial relation to it, e.g., by integrating it into a MR setup. In MR, all kinds of placements are conceivable. The volumetric dataset at the center of RP3 could be stand-alone, in spatial relation to other data, displays or objects, or in-situ, being directly overlayed over a patient or anatomical model. Visualizations can also be attached to interaction panel itself.

The placement of visualizations in the medical domain strongly depends on the *Physical Location* and the *Display Capabilities* of the setup. In the OR, spatially decoupled visualizations are more practical and in-situ visualizations are more feasibly realized as conventional display overlays. In this setting, the importance of the visualization also influences the proximity to the region of interest, but complete coverage of that region should be avoided.

Display Capabilities

Digital visualizations are commonly displayed on pixel-based 2D and stereoscopic 3D screens, or as holograms in 3D space using a Mixed Reality HMD. These different display types and technologies come with individual characteristics and drawbacks in the context of hybrid UIs in the medical domain. The inherently spatial nature of most anatomical data suggests exploration in 3D space with proper depth perception. The potential of the MR HMD not only lies within its stereoscopic vision, but also its capability of facilitating transitions between *Visualization Placement* strategies, as well as multi-modal input techniques, unlimited display space, and natural interaction. In more flexible settings, this technology can be a promising choice to establish hybrid UIs. However, the employment of current MR HMDs is not equally suitable across locations. Some drawbacks include prolonged wear discomfort and short battery life, which would require for surgeons to take it off during surgery, which then further leads to sterility concerns. During surgery, surgeons need to be highly attentive of their physical and social environment, which can be negatively affected by a bulky HMD constraining their field of view. With surgical masks already occluding the lower halves of their faces, partly covering the remaining upper half with a HMD would also hide their eyes and facial expressions, possibly negatively influencing effective communication between medical staff. Another issue is the low contrast of optical see-through devices in brightly-lit settings. While stereoscopic displays, such as the one used in RP2, come with a limited display space and might also achieve higher contrast in dimly lit rooms, they can compensate for most of the remaining drawbacks of HMDs in the OR. They are, however, stationary and are therefore less flexible and restricted regarding their visualization placement. Lastly, conventional 2D displays have the advantage of familiarity and already being established in most spaces, even the OR. Existing setups can be enriched with virtual overlays and multi-modal input technologies. There is also a great body of literature revolving around extending 2D displays in MR, which would be suitable in more flexible settings. The challenges to consider are the limited display space, the missing depth perception, and mostly indirect, unsterile interaction.

Due to the prevalence of 3D data in the medical domain, we see great potential in stereoscopic vision as a display capability. However, MR HMDs are not entirely suitable to be employed in restrictive settings such as the OR. Stereoscopic displays have the potential to be a sufficient addition or replacement, albeit less dynamic and personal. The focus should also lie on enhancing existing 2D monitor setups through situated overlays and more direct, but sterile, interaction techniques.

Interaction Style

The chosen interaction style for a hybrid UI in the medical domain depends on many facets, but especially on the *Display Capabilities* and the *Physical Location* of the application. The three outlined research projects already illustrate a broad range of possible interaction styles, even though they only represent a small part of the research landscape. The most common form of UI interaction in this domain is still conventional, indirect mouse and keyboard interaction, as reflected in RP1. Here, an additional unusual form of interaction arises, namely assisted interaction via another person. Each person present in the OR assumes a specific role, some of them coming in direct contact with the patient and therefore needing to be sterile. One of those persons is the surgeon. A medical professional in the non-sterile area can interact with non-sterile devices and execute interaction instructions by the surgeon, e.g., selecting or zooming into a data set. The need for clear communication adds a layer of complexity to this interaction. The topic of sterility is also reflected within less conventional forms of interaction, such as the big body of existing research revolving around topics like foot, gaze, head, and hand gestures. Both RP2 and RP3 use free-hand and mid-air interaction, the former as a means of facilitating sterility, the latter for intuitive spatial interaction. Considering that touch-less interaction can be beneficial beyond the OR, and that most anatomical data is inherently spatial and can therefore benefit from three-dimensional interaction, we believe that mid-air hand gestures have the potential to be more universally applicable across different settings in the medical domain. Though there are common issues with mid-air gesture interaction, such as arm fatigue and a lack of precision. RP2 addresses this by incorporating color-coded alignment feedback during the interaction, in order to support the user to achieve a precise result as quickly as possible. RP3 further combines spatial, tangible, and touch input in an AR environment with its spatially tracked transparent panel, facilitating 3D data exploration in less restrictive medical environments.

During surgery, the possibility for assisted interaction through a non-sterile member of the surgical team needs to be considered when designing hybrid UIs. This way, conventional input modalities can be utilized while still ensuring sterility. Due to the prevalent need for sterility, touch-less interaction is of high importance in the medical domain. We want to highlight mid-air gestures, despite their known shortcomings, as they not only fulfill the demand for sterility but also offer an intuitive way to interact with three-dimensional anatomical data.

Enhancement Target

We identified two major target points for enhancement in the context of hybrid UIs in the medical domain: the *environment* and the *human*. Enhancing the environment includes working around a static setting, e.g., by adding additional stationary display technologies, similar to RP1, as well as additional input technologies. Human enhancement is the focus of UIs that specifically leverage human skills and capabilities as an input channel, captured through external or body-worn sensors. These diverse skills include actions like hand, head, and body gestures, as well as foot, speech, and gaze interaction. In the medical domain, the enhancement target strongly depends on the *Physical Location*. For instance, in the OR, hybrid UIs should aim for environment enhancements over human enhancements. This is due to multiple factors, such as the inconvenience of HMDs as described in the *Display Capabilities* section, difficulties to include body-worn sensors or devices in combination with sanitary clothing such as scrubs, and direct touch or handheld modalities leading to sterility concerns. If body-worn sensors are to be employed, they should passively capture needed measurements, instead of employing active interaction. If active participation is supposed to be employed, one should opt for touch-less alternatives, such as mid-air gestures, as described in the *Interaction Style* section and realized in RP2. In less sensible contexts, systems like RP3 could support medical data exploration by enhancing the human through mid-air gestures, 3D registered touch input and spatial interaction with the transparent tangible.

Enhancing the human through body-worn senors or handheld devices can be a good focus point for medical hybrid UIs outside of the OR. However, inside the OR, enhancement efforts should be targeted towards the environment, by incorporating suitable stationary input and output devices.

Task Concurrency

In hybrid UIs, concurrent tasks can either be physical in the real world or virtual in a digital system or any combination of both. Medical staff are usually trained to fulfill a primary task like holding the surgical instruments while performing secondary tasks such as observing and interacting with multiple instruments, measuring devices and other staff. An example for the combination of a real-world primary and a virtual secondary task can be found within RP1, where the surgeon has to observe and analyze the 3D overlays of anatomical structures while simultaneously guiding the endoscope through the inner body. Two concurrent virtual tasks might occur during data exploration, e.g., as presented in RP3, where users might want to annotate the volumetric data set while slicing into it with the transparent tangible.

We think multitasking support has a special role to preserve familiar workflows, keep mental load low, and create acceptance for new hybrid UIs and approaches. Therefore, we argue that task concurrency must be carefully considered in the design of emerging hybrid interfaces in the medical domain.

4 Conclusion

Reflecting on the characteristics and commonalities of the research projects, it is clear that the presented facets should not be discussed in isolation; instead, they are highly interconnected and affect each other. For example, using the OR as a physical location, the available physical space and environmental properties already impact possible visualization placements, and a surgeon's primary task limits the repertoire of interaction styles for secondary activities. However, we think hybrid UIs are well suited for such cases as they support secondary tasks and multi-tasking, thus task concurrency. In addition, they inherently allow to enhance established medical settings. Overall, by involving both interaction experts and medical staff, we see hybrid UIs as an enabling concept for bridging the unique requirements of medical use cases and emerging possibilities of novel in- and output technologies. Based on the presented research projects and facets, we hope our work will foster interdisciplinary discussions on the design, development, and evaluation of applied medical hybrid UIs.

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