Interaction Proxemics and Image Use in Neurosurgery

ABSTRACT

Within medical settings there is a growing interest in exploring touchless interaction technologies. The primary motivation here is to avoid contact during interaction so as to maintain asepsis. However, there is another important property of touchless interaction that has significant implications for their use within such settings – namely that interaction behaviour is spatially distal from the device being interacted with. To further understand these implications we present fieldwork observations of work practice in neurosurgery theatres. Drawing on the notion of *interaction proxemics* and the theory of *F-formations*, our analysis articulates the spatial organization of collaborative work practices and interaction in these settings. From this understanding of spatial practices, we discuss opportunities and difficulties relating to the design of touchless interaction technologies for these settings.

Author Keywords

Gestural, touchless interaction, space, proxemics, health, surgery, imaging.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design, Human Factors, Performance.

INTRODUCTION

For several decades now, advances in medical imaging technologies have impacted widely on medical procedures from diagnosis to treatment. Surgery, in particular, is increasingly dependent on medical imaging to visualize and interpret anatomical structures and processes with minimal invasiveness. Capturing, browsing, and manipulating images are a substantial component of many contemporary operating procedures. In recent years, this interaction with images during surgery has drawn attention from a variety of stakeholders and researchers. The analytic orientation of this approach has focused on the requirement of surgical settings to maintain boundaries between sterile and non-sterile practices. This has led to concerns with the transfer of matter arising through traditional touch-based interaction mechanisms. In response, we have seen interaction mechanisms designed to remove the consequences of touch (e.g. wipeable surfaces) or to mitigate contact (e.g. keyboard covers). With recent advances in computer vision, there has also been growing interest in systems that avoid touch altogether through gestural interaction [11, 30, 19].

In this paper, we also wish to explore the potential of touchless interaction systems in surgical contexts. However, rather than being motivated by the need for asepsis, it is clear that other properties of touchlessness warrant consideration in these settings [11, 19, 2]. The particular property that we focus on in this paper is that which deals with touch and touchlessness as a spatial concern. That is, touch-based interaction entails a proximal relationship with the interaction mechanism, whereas touchless interaction supports a more distal relationship with the device (depending on the sensors concerned). The different *interaction proxemics* [27] of these technologies enable and require different spatial relationships between interactors and the technologies with which they are interacting. The broader significance of this is that the spatial configurations of a setting (its architecture, furniture and artefacts) profoundly affect the social, informational, and collaborative practices that take place within them [e.g. 13, 22, 23, 27, 15, 24]. The introduction of touchless imaging systems, with their distal interaction properties, potentially transforms the spatial configurations of a medical setting and thereby how social, informational, and collaborative practices are organized.

With this in mind, our concerns in this paper are with the spatial organization of collaborative work practices involving medical imaging systems in surgical theatres. The findings we present are drawn from fieldwork of neurosurgery procedures. We describe how surgical theatre personnel interact with the current imaging technologies where the interaction is currently mouse- or stylus-based. Through these findings, we articulate the shifting spatial relationships between surgeons and imaging technologies during procedures and the factors shaping these relationships. Our aim is to use an understanding of current practices in surgical settings viewed through a lens of proxemics related to touchless interaction [cf. 19] to uncover implications for the design of touchless interaction systems.

RELATED WORK

There is a long tradition of work articulating how social action and behaviour are influenced by the spatial

CHI 2012, May 5-10, 2012, Austin, TX, USA.

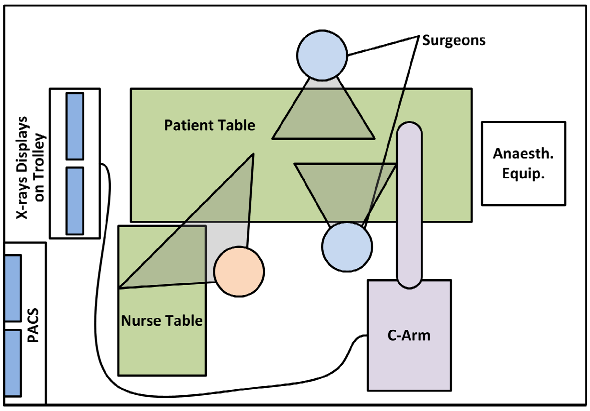
configuration of actors with respect to other people and objects in the physical environment. A number of these have found particular influence with the CHI and CSCW communities [e.g. 3, 7, 5, 14, 1, 12, 27, 24]. It is beyond both the scope and purposes of this paper to offer complete coverage of this work. Rather, our intent here is to highlight some of the key theoretical works and conceptual apparatus that particularly influence, motivate and inform our analytic contributions in this paper. Of particular significance here is Ed Halls' notion of *Proxemics* [13], which explores man's use of space as a specialized elaboration of culture. For Hall, human interaction is fundamentally spatially organized with factors such as interpersonal distances, orientations, architectural arrangements, or configurations of furniture impacting how communication and social interaction unfold in particular settings. Of significance is that man's sense of space and distance is "dynamic because it is related to action – what can be done in a given space – rather than what is seen by passive viewing" (p.108). The significance of this for us is that new interaction mechanisms create different possibilities for action at different spatial distances. The notion of proxemics has been particularly influential within CSCW and HCI [e.g. 20, 12, 27, 6]. For example, Greenberg et al [12], introduce the notion of *proxemic interactions* – that is, interactive behaviours based upon the proxemic relationships (e.g. distance, orientation, movement, identity, and location) between people, digital devices, and non-digital things. A number of authors [e.g. 28, 24] have discussed concepts such as *zones of interaction* around interactive devices and displays where different kinds of human behaviour occur at different distances from the displays with different interactive possibilities and information granularity

Another way to think about the spatially significant interactions around devices would be put forth by O'Hara et al [27] who raise the notion of *interaction proxemics* - how properties of interactive devices configure people in spatial ways with respect to the technology, content, and each other. For example, touch screens require groups of people to be lined up in front of the screen while large screens allow for shared information to be viewed from greater distances. Along related lines, Hornecker and Buur [18] discuss notions of *embodied constraints* in which configurations of space and objects (size, form, or location) and *interaction access points* (options to observe, access, and interact with objects in a space) shape emerging social configurations and behaviours. And a more descriptive treatment of different spaces is given in [6], categorising different types of conceptual spaces around interactive displays including: *interaction spaces, potential interaction spaces, gap spaces, social interaction spaces, comfort space, and activation space.* These concepts help explain why viewing distance differs from interaction distance – this becomes significant in our later discussions of touchless interaction.

Similarly influential theoretical contributions to our understanding of spatial configuration of social action can be found in the work of Kendon [22, 23]. Of significance is his articulation of the *F-formation* – the "system of spatial and orientational behavior" of participants ([22], p.212) – from which we can draw several important concepts for our concerns. One such concept concerns *transactional segments* (the area in front of each body to which attention and action are directed in the context of a particular activity). An F-formation (Face Address or Facing formations) is created when the transactional segments of two or more actors overlap in the context of social interaction forming a shared interactional space to which the participants have mutual access – the *o-space*. In the context of interaction, people continually arrange themselves to sustain the *o-space* – in other words, people arrange themselves in a circle, ellipse, or horseshoe pattern in order to have easy access to one another and excluding the outside world. Of note is that transactional segments are organized not just between actors but also between artefacts and features in the spatial environment towards which action is directed. When we watch television or look at a computer monitor, a transaction segment is defined between us and the display [23]. Several authors in HCI and CSCW have used Kendon's theory to understand technological impact on social action. This includes video conferencing [27], social interaction around interactive tabletops in tourist information centres [24], and the impact of electronic patient records in hospital wards on communication and collaboration [25].

These notions can be applied to imaging technologies within a surgical setting. Our argument is that the interaction proxemics, properties of space, and interaction access points shape and define the transactional segments of the F-formation and o-space in coordinated work. Through our analyses of these qualities we can define the opportunities for touchless interaction in supporting the social action as well as potential pitfalls for successful introduction of touchless technologies.

Other explorations of spatial practices within medical settings also inform our theoretical concerns. Perhaps most notable is Strauss' research on the organization of medical work [29] through *articulation work* and t*rajectories of action*. Such highly-tuned coordinated trajectories of action are enabled through the spatial organisation of particular resources and artefacts in particular settings. This is further emphasised in Bardram and Bossen's studies of hospital settings [1] where *mobility work* is a spatial aspect of work trajectory dealing with the configuration of people, resources, knowledge, and place in order to accomplished collaborative tasks with minimal effort. The significance of this for our purposes lies in the ways the interaction proxemics of touchless interaction will affect the ways that the operating theatre setups comes to be configured in potentially useful ways. Conversely, the use of these touchless technologies will also be affected or even



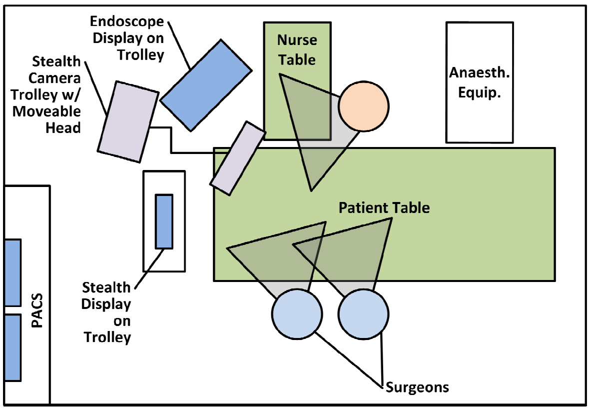


Figure 1. Typical Configurations of Theatres. Theatre 1 on the left and Theatre 2 on the right.

hindered by other prominent features of these setups and their impact on action.

Our work is informed more generally by social studies of work practice within operating theatres [e.g., 4, 8, 16, 9, 17, 21, 31]. While these studies do not focus on spatial issues within surgery per se, the rich descriptions and analyses do provide insight into the spatial organisation of work. Katz [21], for example, is particularly pertinent here, describing the boundaries between different "*realms of cleanliness*" that constrain movement, action, and the spatial organization of work.

Drawing on these insights from the literature, we present findings from a study of image use during neurosurgery. Our analysis focuses on the spatial configuration of imaging systems and their proxemically defined use during procedures. In a similar vein to Johnson et al [19], we use this to discuss further implications for touchless interaction technologies that relate in particular to its spatial properties.

FIELDWORK IN THE OPERATING THEATRE

Our fieldwork was conducted in two operating theatres in the neurosurgery department of a large hospital in the UK. Neurosurgery is concerned with any portion of the nervous system including the brain, spinal column, spinal cord, peripheral nerves, and extra-cranial cerebrovascular system. Oftentimes, the procedures must be performed with minimal invasiveness due to the sensitivity of the tissue (brain surgery for instance) or in order to speed up recovery time and reduce opportunities for complications. During these minimally invasive procedures, imaging systems are required in order to 'see' into the body.

The theatres observed are flanked by patient and equipment preparatory rooms, equipment disposal rooms, and scrub rooms. A typical setup for these two theatres can be seen in Figure 1. Within these setups the patient table is positioned in the centre of the room. The exact orientation of the table depends on the procedure being conducted, its specific approach requirements, and equipment needs. Positioned around the patient table are a range of furniture and medical equipment. These include the instrument trolley perpendicular to the patient table (providing a working area for the scrub nurse to prepare and hand off equipment to the surgeons); a mobile X-ray C-arm; a mobile X-ray control and display trolley (connected to C-arm and from which X-rays are viewed and controlled); anaesthesia equipment next to the patient table but out of the way of the flow of traffic from the preparatory room to the disposal room.

For endoscopic procedures, an endoscopy monitor mounted on a trolley is positioned next to the patient table directly in view of the surgeon. Other specialist equipment included the Medtronic StealthStation® Treon™ Navigation System (StealthCam) consisting of a mounted camera system coupled with a trolley-based display and control unit. This is positioned at the patient table adjacent to the endoscopy monitor. For this system to function the patient's head is fixed in position and an infrared camera is positioned and calibrated precisely allowing the outline of the head to be mapped to pre-operative CT scans. Controlled by a foot pedal, the cameras track the surgical probe and display the location of the tip (whether inside or outside of the skull) on three planes of the CT scans: axial, coronal, and sagittal. These images are displayed on the mobile display trolley component of the system.

While much of the equipment is configured around the patient table, an exception is the PACS (Picture Archiving and Communication System). This is a networked system for accessing pre-operative images, such as MRI and CT scans. The system has two screens that are mounted on the wall away from the patient table – a mouse and keyboard lie on a shelf just below the screens. It is positioned here to enable networked access and because it is a shared resource used for a variety of purposes by different members of the surgical team. As these displays are fixed, the patient table is sometimes specifically positioned to facilitate viewing during procedures that anticipate heavy PACS use.

We observed five procedures totalling 25 hours over the course of several weeks. The procedures were selected as a representative range of work undertaken in neurosurgery and to allow observation of the different imaging systems in practice. Two were spinal fixations (one 'open-cut' and one 'keyhole') in which several vertebrae are anchored together with a device in order to reduce vertebral mobility. Open-cut spinal surgery requires a long incision whereas a keyhole surgery uses small half-inch incisions where smaller surgical instruments are passed through. Two of the procedures were tumour excisions (one in the spine and one in the brain). The fifth procedure was a brain tumour biopsy. For the tumour excision of the spine, an endonasal approach was employed passing the instruments and endoscope through the nostrils along the nasal passage to the point of the tumour on the spine, For the two brain tumours, a craniotomy was performed (openings were created in the skull) and small instruments were introduced into the brain matter to sample or remove the mass.

For each of these procedures, there were typically two surgeons present: one consultant and one registrar. For some of the longer procedures, an additional consultant surgeon would also be present at various points. Much of the surgeons' time is spent at the patient table but as we discuss later, they also have particular needs to move around the theatre. One and sometimes two scrub nurses will also be supporting the surgeons and be positioned in very close proximity to the surgeons next to the instrument table. The number of personnel at the bedside in combination with the various pieces of equipment creates a somewhat cramped and spatially restrictive working environment. In addition to the scrubbed personnel, there were also various non-scrubbed members of the team. These include an anaesthetist who sits next to the anaesthetic equipment, a radiographer who controls the X-ray C-arm and monitors, and various other roaming support staff.

For our observations, we were given freedom of movement around the theatres to observe procedures and practices from a variety of perspectives. In support of these observations, we also had the opportunity for informal conversations with the surgeons and surgical support team (e.g. radiographers, scrub nurses and other non-scrubbed assistants). These conversations were conducted as appropriate within the context of on-going activities in the theatre and were used to help understand technical aspects of the procedures as well as explanations of particular behaviours, practices, and configuration of artefacts in the space. In addition to taking notes, all of the procedures we observed were recorded on handheld video cameras. Analysis of the audio and video allowed a much more detailed and reflective inspection of practices than was possible through observation alone. Our analytic attention focused on the details of how *trajectories of action* and interaction were collaboratively produced in this context. In particular we were interested in how different *transaction segments* and *F-formations* were organized with respect to the various artefacts and team members in these settings in the context of these action trajectories. This analysis was conducted with the aim of identifying how transaction segments, F-formations, and spatial configurations would affect or be affected by the introduction of touchless interaction.

FINDINGS

We present the findings as a series of vignettes, each illustrating key features of the spatial organisation of image use. For each vignette, we discuss the implications of these features for touchless interaction. Vignette 1 highlights issues of separating image use from where it is needed at the bedside. Vignette 2 considers the dynamics and constraints of spatial configurations and how this relates to line of sight between surgeon and imaging displays. Finally, Vignette 3 discusses interference issues arising from intersecting transaction segments in theatre.

Vignette 1 – Control, Perception and Deixis Proxemics

It is the start of an open-cut spinal fixation procedure on a 54 year-old female. The consultant surgeon, RV (foreground in Figure 2a) and the registrar surgeon FG (far side of patient in Figure 2a) are scrubbed up and at the bedside (Figure 2a). RV is pressing and massaging the skin around the patient's spine to ascertain shape and position of the spinal pedicles. As he feels the spine he is discussing aspects of the nature of its curvature with FG. FG offers an opinion but RV is uncertain so steps away from the bedside and moves over to the PACS display on the wall. He looks at the images currently displayed on the screens but these are not sufficient to resolve his uncertainty (Figure 2b). He leans in to the display to get a closer look at the thumbnail images to the left hand side of the left display and identifies a new view (Figure 2c). Being scrubbed up he cannot touch the mouse to bring up the identified view. He turns and looks to see who is available to operate the mouse on his behalf.

RV: "Errr… [looking round then notices Nurse M who is not in scrubs] M?"

M: "Yes?"

RV: "Come here for a second."

RV: Get the mouse and touch the screen there [his finger points at a thumbnail – hovering just inches away from the surface of the screen (Figure 2d)]…. that one there, left."

M: "There?"

RV: "Other one."

Once the correct image was selected, RV then turns to the right side monitor to view the image just opened (Figure 2e). While still looking at the image he raises his voice to indicate his addressing FG (who had continued to prepare the patient) behind him at the bedside: "Concave to the right, agreed".

After directing the nurse to revert back to the previous image that had been displayed, he moves away from the screen and returns to his former position at the patient bedside.

Within the trajectory of action outlined in this vignette are a rich set of features that illustrate aspects of the spatial organization of work and the proxemics of touch vs. touchless interaction. Let us consider some of these further. The first thing of note is seen at the beginning of the sequence. The *transactional* segments of both surgeons are initially organized around the patient's body – the patient being in the *o-space* between the two surgeons. The physical manipulation of the patient and the uncertainty in assessment arising from this leads to the initial discussion with the colleague and the consequent need to refer to the CT images. Of significance here is that the required images are not available, in several ways, within the particular F-formation around the patient. As such there is a need to break this particular F-formation. RV enters a new transactional segment that is organized around the displays rather than the patient. Because the patient and the display are not in the same transactional segment, the two information resources are not ideally positioned so that they can be both taken into account in the formation of medical judgment. In this particular scenario the judgment was not especially complicated but there are instances where there is a stronger need to combine what can be seen and felt on the patient with what is visualized in the medical images. By separating these *transactional* segments in this way, a close interleaving of information access from these different sources is not well supported. An important question to consider is why such a separation in transactional segments arises in this setting. First of all, as a PACS access point within the theatre, it is a resource that is used by multiple members of the team for different purposes throughout the surgery – as such there is no setup that might be considered optimal for any single purpose. Being a fixed display inhibits the flexible reconfiguration as necessary throughout the procedure. Given this positioning, then, there are aspects of the interaction proxemics, which mean RV has to move away from the bedside to the PACS display – these have to do with *control proxemics, perceptual proxemics* and *deixis proxemics*. The notion of control proxemics relates to the touch-based interaction of the mouse. That is, to operate the system, the person needs to be near the mouse at the display. Given the mouse is outside the sterile zone around the patient, RV, being scrubbed, needs to make a judgement about whether to descrub and maintain interaction control or whether to invite someone to control on his behalf. Descrubbing is time consuming and effortful so RV decides that the information gain is not worth the effort, beckoning over a nurse to act as proxy. Significantly, this was not always possible. For example, when a nurse did not have the necessary level of professional vision [10] to understand the necessary image interactions, a supporting consultant surgeon was required to descrub and serve as proxy.

Given the use of a control proxy in this scenario, the other factors leading RV to move away from the bedside to the PACS displays relate to *perceptual proxemics*. This refers to how close the surgeon, RV, needs to be in order to be able to visually resolve sufficient detail in the image for the information purpose at hand. RV has to be close to the display for this particular information task. Indeed, we see further evidence of the perceptual proxemics here as RV leans closer to the display in order to resolve and distinguish between the small thumbnails. Similarly, his

(a)
(b)
(c)
(d)
(e)

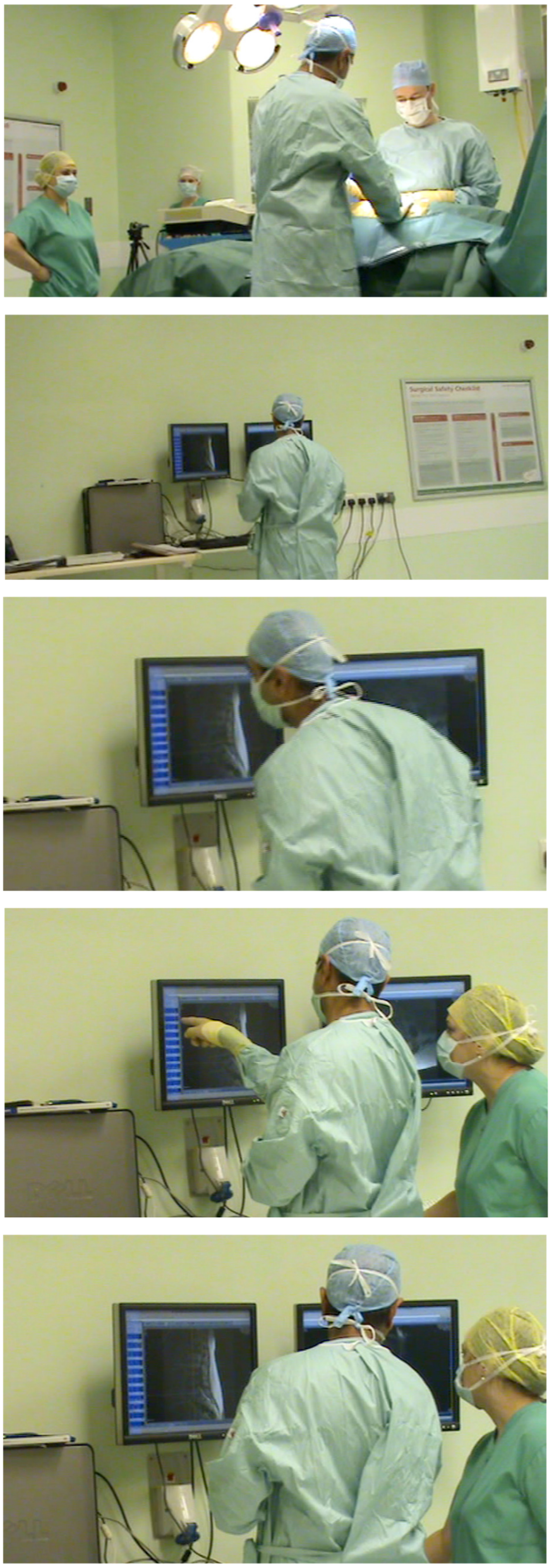


Figure 2. Vignette 1 – Separation of Transactional Segments.

fingers need to be very close to the display in order to unambiguously guide the mouse control being performed by the nurse – this is a form of *deixis proxemics* in which gestures around the images are used in the context of talk – a feature of many image interactions in these settings. As with *perceptual proxemics*, the proximity for deixis depends on the granularity of information being referenced.

At the end of the action trajectory in the vignette, we see difficulties arising from the new F-formation and competing transactional requirements as RV brings the assisting surgeon FG back into the interaction. Because RV has been put in a position where the transactional segment he is immediately engaged in is facing the PACS display and away from FG and the patient, he has to raise his voice to communicate with FG. The configuration of the space and the interaction proxemics are at odds with a desired unified F-formation for this sequence.

From the perspective of touchless interaction, there are a number of important implications arising from the issues highlighted in this vignette. First of all, because touchless interaction allows interaction from a distance, it can potentially allow the surgeons to control the images from the bedside, bringing together the transactional segments with the patient body, the registrar, and the imaging display. That is, touchless interaction here can enable transformative reconfigurations of the space to enable access to information where it is needed. Significantly though, in enabling such transformations it is important to consider different levels of interaction proxemics (control, deixis and perceptual), which may require additional design solutions. So, being able to interact from the bedside may be as much about having larger imaging displays (*perceptual* proxemics) for viewing at greater distances as it is about the *control* proxemics and *deixis* proxemics of touchless interaction at the bedside.

Vignette 2 – Configuration Dynamics and Line of Sight

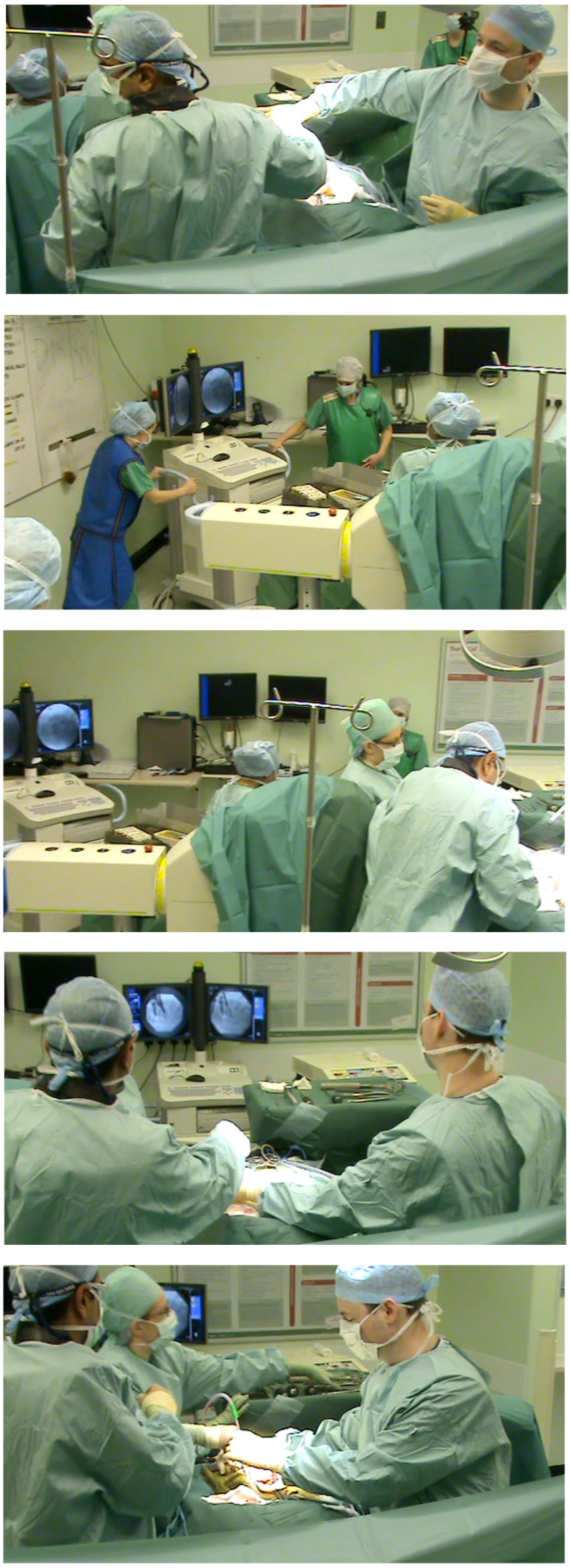
The concerns in this vignette relate to some spatial needs for camera-based touchless interaction: (a) the need for a clear line of sight between the tracking camera and the person interacting with the system; and (b) that sensing and gesture recognition work best at particular distances and orientations to the screen. This vignette highlights the challenges of these settings in meeting these requirements.

> Later on during the same open-cut spinal fixation, the surgeons needed to insert screws into the spinal pedicles. X-ray imaging is required to enable the surgeons to see the depth of the screws. The mobile X-ray C-arm is brought into the theatre and moved over to the patient. The radiographer positions the C-arm around the patient and moves it on command of the surgeon in order to provide a suitable picture of his work area.
>
> The C-arm mobile control and monitor trolley is also wheeled in and positioned by the radiographer. There is limited space to manoeuvre around the bed because the nurse table setup was positioned for training a new scrub nurse. This makes it awkward to position the trolley in an optimal position at the end of the bed for the surgeons to see. As such, the monitor trolley is positioned just behind the C-arm and directly behind the consultant surgeon, RV.
>
> Surgeon RV is on the left hand side of Figure 3a and FG on the right. As they are inserting the screws into the pedicles, their F-formation is organized such that they are facing each other with the patient in the o-space where their transactional segments overlap. In this position, though, RV has his back to the X-ray displays. He is also directly in line of the transactional segment from FG to the displays. When they need to check the depth of the screws, RV instructs the radiographer to initiate the X-ray – “Show me that please”, which she does by pressing a button. In order to view the X-ray monitor, RV has to twist his upper torso and head even further round (Figure 3a). As he does this, he keeps his hand on the instrument inserted into the patient’s spine, holding it very still for the X-ray. FG adjusts his position to the left so that he can view the screen past RV. After a few seconds of viewing the screen, they re-orient their posture and position around the patient. This sequence of adjusting the screw depth and then viewing the X-ray continues for a number of times. RV, frustrated with the arrangement, then says: “There is no way we can get that screen down there is there?” [gesturing to the foot of the patient table]. The radiographer wheels the monitor round but on reaching the corner realizes that the power cord is too short to go any further (Figure 3b). Moving it would require unplugging and rebooting the system rendering it unavailable for several minutes at a point when the surgeons are dependent upon it. So, the machine remains there while the surgeons continue. When they need to view the monitor in this position, the surgeons have to position themselves to view past the scrub nurses (Figure 3c).
>
> The radiographer waits for an understandable break in the procedure and then addresses RV: “Can I unplug it quickly?”
>
> RV: Why?
>
> RG: So that I can move it and also by switching it off and on again it might…”
>
> RV: “OK”
>
> The machine is then unplugged and moved to the foot of the bed. The procedure continues with many more interleaved adjustments followed by review of screw depth on the X-ray monitors (Figure 3d). At various points during these sequences, the scrub nurse passes between the surgeons and the monitors to pick up or replace equipment (Figure 3e). She maintains awareness of the surgeons’ direction of attention and times her actions to avoid crossing their line of sight. In the final part of the sequence, RV and FG swap sides of the patient table to enable RV to change his angle of approach.

Again there is a rich set of issues that are illustrated by this particular sequence. In the opening part of the sequence, we can see how the initial setup creates some incompatibilities in the production of transactional segments – whereby the spatial positioning of the artefacts simultaneously pulls the bodily orientation and attention of the surgeons in two different directions. This is problematic for a number of reasons. First of all, it is difficult to maintain the F-formation with FG in which the patient is in the o-space. We can see how RV orients his torso such that he can keep his right hand present in the patient based o-space while allowing him to turn his head and view the screen. While this allows him to see the screens, it is awkward and somewhat uncomfortable and in particular because of the need to move back and forth between the different transactional segments. This illustration of the potential for bodily awkwardness with respect to imaging technologies in these settings has some significance for our concerns about touchless technologies – namely that it may be difficult to assume and rely upon particular idealized skeletal poses with respect to a potential body tracking camera. Also of interest is the problematic relationship that arises between FG and the X-ray monitors. As the need to view the X-ray monitor comes into play, FG's transactional segment towards the monitor is inhabited by RV, which creates line of sight difficulties both for perception and hypothetical touchless control opportunities.

As we progress through the rest of the sequence, what we see is evidence of a continual reconfiguration of the apparatus and thereby the spatial relationship (angle, orientation, distance, etc.) between the surgeon and the imaging technologies. The dynamics of this are in part based upon the transactional requirements of these particular configurations and proxemic relationships. But significant here, this configuration of artefacts is not always something that can be idealised for particular instances of image interaction. Rather, such configurations are often based on compromise – depending on other artefacts and pieces of equipment need to be accommodated as well as constraints of everyday pragmatic realities (e.g. short cord length).

The latter part of the sequence when the monitors are moved to the foot of the patient table also highlights a number of interesting issues for our purposes. First of all, this is clearly a more comfortable F-formation for RV and FG and one that allows easier transition between the patient and display transaction segments. But what we also see in this part of the sequence is an illustration of multiple setups that make up these settings around which different team members may be organizing their actions at any particular time. So in Figure 3 the instrument trolley is a particular setup of significance for the scrub nurse. With this particular spatial arrangement, there is a transactional segment between the scrub nurse and the instrument trolley which intersects the transaction segment between the surgeons and the X-ray monitor. The consequence of this is that when the scrub nurse leans across to grab or replace instruments on the table, she crosses the line of sight between the surgeons and the X-ray monitors. These intersecting transactional segments interfere with both visual access to the monitors but also the hypothetical line of sight necessary for touchless interaction between a tracking camera and the surgeons.



(a) (b) (c) (d) (e)

Figure 3 . Vignette 2 – Configuration Dynamics and Line of Sight.

The argument here is not a simplistic one of blocking line of sight for both perceptual and potential control purposes. People within these settings show extraordinary awareness of the transactional segments of others. We observe in the scrub nurse how she monitors where the surgeon is looking to try and avoid entering the transactional segment between him and the monitors when it becomes active. There are occasions where she stands back or times her movements to coincide with him turning his view away from the monitors. Such sensitivities would likely be shown also if the transactional segments of the surgeon were to be created by touchless interaction with the imaging displays. The sensitivities to these intersecting transactional segments though create constraints on action and add a coordination burden. This is potentially exacerbated in certain touchless interaction scenarios because the nature of interference is perhaps less easy to determine and therefore accommodate.

Finally, we see at the end of the sequence that the consultant surgeon and his registrar swap sides. At times during the operation the consultant may defer to his registrar in choosing which side of the table he is most comfortable working, but during complicated procedures the consultant may need to take over the procedure. As we see here this involves changing positions to attain a better approach angle (here it is to insert a screw in a pedicle). Again this changes the spatial relationship of the surgeons to the display. Such dynamics of proxemics arrangement to accommodate the physical demands of the procedure have implications for touchless technologies.

Vignette 3 – Interference and Intersecting Segments

In the final vignette, we consider the concurrent use of multiple imaging displays for cross-referencing images.

> A tumour excision at the top of the spine is being performed on a 45 year-old female through an endonasal approach. Two consultant surgeons are performing the surgery (two figures on the left of Figure 4) while a medical student and registrar look on. In the centre is the display for the StealthCam. The display on the right is the endoscopic display. On the wall to the left of the image is the PACS display. Attention is primarily on the endoscopic display as it is the "eyes" for the surgeon. At various points during the procedure the surgeon will ask "Can you Stealth there?"). A footpedal is then used to initiate the StealthCam tracking usually by the other surgeon. The surgeons turn their focus to the stealth screen to see where the probe is located in the patient's anatomy. They then may look at the PACS display to resolve their current location with their intended approach. Then they turn their attention back to the endoscopic display. This back and forth across the displays continues accompanied by some discussion until they agree where they are and what the appropriate course of action is. They then continue with the procedure.

This sequence of action is fairly typical during such procedures. The surgeons need to understand very precisely where they are. The endoscope image gives them some idea of anatomical features, but this needs to be cross-referenced with the image from the stealth machine as well as what the registrar is feeling with the instruments inside the body. In

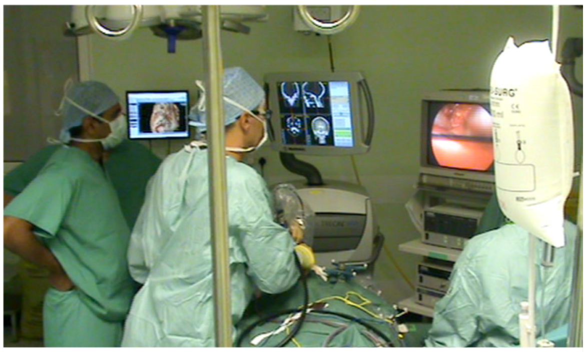


Figure 4. Vignette 3 – Interference and Intersecting Segments.

bringing this information together, they move their attention from one imaging display to the other and to each other as they visualize and discuss the combined image sources. Important here is that the various imaging displays are arranged close together and at complementary orientations to allow fluid movement of attention back and forth. In this respect, the two surgeons and the two key displays are configured in an F-formation where an *o-space* is formed in the centre where the transaction segments of the surgeons and the three displays and patient body overlap.

This use of multiple discrete displays and constructed F-formation with these displays is a typical feature of these surgeries. The particular features are of significance for our discussion of touchless interaction. First of all, this multi display scenario potentially entails multiple pieces of gesture tracking equipment. This raises a potential technical concern, in particular if such tracking equipment is based on IR depth perception techniques. The close proximity of this configuration creates potential challenges in terms of *IR interference* both with gesture tracking equipment and also the instrument tracking equipment. Second is a concern about *interaction interference* arising from the intersecting transaction segments forming the o-space. It is within this o-space that touchless interaction gestures will be performed. The potential difficulty here is that gesturing in front of one display will entail concurrent gesturing in front of the other display in the F-formation – this may lead to inadvertent triggering of image interactions on one display while trying to interact with the other.

DISCUSSION

While in recent years, there has been growing interest in touchless interaction for medical settings, the primary motivation for this has centred on concerns about asepsis. In this respect, touchless interaction technologies are conceived in terms of their avoidance of contact and the transfer of contaminated materials. Our aim in this paper, though, has been to think of touchlessness in terms of its spatial properties. That is, and in contrast to touch-based interaction, touchless interaction entails a *spatial separation* between the actor and interactive device. What, then, does this property of spatial separation specifically imply for the introduction of computer vision-based touchless control of imaging devices in medical settings? In order to help answer this, our fieldwork and analysis have drawn upon various theoretical constructs relating to the configuration and use of space. In particular we have utilised notions of *interaction proxemics* and the theory of *F-formations* to understand how trajectories of collaborative action are organized spatially with respect to the configuration of artefacts in these surgical settings. Further, we can use this analysis to uncover both opportunities where touchless input might enhance and enable new kinds of interaction during surgery, but also to point out where there are challenges in designing and installing such systems.

This particular analytic approach to the fieldwork has highlighted a number of significant issues related to our concerns. First of all, we have seen how current touch based technologies, because of their particular proxemics demands, can sometimes draw the surgeon away from the the place where the image might be most useful – namely at the bedside. This highlights an important opportunity for touchless technology in that it has the potential to overcome this and allow interaction with the images from the bedside (reducing effort costs and enabling better combination of imaging data with perceptual information from the patient's body). In realizing this opportunity, however, the fieldwork has highlighted three dimensions of interaction proxemics that need to be considered – namely *control proxemics*, *deixis proxemics* and *perceptual proxemics*. So such a successful system needs to take into consideration not just how to control the images from a distance but also how it might support visualization and deixis from a distance. This also puts requirements on the interactive devices themselves to support the touchless interaction. For instance, larger screens that can be seen from a distance as well as orientation mobility for reconfigurations both before and during the surgery.

The fieldwork also highlights some challenges for touchless interaction in these settings that relate to requirements for line of sight between surgeon and displays and between tracking cameras and surgeons. There are a number of things of significance here. First is that while the surgical team attempts to spatially configure the room to be as useful and efficient as possible for a particular procedure, the reality is that these configurations are often compromised as they balance the demands of multiple systems and everyday pragmatic constraints. The spatial relationship between the surgeons and these imaging systems are hugely variable in terms of distance and orientation and not always the kind of optimal relationship that we might see depicted in a typical proof-of-concept scenario. But it is one that needs to be considered and accommodated, through efficient and seamless recalibration or through tracking wider or multiple spatial areas.

Similarly, being able to obtain a *visual line of sight* is not the same as having a *gestural line of sight*. The intersecting transaction segments of the different team members in relation to different pieces of equipment around the theatre can impact gestural line of sight. In the cramped conditions around the patient, parts of the surgeon's body may remain hidden (by other equipment and team members) to a tracking camera. In addition, creating an o-space leaves those not a vital part of that interactive system on the outside of the ring, such as the radiographer in Vignette 2. Yet, they are still part of the system of interaction such as cueing the X-ray to create another image. Thus, the gestures and voice commands of the surgeons were created in a way to include those still outside of the o-space. These 'performances' are an important component to maintain. Thus, in touchless interaction, it is important to remember that gestures and voice commands towards the touchless system are not solely for the benefit of the system.

What is also of significance about these settings is that many procedures rely on imaging data from multiple discrete systems. Where possible, these systems are spatially positioned in an F-formation with the surgeons such that they can view and assimilate information from these sources with minimal visual sweep while working on the patient. Such an F-formation again creates a single o-space between the surgeons and these displays. From the perspective of touchless control of these systems, gestures would naturally occur in this o-space. But as we have seen there is a danger of interference both in terms of technical and in terms of inadvertent gestural triggering. This potential for interference in the o-space, presents several challenges that need to be oriented to in things such as our choice of sensors, gestural design, and the selective deployment of touchless interaction on certain devices only. Another point to take away is that for the interactive systems to remain in the line of sight of the surgeons there is a finite amount of space that they can reside in. Since all of these systems are competing for space, the location of the gestural interaction camera is an issue to discuss. Putting it in 'prominent real-estate' such as right in front of the surgeons means that room is not able to be used by other more important displays. Using the 3D space of the F-formation may be a solution. In other words, having the camera on the ceiling facing down may be a more suitable location for the camera or sensor to be supported.

CONCLUSION

Our intention is to raise a set of design considerations on which to reflect in the development and deployment of these systems. What we hope to have shown is how such reflections and considerations can be revealed through careful analysis of the spatial organization of activity and proxemics of particular interaction mechanisms. However, it is a delicate matter to study current practice in order to speculate about how new systems might fit, because they in turn alter practice. While our analysis here has been conducted with particular reference to surgical settings, we would argue that such an analytic approach and the design considerations raised through it could have much broader appeal beyond these settings.

REFERENCES

1. Bardram, J. and Bossen, C. (2005) Mobility Work: The Spatial Dimension of Collaboration at a Hospital. In Journal of Computer Supported Cooperative Work, 14(2).
2. Barre, de la, R., Chojecki, P., Leiner, U., Muhlbacj, L. & Ruschin, D. (2009) Touchless Interaction: 2Novel Cases and Challenges. In *Proceedingss of HCI '09*, Hiedleberg.
3. Buxton, W. (2009) Mediaspace – Meaningspace – Meetingspace. In Harrison, S. (Ed) *Media Space: 20+ Years of Mediated Life,* Springer, London, 217-231.
4. Cassell, J. (1987) *'On* Control, Certitude, and the "Paranoia" of Surgeons'. In Culture, Medicine and Psychiatry, 11, 229-49.
5. Dourish, P. (2006) Re-Space-ing Place: Place and Space Ten Years On. In *Proceedings of ACM Conf. Computer-Supported Cooperative Work CSCW 2006*. 299-308.
6. Fischer, T. and Hornecker, E. Urban HCI: Spatial Aspects in the Design of Shared Encounters for Media Façades. In submission to CHI 2012
7. Fitzpatrick, G. (2003) *The Locales Framework: Understanding and Designing for Wicked Problems*. Kluwer Academic Publishers.
8. Fox, N. (1992) *The Social Meaning of Surgery.* Buckingham: Open University Press.
9. Goffman, E. (1961), Encounters: Two Studies in the Sociology of Interaction. Harmondsworth: Penguin.
10. Goodwin, C. (1994). Professional Vision. In *American Anthropologist 96(3),* p606-633.
11. Graetzel, C., Fong, T., Grange, S., Baur, C., (2004) A Non-Contact Mouse for Surgeon-Computer Interaction, Technology and Health Care 12, IOS Press.
12. Greenberg, S., Marquardt, N., Ballendat, T., Diaz-Marino, R., & Wang, M. (2011, January/February). Proxemic interactions: The new ubicomp? *Interactions, 18*(1), 42-50.
13. Hall, E.T. (196). The Hidden Dimension. Garden City, NY: Doubleday.
14. Harrison, S. and Dourish, P. (1996) Re-Place-ing Space: The Roles of Place and Space in Collaborative Systems. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work CSCW'96*, ACM, 67-76.
15. Hillier, B. (1996) *Space is the machine.* Cambridge: Cambridge University Press.
16. Hindmarsh, J., Pilnick, A. (2002) The Tacit Order of Teamwork: Collaboration and Embodied Conduct in Anesthesia. The Sociological Quarterly, 43 (2).
17. Hirschauer, S. (1991), The Manufacture of Bodies in Surgery. In *Social Studies of Science, 21(2*), 279-319.
18. Hornecker, E. and Buur, J. (2006) Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proceedings of CHI 2006*, ACM, 437–446.
19. Johnson, R., O'Hara, K., Sellen, A., Cousins, C., & Criminisi (2011). Exploring the potential for touchless interaction in image-guided interventional radiology. *Proceedings of the Conference on Human Factors in Computing*, Vancouver, Canada (pp. 3323-3332).
20. Ju, W., Lee, B.A., & Klemmer, S. (2008). Range: Exploring implicit interaction through electronic whiteboard design. *Proceedings of CSCW*, San Diego, California, (pp. 17-26).
21. Katz, P. (1981) Ritual in the Operating Room, *Ethnology, 20*, 335-50.
22. Kendon, A. (1990) Spatial Organization in Social Encounters: the F-formation System. A. Kendon, A. (Ed) *Conducting Interaction: Patterns of Behavior in Focused Encounters*, Cambridge University Press.
23. Kendon, A. (2010) Spacing and Orientation in Co-present Interaction. *In Proceedings of COST 2102 Training School*, Springer Heidelberg, 1 - 15.
24. Marshall, P., et al. Using F-formations to Analyse Spatial Patterns of Interaction in Physical Environments. *Proc. of CSCW'11*, ACM, (2011), 445 - 454.
25. Morrison, C., Jones, M., Blackwell, A. and Vuylsteke, A. (2008) Electronic patient record use during ward rounds: a qualitative study of interaction between medical staff. *Critical Care 12*.
26. O'Hara, K., Perry, M., Churchill, E., Russell, D. (Eds) *Public and Situated Displays: Social and Interactional aspects of Shared Display Technologies.* Kluwer Academic Publishers, London.
27. O'Hara, K., Kjeldskov, J. and Paay, J. (2011) Blended Interaction Spaces. In ACM Transactions on Computer-Human Interaction, 18(1),
28. Prante, T., Röcker, C., Streitz, N., Stenzel, R., Magerkurth, C., van Alphen, D., & Plewe, D. (2003). Hello.Wall – Beyond ambient displays. *Video and Adjunct Proceedings of UBICOMP Conference*, Seattle, Washington, (pp. 1-2).
29. Strauss, A., S. Fagerhaugh, B. Suczek and C. Wiener (1985) Social Organization of Medical Work. Chicago & London: University of Chicago Press.
30. Wachs, J., Stern, H., Edan, Y., Gillam, M., Feied, C., Smith, M., Handler, J., (2006) A Real-Time Hand Gesture Interface for Medical Visualization Applications, In *Applications of Soft Computing*.
31. Wilson, R. N. (1958). Team Work in the Operating Room. In *Human Organization, 12(4),* 9-14.