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Beyond Boundaries A Phenomenological Exploration of Teleoperative Surgical Systems and the Exteriorisation of the Surgical Gesture

Diving in

For more than thirty minutes, the surgeon has been stuck headfirst with both hands inside the patient's abdomen. From inside, precise instructions leak out:

"A tad higher, there!
Now try to reach over
my right arm with the tongs.
Perfect.
Hold that position.
We'll need a compress soon."

The assistant surgeon standing beside the patient stoically follows the surgeon's instructions. The assistant's gaze is not directed at the patient's abdomen, but is fixed on a monitor next to the patient. They pick up the compress that has already been offered to them by the surgical assistant, with a pair of elongated tongs and pushes it through a small plastic tube into the patient's abdomen. On the other side of the abdominal wall, the surgeon takes the compress and gently presses it between the pancreas and the adjacent fatty tissue to draw up the blood that has accumulated there.
Suddenly a problem arises:

"Vision's obscured.
Clear, please."

A drop of blood has made its way from the compress into the surgeon's field of vision, obscuring their view. The surgeon pulls their head out of the patient and the assistant wipes the blood off with a compress. The surgeon then sticks their head right back into the patient. Okay, so obviously the surgeon does not "really" insert their head into the patient. Although the term "really" is becoming increasingly ambiguous in ultramodern operating rooms such as the one I am standing in right now.[1]

While I'm trying to follow the surgery, I'm also trying to stay out of the way of a surgical assistant, an anesthesiologist, or a surgical resident, and I'm hoping not to get yelled at for getting too close to sterile equipment. As you may have guessed, I am not a medical professional, not even semi-professional. I am a design researcher and the reason I am in the way of all these people is because I am interested in something very specific, something that not only changes the way surgeons work, but also challenges the very duality between virtuality and reality by producing proximity and distance in equal measure. But one thing at a time.

As mentioned above, the surgeon does not actually "stick their head" into the patient. In fact, they don't touch the patient at all. Instead, the surgeon is seated in a corner of the operating room in front of a clunky gray console made of plastic and metal that remotely resembles a grotesquely distorted praying mantis with T-Rex arms → Fig. [4].

From this console, the surgeon controls a robot that is about two meters high with four arms, to the ends of which millimeter-sized instruments are attached that extend into the patient's abdomen → Fig. [5].

The assistant surgeon pulls one of these instruments — a stereo-video endoscope — out of the patient's abdomen, detaches it from the robotic arm, and hands it to the assistant next to them to remove the aforementioned blood from its lenses.

As the name "stereo video endoscope" suggests, this rod-shaped instrument — just a few millimeters in diameter — delivers two real-time, high-definition video feeds to the console in front of the surgeon. If one were to watch the two video feeds in sequence, one might think they were identical. But far from it. The videos originate from two independent lenses at the tip of the endoscope. And while they show roughly the same image, they do so from two slightly offset perspectives. This binocular image arrangement delivers a real-time 3D video feed to a binocular display located in the console, allowing the surgeon to extract depth information from the images and thus perceive the patient's abdomen three-dimensionally → Fig. [3].

Conversely, the surgeon controls two small pincer-like controllers below the consoles display, which they can independently move and rotate in multiple degrees of freedom. These motions are then sent back to the robot next to the patient, allowing the surgeon to see and interact with the patient's abdomen in real time.

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1 This fictitious scenario is based on numerous hospitalisations which were carried out within the framework of the interdisciplinary, inter-university research project "Robotic Operations" in cooperation between the TH Köln and the University Hospital Cologne. The project was led by Prof. Dr. phil. Carolin Höfler and Juliane Ahn from the TH Köln and Prof. Dr. Hans Fuch and Dr. Dolores Müller from the University Hospital Cologne. The project was supported by the RheinEnergiestiftung.

This creates a feedback-loop. Images flow from inside the patient to the surgeon, and instructions flow from the surgeon to the instruments inside the patient. The machine thus takes on the role of conveying images and gestures in equal measure. On one side, this allows the surgeon to feel present inside the patient. On the other side, it spatially separates the surgeon farther from the patient than any other surgical instrument.

This machine is the reason why I am here.

Laparoscopy

To better understand how these highly complex machines work, it is important to first clarify some terminology. Although assistant robots with varying degrees of complexity are used in various surgical fields, the following text will deal exclusively with laparoscopic surgery.

Laparoscopy is a subset of minimally invasive surgery. In contrast to open surgery, minimally invasive surgery does not open the patient's body with large incisions. Instead, the instruments needed for the surgery are inserted into the patient's body through incisions that measure only a few millimeters to centimeters in length. Laparoscopic surgery is also minimally invasive, but is limited to the patient's abdomen.[2]

It is noteworthy that laparoscopic surgery, whether robot-assisted or not, does not take place in a pre-existing space, but in an artificial volume. This volume must first be created prior to such surgeries. For this purpose, the patient's abdomen is insufflated with carbon dioxide gas. This creates a completely new and artificial volume of space inside the patient's abdomen in which the surgeon can work — the pneumoperitoneum.

The instrumentation required for the surgery is then introduced into the patient through the abdominal wall via tubular check valves called trocars → Fig. [11].

In non-robotic laparoscopic surgery, these preconditions lead to an altered hand-eye coordination. The surgeon can no longer see the surgical field itself, instead they look at a screen next to the patient → Fig. [6]. This monitor provides a real-time video feed from inside the patient's abdomen. Based on these images, the surgeon then performs surgical procedures inside the patient. This has an obvious but far-reaching consequence: the surgeon's gaze is no longer directed at their own hands, but at a monitor that displays only the tips of the surgical instrument currently in use.

Nevertheless, the chain of action and perception (endoscope → screen → surgeon → action → endoscope → screen → surgeon → action → … etc.) is essentially identical to that of robotic-assisted laparoscopic surgery. The decisive difference rather lies in the integration of images and gestures into the surgical perception.

Waldos

To find answers on how exactly the integration of images and gestures differ in robotic-assisted surgery compared to non-robotic surgery, it is worth looking at the history of the development of surgical robots.

The first instances of remote-controlled operations can be found in 1960s U.S. military history. At that time, the Los Alamos laboratories were looking for a way to handle highly radioactive elements such as uranium and plutonium without exposing laboratory workers to dangerous levels of radiation.

This was achieved by spatially separating the laboratorian from the hazardous material by means of so-called "waldos" — tall mechanical devices — mounted on either side of a separating reinforced concrete wall equipped with lead glass windows.

On the radioactively contaminated side, known as the "hot cell," mechanical arms with crude-looking tweezer-like instruments protruded from the wall and were controlled by mechanical linkages from the other side of the separating concrete wall. The operator was therefore able to see and control the instrumentation inside the radioactive hot cell through the lead glass window, without directly interacting with the hazardous materials.

Although these rough-looking telemanipulators were only vaguely reminiscent of today's minimally invasive surgical robots, their mechanical foundations probably lie here, and the topological separation between a contaminated and a non-contaminated space as well as the tendencies of an "inside" and an "outside" were already present in these early precursors. In addition, these Waldos maintained a natural hand-eye relationship in the arrangement of the instruments and the transmission of the operator's gestures. The operator could interpret the instruments inside the hot cell through the lead glass window vicariously as their own arms and thus perform movements in reference to their own body.

This transfer of the gesture to a "device" is also one of the most striking similarities between these waldos and modern surgical robots, since it is no longer the human hand itself that comes into contact with the target, but the instruments positioned in an inaccessible space. In Los Alamos, this exteriorisation was necessary to handle highly radioactive materials. By transferring gestures from the human hand to the mechanical instruments, the operator can interact with elements that were previously inaccessible to humans due to the intense ionising radiation. Thus, by transferring the gesture to a material that is insensitive to ionising radiation (in this case, steel), the gesture penetrates a realm of matter that was previously inaccessible (radioactive elements).

2 Arnold Pier, Bernd Ablassmaier, eds. *Minimal invasive Chirurgie: Grundlagen, Technik, Ergebnisse, Trends* (Stuttgart, New York: Thieme, 1995), 66.

The posture of the surgeon at the console of the Da-Vinci XI

[1]

The surgeons hands on the console of the Da-Vinci

[2]

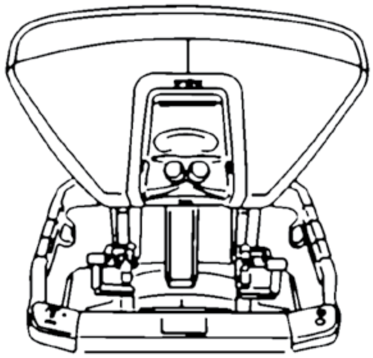
[3]

View through the binocular at the console of the Da-Vinci

Development SRI + DARPA

However, the official historical development of surgical robotics began in the mid-1980s, when the Stanford Research Institute (SRI) started research on remote-controlled systems in parallel with research on the first VR headsets. As a result, the first prototypes required the surgeon to wear a VR headset during surgery. The surgeon's hand movements were captured by data gloves and transmitted to remotely controlled surgical instruments.[3] So, in this early version, the robot was controlled by gestures. However, the concept proved too imprecise for surgical procedures, so in later iterations of the system, the surgeon used the handles of real surgical instruments instead of data gloves, and had a stereoscopic screen embedded in the console in front of them instead of wearing a head-mounted display. In this subsequent iteration, the surgeon controlled the robot by closing and opening handles on actual surgical tongs. By capturing the movement of the real instruments, the surgeon could rely on the haptic feedback they were already familiar with from non-robotic surgery. In addition, the movement of the surgeon's hand was limited to the degrees of freedom the tongs were designed for.

[4]



The console of the Da-Vinci XI (TSW)

This second iteration of the system also already consisted of two separate components. One was the Telepresence Surgeon's Workstation (TSW), a control unit from which the surgeon issued surgical instructions to the system and which displayed intraoperative images, and a Remote Surgical Unit (RSU), which was positioned directly at the patient and carried out the surgeon's commands.

Beginning in the early 1990s, the Defense Advanced Research Projects Agency (DARPA) joined the research on teleoperation systems. DARPA's goal was to improve the system so that surgeons could perform remote surgery on wounded soldiers in crisis and war zones without putting themselves in immediate danger.

DARPA's vision was to implement the RSU in an armored infantry vehicle. The TSW, on the other hand, was to be stationed in a mobile field hospital, far away from actual warfare. This allowed the surgeon to operate in relative safety. To realise DARPA's concept, the prototype from SRI had to be extensively reworked. In particular, it was necessary to decouple the components that were still connected by wires and to enable radio communication between the TSW and the RSU. In addition, a 2×-3× magnification of the surgical field and a display in color and full HD were added. This allowed the surgeon to clearly see intraoperative details down to a millimeter in size. Also, the RSU inside the armored vehicle was shielded from vibration and tremor reduction was implemented on the TSW.[4]

Many of these improvements can be found in similar ways in current systems. The final version of the system developed by SRI in collaboration with DARPA had six degrees of freedom (the human hand has seven degrees of freedom) and had a range of 5 km. The system also used force feedback, meaning it could provide haptic feedback to the surgeon about the pressure applied to the control instruments. Interestingly, this frequently led to ruptured sutures, as the isolated information of the applied force, without additional information such as vibration, pressure, friction, and tension, led to misjudgments. However, when the force feedback was turned off, the high-resolution imagery combined with the depth information from the stereoscopic cameras proved sufficient to correctly estimate the applied forces.[5]

From 1993 onwards, SRI began licensing the patents for the system to various private companies, which developed the system to market maturity. These companies followed different strategies and approaches. For example, they experimented with voice control to position laparoscopic instruments on the surgical table. Unlike later models, the surgeon stood right next to the patient and could control certain instruments by voice.

Later models separated the surgeon again from the surgical field and repositioned them in front of a TSW featuring stereoscopic intraoperative imaging.

In 1995, a privately held company, Intuitive Surgical, was founded and became the world leader in minimally invasive surgical assistance systems in the following decades. Intuitive Surgical was able to add a seventh degree of freedom to systems that previously operated with six degrees of freedom by adding an artificial wrist to the tip of the rod-shaped instrument on the RSU → Fig. [10]. This enabled the tips of the interchangeable instruments to be tilted inside the patient, making much more complex intraoperative movements possible. Intuitive Surgical named these articulating endoscopic instruments "Endowrists". Intuitive Surgical combined these endowrists, which are on a par with the human hand in all degrees of freedom, with the SRI-DARPA prototype and finally sold the "Da-Vinci" system in 1998.[6]

3 Richard M. Satava, "Robotic surgery: from past to future—a personal journey", *Surgical Clinics North America,* vol. 83, no. 6, (Dec. 2003), 2–3.

4 Evalyn I. George, Timothy C. Brand, Anthony LaPorta, Jacques Marescaux, Richard M. Satava. "Origins of Robotic Surgery: From Skepticism to Standard of Care", *Journal of the Society of Laparoendoscopic Surgeons* vol. 22, no. 4 (2018), 4.

5 Evalyn I. George and all, "Origins of Robotic Surgery: From Skepticism to Standard of Care", 7.

6 Evalyn I. George and all, "Origins of Robotic Surgery: From Skepticism to Standard of Care", 10.

Like its predecessors, Intuitive Surgical's Da-Vinci system is a modular system whose components are distributed throughout the operating room. The surgeon treats the patient by controlling the RSU from a control console. The console captures the surgeon's hand movements and transmits them to the endoscopic instruments inside the patient. Both units are connected with wires. Akin to the SRI-DARPA prototype, the Da-Vinci XI is able to feature intraoperative stereoscopic images at different magnification levels in full HD and color, as well as to filter out any tremor on the part of the surgeon through integrated tremor reduction. Instead of real surgical instrument handles as in the first prototypes of the SRI, the handles of the Da-Vinci XI console consist of universal pincer-like instruments that can be freely moved in 3 dimensions and with seven degrees of freedom → Fig. [2]. The tips of the instruments on the RSU next to the patient can also move in seven degrees of freedom, mirroring the surgeon's movements in real time.

Instead of looking at a screen in the operating room — as in non-robotic laparoscopic surgery — the surgeon's entire field of vision at the Da-Vinci XI console is substituted by a stereoscopic display featuring a real-time 3D HD video stream from the endoscope.

Reproduction of Embodiment

The Da-Vinci console TSW is designed for the surgeon to sit while working, their head is tilted slightly downward, directing their line of sight — if the display would not obscure it — at their own hands.

This is interesting since in non-robotic laparoscopic surgery, the surgeon's gaze is directed at a monitor that is typically placed about one meter away from the surgeon at head height. The Da-Vinci XI therefore restores this natural hand-eye relation.

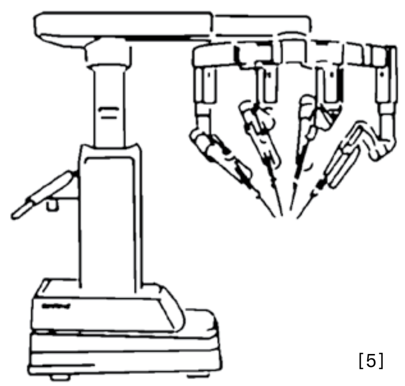
The design of the console thus dictates the surgeon's posture, creating the proprioceptive illusion for the surgeon to look at their own hands, while actually looking at a screen displaying the miniaturised endoscopic instruments inside the patient → Fig. [1]. This can cause the surgeon to feel present inside the patient. However, this trick is only made possible by completely separating the patient from the surgeon.

The system thus creates a unique ambivalence of cognitive hyperproximity and spatial distance. From their perspective, the surgeon is no longer operating next to the patient, but *inside* the patient. The system creates this effect by cleverly integrating human physiognomy into the device: the magnified stereoscopic representation of the patient's body, combined with the reproduction of all degrees of freedom of the human hand, allows the surgeon to vicariously perceive the instruments on the console display as their own hands.

(In)visibility of Gestures

This technological reproduction of the hand-eye relation by the machine is the reason I am standing in an already crowded operating room. I want to see and understand exactly how the machine creates this illusion. But that is easier said than done. The engineers of the machine didn't spend much time thinking how to visualise the reproduction of gestures and the synchronisation between hand and machine. As a result, watching a surgeon perform surgery with the Da-Vinci is, after the initial excitement, rather boring. The synchronisation of gestures by the machine happens out of sight. I can either watch the surgeon's hand movements at the console, or I can look at one of the displays scattered around the operating room to see a magnified view of the surgical instruments executing the surgeon's gestures inside the patient → Fig. [9]. But there is no possibility for me to see both at the same time. In other words: one cannot see the surgeon performing the surgery.

This is also reflected in the participation of the surgical staff. Anyone not directly involved in the handling and preparation of sterile equipment can often be seen using their smartphones or looking at one of the screens showing an oversized view of the surgical area. When I asked some of them if it is interesting to watch the surgeon perform surgery with the robot, they replied that it felt almost like watching television and that the involvement in the surgical procedure was much stronger in non-robotic laparoscopy or open surgery. This makes sense to me since robotic surgery is mediated in two ways: the images are mediated through cameras and displays and the gestures are mediated through sensors and actuators. Bystanders can only see that part of the surgical interaction that takes place inside the patient's abdomen. They cannot see the origin of the gesture — the surgeon's hands — but only its effects executed by the endoscopic instruments shown on the screen.



The "Remote Surgical Unit" of the Da-Vinci [5]

So, to understand how the gesture is translated by the console and transmitted to the robot, it is necessary to show how the gestures of the surgeon's hands are recreated in real time inside the patient's abdomen. Therefore, I carried a set of cameras and camcorders with me, determined to reunite the surgeon's hand movements with the surgical gestures performed by the machine. And in case you were wondering, no, they don't let random people take pictures and videos

[6]

The assistant surgeon looking at a monitor to coordinate his actions

[7]

A bystander looking at one of the screens

[8]

The instruments of the Da Vinci XI protrude through the abdominal wall

[9]

Two monitors in the OR showing the same image in different scales of surgeries. The fact that they let me document this surgery is the result of more than three months of work, dozens of proposals, and many emails with surgeons on the hospital's ethics committee. All this just so I could strap a GoPro action camera under the surgeon's console and point it at their hands.

But it worked, and I ended up with three hours of video showing the surgeon gesticulating in thin air.

But that's only half the footage I need. In addition, the movements of the endoscopic instruments inside the patient's abdomen are also captured by the stereoscopic endoscope and saved to a hard drive. By overlaying these intrasurgical videos with the Go-Pro videos I took of the surgeons' hands, something interesting emerges: the origin of the gesture and its mechanical execution become synchronised, and for the first time the surgeons see their own hands working in unison with the endoscopic instruments inside the patient's abdomen as they work with the robot.[7]

Choreography of Gestures

As with the early telemanipulators in the Los Alamos labs, working with the Da-Vinci exteriorises the gesture from the human hand. The hand itself no longer directly manipulates the environment, but is instead assigned the task of conveying instructions, choreographing actions, and enabling and preparing further interventions.

It was this "choreography of actions" that first drew my attention to the Da-Vinci. During a visit to the Art Biennial in Venice, the Italian filmmaker and artist Juri Ancarani showed two short films from his series *The Malady of Iron*. In this series, Ancarani explores the relationship between man and machine in highly specialised fields of work. The first movie featured the Da Vinci robot and a surgeon working on it.[8] It was Ancarani's intriguing depiction of the robot that ultimately inspired me to seek access to an operating room and to examine the robot in action. However, the second movie Ancarani showed during the Biennial pronounced the role of the gesture in specific human-machine interaction even more. It portrayed a foreman in the Italian Carrara marble quarries instructing two excavator operators with the tiniest of hand movements to eventually free gigantic slabs of marble from the rock face.[9] Besides the cinematic quality of the images and the sheer mass of the marble slabs, Ancarani manages to show how the foreman coordinates and directs heavy machinery using a language "consisting only of gestures and signs".[10] In the way Ancarani highlights these tiny gestures, it becomes evident that it is no longer the human hand itself that releases the heavy stone from the rock face, but its gesture, translated and amplified a hundredfold by the hydraulic cylinders and hardened steel tips of the excavator. The foreman no longer performs physical labor (except for the intense noise, dirt, and heat he must endure), but takes on the task of directing and choreographing an ensemble of steel and marble.

Exteriorisation of Gestures

The French cultural anthropologist André Leroi-Gourhan describes this exteriorisation of gesture through the production techniques of stone blades in the Upper Paleolithic. In the early Stone Age, oval hand axes were initially detached from the flint by a series of vertical blows. This changed fundamentally during the Upper Paleolithic. The hand axe evolved from a core tool to a core from which several blades of predetermined shape were obtained by targeted flaking.

The resulting economic rationalisation of flint as a raw material meant that people could make hundreds of tools from just a few kilograms of flint. This allowed them to settle in places far from natural flint deposits. By using their resources efficiently, people were able to extend the time between intervals when they needed to gather flint, allowing them to travel greater distances or even discover new sources of raw materials.[11]

What is unique about this so-called "Levallois technique" is that the tool (the hand axe) becomes the workpiece (the core) and thus the raw material for new blades, which in turn serve as tools.

The Levallois technique of blade manufacturing thus exhibits a certain self-referentiality, as the core tool initially leaves the hand, only to return as a set of new tools after further processing. Thus, the human hand loses the task of directly manipulating the environment and serves primarily to prepare for subsequent interactions. At the same time, the innate gestures of grasping, turning, and translating remain unchanged by the executing medium.[12]

The exteriorisation of the gesture is thus articulated in two ways: by creating new tools, the human hand transfers the gesture to a tool better suited for a specific task, thus leaving the boundaries and limitations of its own materiality (flesh, blood, bones, nerves, etc.). And by transcending the limitations of the human hand, new spatial and material realms become accessible, which in turn leads to the possibility and necessity to create new tools, thus exteriorising the gesture even further.

End Effectors

The actual interaction with the target medium is therefore no longer performed by the human hand itself, but rather prepared by it through the production of tools. The interaction itself is — both materially and spatially — exteriorised from the human hand. This technological dissolution of boundaries is

7 The video *Overlay Da Vinci* by the author is accessible via www.tetigroup.org/teti-press-journal.html

8 Juri Ancarani, *Da Vinci* (2012), 25mn.

9 Juri Ancarani, *Il Capo* (2010), 15mn.

10 Juri Ancarani, *The Malady of Iron* (2010–2012).

11 André Leroi-Gourhan, *Hand und Wort: die Evolution von Technik, Sprache und Kunst* (Frankfurt am Main: Suhrkamp, 2009), 173.

12 André Leroi-Gourhan, *Hand und Wort: die Evolution von Technik, Sprache und Kunst*, 303.

not only found in the production technology of stone blades, but also in the early telemanipulators at Los Alamos and in the Da Vinci surgical robot. The actual interaction with the target medium is always executed by the last link in a chain of transformation and translation steps of variable length. In robotics, this last link in a kinematic chain is aptly referred to as the “end effector.” In the case of the Levallois blades, numerous tools, deliberately chipped from a previously prepared hand axe, serve as end effectors at the tips of spears or arrows, as blades or axes. In the Italian marble quarries, the tempered steel tip of the excavator serves as the end effector; in the Los Alamos telemanipulators, it is the pincer-like instruments in the radioactively contaminated hot cell; and in the Da Vinci surgical robot, it is the Endowrists in the pneumoperitoneum that serve as the end effector.

Trans-materiality

All of these technologies and practices share the translation and transformation of gestures inherent to the human hand through variable media to ultimately overcome the limitations of the human hand. Stone blades, for example, are harder, pointier, and therefore better suited for cutting than the human hand. The hydraulically operated, tempered steel tips of excavators are many times more powerful and resilient than humans. The telemanipulators are unaffected by ionising radiation, and the endowrists at the tip of the endoscopic instruments on the Da-Vinci XI are smaller and steadier than the human hand.

Of course, the human abdomen was already accessible before the development of the Da-Vinci XI and even before laparoscopic surgery. However, in non-robotic laparoscopy, certain tasks could not be performed due to a lack of dexterity and missing degrees of freedom, or — in non-minimally invasive surgery — it was necessary to open the abdominal wall with large incisions, thereby completely eliminating the boundary between the patient’s body and the surrounding operating room. The introduction of pneumoperitoneum, the ability to view the patient’s abdomen with cameras instead of relying on direct vision, and the invention of tools such as the Endowrist, therefore change the conditions under which surgeons encounter the human body, thereby pushing new technologies and techniques within the boundaries of feasibility.

[10]

Endowrists on a single-use “Vessel-sealer”

Trans-spatiality

The Da-Vinci Surgical Robot, however, takes the exteriorisation of the gesture one step further by using semiconductors and digital signal transmission to spatially separate the surgeon from the surgical gesture. Whereas in the first telemanipulators in Los Alamos the gesture and the end effectors were visibly and structurally connected by mechanical force transmission, an uninterrupted mechanical connection between the end effectors and the surgeon’s hand is no longer existent in the Da-Vinci XI. This is particularly interesting because, although the development history of the system suggests that it was originally designed for remote surgery, and such operations seem to be within the realm of possibility — especially with today’s broadband technology — such operations are usually not performed with the Da-Vinci XI. Instead, all system components are located within the operating room. In fact, very few experimental remote surgeries have ever been performed, although the physical separation between the TSW and the RSU is deeply embedded in the system’s development.

In 2001, a transatlantic remote surgery was performed on a 68-year-old woman in Strasbourg by Intuitive Surgical’s early competitor, Computer Motion.[13] The surgeon operated from New York via a transatlantic undersea communications cable. The average latency during this operation was 155 ms.

In the same year, two Canadian surgeons observed latencies of 150 to 200 ms during surgery over a VPN. One of the surgeons involved, Dr. Anvari, noted that while tele-operations with latencies of up to 200 ms may be possible in theory, proprioceptive irritation could lead to extreme difficulties, including nausea.

These observations seem to be confirmed by the experimental remote surgeries performed with the Da-Vinci in 2008. In four remote surgeries conducted between either Denver and Sunnyville or Cincenetti and Sunnyville, a signal transit time between 450 and 900 ms was observed, as well as severe visual signal dropouts. In addition to these delays and dropouts, there were considerable telecommunications costs, patient safety risks and legal implications.

13 Evalyn I. George and all, “Origins of Robotic Surgery: From Skepticism to Standard of Care”, 11.

Still, I am left wondering why the components of the Da-Vinci are not located in different areas within the campus — minimising telecommunications costs, legal implications, and high latency while allowing the surgeon to perform surgery from a more accessible location within the campus than the operating room.

One quite evident reason for the surgeon's presence in the operating room is the way the Da-Vinci XI is used today: the potential applications of the system have been continuously tested and enhanced. Today, some robotic surgeries (such as the one I am participating in) require certain manual interventions (for example, retrieving specimens from the abdomen or special suturing techniques that are difficult to perform with the robot). The actual use case for the system, therefore, includes both non-minimally invasive surgical procedures and procedures performed with the robot that require a surgeon to be present in the operating room to perform these manual surgical tasks.

Trans-consciousness

But despite the need for some manual intervention, I couldn't really find a convincing answer as to why remote surgeries are basically not performed today. Legal hurdles could be overcome, as the few tele-operations that have been conducted prove, and the cost of telecommunications and latency times should be within the realm of possibility with today's fiber-optic technology and satellite Internet. And tasks that require the presence of a surgeon could possibly be performed by another onsite surgeon.

I suspect the answer is partially to be found in the cognitive and spatial perception of the surgeon. The fact that the surgeon is separated from the patient by the system and at the same time is closer to the patient than in any other surgical environment might not just create an ambivalence between proximity and distance, but a disruption in the surgeon's perception of homogeneous space.

While in open surgery the abdominal cavity is opened by long incisions, thus eliminating a separating layer between the patient's body and the operating room, in laparoscopic surgery the abdominal cavity remains structurally closed and evades the direct gaze of the surgeon. The surgeon's actions inside the abdomen are therefore perceived as topologically incoherent with the perception of their own body in front of the console. While the operators in the Los Alamos laboratory were (presumably) still able to relate the movements of the mechanical arms inside the hot cell to their own movements — presumably experiencing their own body in coherence with the environment — the surgeon in front of the Da-Vinci XI is no longer able to relate their actions inside the patient to the operating room in which they are located. Instead, it seems as if the surgeon's sense of presence shifts from the operating room into the patient. From a phenomenological point of view, working on the Da-Vinci would therefore create a second — artificial — reality for the surgeon that is only partially connected to the macroscopic space outside the abdominal wall.

The use of the Da-Vinci robot is thus always a calculated game with the derealisation of the environment and the reassurance of reality. Derealisation in the moments of "immersion" in the patient and "reassurance" in the moments of re-emergence.

When I asked one of the surgeons about this, they replied:

> *"The feeling of operating with the Da-Vinci [XI surgical robot] is special, because you are immersed in another world, of which, however, you must always be aware that it is a real world and not a make-believe world. This is also why it is so important that the patient — that is, the reality — is right next door and not on another floor, in another building or in another country. On the other hand, this immersion is good because you don't get distracted. You can focus 100% on your task."*[14]

This statement provides a crucial clue as to why modern surgical assistance systems are not used for remote surgery. To reassure oneself of reality, it would be necessary for the patient's body to be in the immediate vicinity to the surgeon. The system provides images from inside the patient and surgical instructions from the console in a way and at a speed that cannot be perceived by the human eye, creating not only the illusion of proximity, but the feeling of *being there*. At the same time, this artificially induced hyper-proximity allows the spatial distance between surgeon and patient to be exceeded.

The ability to stand up from the console, walk next to the patient and, if necessary, perform manual interventions on the patient's body allows the surgeon to resolve the cognitive dissonance between proximity and distance and to integrate the previously perceived images into a coherent spatial experience.

From Subjects to Objects

In the meantime, the operation is approaching a critical stage. As described above, in certain surgeries, such as the one I am currently attending, there are specific surgical tasks that require manual intervention by the surgeon.

To do this, the surgeon stood up from the console, washed their hands, put on a sterile apron and was handed sterile gloves by an assistant. Using a special scalpel that can cut and cauterise with high-frequency alternating current, the surgeon expands one of the trocar entry points by about 5 cm and spreads the incision with a plastic cuff.

Meanwhile a surgical assistant explains to me that despite the minimally invasive nature of the surgery, the widened incision is necessary to retrieve the previously exposed tumor and reconnect the esophagus to the digestive tract using a special stapling device. I don't pretend to understand exactly how this proce-

14 Prof. Dr. Hans Fuch, UK Köln (own translation).

dure works. What strikes me, however, is the fact that the enlarged incision exposes the endowrists of the Da-Vinci's instruments which were previously hidden from view—the separation between the patient's abdomen and the operating room through the abdominal wall no longer exists. The assistant surgeon seems to have noticed this as well, as they waves me over and enthusiastically asks me to take a picture of the now exposed view of the patient's abdomen.

> *"Take a picture of this!*
> *You can finally*
> *see the instruments of the Da Vinci!"*

I feel a little queasy. I'm not used to seeing large open incisions, let alone a person's internal organs. Nevertheless, I step next to the surgeon, taking great care not to touch anything. The lighting conditions are difficult. The operating room is almost completely darkened to increase the visibility of the many screens around the room. At the same time, the bright light from the endoscope shines through the wound. I have to make a decision. Do I opt for a short exposure to capture the intricate details inside the body, or do I extend the exposure to reveal the rod-shaped instruments of the Da Vinci on the opposite side of the abdominal wall? The situation is a bit ironic. Although the abdominal wall has been dissolved and there is no longer a spatial separation between the interior of the body and the operating room, I am unable to show how the Da Vinci's instruments penetrate both spaces at the same time. But I am running out of time. The operation must continue and I must leave my position next to the patient. I decide in favor of a short exposure time and pull the trigger.

The image is poor. I am not good at taking pictures, especially in stressful situations, and the image proves both. 90% of the picture is completely dark, but I still managed to overexpose the incision. I also couldn't show the tip of the instrument and the far end of the cavity is out of focus.

Even though I kind of screwed it up, I find this photo particularly interesting because I know the whole picture. I saw the instruments of the Da-vinci penetrate the abdominal wall and I could see the endowrists inside the patient's body through the large incision.

Not being able to capture the moment due to my limited photographic skills left me disheartened. However, driven by desperation, I turned to Photoshop and experimented with the exposure settings, and to my surprise, the information was there! It is noisy and the colors are off, but after I masked out the incision itself and increased the exposure of the rest of the image, you can finally see how the instruments of the Da-vinci penetrate the patient's skin.

With this additional information revealed, this became one of my favorite images of the entire surgery because, although very poor, it gives a fleeting glimpse of what this machine does at its core. How it condenses the surgical gesture into pure intent through its sensors, semiconductors, and coils. How it pushes that information through fiberglass wires and motors, skin and flesh. Only to reinstate it at just the right time and place to serve its purpose.

In this image I see the inner workings of the machine It lifts the curtain of skin to reveal the magician. And just like in the Wizard of Oz, it's not magic that's at work here. Instead, it is accumulated history → Fig. [8].

Be it the skillfully chipped stone blades of the Upper Paleolithic, the Waldos at Los Alamos in the 1960s, the many Da-Vinci prototypes created by SRI and DARPA in the 1990s, or the excavators in the Italian marble quarries. Similarly to all these examples, the Da-Vinci XI is just the latest incarnation of a mechanism that, at its core, communicates intention through materiality. Or, as media philosopher Vilém Flusser might have put it, all of these technologies serve to "draft" realities from possibilities.[15]

By dissolving the separating layer between the operating room and the abdomen, the virtuality of the pneumoperitoneum collapses and it become reintegrated in the macroscopic space of the operating room. But something else interesting happens here. The immersion doesn't simply collapse together with the abdominal wall. Instead, the now exposed view onto the microscopic instruments grants the surgeon another perspective on their own actions. Just like watching a livestream of someone filming you from behind, a shift in perception occurs. The previously perceived reality of the pneumoperitoneum through the binocular lenses of the Da-Vinci is suddenly alienated when viewed from the macroscopic reality of the operating room. In this moment of re-emergence, the surgeon's previously experienced subjectivity becomes the object of their new point of observation beside the patient. Or in the words of Vilém Flusser:

> *"We are no longer subjects of a given objective world, but projects of alternative worlds. We have risen from our submissive subjective position into projection. We are growing up. We know that we dream."*[16]

But as the surgeon takes off their gloves and removes their apron to return to the Da-Vinci console to perform the final steps of the surgery, I can't help but wonder which of the two realities feels more alien to them.

Conclusion

After six hours the operation came to an end. Everything went well and there were no complications. The fragile choreography of metal and semiconductors, of flesh and skin is over, and all that remains of this strange ballet of proximity and distance will be four small and one slightly larger scar on the patient's skin (as well as some flatulence due to the expelled CO_2 gas).

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15 Vilém Flusser, *Medienkultur*, Stefan Bollmann ed. (Frankfurt am Main: Fischer Taschenbuch-Verlag, 2008).

16 Vilém Flusser, *Medienkultur*, 213 (own translation).

While the Da-Vinci is in no specific way new — laparoscopy existed before the Da-Vinci, and remote operations are a sad reality of modern drone warfare — it manages to combine these technologies in a way that produces some phenomena that were initially hard for me to grasp, and even harder to fit into a coherent picture.

By exteriorising the gesture from the human hand and transferring it to the end effectors within the patient, the origin of the gesture and its execution become spatially separated. In this spatial separation, I can see some parallels with André Leroi-Gourhan's description of the production of stone blades in the Upper Paleolithic. Gourhan illustrates how the tool initially leaves the human hand to serve as a raw material for subsequent, more refined tools. This rationalisation of flint through innovative flaking techniques allowed humans to settle farther from natural flint deposits, thereby expanding into new territories.

Another, more recent example of this concept can be found in the waldos used in the Los Alamos laboratories. Here, the gesture is transmitted to an end effector capable of handling radioactive material through mechanical force transmission. In this case, the "new territory" isn't a spatial domain in the Euclidean sense, but rather a new domain of physics made tangible by this technology.

Finally, in the Da Vinci system, the exteriorisation of the surgeon's gesture allows the application and development of new techniques within the pneumoperitoneum. Previously, these techniques were either impossible to perform without large incisions or significantly prolonged the operation, thereby increasing the risk to the patient during anesthesia. The field opened up by the Da Vinci is therefore both technological and medical. By capturing the surgical gesture, scaling it down, stabilising it against potential tremors, and restoring it with full degrees of freedom, the surgeon can perform virtually any directional rotation that is natural to the human hand within the patient's body.

In all of these technologies, the exteriorisation and delimitation of the gesture opens up new technological, spatial, or material domains. The gesture transcends the material constraints of the human hand and transfers its intention to an entity that is capable or better suited to perform a specific task.

This delimitation of the gesture can be found in the most diverse technologies and practices, and in different periods and places throughout human history. Gourhan understands the exteriorisation of gestures as a profoundly human (though by no means exclusively human) activity. In Da Vinci's developmental history, it is the gesture of grasping that is realised through a variety of technologies and practices, thereby spatially distancing itself from the hand. It is this inner mechanics of exteriorising the grasping gesture that gives the Da-Vinci its trans-industrial character beyond its own developmental history. In addition to the Waldos in Los Alamos, the excavators in the Italian marble quarries, and the developmental history of the Da Vinci itself, I can think of several other examples of this technological exteriorisation of the grasping gesture. Be it the first appearance of chopsticks to pick up food, a blacksmith's wrought-iron tongs, or maybe a fisherman's net. It seems as if the idea of transferring the grasping gesture to a medium is deeply rooted in the history of mankind.

A single-use trocar with integrated vents

[11]

But it is not only the gesture that gets spatially delimited. The surgeon's vision is also exteriorised. Stereoscopic cameras deliver real-time, high-resolution images to the console. By forcing the surgeon into a seated position with their head tilted slightly downward at their own hands, the machine creates the proprioceptive illusion for the surgeon to look at their own hands.

This instantaneous transfer of images and gestures to and from the surgeon ultimately allows them to immerse themself in the patient and perceive this artificially created volume of space as real.

I claimed that the surgeon experiences some cognitive dissonance when using the robot. In my opinion, this is not an accidental side effect, but a direct consequence of the way the robot works. It is designed to immerse the surgeon in the abdominal cavity by eliminating any possible disruption to the immersion, and it does so amazingly well. The technology used in the robot surpasses the human ability to distinguish between artificially conveyed images and unmediated perception. The resolution of the endoscopic cameras and the screens inside the console is too high for a human to be able to select individual pixels, the delay between the execution of the gesture at the console and its implementation inside the abdomen is too small to be noticed, the arrangement of the endoscope and the endowrists inside the patient feels too similar to the posture the surgeon assumes at the console, and the degrees of freedom of the endowrists are essentially identical to those of the human hand.

It is the combination of all these features and capabilities that allows the surgeon to overcome the material limitations of the human body and perform surgical tasks that would otherwise be impossible. But, as obvious as it may seem, it is these very characteristics that ultimately separate the surgeon from the macroscopic reality of the operating room. By successively and methodically eliminating every stimulus from the external environment, the surgeon is given the illusion of a completely detached artificial reality which they know to be very real.

As a result, the surgeon experiences the inside of the patient's body as a decoupled, instantly responsive reality. At the same time, they must constantly remind themself that any action they execute can have very real and irreversible consequences. It seems plausible to me that the cognitive dissonance is therefore based on the quality of the exteriorisation of gesture and image, and the resulting task for the surgeon of constantly reconciling the reality of the patient's abdomen with their own physical reality.

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