Automated killing and mediated caring

How image-guided robotic intervention redefines radiosurgical practice

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Abstract. Robot-based intervention in clinical contexts establishes new forms of collaboration between physicians and medical agents. In particular, image-guided robotic intervention such as radiation cancer therapy relies on cooperation between human and robotic actors. This setting comprises an epistemic and a pragmatic dilemma: if the tools and devices increasingly shape, impact and govern medical decisions and actions, how do we describe this form of hybrid agency? What are the implications for medical practice if robots and non-embodied artificial operators gain authorship and autonomy from their human counterparts? If medical intervention is no longer performed within the range of the physician's hands and eyes as well as his epistemic capability but are executed by machines and algorithms, the question is who actually does the "caring" and how robotic applications redesign and redefine the medical scenario. To tackle that problem the paper will discuss how the kill-chain in radiation therapy relies on black boxing its very own inner functions and politics through visual surfaces. It analyses the software based visual interfaces of the CyberKnife radiosurgical system in order to show how it preforms and redefines the options of access for the physician into the patient's body. As images can actually misguide clinical intervention, it proposes reconsidering established forms of iconic knowledge in the context of a clinical environment that is increasingly governed by medical and care agents.

1 GOVERNED BY MACHINES: SURGICAL STRIKES

The trend towards remotely controlled weapons has changed the spatial relations of military conflicts. Military robots such as drones or other so-called unmanned vehicles have not just transformed the battlefield into a distant and disembodied space, but have also established modalities of remote interaction in which machines determine the only relation between the different targets and actors. What differentiates remote-controlled from long-range weapons is that they "allow their operators to monitor their target area for lengthy periods before deciding whether, when, and where to strike" [1]. The spatial mobilization of real-time sensing and observation has enabled forms of intervention that require reconsideration of how technology influences and governs workflows and decision-making processes. In particular, the use of drones or so-called unmanned aerial systems has shown how the operator's actions are profoundly influenced and affected by complex technological mediation [2]: navigation and operation of drones significantly rely on machine-generated content that is often the only form of visual access to a target. This particularly applies when there is no direct visual contact with the operation field: what is being looked at is no longer seen but visualized (Figure 1). The mediating role of visualization technology is a key issue within a new kind of intervention in which images reorganize the relation and the borders between humans and technology.

Figure 1. Predator drone pilot and sensor operator at Balad Air Base, Iraq, August 2007. (Photo by Master Sergeant Steve Horton, United States Air Force. Iraq, 2007)

The loss of individual autonomy in a so-called network-centric warfare that goes along with this kind of real-time robot-guided intervention has been a widely discussed issue with regard to ethical concerns: who is responsible for their action if weapon

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systems today are automated, autonomous or intelligent and how do their operators share authorship with them?

As for robot-guided intervention in medical practice, ethical concerns are still not in the spotlight of the debate. In other respects however, it is particularly noticeable that the rhetoric of robot-controlled 'surgical precision' occurs in political statements on drone strikes and has been successfully transplanted into public discourse about drones by the Obama Administration: "It's this surgical precision – the ability, with laser-like focus, to eliminate the cancerous tumor called an al-Qa'ida terrorist while limiting damage to the tissue around it – that makes this counterterrorism tool so essential," as John O. Brennan, now Director of the Central Intelligence Agency (CIA), pointed out on his speech about "The Ethics and Efficacy of the President's Counterterrorism Strategy" in 2012 [3]. As problematic and misleading as this analogy may seem on closer examination, it nevertheless points to a structural resemblance of the technological conditions between military and medical interventions – between killing and caring. The fact that surgeons, just like drone operators, nowadays control highly effective and supposedly precise machines via visual interfaces and therefore do not catch immediate sight of the operating field triggered a debate on the ethics of 'intelligent' killing machines [4]. In clinical practice, however, knowledge and reflection on how medical devices shape and inscribe themselves into the treatment process remain comparatively limited – despite the fact that physicians today operate not only on human bodies but also increasingly on, with and through images that define and mediate the medical intervention. Medical technology developers, on the other hand, increasingly implement robot-controlled applications in clinical practice but are highly cautious about ascribing to them any form of collective agency or loss of individual autonomy.

Enabled by innovations in the field of real-time imaging as well as network and sensor technologies, remote-controlled warfare points to structural resemblances with remote controlled radiosurgery – both are significantly based on visualization technology. They are driven by the promise to eliminate the disparity between vision and visualization through "intelligent" imaging technology. By performing operations via an interactive layer of iconicity, they conduct modalities of targeted killing that detach killing from bodily presence, cognition and perception. While medical practice usually deploys technology in order to support the physician, today's medical robots are designed to mediate interaction between physician and patient. Their application goes way beyond the context of merely improving conventional medical methods and treatment options. Robot-based intervention has coined the idea of "integrated," "autonomous" and "intelligent" healthcare "systems" in which the patient is embedded in a hybrid network of artificial and care agents that have fundamentally changed the standard operating procedures of diagnosis and therapy [5].

The trend towards robot-based medical intervention has certainly revealed new perspectives in healthcare, but it nonetheless confronts medical treatment and care with an epistemic and a pragmatic dilemma: if the tools and devices increasingly shape, impact and govern medical decisions and actions, how do we describe this form of hybrid agency? What are the implications for medical practice if robots and non-embodied artificial operators gain authorship and autonomy from their human counterparts? If medical intervention is no longer performed within the range of the physician's hands and eyes as well as his epistemic capability but are executed by machines and algorithms, we need to ask who actually does the "caring" and how robotic applications redesign and redefine the medical scenario.

2 THE 'KILL-CHAIN' OF RADIATION SURGERY

The contemporary rise of robotic technology and machine vision is significantly transforming the healthcare sector [6]. In particular, radiation therapy is a medical field in which technologies such as the image-guided robotic radiosurgery system CyberKnife are establishing a "kill-chain"[2] that is mediating between physician and patient in course of therapeutic treatment.

Figure 2. Illustration of the CyberKnife treatment setting's main components, on the left side the RoboCouch with a patient, on the right side the radiation source mounted on a robotic arm. (Copyright: Accuray Inc.).

The CyberKnife treatment system promises to 'cut out' a tumour inside the patient's body even more precisely than a surgeon's scalpel by applying high-energy radiation through a linear accelerator that is mounted on a robotic arm as shown in Figure 2 (right) [8]. The assurance of the robot's precise operation for treating benign and malign tumours is mainly based on the application of imaging and image-guidance technologies. But before the robot-based and image-guided technologies can carry out the radiation treatment without harming healthy tissue they themselves require both a 'precise' planning of the treatment as well as the alignment of the patient to the robot during radiation.

For the CyberKnife both diagnostics as well as the treatment planning are carried out using medical imaging technologies, such as computer tomography (CT) or magnetic resonance

[2]Gregory uses the term kill-chain to characterize the setting of military interventions by unmanned aerial systems as "a dispersed and distributed apparatus, a congerie of actors, objects, practices, discourses and affects, that entrains the people who are made part of it and constitutes them as particular kinds of subjects." [7]. Image-guided interventions in medical contexts share similar structural features and are also characterized by tying together a heterogeneity of practices, actors, discourses and expertise in order to achieve a precisely defined goal but without obviously stating their inner relations and micro politics.

tomography (MRT) and corresponding software applications. In many cases, CT or MRT visualizations provide the only aesthetic basis for physicians to get hold of the morphology and entity of a tumour. If the patient does not undergo surgery before radiation therapy no histological samples can be collected to define the object of interest more clearly and for this reason to supplement diagnostics. This marks one of the crucial functions of images and visualization technologies in course of the treatment. Images guide the process of diagnosing tumours in the first instance and thereby provide one of the main interfaces between patient and physician. At the same time, they define the range of aesthetic access to the inner body and lay the referential foundations for further image-guided procedures.

Largely overlapping with the diagnostic process is the phase of treatment planning. The pre-planning of radiosurgical intervention is of special importance because it defines how the robot itself will treat the patient. Since the radiosurgical system is mainly used for radiating clearly circumscribed tumours in the brain, spine or lung, it applies a very high dose in a limited number of sessions. If the planning of the paths of rays is not correct, the high-energy beams might be directed toward healthy tissue. CyberKnife's pre-planning software enables the physician to visually program the later radiation procedure in that he or she can interactively mark the tumour, sensitive tissues and the path of rays within image data gathered by CT or MRT. Again, visualization is applied to mediate between the planning of the physician and the physical body of the patient. What the physician cannot see and cannot visually anticipate within the preplanning images cannot be carried out in the later radiation. Hence these preconditions already define the later operation of the medical care robot in situ because the simultaneously digitally and visually encoded plan is processed to the workstation of the robotic system and used as the "patient input" [9] for operation.[3]

Therefore, during the phase of diagnostics and pre-planning, physicians in the field of radiosurgery need to interpret and literally handle different visual information that provides an 'aesthetic breach' into the operation of CyberKnife that finally intervenes in the patient. Like other contemporary remote-controlled and network-centric technologies, image-guided robotic intervention in radiosurgery establishes a structural setting that relies on the separation of physician, patient and technology while simultaneously tying them together on visible and interactive screens. These interventions can only be successfully conducted if the physician forms a 'strategic alliance' with the robotic system via graphic user interfaces since the treatment procedure is not within reach of the physician's own body. But the visual interfaces do not simply extend or supplement human capabilities; they provide a certain idea of the interventional scenario by enabling and black boxing their very own operative agency and autonomy [11]. Aspects of the robotic intervention that the user cannot or does not visually perceive are often not within reach of his or her therapeutical decisions. But without the delegation and abstraction of the technology's functions to aesthetically amendable interfaces an everyday work routine is hard to accomplish. Within this hermeneutic dilemma between enabling and black boxing, the realms of possibility for operations like the 'automated killing' of tumour cells are constituted. To gain access to the medical advantages of the CyberKnife system the physician as a user also has to align himself/herself and the patient to the conditions established by the robotic system. Awareness that the system's preconditions are embodied by images and software and imposed on users before the actual radiation treatment starts has not gained much attention in the subject-specific discourse.[4] Likewise, the issue of how the image-guided 'co-operation' of medical and technical staff with the robotic system is designed for intraoperative contexts has not yet been broached.

3 ALIGNING ROBOT AND PATIENT TO INITIATE AUTOMATED KILLING

The intra-operative control of the CyberKnife's robotic operations for 'automated killing' of tumour cells is delegated to another software with its own visual interface. Again, a graphic software interface provided by the robotic system mediates and defines interaction between medical staff and patient. In particular, it is used to monitor the alignment of patient and robot by comparing pre- and intraoperative visualizations. The so-called registration procedure ensures that the radiations beams are applied to the patient's body according to plan.

"When the planning is completed, the physicians and surgeons have to match the robot's coordinates with the patient's anatomical reference points by mapping the physical space to the robot's working frame. This process is called 'registration'. Once appropriately registered, the robot can autonomously perform the desired task by exactly following the pre-programmed plan"[13].

The 'autonomous performance' of the robot can only start when medical and technical staff have guaranteed the correct registration of robot and patient [14]. This legal requirement points to aspects of how robot and users have to 'co-operate' in order to start a certain intervention and also evokes questions of how autonomous robots can actually act. The CyberKnife treatment delivery software asks the technical and medical staff to "please visually inspect"[5] the correct correlation of patient and robot. The decision to start the radiation process needs to be legitimized by human actors and their perception by means of a visual comparison.

[3]Godfrey Hounsfield, known as one of the inventors of computer tomography, points to the advantages of CT for pre-planning purposes by stating that "with the aid of CT therapy planning computer programs, we can position the therapy beam automatically with precision in a few minutes. The system is linked to a CT diagnostic display console and a color display monitor which shows the radiation isodose distributions overlaid on the basic CT scan itself (...). The scan is used as the "patient input" to the system, and areas of interest such as tumor, bone, lung, or sensitive organs are outlines by an interactive light pen." [10].

[4]On the contrary, critical discourses about e.g. drone strikes discuss the epistemic and operative status of visualizations and imaging technologies that suggest the idea of a "video game war" [12].

[5]The request "Please visually inspect" is displayed within the graphic user interface of the control software as soon as the robotic system finishes the registration process. Before the registration process the patient lays down on CyberKnife's Robo Couch (as shown in Figure 2, left), a six degree of freedom couch that adapts the patient's position proportional to the robotic arm with the linear accelerator (for a technological and mathematical description of the CyberKnife positioning system see further Takakura et al. (2010) [15]).

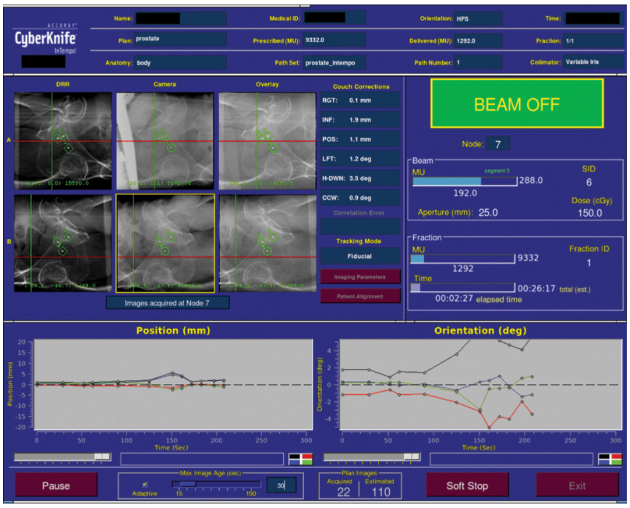

Figure 3. Screenshot of the treatment delivery software for the CyberKnife system, adapted from (Kilby et al. (2010), [16]).

Pre-operative image data from computer tomography (Fig. 3, left column) needs to be compared with intra-operative visualizations gathered by the robot's X-ray technology system (Fig. 3, central column). The software interface provides an overlay of both visualizations (Fig. 3, right column) for the staff to inspect whether the patient is registered accurately or if the current position differs from the pre-planning images. Interestingly, the technologically and aesthetically more advanced CT visualizations are computed back to digitally reconstructed radiographs (DRR) to match the aesthetics of the intra-operative X-rays. Since the CyberKnife system is only equipped with X-ray technology, the visual comparison is based on radiographic aesthetics. Radiographs contain more complex visual information because the technology is based on the projection of three-dimensional objects onto a two-dimensional plane. Therefore, shadowing and overlapping of structures occur that need to be taken into account when analysing the radiograph. In rare cases operative disruptions occur in the negotiation process between machine vision (?) and human visual cognition concerning the registration of patient and robot. This contests the visual expertise of physicians but in equal measure it illustrates how technological and robotic conditions are entailed to clinical workflows, even though it seems as if human perception is the predominant factor in decision-making. Physicians need to rely on the imaging, localization and visualization technologies that the robotic system provides since they are the only intra-operative access to the patient's body. The graphic user interface of CyberKnife's control software assembles the constant cooperation and negotiation of physician and robot by setting its very own conditions. The 'autonomy' of CyberKnife's operation relies on a human decision that can only be reached according to the system's standards.

4 CONCLUSIONS: AUTONOMY AND AUTHORSHIP IN MACHINE-HUMAN COLLECTIVES

The fact that medical robots increasingly determine medical therapy and often provide the only form of access to the operation area requires us to conceptualize them as care agents rather than to merely conceive of them as passive tools. But if the physician's action is based on confidence in and cooperation with the robot, what kind of operative knowledge does this kind of agency require and how does it change the modalities of medical intervention?

As visual access must increasingly be thought of as influenced and controlled by machines and as visualizations become the central interface between physician and patient, it is crucial to trace and reveal their implicit agendas and ethical implications in order to explore the chances and the risks for clinical practice. The epistemic, aesthetic and operative challenges of the visual regimes in the field of image-guided robotic intervention require a structural and application-oriented investigation of the medical setting. The analytic focus on image-guided technologies and on visualization practices provides an approach to explore the micro politics that are embodied by robotic technology and how they affect everyday clinical routine: the extension of the anthropological and physical boundaries of vision, which is no longer exclusively bound to the ability and function of the physician's eye must be thought of as a cooperation with the machine. As a mediated experience this implies loss of individual autonomy that results in new kinds of epistemic difficulties and possible failures.as well as a redistribution of responsibility towards support staff, hardware developers and software coder.

The fact that robots gain authorship from their human counterparts also affects the physician's professional self-conception and his relationship with the patient. As Lenoir has pointed out, "we do not think of surgeons as authors and writers. Alongside fighter pilots and extreme athletes they are typically depicted as persons of action, autonomous agents in the most vital sense who bring vast fields of knowledge, decision-making ability, and practical, technical skill to bear in a life-and-death instant" [17] But since surgical intervention has become a computer-mediated practice that inscribes the surgeon into a complex setting of medical care agents, it is no longer the patient's body but the image of the body that is the central reference for the surgeon.

As the operator of robot-guided intervention the physician accordingly needs to address and cope with the specific agency of the machine. In addition the visual interfaces need to communicate and convert their technological complexity to humanly amendable surfaces. The analysis of visualizations and their interactive strategies may provide a valuable and focussed access to the black-boxed inner workings of robotic technologies. These studies need to be conducted both in clinical settings as well as in industry contexts to reveal the complex entanglements and simultaneous friction between design and engineering on the one hand and contexts of application on the other. Additionally, courses for the training of an applied iconic knowledge should be integrated in the curricula of medical education and training to raise a more fundamental awareness for the (pre-)conditions of image-guided robotic technologies in clinical settings.

As the debate about the ethics of robotic agency is extensively discussed in regard to warfare, the analysis of analogies to the structural settings and modalities of medical image-guided intervention may build upon the current debate. In particular the reference to the navigation of unmanned aerial systems and the autonomy of "intelligent" weapon systems could help establish ethical guidelines for the field that would complement the demand for an applied iconic knowledge in clinical environments.

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