

The application of 4K to
education in microscopic
surgery



Colophon

This publication was commissioned by SURFnet and produced by Waag Society.

Interviews were conducted with Henny Bekker, Evert Jan Evers, Wilko Grolman, Ralph Koning, Wladimir Mufty, Sandra Passchier, Thomas Scholz and Gert-Jan Verheij.

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If you find any part of this documentation to be in error, please send your comments to SURFnet (surfnet.nl) or Waag Society (waag.org).

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Zeiss Axio S88



Intopix 4 x 3G SDI



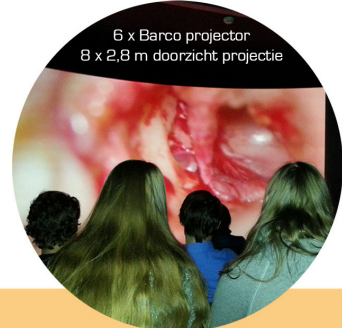
Decklink 4K Extremum



Sony F55



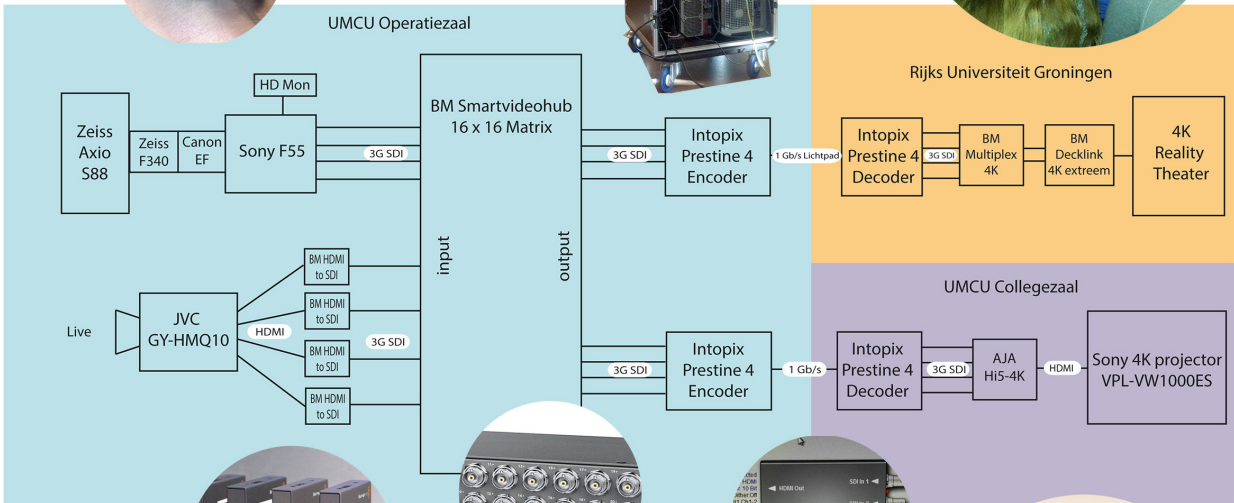
Carl Zeiss f340



6 x Barco projector
8 x 2,8 m doorzicht projectie



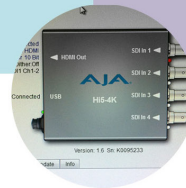
2 x Intopix
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BM HDMI to SDI



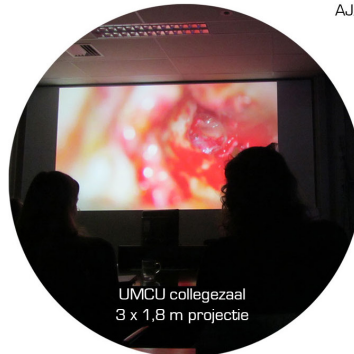
BM Smartvideohub



AJA HI5-4K



JVC GY-HMQ10



UMCU collegezaal
3 x 1,8 m projectie



Sony VPL-VW1000ES

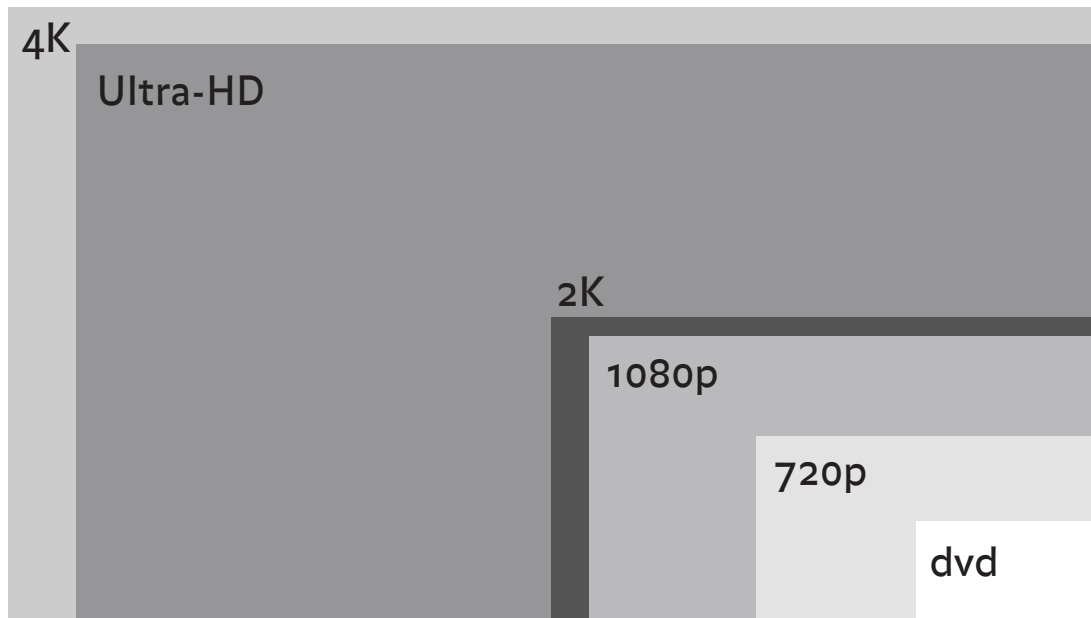
Introduction

On December 11th in 2013, SURFnet, UMC Utrecht, RUG, Plus Vorm and Waag Society performed their first, worldwide educational application of 4K to live surgery. A dedicated team of surgeons, technicians, a photographer, and an educational specialist streamed footage from three surgical ear operations at the UMC Utrecht in acutely high resolution to two lecture rooms (one nearby and one over 150 kilometres away in Groningen). Medical specialists and students were able to follow the surgery in 4K, and could communicate directly with each other via secure video conferencing connections. A dedicated light path was used between Utrecht and Groningen to ensure an uninterrupted transmission and patient privacy.

In this publication, we have gathered the experiences and lessons learned from the project partners to aid in the understanding, reproduction, and scaling of the experiment.



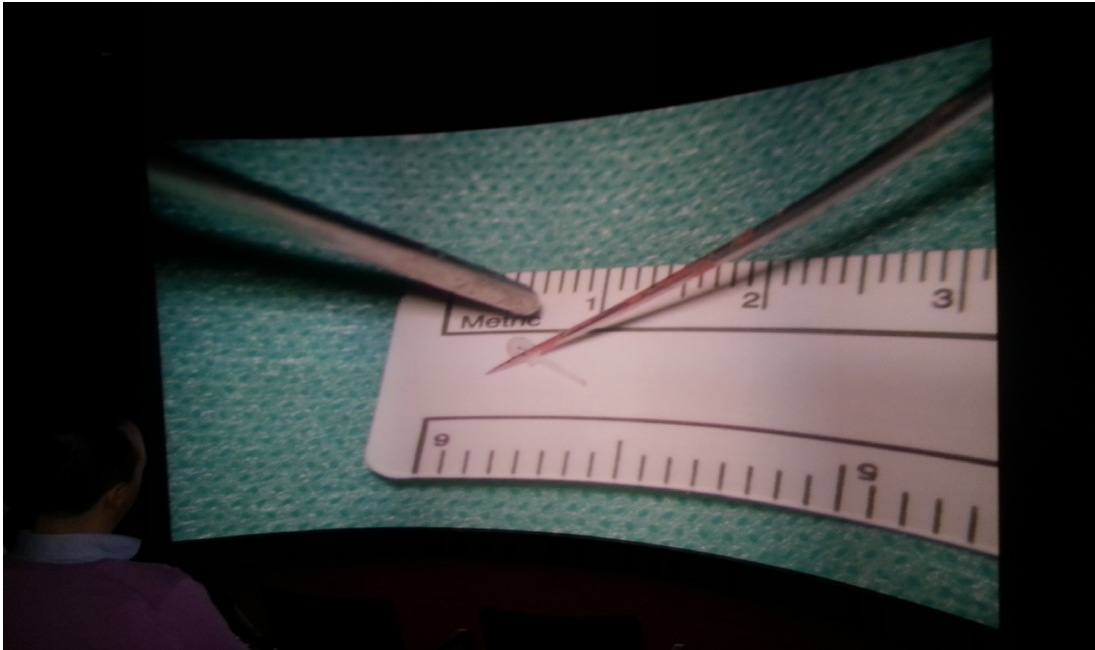
4K video is the next generation of television picture quality, displaying four times the detail of HD. Ultra HD (UHD) is slightly smaller, as can be seen in the image below. Watching 4K or UHD, you'll see everything on screen in crystal-clear clarity and sumptuous detail. An UHD picture is 3,840 x 2,160 pixels (more than 8 million pixels in total), which is about four times the number in 'normal' high-definition (1,920 x 1,080). The detail and depth of the picture is such that it almost feels stereoscopic at times. 4K and UHD work with very large data files and—when uncompressed—requires a very high bandwidth to convey the level of detail (typically 1Gb/s or more).¹



A **light path** is a direct, secure, and fast network connection between two points (such as between a researcher in the Netherlands and a telescope in China). The bandwidth is typically 1Gb/s or more. This offers unique, worldwide possibilities like more efficient research, sharing facilities or large datasets, or creating instant backups. In this project, a light path was used to transmit 4K video live from an Operation Theatre in Utrecht with a visualisation room in Groningen, over 150 km away.²

Background

Surgery is a highly visual activity. Surgeons must be able to decide safely where to insert their scissors and scalpels while carefully avoiding certain vessels and nerves. To become a surgeon takes many years of study and many hours of practice. Part of this study involves watching live or recorded surgeries, and questioning an experienced surgeon as he performs the operation under study. This, however, is difficult because of practical constraints. For reasons of hygiene, the number of people in Operation Theatres is limited. Also, many operations require the use of microscopes or very small cameras to convey the images necessary to make decisions and guide movements and incisions.



The advent of high-quality, live video might help alleviate these constraints. By using 4K (and possibly beyond), students and doctors can witness surgeries both directly and through microscopes from an almost first-hand view. By projecting the resulting images on larger-than-life screens and allowing students to ask questions remotely, education can be enhanced and reach a wider audience. In the future, there might be a network of doctors willing to have students “dial in” when their studies demand it.



For a few years, the members of the LION foundation³ have been exchanging live video conferences where students can dial in to operations and ask questions to the operating surgeons. LION is a worldwide video conferencing network dedicated to Otolaryngology⁴. Currently, this is done in HD. Professor Wilko Grolman, president of the LION foundation and head of the Department of ENT at the University Medical Center Utrecht, wanted to experiment with video in higher quality. In collaboration with UMC Utrecht, SURFnet and Waag Society, CineGrid Medical was born.



CineGrid Medical builds on the learnings from **CineGrid Amsterdam**. CineGrid Amsterdam ran from 2008 until 2012, and was a collaboration between eleven wide-ranging organisations in the Netherlands including SURFnet, SARA, University of Amsterdam, Dutch Film and Television Academy and Waag Society. Together, they stimulated and researched the production, transmission, and screening of acutely detailed video material in 4K and above.

A large quantity of original 4K material was produced in conjunction with artists, cinematographers, and animators. Live streaming, however, was difficult and uncommon due to the limited availability of cameras, high bandwidth networks, and encoding/decoding equipment. Since then, the equipment (notably cameras and screens) have become commercially available. This has made commercial and societal applications in real-world settings possible.

The **LION Foundation** was created in 2006 as a non-profit organization. The aim of LION is to create a permanent, interactive, high-speed network for Continuing Education in Otolaryngology and to promote distance learning worldwide using modern video conferencing technologies.

The annual program offers participants around the world direct and interactive access to international experts in the various fields of Otolaryngology. The concept of a global network is greatly enhanced by a constantly accessible highly interactive video conferencing system. This allows for high quality image and sound transmission. While the formal conference and meeting remain the staple of organized CME worldwide, LION offers new trends in this field to enhance distance learning. The LION network can be used for live surgery, panel discussions, and formal conferences with Powerpoint-type presentations.⁵

The objectives of CineGrid Medical

CineGrid Medical set out to provide a high quality learning experience through making use of 4K in combination with high quality networks. Here, we describe the goals from the perspectives of the partners.

University Medical Center Utrecht

Prof. dr. Wilko Grolman⁶, Head of the Department of ENT⁷ and director of the Division of Surgical Specialties (dHS) in the University Medical Center Utrecht (UMC Utrecht), has always been highly interested in technology. He works with innovative technologies like 3D microscopy and live video conferencing in education. He has been enabling continuous, distance learning for years—primarily in the LION network, which brings together the top twenty E.N.T. specialists from around the world. He is intrigued by improving learning processes through using senses other than just sight and sound (like touch and smell). For Prof. Grolman, 4K technology is an interesting development. Surgery is both highly visual, and relies heavily upon feeling with your hands. Anything you can improve visually will result in better information for the surgeon. It's difficult to prove scientifically, but for Prof. Grolman, the outcomes of the project are positive. The next big thing, however, is 3D.⁸

SURFnet

SURFnet—co-initiator, funder, and technical partner—has had long-term experience with streaming experiments in 4K within the CineGrid Amsterdam project. After that project ended, the goal became to use 4K for practical applications in either research or education. The equipment used to be expensive and very complex, but this recently changed. Both cameras and screens have become available on the professional and consumer markets, allowing for capturing and screening in 4K at reasonable prices. At the same time, there have been advances in network technology. Multi Service Ports⁹ make the configuration of dedicated, high-bandwidth networks easy and straightforward. Within CineGrid Medical, all this came together in a real-world use case.¹⁰

University of Groningen

For the medical faculty and The Center for Information Technology of the University of Groningen (RUG), the main goal was to bring innovation into their educational programme. Being part of this project was a unique opportunity. Most of the difficulties involved—mainly filming in the Operation Theatre (OT)—were taken care of by the partners. It was not the technology that mattered. Instead, it was both how the technology was applied, and the reactions of the medical staff and students to these technological developments that counted.¹¹



Plus Vorm

For Thomas Scholz, independent cinematographer and sole proprietor of Plus Vorm, the objective was to connect a 4K camera to a state of the art operation microscope, and to go beyond 4K recordings into live switching. He aimed to switch between a presentation camera and a 4K camera. The challenge was also to stream perfectly and without hiccups. The latter was a success, but the former proved too technically challenging at this stage.¹²

Department of Information Technology UMC Utrecht

As far as Evert Jan Evers, Department of Information Technology (DIT) at the UMC Utrecht, can recall, this was the first time the hospital made serious use of a light path connection while streaming medical data from the UMC Utrecht to Groningen. The objective for DIT was to determine how to get the connections to work, and to accurately describe the experience so that it could be reproduced—all within the security and privacy standards of the department. They opted for a completely isolated network connection (light path entry point to OT and OT to conference room). Separate switches were installed so no data could leak from or enter into the hospital network. Additionally, they installed separate connections for the camera and for viewing the patient records in the OT.¹³

Waag Society

For Frank Kresin, Research Director at Waag Society, CineGrid Medical was a means to bring the state-of-the-art technology and practices into real-world use-cases beyond cinema and television. Hospitals and operations, in particular, are a challenging and rewarding environment for this because they require a high video resolution and have a high demand for privacy and security. Working with professionals from different fields can lead to innovation when people become mutually inspired. In Frank's view, this was certainly the case.¹⁴

Roles in the project

The partners each had different roles in the project. In this chapter, these roles are described.

University Medical Center Utrecht

Prof. Grolman provided the inspiration for CineGrid Medical, and pushed through to make it happen. For this project, he combined his hobby with his daily work. Prof. Grolman performed the surgery, explained what he was doing for the audience, and answered questions when they arose. He also brought in his expertise and live streaming equipment (the converter for the microscope and the video conferencing system were his).

Prof. Grolman¹⁵ carried out a stapedotomy¹⁶. This is an ear operation performed on people suffering from otosclerosis¹⁷, a condition that causes deafness. In this operation, one of the three, tiny ossicles is replaced by a prosthesis.



A **stapedectomy** is a surgical procedure of the middle ear that aims to improve hearing. If the stapes footplate is fixed in position, rather than being normally mobile, a conductive hearing loss results. It is possible to improve hearing by removing the stapes bone and replacing it with a micro prosthesis (a stapedectomy), or by creating a small hole in the fixed stapes footplate and inserting a tiny, piston-like prosthesis (a stapedotomy). Nine out of ten patients who undergo the procedure will come out with significantly improved hearing while less than 1% will experience worsened hearing ability or deafness. Successful surgery usually provides an increase in hearing ability of around 20 dB. That is as much difference as having your hands over both ears, or not.¹⁸

SURFnet

SURFnet delivered the primary vision and funding for the project, as well technical knowledge and the implementation of the network (including the light path). Their team included Sandra Passchier, who initiated the project with Prof. Grolman, and acted as the formal manager. Henny Bekker was in charge of the overall architecture of the network and 4K technology (including intermediation), and the network layout. Ralph Koning worked as a consultant on the network plan and the settings for the light paths, routing, and the live screening. Wladimir Mufty was responsible for parts of the 4K technology, connecting, and decoding. All technical staff members are highly experienced with 4K recording, transmission, and screening—mainly thanks to the CineGrid Amsterdam project.

University of Groningen

The University of Groningen organised a live, interactive viewing of the surgeries for their students and the medical staff. Gert-Jan Verheij (Centre of Information Technology/ education) was responsible for the implementation of the technical part and the project management of the educational aspects. Gert-Jan made sure his technical department worked with the CineGrid Medical crew from SURFnet. He also moderated the interaction with the students and staff on the spot in Groningen. For this, he ensured the questions asked during the operations were of high quality. He also developed a survey to evaluate the viewers' opinion.

From an educational point of view, the project results were satisfactory. However, more knowledge transfer within the medical faculty would have been appreciated.

Plus Vorm

Thomas Scholz is an all-round audiovisual engineer who has worked with Waag Society and SURFnet on a number of 4K projects. Within this project, Thomas acted as a technical consultant, preparing and handling the 4K camera and imaging, and making sure the video streams to the RUG and the colloquium hall were on-line and uninterrupted. He operated the encoders in the Operation Theatre (OT) and prepared the decoding setup in Groningen prior to the event.

Department of Information Technology UMC Utrecht

On behalf of UMC Utrecht, Evert Jan Evers works at the Department of Information Technology (DIT). He has a technical background in network technology, and worked on light path trajectories with SURFnet before. Evert Jan provided the contact with and the technology for SURF, taking care of the "last mile" (from the entry point of the light path to the camera in the OT) and the information security. This proved to be a major task, where over six in-house technicians were employed.

Waag Society

Waag Society's team consisted of producer, Maïke Bisseling; communication staff, Susanne Afman and Jimena Gauna; and research director, Frank Kresin. Maïke was responsible for overall production and coordination of the action and actors, and making sure internal communication and planning worked well. Susanne and Jimena took care of blogging and general communications. Frank used his experience as CineGrid Amsterdam manager, and moderated the interaction between Prof. Grolman and the students at the UMC Utrecht colloquium room.



Outline

The project consisted of several parts that, together, make the educational use of 4K in surgical microscopy possible. These are outlined here. A detailed equipment list can be found in Appendix I – Special Equipment.

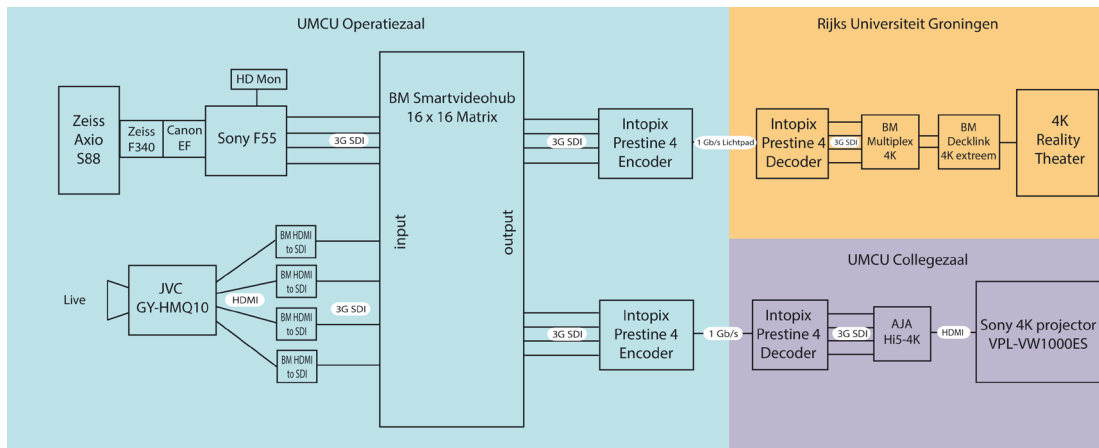


Image acquisition and encoding

Image acquisition was done via a rented Sony F-55 professional grade 4K camera with four 3G/SDI coax outputs. The F-55 has a convenient lens fitting that can be converted into a standard CANON EF fitting with an adapter. This, in turn, needed to be fixed onto the Zeiss S88 operation microscope used in microsurgery. Prof. Grolman was in possession of the necessary adapter, and, although the camera was rather heavy, after adjusting the moving frame of the microscope everything worked fine. The whole setup had to be covered in plastic to forgo any chance of contamination of the patient. During the operation, Prof. Grolman moved and focused the microscope, and operated the camera. The resulting image matched exactly what was seen through the ocular (albeit not in 3D as the surgeon sees it, but in 2D). Because of the magnification factor, any occasional bumps to the microscope lead to severe shocks in the 4K image.



The four 3G-SDI outputs of the camera were fed into a digital mixer (the Blackmagic Smart Videohub¹⁹) that could multiply the original output by two. The resulting signals were given to two separate Dell Precision T7500 encoding computers with intoPIX Pristine 4 Encoder cards²⁰. These encoders converted and compressed the signal 10:1 into a JPEG 2000 stream of under 1Gb/s so they could fit the light paths. This compression factor is visually lossless.

The Operation Theatre (OT) was outfitted with an HD monitor to view the resulting image. At the same time, the camera recorded the operation in a compressed format, and the resulting files are in the order of 6TB.



Originally, the goal was to switch during the operation between two 4K cameras: the Sony F-55 for the microscope, and a separate JVC GY-HMQ10 4K camera²¹ for an overview. Unfortunately, the output signals of the cameras were different, which led to small synchronisation errors on the mixer, and blackouts in the combination of encoders and decoders. Therefore, this option was dismissed.

The initial plan was to place the computers and the other equipment outside the OT, which meant that some cables needed to leave the OT to be fed into the decoders. This option turned out to be impossible because the OT is pressurized to ensure that any airborne micro-organisms (e.g. bacteria) from the environment that may infect the patient are kept out. In short, the door must stay closed. This meant that all the equipment had to remain within the OT (the only outputs being network cables to the standard network ports²²). Therefore, some extra requirements had to be added to the setup²³.

The context of the OT meant that every piece of equipment had to be galvanically isolated to prevent possibly dangerous electrical currents from harming the patient. OT equipment must conform to very high standards to which typical computers and cameras do not adhere. Therefore, DIT provided a special transformer, and the neatly packed equipment was set up to take the current only from it. After testing, this was deemed adequate and safe.



Galvanic isolation is a principle of isolating functional sections of electrical systems to prevent current flow; no direct conduction path is permitted. Energy or information can still be exchanged between the sections by other means, such as capacitance, induction or electromagnetic waves, or by optical, acoustic or mechanical means.

Galvanic isolation is used where two or more electric circuits must communicate, but their grounds may be at different potentials. It is an effective method of breaking ground loops by preventing unwanted current from flowing between two units sharing a ground conductor. Galvanic isolation is also used for safety, preventing accidental current from reaching ground through a person's body.²⁴

Network and Transmission

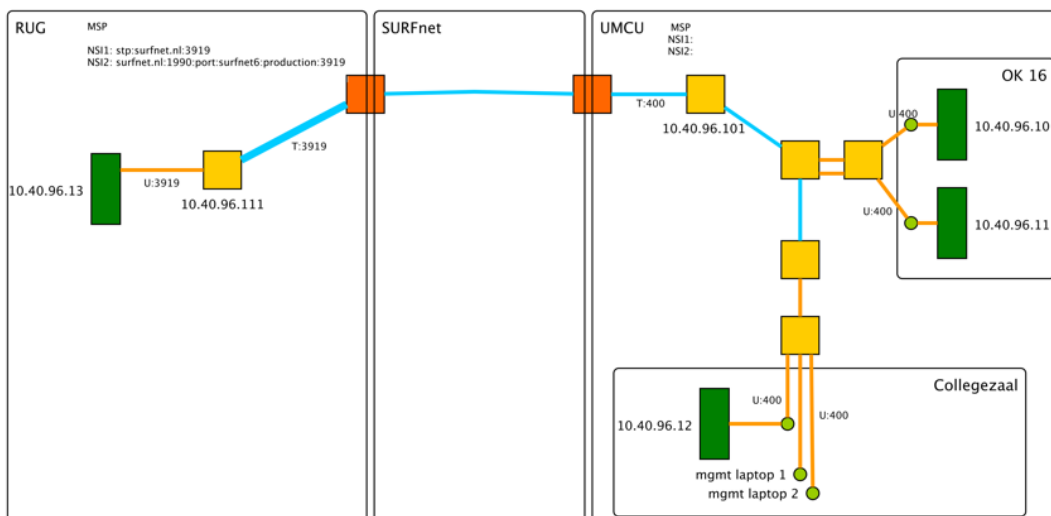
For 4K video transmissions, a minimum bandwidth of 1Gb/s is needed. To accommodate for this bandwidth, and to conform to the privacy standards in a hospital environment, it was decided to build a completely separate network²⁵ consisting of switches and light paths connecting the OT with a colloquium hall in the UMC Utrecht and the Reality Theatre at the RUG. Fortunately, both the UMC Utrecht and the RUG were fitted with a Multi Service Port (MSP) that allows for the straightforward configurations of point-to-point light paths. Configuring the network connection between both locations proved to be easy.



A Multi Service Port enables organisations to use multiple light paths simultaneously, maximising the efficiency of the port and ensuring there is always sufficient network capacity. Multi Service Ports are especially useful for setting up light paths to provide access to dislocation systems or connect them to cloud providers, for instance.²⁶

The biggest challenge was “the last mile”—the connection between the centrally located MSP, the OT and colloquium hall at the UMC Utrecht, and the MSP and the Reality Theatre at the RUG. They had to provide an uninterrupted (and therefore undelayed) flow of network traffic. In both cases, the job was to be done by the internal departments responsible for the networks. Routing took careful planning and extra network machinery to make sure it was totally sealed off from the other networks to prevent compromising the video material. During the process, it was discovered that the galvanic isolators for the network in the OT needed to be upgraded to 1Gb/s, which resulted in a relatively minor investment of a few hundreds of Euros. Also, the experience of the SURFnet team was needed to ensure the correct workings and routing of the access points.

4K streaming UMCU–RUG netwerkoverzicht 4K deel 14–11–2013



Because the OT schedule is made at the last moment, flexibility and careful checking with all parties involved is obligatory. From this, it became clear that planning cannot start early enough (preferably more than six months in advance). It is also essential to have all people involved together at a kick-off, so everybody understands the goal of the project and their role within it.


Screening and Projection

The operations at the UMC Utrecht were screened in two locations at once: a colloquium hall at the UMC Utrecht and an auditorium at the RUG. At the UMC Utrecht, the projection was done using a Sony 4K projector²⁷. At the RUG, the screening was shown in the Reality Theater, employing six full-HD projectors that made a seamless image in a very high resolution possible. In both locations, the rooms were filled with medical students and personnel (about 30 people in total).

The image arrived JPEG-2000 encoded via fiber and was decoded via intoPIX Pristine 4 decoders²⁸, that were subsequently converted to HDMI. At the UMC Utrecht, this fed the projector directly using a 3G-SDI to HDMI 1.4a AJA HI5 4K adapter. At the RUG, another conversion involving Blackmagic cards was needed to prepare the signal for the Reality Theatre.

During setup and testing, it proved necessary to choose the right frame-rate, resolution, and colour depth settings for all the components to ensure proper transmission and screening. Eventually, Thomas Scholz had to travel to Groningen to find out which settings worked well for the Reality Theater²⁹. Then, the general technical pilot adage kicked in: "If it's not broken, don't fix it."



 **The Reality Theatre³⁰** is a Virtual Reality setup for interactive 3D presentations to large groups of people. Popular applications include office design, landscape design and other architectural visualizations. In the Reality Theatre, 3D ('stereoscopic') images are projected onto a super-wide, cylindrical screen. An audience of up to 19 viewers can watch 3D images created in real time by a high-end visualization cluster. The transparent screen is almost 10 metres wide and 2.80 metres high, and surrounds the viewer with a 135 degree field-of-view. Behind the screen are six full HD projectors producing 120 images per second. (that is nearly 1.500.000.000 pixels per second !)³¹

Interaction by way of videoconferencing

An important part of the demonstration was enabling live interaction between the surgeons and the students at the two viewing locations. It was decided to use a proven technology: the existing Lifesize³² HD video conferencing setup used by the LION network during their regular screenings. The setup enables fully encrypted transmissions, which were required by the strict privacy rules observed in the hospital. This setup was owned by Prof. Grolman, who has ample experience in using the technology, and acted as master of ceremony while performing the operation.



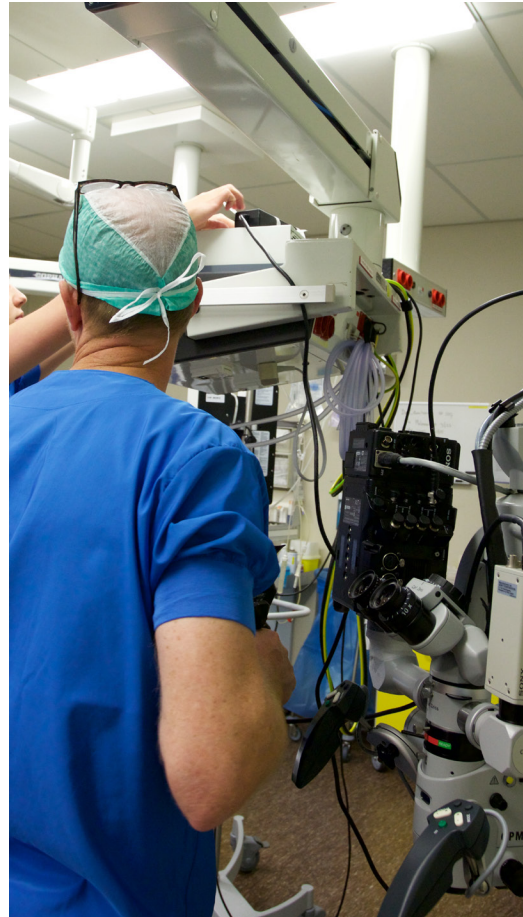
The video conferencing setup consisted of three nodes connected by a Multipoint Conference Unit hosted at SURFsara³³ in Amsterdam. Each node had one or more microphones and a HD screen through which participants could see each other. Prof. Golman wore a wireless head-microphone. During the surgery, he explained what he was doing, and (at certain moments) allowed for questions from Groningen and the Colloquium hall. At each viewing location, a moderator was present to mediate between the viewers and the OT.



Because the video conferencing setup and the 4K video via the dedicated light path had different latencies, the video had a delay of almost a second in relation to the audio. This proved occasionally annoying, but was generally workable. Also, during part of the transmission, the audio became slightly distorted (probably due to incorrect audio settings).

Planning

CineGrid Medical took almost a year from the initial planning to the actual transmission. There are several reasons for this. First of all, the collaboration between some of the partners was new, and it took some time for them to become acquainted. Secondly, the exact technical configuration was new, and needed to be thoroughly tested. Lastly, the pilot schedule had to match the operation schedule.



Preparation

Preparation included: finding and talking to all parties involved; drafting the technical architecture; acquiring and hiring the right hardware; and performing a test capture at the actual location in the UMC Utrecht Operation Theatre (OT). SURFnet and DIT were in charge of the technical architecture, while Waag Society was responsible for overall planning and communication between the parties involved. The hospital environment meant special requirements both for the hardware that had to enter the OT, and to ensure the privacy of the patient.

The hardware needed to be tested and had to conform to the high safety requirements in the OT. This was a challenge regarding the aforementioned Galvanic Isolation that was greatly helped by the DIT of the UMC Utrecht. The encoders, converters, transformer, and the Blackmagic video hub were built into a convenient flight case that proved very efficient.

Prof. Grolman had a lot of previous experience connecting operation microscopes to camera systems, and had the right optical converters to achieve this with ease. The Sony F-55 camera was chosen both because it had the right fittings to connect to the Zeiss S88 microscope³⁴, and because it had the necessary 4K outputs.

Then, a special, separate network was built within the UMC Utrecht from the OT to the colloquium hall and from the OT to the Multi Service Port. Under no circumstances were the data liable to be intercepted. The OT network filter ports had to be upgraded to allow for the high bandwidths, and special switches were installed at strategic locations. Patching the right ports proved to be a challenge due to last minute changes in the OT schedules. Finally, inside the UMC Utrecht, light paths were used to connect the different locations.

A few weeks before the actual screening, a test was performed in another OT within the UMC Utrecht. Based on the results, the settings were changed and everything was ready for the execution.

Execution

The execution began by putting in place the equipment the night before the operation. The surgeries were to be performed by Prof. Grolman and Dr. Tange on three patients with hearing problems. The technicians from SURFnet, DIT UMC Utrecht and Thomas performed their tasks, and returned early the next morning to start up the transmission. The video conferencing setup worked, and the three venues could hear each other well. Due to last minute changes in settings, the 4K video stream from the microscope came on-line just five minutes before the start of the operation. A detailed call-sheet can be found in .

The transmissions themselves went as planned. Each began after the patient had been put under anaesthesia, and was covered with an operation cloth so he or she could not be recognised. Thomas Scholz was in the OT and was responsible for image quality and encoding; Ralph Koning, Wladimir Mufty and Henny Bekker were responsible for 4K technology and screening in the colloquium hall; Gert-Jan Verheij was at the RUG with several technicians and the students; Frank Kresin moderated in the colloquium hall; and Maïke Bisseling moved between the colloquium hall and the OT to facilitate communications. While Prof. Grolman and Prof. Tange were operating, Prof. Grolman commented on the actions that were seen in the colloquium hall and the Reality Theater in Groningen at once. On several occasions, the remote students or staff had some questions that were conveyed via the moderators. The interaction went well. Between the operations, Prof. Grolman and Dr. Tange came to the colloquium rooms for further explanations using the whiteboard.



Sound quality deteriorated slightly during the operations (likely due to an incorrect setting of the microphone gain), but this did not interfere with the understanding or the interaction. Image focus was sometimes hard to achieve, which was mainly due to the fact that there was no 4K monitor in the OT to give visual feedback. The HD video conferencing setup worked well. The encoders had to be restarted about three times during the transmission when synchronisation was lost, but this solved the problem quickly. Technical communication and coordination between the colloquium hall and the OT proved challenging due to the lack of an audio back channel with Thomas Scholz.

Response

CineGrid Medical was deemed a success. The operations were both streamed and viewed in 4K; the interaction between the students and the surgeons went well; students were impressed by the quality of the image; and the resolution greatly enhanced their understanding of the operation.

The quality of the image proved stunning. It provided the audience simultaneously with an overview of the scene and a close-up of the area affected by the surgeon and his tools. The students could follow the actions of the surgeons, and were generally very satisfied with the interaction.

Gert Jan Verheij (Advisor ICT & Education, Educational Support and Innovation) and Jaap van der Leest (Nestor ICT Sector F Medische Wetenschappen/UMCG) conducted a questionnaire to learn from the responses of nine students and five members of staff. A short summary (in Dutch) of the results is given in Appendix III – Questionnaire University of Groningen.



Lessons learned

The technology used in CineGrid Medical is developing at an incredible rate. Computers are getting faster; disk space is increasing; 4K cameras, projectors, and screens are getting better; and decoders and mixers are less prone to stopping in the middle of a transmission. This means that any implementation of live 4K transmissions (or beyond) will become easier, cheaper, and less risky each year. At this point in time, if there is point-to-point access to high-speed networks like the SURFnet light paths, there is no technical reason why 4K could not be used for streaming.

This chapter contains several lessons that were learned from the experiment.

Technology and Network

Two things stand out. First, there is the issue of “the last mile.” Setting up light paths via Multi Service Ports is straightforward, and can be done quickly (within a few weeks or days of initiating the project) provided that the Multi Service Ports are in place on both sides of the desired connection³⁵. Via these light paths, data can flow at unprecedented bitrates, in huge volumes, and over vast distances reliably, safely, and quickly. The difficult part is getting from the Multi Service Ports to the in-house locations for capturing and screening. In most organisations, this requires the collaboration and dedication of the in-house IT department. For CineGrid Medical, over six in-house technicians were involved. In extremely sensitive cases (like hospital environments), privacy, security, and safety are of major importance, and make any kind of ad hoc transmission impossible. Plan your last mile early, thoroughly, and with all stakeholders involved.

The second issue arises with end-to-end testing. However reliable the state-of-the-art of the individual components have become, the exact combination of these parts might be novel, and could therefore give rise to unexpected problems. So, before the actual date, make sure that there is at least one test during which you have everything in place as it should work on the day of the transmission. In CineGrid Medical, many issues were discovered during the on-site test, and those that occurred later were often due either to adding different components or changes in settings. And remember: when you get the set-up right, write everything down and don’t alter it until after the (successful) event.

Communication

The biggest lessons from CineGrid Medical are, however, non-technical in nature. Instead, they are about communication at the inception, during preparation, during the transmission, and soon thereafter.

At the start, state your goals clearly and unambiguously. When will you be happy with the result? What is most important, and what comes second? What partners are involved, and what are their roles? And, finally, who will pay for the costs, and cover the unavoidable risks? Make sure that every partner on the team is familiar with these goals and agrees with them.

At least once during preparation, gather all the people that will collaborate together in one room at the same time. Make sure that everybody gets the broad picture of the entire project and understands the details with which he or she is involved. Make sure communication lines are short.

During the transmission, arrange a separate audio back channel (and possibly a separate video back channel) between each location³⁶. Make sure the photographer can talk to the technicians in private, and preferably arrange a director that is in charge of the entire screening. In CineGrid Medical there was no such back channel, and at several times this became a real nuisance—especially when encoders had to be restarted.

Make sure that there is a proper debriefing immediately following the event. Try to get everybody’s view on what went well and what went wrong. Jot down lessons learned for next time, and celebrate the event as an important step in the development of distance education, and (in this case) telemedicine.

Finally, make sure that—well before the screening—all stakeholders (remote or otherwise) and (possibly) the press are informed of the upcoming event. This leads to a greater number of participants, more first-hand experiences, and potential ambassadors. A picture is worth a thousand words, and—in 4K—it is worth even more. Seeing is believing.

Adoption

Although the pilot was successful, wider implementation in research and education has yet to come. With the exception of Avans University of Applied Sciences (who started using 4K in microscopic imagery), there has been little follow up. The interviewees mentioned several reasons for the lagging adoption. First of all, any new technology takes time. The technology, however advanced, still takes considerable skill and some money to implement. And finally, use cases that take advantage of extremely high quality are still sparse. However, CineGrid Medical has proven empirically that using newly available, extremely high-quality visualisations has a clear value. It is worthwhile to take on the challenge, use the available knowledge, and show the students, staff, and colleagues that with some help – it can be done.

Acknowledgment

Prof. Grolman would like to thank the young doctors of his department who were always willing to help whenever asked, and—especially—the patients who are willing to participate (after signed informed consent) in live events like CineGrid Medical.

Appendix I – Special Equipment

	Aantal	Stroom	
UMCU - Operatiezaal			
Sony F55 4K camera	1 x	45	http://pro.sony.com/bbsc/ssr/show-highend/resource
JVC GY-HMQ10 4K camera	2 x	200	http://pro.jvc.com/prof/attributes/features.jsp?model_
DELL Precision T7500 - Intopix Prestine 4 encoder	1 x	1100	http://www.dell.com/nl/bedrijven/p/precision-t7500/pd
SDI breakoutbox	1 x		http://www.intopix.com/uploaded/Download%20Pro
DELL Precision T5500 - Intopix Prestine 4 encoder	1 x	875	http://www.dell.com/nl/bedrijven/p/precision-t5500/pd
SDI breakoutbox	1 x		http://www.intopix.com/uploaded/Download%20Prodi
DELL 17" LCD scherm	1 x	75	http://www.dell.com/ed/business/p/dell-u2410/pd
BlackMacic Miniconverter HDMI to SDI	4 x	528	http://www.blackmagicdesign.com/products/minico
BlackMagic SmartVideoHub	1 x	200	http://www.blackmagicdesign.com/products/videoh
SDI Kabel 10 meter	8 x		http://en.wikipedia.org/wiki/Serial_digital_interface
SDI Kabel 1 meter	8 x		http://en.wikipedia.org/wiki/Serial_digital_interface
19" Rackcase 100 x 55 x 75 cm	1 x		http://www.licht-geluid.nl/shop/p-12254-caymon-fc
Totaal Stoomverbruik		3023	Watt (13,74 A)
UMCU - Collegezaal			
DELL Precision T5500 - Intopix Prestine 4 encoder	1 x		
SDI breakoutbox	1 x		
DELL 17" LCD scherm	1 x		
AJA converter HI 5 - 4K, SDI to HDMI	1 x		
Sony Sony VPL-VW1000ES	1 x		
RUG			
DELL Precision T7500 - Intopix Prestine 4 decoder	1 x		
SDI breakoutbox	1 x		
DELL 17" LCD scherm	1 x		
AJA converter HI 5 - 3G, SDI to HDMI	4 x		
BlackMagic Decklink 4K extreem	1 x		
BlackMacic Miniconverter SDI Multiplex 4K	1 x		
SDI kabels 5 meter	4 x		

Appendix II – Call sheet

Time	Action
06.30	Maïke, Thomas, Henny present at main entrance of UMC Utrecht
07.00	Frans, Jaap en Gert Jan present in Groningen - RUG
07.00	Testing connections and general technical check
07.30	Operation Theatre ready - Thomas & Maïke
07.30	Colloquium hall ready: Henny & Wladimir
07: 30	RUG - ready: Frans, Jaap & Gert-Jan
07.30	Patient enters the OT and is anaesthetized (DO NOT FILM – PATIENT ENTERS THE OT AWAKE): Maïke & Thomas out
07.45	Patient anaesthetised
07.45	Thomas & Maïke enter OT - start live streaming
07.45	Henny & Wladimir ready in Colloquium Hall to receive live stream
07.50	Dr. Tange arrives in OT
08.00	Dr. Tange ready for surgery
08.00	Surgery Dr. Tange starts: test live streaming
08.00	Break for CineGrid Medical project team
09.00	Sandra Passchier arrives
09.00	OT ready: Thomas & Maïke
09.00	Colloquium hall - ready: Henny & Wladimir
09.00	RUG - ready: Frans, Jaap en Gert-Jan
09.00	Patient enters the OT and is anaesthetized (DO NOT FILM – PATIENT ENTERS THE OT AWAKE): Maïke & Thomas out
09.15	Patient anaesthetised
09.15	Thomas & Maïke enter OT - start live streaming
09.20	Prof. Grolman arrives in OT
09.30	Prof. Grolman ready for surgery
.... 50 minutes
10. 20	Surgery finished patient awakens & leaves the OT – OT cleaning
10.45	ent enters the OT and is anaesthetized (DO NOT FILM – PATIENT ENTERS THE OT AWAKE): Maïke & Thomas out
11.15	Prof. Grolman ready for surgery
13.15	Surgery finished

Appendix III – Questionnaire University of Groningen

You are about to visit a pilot surgery lesson in extremely high visual quality. This might become a new approach for the new curriculum for the faculty of medicine. It could also help to form educational communities. What follows is a number of questions that will help us to understand the next steps we might take.

1. How do you judge the picture quality? Is it sufficiently clear to discern the details mentioned?

- In places where the image is focused, the quality is excellent
- Quality is very good. Small, specific parts were accurately represented
- Focusing is sometimes slow, which is distracting
- Very good quality. Very useful if you have some prior knowledge
- Focusing after the advice of the surgeon was sometimes necessary
- Very useful
- Details were incredibly well depicted. Did not expect it to be so good
- Picture quality is fantastic, though sometimes the image lapsed

To summarize, the picture quality exceeded expectations. Sometimes focusing caused delays.

2. What do you think of the possibility to split operation and explanation into separate images? Do you see better opportunities?

- Such imaging is effective. An accurate picture of the surgery itself and the situation in the Operation Theatre can be made.
- Delay is a drawback. But, if the doctor that explains and points out the interesting parts keep this in mind, it poses no problem.
- It helps in the overall understanding.
- Very good choice. It is comfortable to listen while watching the interpretation and the operation itself on two separate screens.
- Explanation during surgery helps to better understand the medical story.
- A balance between asking questions during the surgery and discussing afterwards, gives the best opportunities for education
- This way, an accurate understanding is formed from the situation in the Operation Theatre.
- Split view (for explanation and actual operation) would allow for an easier understanding of the operation.
- Preceding the surgery with a short explanation would enhance understanding before starting to broadcast the surgery on two screens with simultaneous explanation.

To summarize, working with two monitors (Operation Theatre and explanations by the physician) has a positive effect on the viewer.

3. Is the sound quality good enough? What could be better?

- Sometimes lacks quality and experiences dropouts
- The connection is occasionally dead
- There is a delay between picture and sound
- Differences in loudness and quality
- Delay was sometimes annoying
- Some noise occurred when the doctor spoke.
- Delay was annoying
- Delays make it difficult to follow some parts of the operations
- Sound was sometimes grainy and delayed
- Between image and sound was a delay

To summarize, audio and image were out of sync. We experienced a delay of two to three seconds.

4. At what moment in the curriculum should a surgery college take place, and why?

- In the block week in which the problems are discussed.
- Halfway through the module, so you already know what the surgery is about, but can still learn a lot. This creates a thorough understanding of the subject matter.
- Halfway through the block, at which point you have enough knowledge (important for grasping the subject matter).
- At the end of a block. Then, you have all the knowledge and you are able to follow the operation. This allows to pose more specific questions.
- Halfway through the block: this allows for sufficient knowledge to enable discussions and deepening of the knowledge during the surgery.
- In the master phase (much later, at the end of the study). A bachelor's program is meant to enthuse students. But, to acquire and increase actual knowledge, surgery college in this later stage is more meaningful.
- Halfway towards the end. Existing understanding and knowledge facilitates learning
- After the anatomy lessons concerning the condition.
- In the middle of the block, because you've got the basics and you can visualize the operation easier during the surgery college.

To summarize: the students each have their own vision.

5. For which applications surgery college would be useful?

- ENT, Orthopaedics, Dermatology
- Useful for the understanding of anatomy
- Oncology, partly surgery
- Ophthalmology and Cardiology
- Preferably use it in the master degree program as it is specialized by nature
- Topics and operations concerning a lot of anatomy
- Treating of tumours during surgery

To summarize: the students each have their own vision.

6. How could the involvement of students be increased?

- Setting up of working groups
- Interactive sessions: pose questions to the students and have them ask questions too
- Having questions previously completed online, as was done here, well suits the modern technologically apt student
- Through direct anatomy tests
- By seeding good information via working groups
- By making presenting or reporting afterwards obligatory

To summarize: the students each have their own vision

7. How long should an operation college last?

- 1.5 to 2 hours
- 2 to 3 hours
- Certainly no longer than 2.5 hours
- After 2 hours the concentration fades

To summarize: 2 hours is the desired time.

Notes

- 1 Adapted from: <http://www.which.co.uk/reviews/televisions/article/advice/what-is-4k-tv>
- 2 Adapted from: <https://www.surf.nl/en/services-and-products/surflichtpaden/index.html>
- 3 More information on <http://www.lion-web.org>
- 4 More information on <http://en.wikipedia.org/wiki/Otorhinolaryngology>
- 5 Adapted from http://www.lion-web.org/pages/aboutus/lion_foundation.html
- 6 <https://www.linkedin.com/pub/wilko-grolman/7/492/73a>
- 7 <https://nl-nl.facebook.com/KNO.UMC.Utrecht>
- 8 More information on UMC Utrecht: <http://www.umcutrecht.nl/en/About-us>
- 9 More information on <https://www.surf.nl/en/services-and-products/surfinternet/physical-connection-to-surfnet7/index.html>
- 10 More information on SURFnet: <https://www.surf.nl/en/about-surf/subsidiaries/surfnet>
- 11 More information on RUG's Center for Information Technology: <http://www.rug.nl/science-and-society/centre-for-information-technology/>
- 12 More information on Plus Vorm: <http://www.plusvorm.net>
- 13 More information on DIT: <http://www.werkenbijumcutrecht.nl/Paginas/Directie-Informatie-Technologie.aspx> (in Dutch)
- 14 More information on Waag Society: <https://www.waag.org/en>
- 15 More information on the research of Wilko Grolman (including Otosclerosis) https://www.researchgate.net/profile/Wilko_Grolman
- 16 More information on <http://en.wikipedia.org/wiki/Stapedectomy>
- 17 More information on <http://en.wikipedia.org/wiki/Otosclerosis>
- 18 Adapted from: <http://en.wikipedia.org/wiki/Stapedectomy>
- 19 More information can be found at <https://www.blackmagicdesign.com/products/smartyvideohub>
- 20 More information can be found at http://www.intopix.com/uploaded/Download%20Products/intoPIX%20PRISTINE%20JPEG%202000%20BOARDS_Nov09.pdf
- 21 More information on http://pro.jvc.com/prof/attributes/features.jsp?model_id=MDL102132
- 22 Each OT turned out to have four standard network ports, whereas five were needed in this setup: 2x 4K stream, 1x video conferencing, 1x telephone system and 1x PC for medical purposes. The ensuing problem was solved by adding yet another switch in the OT.
- 23 The standard network ports were originally equipped with 100 Mb/s filters that had to be replaced to allow for the 1 Gb/s video streams. An additional challenge proved to be the standard security MAC address filters that delayed the addition of additional network ports via an extra switch.
- 24 Adapted from http://en.wikipedia.org/wiki/Galvanic_isolation
- 25 This separate network was based on VLAN technology and "flat switched".
- 26 Adapted from <https://www.surf.nl/en/services-and-products/multi-service-port/multi-service-port.html>
- 27 The Sony VPL-VW1000ES, <http://store.sony.com/4k-home-theater-es-projector-zid27-VPLVW1000ES/cat-27-catid-EOL-Home-Theater-Projectors>
- 28 More information on the Pristine Decoders can be found at http://www.intopix.com/uploaded/Download%20Products/intoPIX%20PRISTINE%20JPEG%202000%20BOARDS_Nov09.pdf
- 29 The combination of IntoPix and BlackMagic boxes required downgrading the colour encoding from 16 to 8 bits.
- 30 For more information, refer to <http://www.rug.nl/science-and-society/centre-for-information-technology/research/hpcv/faciliteiten/realitytheatre>
- 31 Adapted from <http://www.rug.nl/science-and-society/centre-for-information-technology/research/hpcv/faciliteiten/realitytheatre>
- 32 More information on <http://www.lifesize.com>
- 33 More information on <https://surfsara.nl/nl>
- 34 More information about the Zeiss S88 can be found at http://www.zeiss.com/meditec/en_de/products---solutions/spine-surgery/surgical-microscopes/opmi-vario-s88.html
- 35 If they are not, setting up these light paths can take weeks or even months.
- 36 OT's are essentially Faraday Cages – so mobile phones don't work (and are generally not allowed).