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**Abstract:** Existing challenges in surgical education (See one, do one, teach one) as well as the Covid-19 pandemic make it necessary to develop new ways for surgical training. This is also crucial for the dissemination of new technological developments. As today's live transmissions of surgeries to remote locations always come with high information loss, e.g. stereoscopic depth perception, and limited communication channels. This work describes the implementation of a scalable remote solution for surgical training, called TeleSTAR (Telepresence for Surgical Assistance and Training using Augmented Reality), using immersive, interactive and augmented reality elements with a bi-lateral audio pipeline to foster direct communication. The system uses a full digital surgical microscope with a modular software-based AR interface, which consists of an interactive annotation mode to mark anatomical landmarks using an integrated touch panel as well as an intraoperative image-based stereo-spectral algorithm unit to measure anatomical details and highlight tissue characteristics. We broadcasted three cochlea implant surgeries in the context of otorhinolaryngology. The intervention scaled to five different remote locations in Germany and the Netherlands with low-latency. In total, more than 150 persons could be reached and included an evaluation of a participant's questionnaire indicating that annotated AR-based 3D live transmissions add an extra level of surgical transparency and improve the learning outcome.

**Keywords:** surgical education, COVID-19, remote surgery, telepresence, augmented reality (AR), stereoscopic imaging, 3d reconstruction, multi-spectral imaging

***Corresponding author: Jean-Claude Rosenthal,** Fraunhofer HHI, Vision and Imaging Technologies, Berlin, Germany
**Armin Schneider,** Munich Surgical Imaging, Munich, Germany
**Eric L. Wisotzky,** Fraunhofer HHI, Vision and Imaging Technologies, Berlin, Germany
**Senna Meij, John van den Dobbelsteen,** Delft University of Technology, Faculty of Mechanical Engineering, BioMechanical Engineering, Delft, The Netherlands
**Philipp Arens, Florian C. Uecker,** Charité – Universitätsmedizin Berlin, Department of Otorhinolaryngology, Berlin, Germany

## 1 Introduction

In 2020, the Covid-19 pandemic changed medical care dramatically in many ways. Digital teleconsultation services are being rolled out with high priority. More and more patients and general practitioners are using telemedicine applications or video conferencing tools in their daily routine. In 2017, only 2% of practicing doctors used video consultation in Germany. In 2020, approximately 50% of all practicing doctors offered video consultations, with an expected growth of 10% in 2021 [1]. This positive development contrasts with existing solutions for surgical training which still follows the classic teaching paradigm of „See one, do one, teach one“ (SODOTO). These limitations become even more critical in pandemic scenarios when physicians could not be trained due to contact restrictions or cancelled routine/complex interventions. However, surgical training for assistant surgeons and healthcare professionals during continuous medical education (CME) requires the acquisition of extensive surgical knowledge, training of new methods, and interventions under supervision. In addition, CME requires travel activities as such training's are mostly centred at university hospitals.

Different new approaches are currently evaluated to solve some of these limitations using immersive technologies like Mixed-/Augmented Reality or stereoscopic 3D [2]. In surgical microscopy, one of the essential training features is the stereoscopic 3D visualisation of the surgical scene which is valuable in many ways to 'understand' the patient's anatomy, e.g. depth perception to assess the dimensional relationship of specific anatomical structures. However, due to space limitations in ORs and hygienic restrictions the direct 'surgical view' cannot be shown to all trainees, continuously. This is even more 'problematic' for 2D video broadcasting of surgeries during medical congresses leading to the loss of depth impression, having only limited communication channels and often come with a significant delay. The TeleSTAR system addresses these issues by providing a scalable, low-latency AR-based stereoscopic 3D video processing chain of the microscopic intervention to multiple remote locations including a bi-lateral audio communication channel, partly based on the work described in [3]. Chapter 2 describes the overall system design to improve the pandemic-safe surgical learning experience in remote scenarios. Chapter 3 evaluates the conducted courses w.r.t. lessons learned and user feedback. Chapter 4 discusses results and gives an outlook for other potential use-cases of the TeleSTAR system.

# 2 Materials and Methods

The system uses a full digital surgical microscope (ARRISCOPE, Munich Surgical Imaging, Munich, Germany). The microscope has a resolution of $2x1920x1080px$ and a framerate of 60 images. It comes with several synchronized video outputs, an integrated touch panel as well as and a modular software AR-interface which can be injected into the live video pipeline. To operate the whole system three persons (2x surgeons, 1x IT engineer ) are needed in the OR and one person per remote location. The following sections describe the hardware and network setup (Sec. 2.1) and gives some insights into the AR-based software tools (Sec. 2.2).

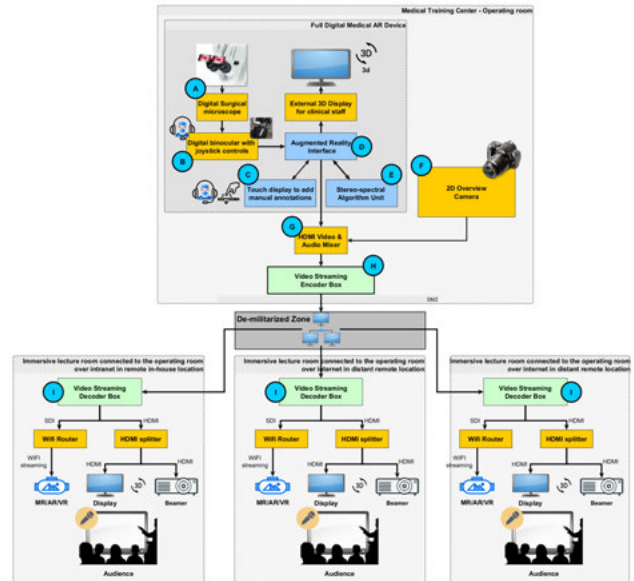


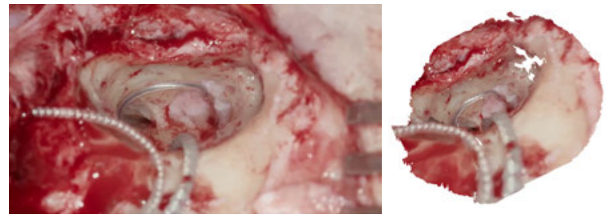

**Fig. 1:** Scalable AR-based 3D system design for remote surgical education.

## 2.1 Scalable Remote System Design

The overall system and its associated dedicated hardware (see Fig. 1) are designed in such a way that a scalable, low-latency and synchronized broadcasting can be guaranteed up to five remote locations. The system key components to allow remote training adding an extra level of surgical transparency are as follows:

1. An AR-based 3D video processing pipeline using digital surgical microscope including an interactive visual communication interface (see also section 2.2 for details) and a picture-in-picture mode, providing an enriched 'surgical view' to trainees in stereoscopic 3D. The related elements are depicted in Fig. 1A,D,E.
2. A low-latency bi-lateral audio channel between the OR and remote locations so that the main surgeon can comment the intervention and trainees can ask questions. Therefore, the main surgeon is equipped with a lightweight Bluetooth headset (Fig. 1B). The comments are embedded into the video signal of the surgical microscope and broadcasted to the audience. The assistant surgeon wears wireless headset (Fig. 1C) and receives questions from the audience via a video conferencing software. Incoming questions will be selected by the assistant surgeon in the OR to avoid distraction of the main surgeon. Then, the main surgeon repeats the question to distribute the question to all remote audiences and gives a detailed audio-visual answer.
3. An optional external 2D (pseudo-3D) overview camera looking at the surgical scene to document the intervention from an outside perspective to give insights about general OR workflows, e.g. the cooperation between the surgeon and the clinical staff preparing the next step of the procedure (Fig. 1F).
4. A multichannel audio and video mixer consolidates all audio and video streams (Fig. 1G) by combining and synchronizing the data sources described in previous items (1)-(3) into one final HDMI signal which is prepared for network transmission.
5. A low-latency and secured network configuration using a hardware h264 video encoder in the OR accepting a HDMI input signal (Fig. 1H) to broadcast the visually enriched and audio commented 3D video stream to multiple remote locations. Each location has a hardware h264 video decoder (Fig. 1I) receiving the AR-based video stream including audio comments from the surgeon. The secured connection between the hospitals network and the remote location is realised by a de-militarized zone (DMZ). The DMZ is installed on a virtual server using a reverse proxy that forwards the internal video stream to the external connections request. In addition, the known and static remote peer IP addresses needed to be configured and registered in the firewall to avoid unauthorized access.

**Fig. 2:** Annotations of the surgical scene performed in the OR using the touch display are shown in the remote lecture room.



(a) (b)

**Fig. 3:** (a) Left view of stereoscopic image pair used for 3D reconstruction (b) Dense reconstructed point cloud of a cochlea implant

## 2.2 Intraoperative AR Tools

The interactive AR-based toolchain is an essential part of the overall system (s. Fig. 1D) and consists of two modules (1) A manual annotation tool using a digital pen (2) An (semi)-automated algorithm unit for image-based measurements and spectral tissue imaging.

### 2.2.1 Interactive Annotation Module

The annotation module is depicted in Fig. 1C. It has a touch display that allows the assistant surgeon to annotate the surgical image in real-time with virtual landmarks, highlight anatomical (risk) structures. Fig. 2 shows the annotated image in the remote lecture room.

### 2.2.2 Stereo-spectral Analysis Module

The stereo-spectral algorithm modules in Fig. 1E is designed to support two important tasks during surgical education. (1) The understanding of anatomical dimensions by offering image-based measurements and (2) the correct interpretation of tissue characteristics with the help of multi-spectral imaging. **Image-based 3D Measurements:** After a calibration of the optical system, the user can perform stereo image-based measurements by means of triangulation using a joystick attached to the binocular for precise true-to-scale distance measurements between anatomical regions. Fig. 3 shows the 3D reconstructed point cloud while the cochlea implant is inserted into the inner ear. The underlying algorithm uses the method described in [5]. **Multi-spectral Illumination:** The surgical microscopes comes with a LED-based spectral illumination unit. Fig. 4 shows the extraction of 12 different wavelengths fostering the process of tissue differentiation, e.g. the determination of risk structures like nerves or cholesteatoma tissue, which is destructive proliferative tissue [6].

# 3 Results

## 3.1 Trainee Feedback

We broadcasted three AR-based 3D videos of cochlea implant surgeries in January, September and November 2020. The system scaled up to five different remote locations in the Netherlands (TU Delft, Rotterdam/Erasmus MC) and Germany (Fraunhofer HHI Berlin, Ludwig Maximilian University of Munich, Charité - Universitätsmedizin Berlin) with low-latency and offering a delayed 2D YouTube stream with no communication options. In total, more than 150 persons could be trained including healthcare professionals, biomedical engineers and medical students. The courses were accompanied by a participant's questionnaire consisting of 19 questions partly based on the work of [4]. All questions have been categorized into four topics to assess the need, quality and benefits of the TeleSTAR system in the context of remote surgical education using interactive digital tools (Fig. 5). 62 participants have answered the questionnaire. The $1^{st}$ topic 'Pre-Knowledge' deals with the level of participant's digital literacy. The $2^{nd}$ topic '3D Video & Audio' focuses on the perceived audio/video quality during the courses in remote locations. The $3^{rd}$ topic 'AR Information for Surgical Education' assesses the quality and potential of interactive digital AR tools. The $4^{th}$ topic 'Remote & Self-Learning' wants to find out if TeleSTAR's interactive AR approach could also be beneficial for @home scenarios and self-study. The overall feedback was very positive for all topics on a rating scale ranging from 1 (strongly disagree) to five (strongly agree) and all trainees clearly highlight the potential of the TeleSTAR system.

## 3.2 Runtime Performance

The pipeline has three bottlenecks that affect the overall runtime performance: (1) the main digital video processing pipeline including the transcoding processes (2) the stereo-

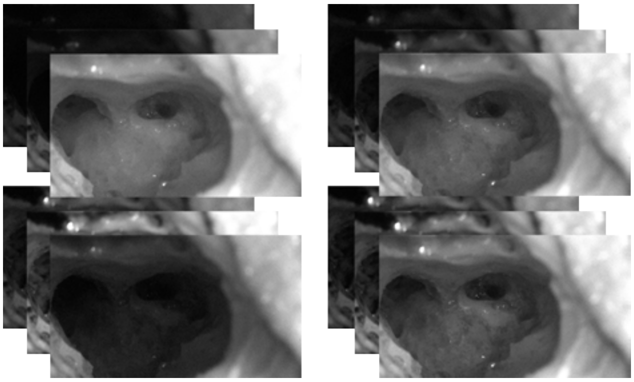


**Fig. 4:** Multi-spectral image sequence captured with integrated LED illumination unit during the course unit

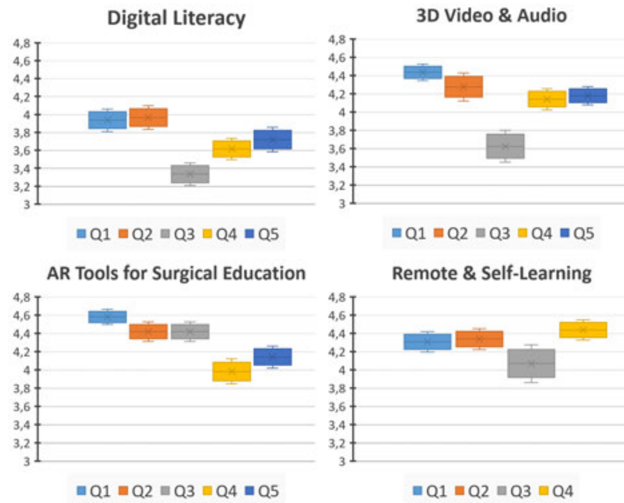



**Fig. 5:** Topic-based evaluation of participant's feedback showing a benefit for remote surgical education using the TeleSTAR system. The scale ranges from strongly disagree (1) to strongly agree(5).

spectral analysis module and (3) the underlying network bandwidth. The transmission time of the surgery from the OR to the lecture rooms was about 600-700ms depending with measured round-trip-times of 20-30ms and configured cache sizes on the remote end plus another 200-300ms for the audio reverse channel into the OR. Hence, the total transmission time was slightly below one second in average allowing a seamless and interactive communication between the instructing surgeon and remote trainees as the tempo-spatial consistency was still accurate enough. The importance of the two common latency limits for surgical handy-eye coordination (50-80ms) and for conferencing tools (200ms) could be neglected in our case as the remote trainees viewed a synchronized video with embedded audio and did not see additional actions in the OR that might interfere with the individual perception of the scene.

## 4 Discussion and Conclusion

TeleSTAR provides a highly scalable solution for remote surgical education solving limitations for educational programs during pandemic situations. Therefore, an adaptive combination of modular software and hardware modules guarantees a seamless way of audio-visual communication between experts and trainees. In addition, an extra level of surgical transparency could be added through a special interactive AR interface. In future, such AR tools can be used as a general intraoperative assistance system by support from remote or on-site experts and can be adapted to other surgical domains, easily.

**Author Statement**

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## References

[1] Mannheim Institute of Public Health, Social and Preventive Medicine. Ärzte im Zukunftsmarkt Gesundheit 2020/1. Heidelberg, Heidelberg University, 2020.

[2] Viglialoro RM, Condino S, Turini G, Carbone M, Ferrari V, Gesi M. Augmented Reality, Mixed Reality, and Hybrid Approach in Healthcare Simulation: A Systematic Review. Applied Sciences. 2021;11(5):2338. doi:10.3390/app11052338

[3] Wisotzky EL, Rosenthal JC, Eisert P, Hilsmann A, Schmid F, Bauer M, et al. Interactive and Multimodal-based Augmented Reality for Remote Assistance using a Digital Surgical Microscope. 2019 IEEE Conf on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, pp. 1477-1484.

[4] Weiss NM, Schneider A, Hempel JM, et al. Evaluating the didactic value of 3D visualization in otosurgery. European Archives of Oto-Rhino-Laryngology. 2020;278(4):1027-1033. doi:10.1007/s00405-020-06171-9

[5] Allan M, Mcleod J, Rosenthal JC, Hu Z, Gard N, Eisert P et al. Stereo Correspondence and Reconstruction of Endoscopic Data Challenge (SCARED). https://arxiv.org/abs/2101.01133. Published 2021. Accessed July 3, 2021.

[6] Wisotzky EL, Rosenthal JC, Wege U, Hilsmann A, Eisert P, Uecker FC. Surgical Guidance for Removal of Cholesteatoma Using a Multispectral 3D-Endoscope. Sensors. 2020; 20(18):5334. https://doi.org/10.3390/s20185334