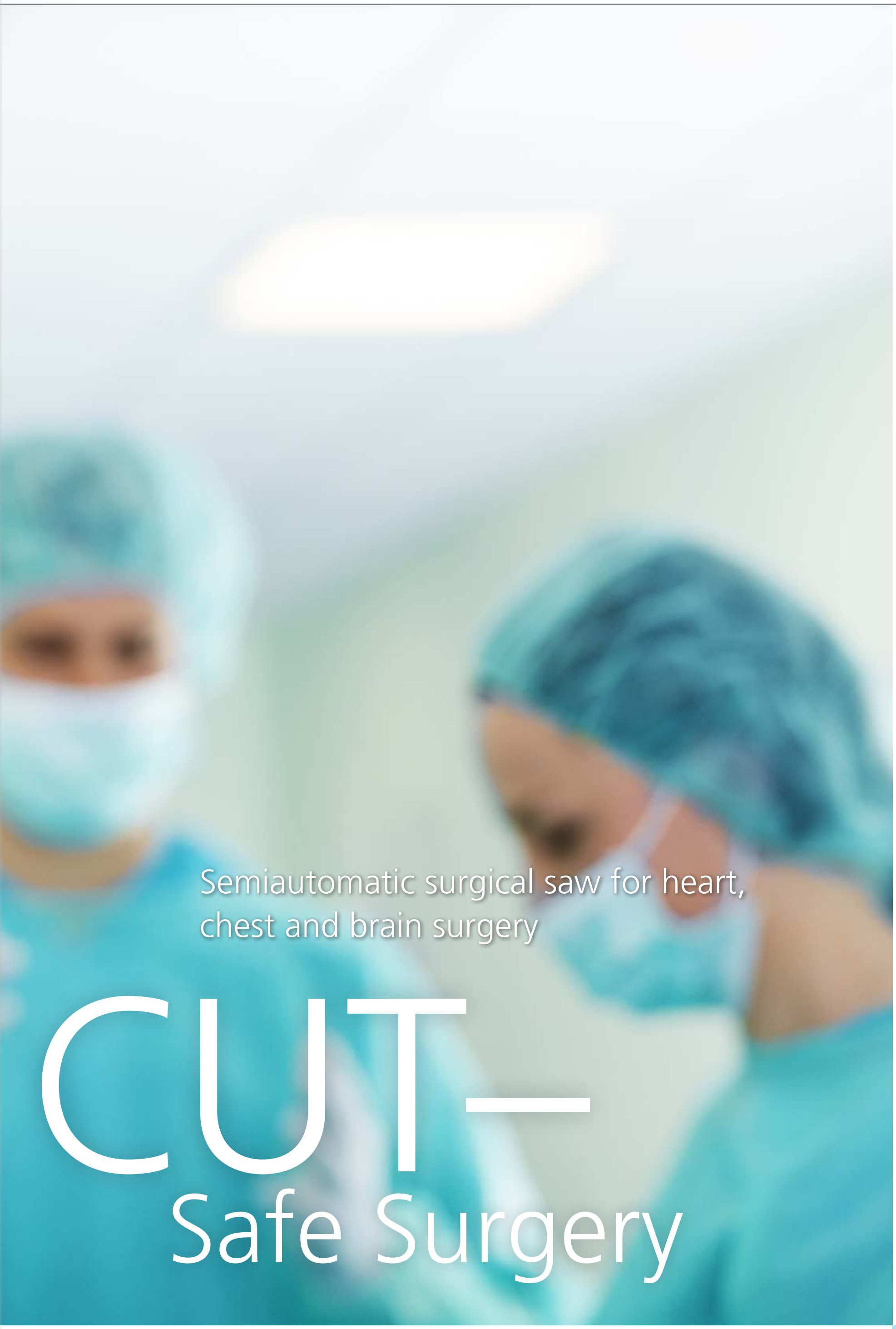
smart

Currently under development is a semiautomatic, handheld surgical saw for cutting bone tissue safely in neuro- and cardio-thoracic surgery. The surgeon and the “intelligent instrument” work together synergetically. While the surgeon guides the instrument on the bone surface and performs high-level process control, the incision depth is adjusted completely automatically with the help of computer tomography (CT), ultrasound, or optical sensors, and dSPACE real-time hardware.



Semiautomatic surgical saw for heart, chest and brain surgery

CUT– Safe Surgery

Figure 1: The new, semiautomatic smartCUT surgical saw (left: the symmetric rotation instrument for skull incisions, right: the thoracic surgery instrument, which is optimized for linear cuts).

Avoiding Trauma to Soft Tissue

Even today and under optimum conditions, many surgical interventions pose major challenges, e.g., in cases of vital soft tissues directly adhering to the bone structures which are to be cut during brain and cardio-thoracic surgery. Solely close collaboration between well-experienced surgeons allows such interventions to be performed safely and with the best possible result for the patient. Nonetheless, both applications still involve a comparatively high risk of complications. Thus, any improvement to the surgical instruments could help to greatly enhance patient safety. This is why the smartCUT semiautomatic saw is being developed at the Chair of Medical Engineering at RWTH Aachen University, with the aim of avoiding trauma to soft tissue structures during resternotomies and craniotomies. The new instrument relies on synergetic interaction with the surgeon. Haptic and visual feedback enable him or her to monitor the procedure directly. The precision and reliability of a machine combined with the high cognitive skills of a human being – such as the ability to respond to unexpected events – produce an ideal synergetic interaction.

Smart Control of Incision Depth

For optimal soft tissue preservation, the instrument's smart incision depth control combines sensor-based control with a sawing method that is specially adapted to avoid damaging soft tissue. Soft tissue protection is provided by the saw blade's circular oscillations. Unlike the rigid bone structure, the soft tissue is able to oscillate with the blade, and thus prevents trauma to a certain extent. Such a technique is necessary in order to be able to cut through the bone and to compensate for the tiny errors in determining incision depth that result from capturing spatial positions and other sensor data, and from medical imaging. Three different variants were developed and tested for the sensor-based incision depth control:

> "Thanks to the flexibility of the dSPACE real-time system, the system was quick to adapt to different sensor and imaging modalities. With relatively little effort, it can also be transferred to systems with different kinematics and degrees of freedom."

Alexander Korff, RWTH Aachen

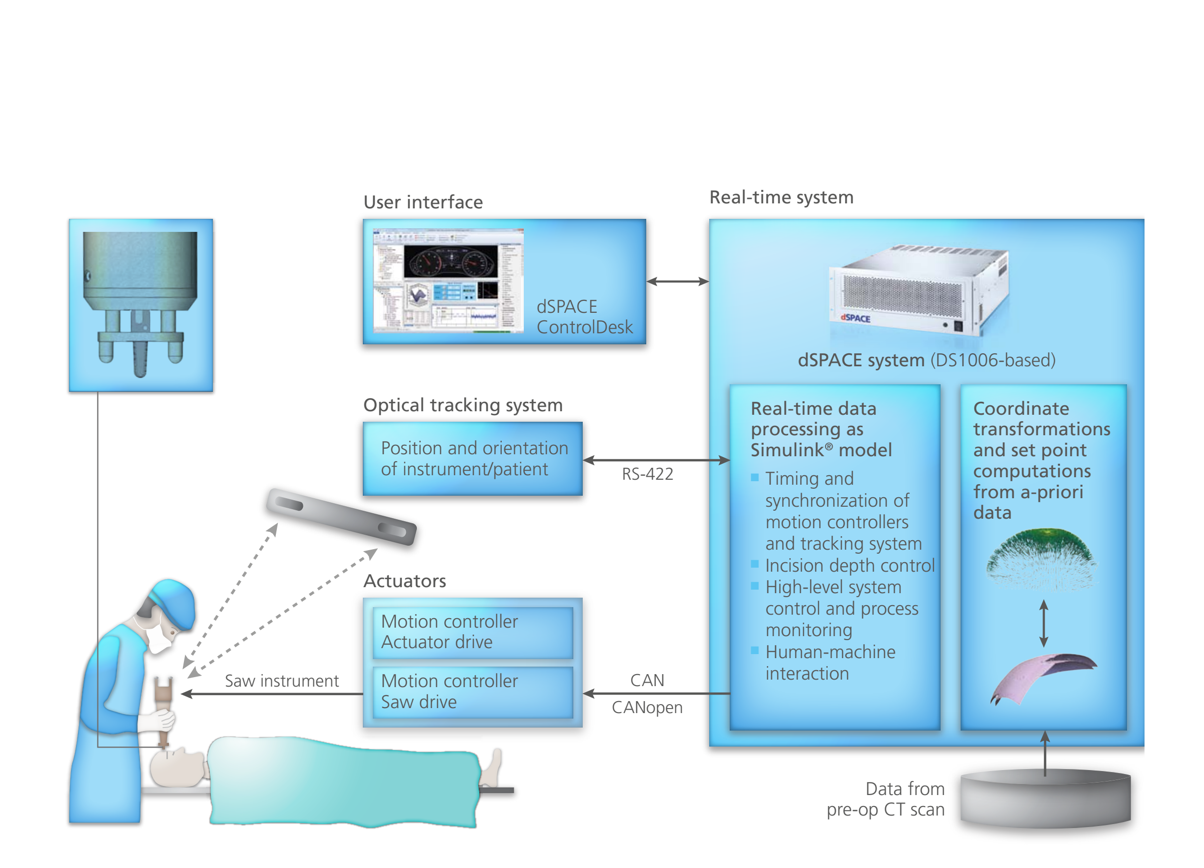


Figure 2: Using computer tomography (CT) data to open the skull with smartCUT.

- *CT-based:*
  Three-dimensional multi-layered images from a preoperative computer tomography (CT) scan are processed and then used with a dSPACE real-time system and an optical tracking system (that determines the instrument's position relative to the patient) to perform real-time incision depth control. The essential process steps, such as optical instrument tracking combined with CT imaging, are routinely used in neurosurgery nowadays.
- *Ultrasound:*
  While the CT-based method requires data to be collected before the intervention, with ultrasound, data is captured via an ultrasound probe during the operation. The method has been optimized for the linear sectioning of bone required for resternotomies. As with the CT-based method, a dSPACE real-time system is used for incision depth control, but in contrast to the CT approach, position data capture is implemented with a linear encoder.
- *Optical sensor:*
  An optical fiber is integrated into the saw blade and combined with a color sensor to determine whether the tip of the saw is in contact with bone or with soft tissue. Unlike the other two methods, this one can continuously and directly identify the position of the saw blade tip relative to the dividing surface between bone and soft tissue. The dSPACE real-time system ensures the precise distinction between bone and soft tissue and enables control of the incision depth.

smartCUT places great emphasis on human-machine synergy. The surgeon has control of the overall process and can freely select the medically most appropriate incision path, and also draw on his or her experience to specify individual parameters such as the cutting speed. The technical system performs the parts of

smartCUT in Brief

smartCUT is a semiautomatic surgical saw for cardio-thoracic and cranial surgery.

- Safe sectioning of bone structures (skull, thorax) while avoiding trauma to adjacent soft tissue
- Soft tissue partly protected by special saw kinematics (micro oscillations)
- Intelligent, sensor-based incision depth control: CT, ultrasound and optical
- dSPACE real-time system for sensor data capture and evaluation, safety, implementing human-machine interaction and controlling the overall system

Interview

The Neurosurgical Clinic at the University Clinic of the Ruhr-Universität Bochum carried out practical tests with smartCUT in a pilot project. The surgeon, Prof. Dr. Kirsten Schmieder, describes her impressions.

Prof. Dr. Schmieder, when you work on an artificial skull, how does a semiautomatic surgical saw handle as compared with conventional methods?
We're in a good position to compare, because we also used the conventional method on an artificial skull. Our experience shows that the prototype currently available is very usable as regards handling.

What advantages does the instrument have for the surgeon?
There are two advantages in using the smartCUT instrument. The first: We believe that accidental opening of the dura will occur less often during trepanation. The second: It produces a narrower cut, which reduces the risk of inadequate bone formation and closure after the skull flap is reattached. This affects the overall cosmetic result, an aspect that is quite rightfully receiving increasing attention.

How do you assess its potential for use on real patients?
It is our belief that the final product will have a good chance of replacing, or at least supplementing, the established technology. So we would be very happy to help bring the current prototype up to market maturity.

Thank you for talking to us!

Prof. Dr. Kirsten Schmieder, Director of the Neurosurgical Clinic at the University Clinic of the Ruhr-Universität Bochum, Germany.

the sawing process that cannot adequately be controlled manually, such as safely controlling and monitoring the incision depth. This makes tough demands on the real-time system and the control algorithms, especially with regard to the data that has to be available and processed online (such as parts of the CT data).

Model-Based Development of smartCUT

The real-time system used by smartCUT is a dSPACE system installed in an Expansion Box and equipped with a quad-core DS1006 Processor Board and various I/O boards (DS3001, DS4003, DS4201-S, DS4302). The software is the ControlDesk® experiment software and Real-Time Interface (RTI), plus the RTI CAN MultiMessage Blockset and the CANopen Master Solution for the CAN bus connection to the hardware. The real-time system is responsible for overall control, which includes incision depth control, data capture and processing, and implementing human-machine interaction. Model-based development with dSPACE tools proved to be an advantage in several ways:

- It provides an integrated data processing workflow. First image and signal processing (data preprocessing) is used in MATLAB®/Simulink®, after which the control of the system is created in Simulink and tested offline. The dSPACE RTI blocks are integrated, the preprocessed data is then integrated directly into

the model, and tests are performed with the dSPACE real-time system. ControlDesk and MATLAB/Simulink are used for capturing and evaluating the measurement data.
- Even with large data volumes (from CT and ultrasound scans), the image and signal processing functionality is easy to integrate into the model for use with the dSPACE real-time hardware.
- The solution is available as a transparent, overall model with a uniform tool environment which can easily be operated and evolved to a higher level by students and staff at RWTH Aachen University.
- With this model-based approach and the modular dSPACE system, the modules developed for smartCUT are easy to adapt to other mechatronic systems used in surgery and medicine.

Results of the Pilot Project

This first practical experience with the instrument clearly demonstrated the different characteristics and advantages of the three methods.

- *CT-based:*
  In practice, the separation between measuring the structure (by the pre-op CT scan) and actually making the incision leads to a long chain of errors. The limited precision of optical tracking and the complexity of the overall system are particularly challenging. However, the errors that occur can be offset by the intrinsic soft tissue protection (circular oscillation of the saw blade). This method might especially be used in neurosurgery, where the necessary systems (such as optical tracking) and methods (such as registering the image data with the patient coordinate system) are already established procedures in neuronavigation.
- *Ultrasound:*
  This method is especially suitable for cardio-thoracic surgery, because unlike the CT-based method, it requires neither optical tracking nor CT data. Interoperative data acquisition using an ultrasound probe means that a simple linear encoder can be used to directly relate the spatial positions and measurement data to one another.
- *Optical sensor:*
  This method proved its suitability for both medical applications. Because measurement data is captured during the incision, no additional imaging is required during or before the operation. This approach is therefore very similar to the standard workflow for the two interventions. ■

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Conclusion and Outlook

Comprehensive laboratory tests were performed on artificial bone to demonstrate the feasibility of the smartCUT instruments with the three different methods. In the near future, research will focus on further optimizing the control strategy, and on better integration of the sensors into the saw blade. The dSPACE real-time system will surely continue to play a decisive part in development and control optimization.

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