Mathias Leopold*, Thomas Hoffmann, Klemens Opfermann, Enrico Pannicke, Elmar Woschke, and Georg Rose

Concept of a multi sensor and freely configurable patient table for CT applications

https://doi.org/10.1515/cdbme-2018-0120

Abstract: Conventional computed tomography (CT) systems are encapsulated in hardware and software. Integration of further imaging modalities and sensors which can acquire prior knowledge for dose saving image acquisition and reconstruction techniques are barely possible. Within the scope of our research project, an open interface and freely configurable CT system is now being developed. The integration of further modalities and sensors into this system is a main target. A subproject deals with a multi sensor patient table, which provides additional information through integrated sensors.

In particular, force sensors are installed inside the patient table to determine the patient's mass. This value can be used to specify the required tube voltage, so that a more precise setting can be made in comparison to today's clinical practice. Studys show that a more precise kVp estimation can significantly reduce patient dose. Sensors for the monitoring of respiration and pulse are also integrated into the setup of the patient table. On the one hand, these are designed to encourage the patients to minimize disturbing movements and on the other hand to generate trigger signals for the examination.

In addition to the sensor concept of the table, a position control system for vertical and horizontal movement of the table is integrated. The position of the table can be adjusted using different input devices so that a fast and intuitive handling of the table movement can be achieved for standard diagnostic and CT guided interventional procedures.

The communication between all sensors, actors and the CT ist realized via the Robot Operating System (ROS) framework.

Keywords: patient table, CT, computed tomography, data acquisition, vitality functions, image reconstruction, dose reduction, multimodality, open interface, ROS

***Corresponding author: Mathias Leopold,** Institute for medical engineering, Otto von Guericke University Magdeburg, Magdeburg, Germany, e-mail: leopold@ovgu.de

Thomas Hoffmann, Klemens Opfermann, Enrico Pannicke, Georg Rose, Institute for medical engineering, Otto von Guericke University Magdeburg, Magdeburg, Germany

Elmar Woschke, Institute for mechanical engineering, Otto von Guericke University Magdeburg, Magdeburg, Germany

1 Introduction

Present patient tables for CT applications only have an interface for external patient-related sensor systems such as ECG, oxygen saturation et cetera. There is no automated recording of further patient data. Information about the patients anatomy and physiology is demanded for various diagnostic and image guided therapeutic procedures. In case of a CT examination, the use of a low radiation dose is mandatory (ALARA principle) as X-rays can have negative effects on the organism. Gaining prior knowledge about the patient and its anatomy can help to minimize the radiation dose [1]. E.g. information about the patients volume can help to predefine parameters of the CT tube current modulation or even save a topogram. In addition, by monitoring patient parameters, e.g. movement and respiration, supporting data for CT imaging can be recorded. This allows to give better imaging parameter assumptions or even reduces motion artifacts in CT images. The collected sensor data can be stored in a "digital patient file" for following diagnoses. In this paper we present a concept of a multi sensor patient table with the scope of gaining valuable data for dose reduction in CT.

2 Materials and methods

In the following we defined patient parameters which are valuable for CT imaging and identified suitable sensors. Those were integrated into the mechanical setup of the patient table. Additionally the tables steering concept and the communication network of all modules is introduced.

2.1 Patient monitoring

One of the parameters that is entered manually by the medical employee is the weight of the person to be examined. This is necessary for setting the correct tube voltage. Automated measurement of the patient's weight within the patient table reduces errors and results in more accurate adjustment of the tube parameters [2, 3] . To achieve this, force sensors were integrated into the base of the table as presented in [4]. Figure 1 shows the integrated design of the sensor. The used force sen-

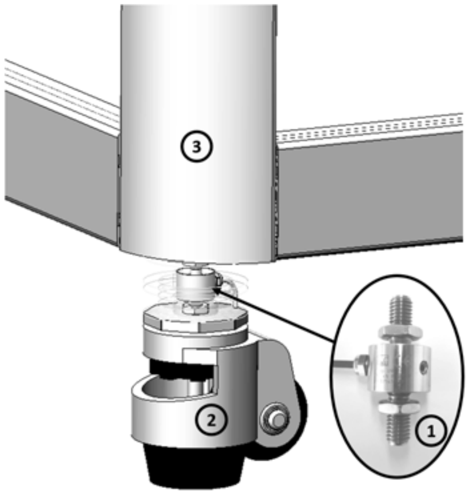

Fig. 1: CAD model of the force sensor which is integrated in patient table. *1 - Force sensor (HBM U9C), 2 - Jacking Castor, 3 - Base frame*

sor U9C of HBM has a measuring range of 2 kN. A microcontroller processes the sensor signals and makes them available to the operating software of the overall CT system.

Another important point is the patient's respiration. In the case of thorax and abdominal CT, patients have to stop breathing while the scan is performed to avoid motion artifacts in the images. The feedback of the respiratory motion signal can animate the patients to minimize motion during the examination. Such optical feedback system can be installed in the diagnostic room or directly at the CT gantry. In order to ensure a recording of respiration, a sensor is integrated into the table top. A similar approach has already been shown in [5]. To record the respiration, a pneumatic sensor is integrated (see figure 2). The sensor systems contains of an air-filled polymer pad (ITP GmbH) with an external pressure sensor which is connected via plastic tubes. The pressure sensor is connected to the microcontroller of the patient table. The attenuation properties of the sensor were also investigated by comparison of the Hounsfield values with a classical CT table pad.

2.2 Steering concept

Another key feature is the steering concept of the patient table. This should be flexible and adaptable to the individual requirements, e.g. for diagnostic or therapeutic procedures. The basic functions needed for manual table adjustment are vertical and axial movement, which are made possible by three different control variants: joystick, tactile floor and computer input.

Positioning by joystick is primarily used for the standard diagnostic examinations. The input device used here is a 3Dconnexion SpaceMouse Wireless, which has 6 degrees of freedom and two additional input keys. The tactile floor concept includes a matrix of different pressure sensors in a ground plate, as introduced in [6]. This approach is primary designed for interventional procedures in CT, such as brachytherapy. Steering via software input in the control room can be carried out in different ways, by direct input of the operator or by precalculated positions from other modalities. This point leads to the overall control and communication strategy for the entire CT system.

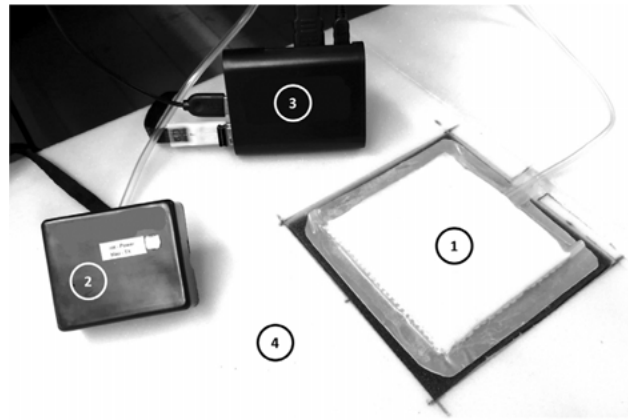

Fig. 2: Setup of the integrated pressure sensor for measuring of respiratory motion. *1 - Elastomeric pad, 2 - Pressure sensor, 3 - Microcontroller board, 4 - Patient table*

2.3 Communication strategy

The Robot Operating System (ROS) software framework is used to control and interact with the individual components of the CT system. The components are inserted as nodes into a network. A master coordinates the communication between the individual nodes. Sensor and control information are published as messages to a topic from the sending nodes and the receiving nodes subscribe to this topic to obtain the information. The physical objects behind the nodes can easily be exchanged, and several nodes can send or receive similar data. In the example of the patient table, the motor control receives information about the required height and axial position. This information is provided by one of the possible variants - joystick, tactile floor or computer input. Figure 3 shows the basic principle of the overall control system.

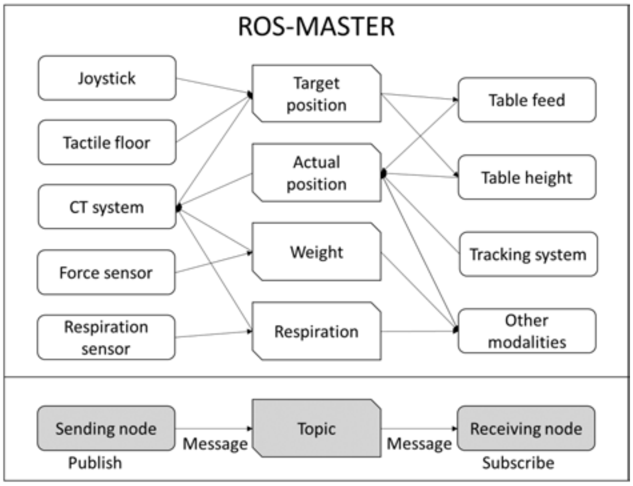

Fig. 3: Basic principle of communication in ROS network for the patient table.

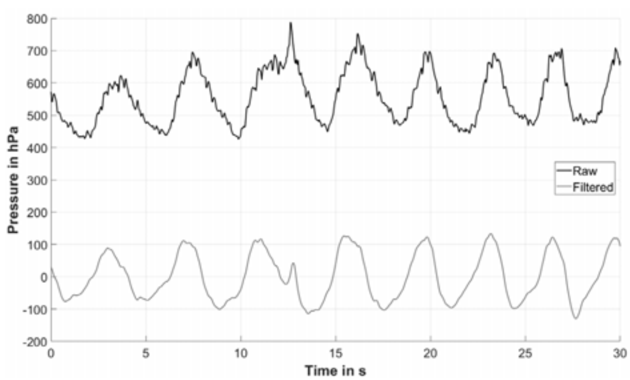

Fig. 4: Signal of respiration sensor, raw (upper graph) and filtered pressure data (lower graph) over a time period of 30 s.

3 Results

The sensor and steering concept was mechanically implemented in the table setup. The evaluation of the sensor signals via microcontroller and the publishing of data within the ROS network is established.

The developed pressure sensor concept was able to depict respiratory motion signals from different subjects. The individual respiratory motion is clearly to identify in the measurement curve (see Figure 4). A second order butterworth filter was used to remove noise, drift and offset from the signal. A fast Fourier transform (FFT) of the raw data showed a distinct peak at a frequency of 0.26 Hz, which corresponds to the respiratory frequency. Figure 4 shows a peak in the range of 12 s to 13 s, which was caused by the test person's movement.

4 Conclusion and Future work

It has been shown that the sensor concept of the patient table is able to detect weight, respiration and pulse. The pressure sensor technology enables to detect respiration and pulse for trigger signal generation. This technology has so far been able to be used under experimental conditions with compliant patients with little other movement. The movement strongly influences the pressure sensor so that results can be distorted. By further optimizing the evaluation and filtering of the signals, it will be possible to detect disturbing signals. The patient's weight can be recorded automatically before the examination. In addition, a future volume measurement is advantageous, as further parameters for the dose reduction can be obtained. The concept of the table also allows for additional sensor technology.

Author Statement

Research funding: The work of this paper is funded by the Federal Ministry of Education and Research within the project 'KIDs-CT' under grant number '13GW0229A'.. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] Thakur Y, McLaughlin P D, Mayo J R. Strategies for Radiation Dose Optimization. Current Radiology Reports, Volume 1, March 2013, DOI: 10.1007/s40134-013-0007-y

[2] Kalra M K, Maher M M, Toth T L, Hamberg L M, Blake M A, Shepard J-A, et al. Strategies for CT Radiation Dose Optimization. Radiology Vol. 230 Nr. 3, 2004, DOI:10.1148/radiol.2303021726

[3] Kalra M K, Prasad S, Saini S, Blake M A, Varghese J, Halpern E F, et al. Clinical Comparison of Standard-Dose and 50% Reduced—Dose Abdominal CT: Effect on Image Quality. American Journal of Roentgenology 179, 2002, DOI:10.1148/radiol.2303021726

[4] Chung G S, Choi B H, Jeong D-U, Park K S. Noninvasive Heart Rate Variability Analysis Using Loadcell-Installed Bed During Sleep. Proceedings of the 29th Annual International Conference of the IEEE EMBS, 22 - 26 August 2007,Lyon, France

[5] Šprager S, Đonlagić D, Zazula D. Monitoring of basic human vital functions using optical interferometer. 10th International Conference on Signal Processing (ICSP 2010), 24 - 28 Oct. 2010, Beijing, China
[6] Hatscher B, Luz M, Nacke L, Elkmann N, Müller V, Hansen C. GazeTap: towards hands-free interaction in the operating room. Proceedings of the 19th ACM International Conference on Multimodal Interaction (ICMI 2017). ACM, New York, NY, USA, 243-251. DOI: 10.1145/3136755.3136759