Mock loop for bubble generation in a centrifugal blood pump for fault simulation

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In extracorporeal blood circulation intensive care treatments, the occurrence of gas within the circulation is one known major hazard. This gas volume can cause severe harm to the patient like infarctions. Consequently, within risk assessment for these treatments gas bubbles are usually addressed by either constructive or signal based approaches. All signal-based approaches do have in common that they need a sufficient amount of data to be parameterized. These data can only be acquired in animal experiments or laboratory experiments, since they would potentially harm the patient.
Hence, we designed a mock loop, which is automatically able to create annotated data of gas bubbles injected to an extracorporeal circulation. We were able to run this setup at a periodicity of 15 seconds, which results in 240 annotated measurements per hour. For the evaluation, we created 1095 bubbles of varying sizes. The elaborated setup enables us to produce a great amount of annotated data, which is shown to be comparable to manually generated data in a convenient manner.

Low-cost physiological simulation system for endovascular treatment of aneurysms

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Minimally invasive procedures are more and more becoming the standard treatment for many surgical procedures such as the treatment of cerebral aneurysms. In an endovascular procedure the aneurysm is filled with flexible platinum coils leading to embolization and blocking the blood flow in the aneurysm. This established treatment needs high skills and experience on the surgeon. In order to practice and plan a specific procedure or test a new device, a realistic simulation environment is needed. Modern 3D printing technology allows the fabrication of patient specific models incorporating the exact geometry of the pathological anatomy.

This article describes the development of a low-cost physiological simulation system for the training of the endovascular treatment of aneurysms. In order to practice the procedure in a realistic scenario, a 3D printed model of the aneurysm is embedded in a fluidic simulation system. In addition to the patient-specific anatomy of the aneurysm a pulsatile water flow is generated, which emulates the influence of blood flow on the behavior of catheters and coils during deployment.

The system consists of a controllable pump circuit generating a pulsatile flow which can be regulated automatically and additionally controlled externally by the user. For a suitable representation, a display which graphically represents the sensor data and settings is employed. The components were compactly integrated in a small case allowing for easy deployment in training workshops. The simulation setup was successfully tested in prospective patient specific treatment planning and workshops for students.

Observer-based controller design for the minimally invasive surgery

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Due to its advantages like minimal trauma and a low risk of infections, the minimally invasive surgery (MIS) has become the standard operation technique for many surgical procedures. In the MIS, the surgical instruments are inserted into the operation area through small incisions and the surgeon operates with no direct view, only with the use of fiber optical systems. Therefore, the main tasks from an engineer's point of view are to maintain visibility and give the surgeon sufficient space to perform his work. The first objective is achieved by flushing the operation area with a rinsing fluid, the latter by applying a pressure for inflation. In the considered application those tasks are achieved by the usage of a so called double roller pump. This type of pump offers the possibility to transport the rinsing fluid without the risk of contamination from the environment. The main challenge for the pressure controller design is the non-measurable controlled variable due to technical and economical aspects. Therefore an observer-based approach was chosen and the technical as well as the biomedical subsystem and their essential characteristics were independently modelled. Special emphasis was put on modeling the distubances induced by the peristaltic behavior of the used double roller pump. This knowledge was than incorporated in the development of an extended Kalman filter, which reconstructs the pressure in the operation area. For validation purposes, a PI controller using the technique of loop shaping was designed separately. The proposed observer-based control structure was than tested on a simulator in the laboratory.

Automatic Detection and Classification of Cardiopulmonary Diseases using Deep Structured Learning

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Deep structured learning serves as a non-linear black box model to classify the cardiopulmonary diseases based upon the input-output relationships. Two different diseases, namely arrhythmias and apnea, are of interest in combination with a new setup of a contactless multi-sensor system. In this particular system, a capacitive electrocardiogram (cECG) and a magnetic induction (MI) sensor are applied for the signal acquisition. A further model of a convolutional neural network (CNN) and a hybrid model (CNN combined with a recurrent neural network (RNN)) are applied for the detection and classification of the diseases. The cECG signal was used for the classification of arrhythmias while the MI signal was applied for the detection of apnea in real-time. To process and analyze big data, the state-of-the-art lambda architecture is proposed in order to organize the data into a streaming layer and a batch layer. A CNN model was applied for the classification of cardiac arrhythmias and a hybrid model with the structure of long short-term memory (LSTM) was used for the classification of apnea, respectively. The CNN model of six layers has been applied for the classification of arrhythmias into four main categories, namely normal, left bundle branch block (LBBB), right bundle branch block (RBBB), and premature ventricle contraction (PVC) with the average accuracy of 99.2%. While the hybrid model was able to detect apnea with the highest accuracy of 90%. With the aid of deep structured learning, apnea detection and arrhythmia classification can be realized in the proposed contactless multisensor system that may apply these to a real-time application of various clinical scenarios.

A long-term setup for kidney perfusion

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Our work focuses on the development of an automated long-term organ perfusion system, to achieve a perfusion time of at least 24h, as bridge to transplant system, and additionally as *in vitro* test system for medical devices (like oxygenators). The system has to be automated in order to achieve adequate reproducibility, physiological conditions, and the employment of reasonable manpower. In a stable *in vitro* test system, clinically relevant complications, like blood clot formation and inflammatory response, could be investigated without the need for animal trials. The stable perfusion of a porcine kidneys over 6 hours with automatic acquisition of the medical devices was realized as proof of principle. The concluded work focuses on the identification of relevant perfusion parameters and the development of the necessary automation devices. This includes a stable temperature of the perfused organ, a sufficient oxygenation and the adaption of blood pump settings, to guarantee a desired pressure at the inlet of the organ. An online blood gas analyzer is used for monitoring and controlling potassium, pH-value, oxygen saturation and partial pressures of oxygen and carbon dioxide. Furthermore, the ureter fluid is measured by scaling as indicator of a secretion mechanisms of the kidney and as loss of perfusion fluid. The overall loss of the perfusion fluid is measured with a capacitive level sensor in the circulations reservoir. All data is collected via an embedded network, which is also responsible for the dedicated control tasks. This includes maintaining the blood pressure, temperature and compensation of fluid loss by addition of e.g. ringer solution. The necessity of further models and control algorithms like pH-value stabilization is part of current research.

A Drive Mechanism for a Blood Pump Integrated in an Oxygenator

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The achievement of a low priming volume of the components in an extracorporeal perfusion system for neonatal and pediatric patients is an open research question. This paper presents a concept of a pump-oxygenator in which an oxygenator and a pulsatile blood pump are combined in one housing. For operation of the pump-oxygenator, a special actuating system for the pump process was designed. It consists of a piston pump which is directly driven by a voice coil actuator (VCA). A servo positioning system was developed to assure the piston motion according to predefined reference trajectories. First experimental results indicate the feasibility of driving this blood pump with a VCA. In an in-vitro study, the pump produced mean flow rates of 60-900 mL/min with stroke frequencies in the range of 60-240 beats per minute.

Toward minimal-invasive cochlear implantation: A study on the accuracy and repeatability of a single drill tunnel approach

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Since more than four decades, cochlear implants (CI) are typically used to treat patients suffering from profound sensorineural hearing loss. Therefore, CIs consist of an implanted stimulator receiver with a connected electrode array and an external sound processor. To restore hearing, the electrode array will be inserted into the cochlea and used to stimulate the intracochlear auditory nerve cells. However, as the cochlea is located deep inside the temporal bone of the patient and has to be reached by an invasive and risky surgery.
To reduce the risks, the operation time, and the costs of the cochlear implantation, we developed a minimal-invasive, stereotaxic operation approach. Thereby, the conventional access to the cochlea should be replaced by a single small drill tunnel through the temporal bone. Covering the complete surgery procedure, we performed an accuracy and repeatability study with ten human cadaver temporal bones in order to verify the benefits of the new approach.
A stereotaxic frame was mounted with boneanchors on the cadaver and a cone beam computed tomography (DVT) was performed in order to identify the cochlear and risk structure positions in respect to the position of the mounted frame. Following this, the optimal position of the drill path was calculated and a drilling jig was manufactured fitting to the stereotaxic frame. Using this, a drill tunnel was applied to the cadaver temporal bones and the accuracy of the drilling was evaluated using a coordinate-measuring machine and a second post-operative DVT scan.
Good agreement between the calculated and the measured drill path position was achieved, indicating the feasibility of a minimal-invasive cochlear surgery. Based on these results, we expect that the presented approach can be used to re-place the conventional surgery in order to increase the patient safety and to decrease the operation time and costs.