Westfälische Hochschule

University of Applied Sciences
Gelsenkirchen Bocholt Recklinghausen

Research and Development at the Westphalian University

Research Report 2014 – 2017

Knowledge. That matters.

Foreword

Research at the Westfälische Hochschule (2013 – 2017)

In the year 2017, the Westfälische Hochschule (Westphalian University of Applied Sciences) celebrated 25 years of its existence. Originally founded as a School of Engineering, the university today operates in a much wider range of fields, as the contributions in this Research Report demonstrate.

Research activities range from social sciences and sociological questions to the technical and natural sciences and the challenges of achieving secure internet communications which are increasingly affecting us all today.

The Westphalian University of Applied Sciences has long been known as a powerhouse of ideas where young people work with their professors to develop their initial ideas right through to the stage of an actual product and, at the end, venture to take the step of founding a new company. This leads to the creation of new jobs, and not only for the highly-qualified graduates of our university, for, after all, those who produce goods and services also need plenty of helping hands. And what is worthier of "the toil of noble men"* than striving to create jobs?

I am very pleased that the research carried out here at the Westphalian University of Applied Sciences is starting to have an increasingly strong impact in this area too, and I can only encourage all members of our university to go further down this path.

With the building of the "InnoCent", space for the setting-up of young companies has successfully been established right next door to our premises in Bocholt. This can above all be traced back to the huge efforts of local entrepreneurs and other key players in the region. The executive board of the Westphalian University of Applied Sciences is now working towards setting up comparable facilities in Gelsenkirchen in the next few years.

I am looking forward to being able to continue working with you in the coming years on the establishment of the Westfälische Hochschule as a driver of innovation for the region. On behalf of the entire executive board of the Westfälische Hochschule, I would like to offer my sincere thanks to all those who are accompanying us on this path.

* Friedrich Gottlieb Klopstock (1724-1803), "Ode to Lake Zurich"

For the executive board of the Westfälische Hochschule (Westphalian University of Applied Sciences)

Prof. Dr. Michael Brodmann
Vice-President

Michael Brodmann
Vice-President Research and Development

"Magnetic Particle Imaging" with Ferromagnetic Carbon

Nanofluids, defined as fluids with suspended nanoparticles, are of interest for biomedicinal applications. "Magnetic Particle Imaging" (MPI) is a ground breaking new imaging procedure. It uses superparamagnetic iron oxide particles and measures their response of their non-linear magnetisation to external magnetic fields. MPI allows a qualitative visualisation of the concentration of nanoparticles in real time. It promises greater sensitivity compared to MRI (Magnetic Resonance Imaging) as well as spatial and time resolution. Therefore, MPI is envisaged for example in functional heart diagnosis. With a biofunctional encapsulation of the nanoparticles, MPI could be suitable for tumour treatment.

In the following, a biocompatible nanofluid based on a carbon material that is ferromagnetic at room temperature will be presented. We are also presenting the modelling and the results of numerical investigations of the suitability of ferromagnetic nanoparticles for MPI and MPI-images with this material.

The research coordination is with the Departamento de Física, Universidade Federal de São Carlos (UFSCar), Brazil, where the ferromagnetic carbon is manufactured, and with the Laboratorium Medizinphysik (Medical Physics Laboratory), Westfälische Hochschule (Westphalian University of Applied Sciences), Gelsenkirchen Campus, which is undertaking the modelling and calculation of the MPI images. We had the good fortune of being able to look after excellent exchange students, without whom these results would not have been conceivable.

Ferromagnetic Carbon

Ferromagnetic carbon can be produces by a vapour-phase redox reaction in a nitrogen atmosphere. The magnetic domains are measured to 1 µm using atom-/magnet power microscopy (AFM/MFM). Recent reports confirm that ferromagnetism arises from defects which spread in the process. The characterisation of the nanofluid by transmission electron microscopy (TEM) reveals a platelet shaped morphology. The size of the particles in the nanofluid is calculated at 10 nm, and hysteresis proves the ferromagnetic behaviour.

MPI-Imaging

In an MPI-Scanner model, two Maxwell coil pairs arranged at a separation of d = 1 m generate the stimulating magnetic fields. Their gradients are 2.5 T/μ_0m, the measurement field is 30 mm x 15 mm. The response of the nanofield, i.e., the measured signal, is determined by hysteresis; in the ferromagnetic case it is described by a differential equation which is solved numerically. Finally, the signal is reconstructed into an MPI image with the single value resolution.

In the illustration, MPI-images of superparamagnetic iron oxides are compared with ferromagnetic carbon. The two-dimensional object was reconstructed with a resolution of 64 x 64 Pixels. The image contrast improves with higher concentrations of particles. The picture quality is comparable, although the ferromagnetic carbon generates a more angular image. Because of the currently low saturation magnetisation of the ferromagnetic carbon, the generation of a strong MPI signal will only be possible in the future. The development of a clinical MPI scanner for human medicine also needs further research.

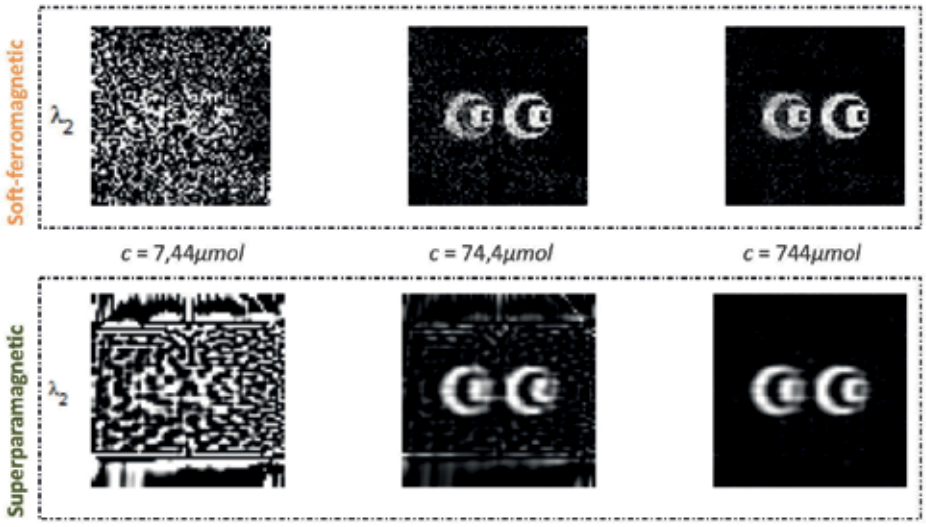

Fig. 1: Reconstructed MPI-images of a two-dimensional phantom with a fixed parameter of regularisation (λ) and different concentrations c of the superparamagnetic (bottom) and ferromagnetic nanofluid (top)

Current Publications on the Subject //

[1] Euting, S.; Araújo-Moreira, F. M.; Zylka, W.: Magnetic Particle Imaging using Ferromagnetic Magnetization. In: *Proceedings in Physics*. 140. Wiesbaden: Springer, 2012. DOI: 10.1007/978-3-642-24133-8_3.

[2] Araújo-Moreira, F. M.; Euting, S.; Zylka, W.: *Biotechnological applications of nanostructured magnetic carbon*. Brazilian Materials Research Society (MRS) Meeting, Florianapolis, 2012.

[3] Euting, S.; Araújo-Moreira, F. M.; Zylka, W.: Magnetic Particle Imaging using Ferromagnetic Carbon. In: *Biomed Tech*, Vol. 56, 2011. DOI: 10.1515/BMT.2011.236.

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Models for the Growth and Therapy of Tumors – Personalized Prognosis via Medical Imaging

220,000 people annually are dying from malignant tumors in Germany alone. More than twice this number are diagnosed with cancer within the same timeframe. Despite these facts, recent "breakthroughs" in medical treatment with so-called immune therapy or with the understanding of the spatiotemporal progression of tumors and the effect of a therapy with mathematical models have been discussed. These models demonstrate the biological, biochemical and physical processes leading to tumor formation. Currently certain model parameters can be derived from medical imaging, e.g. Magnetic Resonance Tomography (MRT) and Positronic-Emissions-Tomography (PET) and enable a patient-specific calibration of the models. The numerically generated solution of the equations provides prognoses regarding the type and quantity of tumorous cells and their geometrical distribution.

Models of Tumor Growth

Instead of following the traditional classification of continuous and discrete models, hybrid multiscale models working on diverse scales have recently been examined simultaneously. For example, the biochemical reaction kinetics occur on the microscopic scale, while the cell division in the cell cycle and migration progresses occur on the mesoscopic scale. The formation of a tumorous structure is linked to the macroscopic scale of the tissue. The diagnostic tomography imaging, which currently provides the initial proof of an existing tumor with a resolution of approx. 0.5 mm operates on this scale as well.

For example, an avascular (without blood vessels) tumor consists of mobile cells which can proliferate and migrate. If the cell density is exhausted in one location, the cells migrate in a stochastic process (cellular automaton) in all neighboring directions and promote the tumor growth. The values of the model parameters can be derived from in-vitro experiments on cell cultures (proliferation) and from the patient's MRT- and PET images (diffusion, oxygen density). It is remarkable that the multi-scale model is able to reproduce the known macroscopic characteristics of avascular tumors: One, a necrotic core (dead tumor cells) surrounded by a halo proliferating or temporarily dormant (quiescent) in the G_0-Phase cells will form. Secondly, the avascular expansion in the model determined by the oxygen density stops at a maximum tumor size.

Model for (Radiation) Therapy

Diverse points for linking a therapy are available in a multi-scale model. For example, on the microscopic scale, the immune therapy approaches the phase transfers in the cell cycle (checkpoints), in contrast to radiation therapy, more specifically, radiation with an energy dose measured in Grey (Gy). Typical clinical time schedules (fractionations), diverse tumor types and empirical laws for the survival probability of the cells can be taken into consideration. For example, head-neck tumors respond rapidly, in contrast, prostate tumors respond slower to radiation therapy, which is reflected in the results of the model.

If the patient-specific oxygen density derived from PET and the cell cycle in the model is taken into consideration, the findings are that the survival probability of tumor cells in a hypoxic environment (e.g. necrotic tumor core) is higher. The results show that the consideration of oxygen in specific planning of radiation therapy is beneficial for not overevaluating the therapy results. This particularly applies to prostate tumors which have a high repair capability.

A Clinical Case – Glioma

The ultimate goal of modeling tumors is to support therapy decisions in a clinical environment. One approach is to use longitudinal PET and MRT time series. The model is calibrated with two images from neighboring stages. The personalized prognosis is calculated, e.g. tumor size, thereafter in a third stage. The model can be validated if images are available in the third stage as well. This approach was used for a glioma (brain tumor). Since radiation therapy was performed prior to the third stage, the comparison between the calculated and actual cells and the tumor size also reflects the effectiveness of the radiation treatment.

Challenge and Vision

In addition to the mathematical and numeric complexity, one of the most important challenges in modeling tumor growth is the availability of patient-specific data for calibrating the model. The data must contain anatomical, metabolic and functional information with sufficient spatiotemporal resolution.

Currently the prognoses of tumor growth is based on expectation values which are derived from population-extensive databases. If the models are successfully developed and clinically validated, the tumor models will contribute to changing the scenario and assist in making a prognosis based on the patient's specific data.

Current Publications on the Subject //

[1] Krebs in Deutschland 2011/2012. 10. Ausgabe. Robert Koch-Institut (Hrsg.) und die Gesellschaft der epidemiologischen Krebsregister in Deutschland e.V. (Hrsg.). Berlin, 2015.

[2] Roque, T.; Kalkan, Z.; Zylka, W.: Biological effectiveness in hypofractionation: Modeling tumor survival probability for large doses with a stochastic cell-cycle model. In: *Biomed Tech*. Volume 57 Suppl. 1, 2012, DOI: 10.1515/bmt-2012-4111.

[3] Roque, T.; Zylka, W.: Integration of Patient Specific MRI Imaging Data into a Stochastic Low-Grade Glioma Model. In: *Biomedical Engineering / Biomedizinische Technik*. Volume 58 Suppl. 1, 2013, DOI: 10.1515/bmt-2013-4342.

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Technologietransfer
Felicia Plantikow-Voßgätter
Dr. Elisabeth Birckenstaedt
www.technologietransfer.w-hs.de

Graphic design //
Jutta Ritz, Felicia Plantikow-Voßgätter

Photos/Illustrations //
Westfälische Hochschule

Translation //
Lingua-World® GmbH

Printing //
Druckerei Schneider, Gelsenkirchen