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Artificial Neural Network Modeling of Monte Carlo and Mean-field Ising Hysteresis

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During recent years, ferromagnetic materials have become more and more attractive in terms of both fundamental and technological interest e.g. in magnetic recording applications [1,2]. In such applications, the amplitude and frequency dependence of hysteresis parameters are of important consideration. Theoretical studies e.g. Monte Carlo simulations [3] and mean-field analysis [4] have long focused on the use of power law scaling to investigate how hysteresis properties response to external field parameters (i.e. amplitude (H_0) and frequency (f) of the applied field) in a form of $A \propto f^{\alpha} H_0^{\beta}$ where A denotes the hysteresis area, α and β are exponents to the scaling. In spite of its reasonable success on finding how hysteresis area relates to the field, each exponent obtained in this way is not truly independent. This is since with a small number of data, the non-linear regression for multiple independent variables (i.e. f and H_0) has limitation arisen from convergence problems. Therefore, α and β were generally extracted separately. Specifically, one exponent was extracted at a time. However, though this method is sound, the extracted exponents are very vulnerable where a small change or error in α could cause a considerable change in β. Moreover, the hysteresis behavior is also very different between low and high frequency regions, so one has to propose two different power law scaling relations applicable to the low-frequency and high-frequency limits. Being evident, this power law technique becomes problematic unless the frequency region (high or low) is known in advance. Consequently, in this work, we aim to provide another sophisticate technique which can be used to model the hysteresis behavior i.e. the artificial neural network (ANN) due to its ability to 'learn' from experiences (examples). In this work, the ANN is used to model ferromagnetic Ising hysteresis obtained from Monte Carlo simulation and mean-field analysis. The ANNs were trained with inputs which is the hysteresis area. The inputs were split into training data, testing data and validation data. During training, validation data were used to prevent overtraining. After the network has been trained, it was used to predict hysteresis area of the unseen testing patterns of input. The predicted and the testing data were found to match very well which suggests the ANN success in modeling hysteresis properties.

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Spintronic Biochips for Biomolecular Recognition

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Integrated spintronic biochip platforms are being developed for portable, point-of-care diagnostic applications. The platforms consist of a microfluidic unit where the bioassay takes place, an arraying and detector chip consisting of target arraying current lines and integrated magnetoresistive sensors, and electronic control and readout boards. Probe biomolecules are immobilized by microspotting over sensor sites, and target biomolecules, labeled with magnetic nanoparticles are arrayed over the probe sites (magnetically assisted hybridization). After proper washing, hybridized targets are recognized by the fringe fields created by the magnetic beads, detected by the incorporated magnetoresistive sensors. Detecting geometries will be reviewed, using either out-of-plane or in-plane bead excitation, and dc or ac detection/excitation. Detection limits using spin valve and tunnel junction sensors will be presented, depending ultimately on platform electronic noise, and sensor noise characteristics. Applications to gene expression chips (Cystic Fibrosis gene mutation detection) and imuno assay chips (anti-body-antigen recognition, e-Coli, Salmonella detection) will be presented. Spintronic biochip are also being integrated into multi -module lab-on-chip platforms including i) biomolecule extraction from biological fluids (magnetophoresis), ii) PCR modules (if required), and iii) the biomolecular recognition module. Alternative spintronic biochip geometries will also be presented (lateral flow biosensors), where a magnetoresistive reader scans the surface of a porous strip, where labeled target biomolecules bind to immobilized probes. Finally, a brief review of other biomedical applications of magnetoresistive sensors will be given, from hybrid sensors targeted at biomedical imaging, to magnetic tweezers/sensors for DNA translocation monitoring.

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Paulo Freitas is a Full Professor of Physics at the Instituto Superior Tecnico (IST) in Lisbon, and the Director of INESC Microsystems and Nanotechnologies. Current research topics include MRAMS, read heads for ultra high density recording, magnetoresistive biochips, and sensors for biomedical applications. He has been involved in research in the area of magnetoresistive materials and devices since he received his Ph.D in Solid State Physics from Carnegie Mellon University in 1986. His PhD thesis was on the subject of anisotropic magnetoresistance of ferromagnetic thin films and alloys. He then joined IBM Research at Yorktown Heights as a post doctoral fellow working on high-TC superconductivity and transport properties of ferromagnetic thin films. In 1988 he joined INESC in Lisbon, where he started the Solid State Technology Group. In 1989 he became Professor of Physics at the Instituto Superior Tecnico in Lisbon. From 1992 to 1996, he was responsible for the start up and operation of INESC´s ASIC back-end of the line microfabrication facility. From 1996 till now, his research areas expanded to magnetoresistive read elements for magnetic data storage, magnetoresistive sensors, MRAMS, and biomedical applications including magnetoresistive biochips. He became director of INESC Microsystems and Nanotechnologies in 2001, and Full Professor of Physics at IST in 2002. Over this period, he co-authored over 200 technical papers and several chapter books. Professional activities include membership in IEEE, participation in several Publication/Program/Advisory Committees of MMM and Intermag Conferences.