Foreword

Engineering Science is concerned with the understanding, analysis, modelling, design, fabrication, manipulation, optimization and control of the human-built world by a marriage of fundamental sciences with technology. Thus, by its very nature, Engineering Science is a highly multidisciplinary activity that seeks to transform our fundamental knowledge about the workings of nature into useful materials, processes and products spanning a wide range of length-scales from nano- to terrestrial scales. In particular, engineering science research in the last decade has witnessed an unprecedented coming together of micro/nano/molecular with biology and computer/information sciences, as well as a greatly increased emphasis on the novel solutions to the problems of energy, water, environment, health, food, transportation, information and security.

Both the achievements and the challenges in the above areas are so vast, and their details so daunting, that to even superficially introduce the basic engineering science themes in a series of five papers (or even fifty!) is an impossible task. We have therefore chosen to focus on a few core tools and competencies of engineering sciences—mechanics, materials, devices, algorithms and modelling of complex systems, to illustrate some of their new and exciting applications, although in very limited settings. The idea is to just introduce a whiff of some of the many directions in which the core competencies of engineering sciences are being manifested today.

The article by **G. K. Ananthasuresh** and **Suman Chakraborty** on *Micromechanics of engineered and biological systems* illustrates nicely some of the directions in which the classical area of mechanics is evolving with the advent of micro and nano technologies and the emerging interest in biological behaviour at the single cell level. The paper discusses three interesting aspects of micro-mechanics and their interplays: coupling of several energetic and length domains, behaviour of fluids on small scales, and cellular biomechanics. There is now a large and growing body of work that deals with coupled multiphysics simulations and design within the area of computational micromechanics, for example, electrostatics and elastic mechanics can be combined into a single unified set of governing equations, which may help develop electro-elasticity in a way similar to thermo-elasticity or aero-elasticity. The second aspect deals with the biophysical and continuum mechanic approaches to the mechanical behaviour of the cells. The third aspect of mechanics discussed is micro-fluidics, where fluid motion at the small scales is often intriguing, exhibiting the dominance of surface effects, anomalous frictional effects and interfacial phenomena in flow actuation, manipulation, and control.

Engineering science is concerned not only with a fundamental understanding of materials and devices, but also with their rational design to meet some useful needs in an efficient and optimised way. Thus, the problems of fabrication, manufacturing and ease of application, together with economy, must be addressed. The chapter by **Jonathan Siegrist**, **Régis Peytavi** and **Marc Madou** titled *Microfluidics for biological analysis: Triumphs & hurdles of CD platforms* illustrates an interesting and creative use of basic microfluidics to development of sample-to-answer platforms focusing on protein and nucleic acid diagnostics. Easy to use, point-of-care centrifugal microfluidic platforms based on the widely available compact-disc format are discussed, along with the advantages they hold to tackling multiple tasks involved in molecular diagnostics. In a larger context, this chapter addresses three of the key concerns of engineering science. First, details often overlooked by the fundamental sciences can be critical and must be addressed rigorously in an actual application that is likely to succeed both in its function and in the market place. For example, many of the hurdles yet to be overcome in the nucleic acid diagnostics field revolve around preparation of the biological sample, a subject often ignored or taken into account only as an afterthought. Second, all widely accepted technologies must not only be scientifically sound, but even more importantly, they should have a user acceptability based on their integration with the existing platforms and the ease/economy of use. Third, to achieve the above two goals, existing ideas have to be often re-interpreted in new and creative ways.

The search for new materials with novel or improved functionalities to meet ever more exacting applications is one of the central concerns of engineering. The area is bustling with activity under such colourful names as nanomaterials, designer materials, meta-materials, advanced materials, functional materials, smart materials, intelligent materials and who knows, maybe even conscious materials in the not too distant future?!. Bio-mimicking or inspiration from nature for the design of new materials is also a powerful idea increasingly being used. The chapter on *Super functional materials: Creation and control of wettability, adhesion and optical effects by meso-texturing of surfaces* by **Vijay M Naik**, **Rabibrata Mukherjee**, **Abhijit Majumder** and **Ashutosh Sharma** presents an introduction to a class of materials that acquire a new functionality by surface meso-structuring, often without changing the chemical nature of the material. Some interesting examples of this class of materials in nature, where a new function is engendered by small scale micro/nano structures on its surface, are super-hydrophobic and self-clean lotus leaves (and a whole lot of other leaves and surfaces), vibrant colours of peacock feathers and butterflies and strong, but reusable (!) adhesion of insects and geckos. The chapter covers the basic physics of structure-function relationships in such materials and a brief on soft micro-fabrication tools used for engineering of such super-functional surfaces.

Of course, not everything in engineering sciences is based on physio-chemical-bio axis, but mathematical science plays a very important role in the fundamentals of algorithms, computations and modelling/analysis of complex systems, both naturally occurring and man-made. Two pristine examples of such powerful mathematical analysis are provided in the chapters by **Manindra Agrawal** and **Ramprasad Saptharishi** titled *Classifying polynomials and identity testing* and by **M Vidyasagar** titled A *tutorial introduction to financial engineering*.

The paper by Manindra Agrawal and Ramprasad Saptharishi discusses a typical problem in computational complexity, namely: What is the intrinsic difficulty of computing a polynomial, and determining whether two polynomials are really the same? Determining the intrinsic difficulty of a computational task is a non-trivial exercise, because the objective is not merely to analyse the complexity of a specific algorithm, but in some sense, the complexity of the *best possible* algorithm. Agrawal and Saptharishi show that, while there are 'low-hanging fruits', in general this problem class displays surprisingly large diversity and poses many intellectual challenges. Similarly, the problem of determining whether two polynomials (specified in possibly different ways) are really the same is also very challenging. One can try for a 'randomized' algorithm of just evaluating the two polynomials at a 'randomly chosen' argument, and see if the two polynomials evaluate to the same answer. If not, then clearly the two polynomials are different. However, one could be unlucky in that the two evaluations just might be equal, even though in reality the two polynomials are not the same. This is one of the characteristics of randomised algorithms, namely that they work 'almost always' but not 'always'. This type of issue is also discussed in the paper by Agrawal and Saptharishi.

The paper by Vidyasagar provides a tutorial introduction to a very timely topic, namely quantitative finance. The use of mathematical methods to compute prices of financial instruments is not exactly new. However, with the advent of high speed computation and improved understanding of the underlying mathematical issues, quantitative finance has become 'mainstream' during the past ten to fifteen years. Nowadays it is quite common for engineering and statistical physics graduates and PhDs to consider Wall Street or 'The City' in London as an equally viable career option (!) compared to more traditional engineering occupations. The paper by Vidyasagar gives a first-principle exposition of most of the key ideas in option-pricing. One of the timely parts of this paper is the section entitled 'What went wrong?', which discusses the role of mathematical modelling, if any, in the recent financial downturn.

It is hoped that the collection of these five articles, limited as it is in its scope, will nevertheless afford the reader a glimpse into some of the diverse and exciting paths currently being traversed by Engineering Sciences.

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