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Sensor Technologies

Healthcare, Wellness and Environmental Applications

Michael J. McGrath and Cliodhna Ní Scanaill

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Sensor Technologies: Healthcare, Wellness, and Environmental Applications

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For my girls, Aisling, Aoise, and Doireann—I love you dearly.

—Michael J. McGrath

Nige and Sophie—this would not have been possible without your love and support.

—Cliodhna Ní Scanaill

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About the Authors

Dr. Michael J. McGrath is a senior researcher at Intel Labs Europe. He has been with Intel for 14 years, holding a variety of operational and research roles. His areas of interest include ambient and body-worn sensor applications, networking technologies, mobile technologies, and data management techniques. Michael was previously a principle investigator at the TRIL Centre, where his research focused on the development of technologies to support independent living. Michael coauthored the book *Wireless Sensor Networks for Healthcare Applications* (Artech House, 2009). He received his B.Sc. in Analytical Science from Dublin City University in 1992 and a Ph.D. in sensors and instrumentation from Dublin City University in 1995. In 1999, Michael received a graduate diploma in information technology from Dublin City University, a graduate diploma in computing from ITB i 2004, and a master's degree in computing from ITB in 2007. Michael is a chartered chemist and a chartered scientist.

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Dr. Dawn Nafus is a senior research scientist at Intel Labs, where she conducts anthropological research to inspire new products and strategies. She holds a Ph.D. in anthropology from the Universit of Cambridge and was previously a research fellow at the University of Essex. She has published widely on technology and society in academic journals, and has worked with public policy makers an industry leaders on issues such as widening participation in open source communities. Her research interests include experiences of time, beliefs about technology and modernity, the politics of measuring global technology adoption, and the anthropology of numbers.

About the Technical Reviewers

Dermot Diamond received his Ph.D. and D.Sc. from Queen's University Belfast (chemical sensors, 1987, Internet scale sensing, 2002), and was vice-president for research at Dublin City University (2002-2004). He has published 300 peer-reviewed papers in international journals, is a named invent in 18 patents, and is coauthor and editor of four books. Dermot is a director and founding member of the National Centre for Sensor Research (www.ncsr.ie) at Dublin City University, a principal investigator at the SFI-funded CLARITY Centre for Sensor Web Technologies (www.clarity-centre.com/), and an SFI-funded investigator in the INSIGHT Centre (www.insight-centre.org). In 2002, he was awarded the inaugural silver medal for sensor research by the Royal Society of Chemistry, London, and in 2006 he received the DCU President's Award for research excellence. His research focuses on the fundamental science of stimuli-responsive polymers, the development of futuristic autonomous chemical sensing platforms, and the use of analytical devices and sensors as information providers for wireless networked systems; that is, building a continuum between the digital and molecular worlds. Details of his research can be found at www.dcu.ie/chemistry/asg.

Chris Nugent received a bachelor of engineering in electronic systems and Ph.D. in biomedical engineering, both from the University of Ulster. He is now professor of biomedical engineering at the University of Ulster.

Chris's research addresses the design, development, and evaluation of mobile and pervasive technologies in smart environments. The main application of this work to date has been in the domain of ambient assisted living. He has published extensively in these areas, with work that spans theoretical, clinical, and biomedical engineering domains.

Currently Chris is group leader of the Smart Environments Research Group. The group's aim is to using an integrated and multidisciplinary approach, advance research to support and monitor people within their homes and beyond.

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Michael J. McGra

Foreword

The Arithmetic of Life

Have you ever dived among the molecular landscapes of a rock sample through the “lens” of an electron microscope? Seen into the pitch darkness with an infrared camera? Traveled down your intestine with a miniature pill camera? Examined the toe of a baby scheduled to be born in five months? The world is full of mystery and wonder that’s beyond the reach of our traditional five senses.

Now the time has come for us all to see and feel the magic beyond, inside, and outside of ourselve Sensing in and around humans is the story of uncovering, discovering, and recovering, whether we’re capturing the signal of our heart beat, measuring oxygen levels in our blood flow, detecting the electrical impulses that bring life to our muscles and nerves, or letting our breath and bodily fluids te happy and sad stories about our present and future. We can sense and make sense of all this and put i all to enormously good use.

Biosensors that sense our health and well-being are on the way, and they are coming to our everyday life. I use the definition of “biosensors” quite broadly, as sensors that detect and measure attributes of our bodies and the environment in which we live. So here’s the plan: we all will employ biosensors to expose the invisible, measure the exposed, intensify these measurements, make sense o the intensity, and trigger actions and alerts based on this sensing on an unprecedented scale.

Why, and why now? Because we are ready, and because we must. We are ready, as major technological trends are converging: the information revolution is upon us with global networking, popular computing, and computer programs (“apps”) as commodities; and nano-technological advances are paving the way to put the right sensors into many hands. We must, because there are major problems to solve and needs to satisfy in many aspects of life.

We are very fortunate to be living in a day and age where military, medical, and industrial advancements are standing in line to join the smartphone revolution. This is made possible by the promise of global popularity and an adaptation of requirements relevant to daily life rather than to rocket science or open heart surgery.

Living by Numbers

To me, all of this is very personal. I’m a diabetic, and technology is keeping me alive—and thankful for the development of the glucose biosensor more than 30 years ago. The role of sensing in my daily life has helped to mold my approach to biosensing as a strategic thinker in a global, technologically pioneering company.

Diabetes is the prime example of a condition managed by information technology. Essentially, the condition is an interplay between carbs consumed, medication taken, and physical activity—as monitored by a personal biosensor. By interplay, I mean doing the arithmetic: if my ice-cream cone boasts 28 grams of carbohydrates, I divide by 4 (my own specific coefficient) and inject seven units

Insulin. If my biosensor, also known as a glucometer, reads 100 units too high, I divide by 50 and inject 2 units. And if it reads below 70, I gobble some 25 grams of sugar. A bit complex, but this is how it works, and it really does work.

Today, there are tens of millions of glucometers out there. The recent introduction of the next big thing in healthcare systems, continuous blood monitoring, is absolutely revolutionary—for those wit the condition, for doctors, and for payers. Not only will we be able to manage blood sugar with a higher resolution that better mimics our impaired metabolism, the increased visibility into the full daily routine will provide exciting new insights and practices, easing the burden of daily managemen We will be able to recognize the immediate cause and effect of our actions, and eventually improve our quality of life and lower healthcare costs. Today, many experts will admit, this is still a world of mystery to the caregivers and sufferers alike.

The opinionated information technologist will readily generate expectations for the final frontier– the "artificial pancreas." This is not an implanted organ but rather a piece of software that inputs continuous glucose measurements and calculates instructions to forward to a connected insulin pump The eager medical technologist will readily come up with several other conditions that could follow a similar development path with much associated promise.

Magical Transitions of Power

You have the right to be amazed: diabetics today are living through a major transition in medical systems, a transition to an era of self-service medicine. Yes, in effect we prescribe our own dosages o a dangerous drug, a relatively small overdose of insulin could be deadly.

The expectation is that the story of biosensing is also the story of a magical transition of power. The 21st century is offering us opportunities to look inside ourselves, see the invisible, look beyond our legacy frames of perception, and shatter the power of the few that operated huge and expensive machines to do all this before. Remember what the digital camera and the camera phone did to the world of photography? We are headed toward an era of such disruptions across a wide array of domains—medicine and wellness, food and diet, water, electricity, environmental monitoring, and home care. Sensing will play a key role in the quality of healthcare delivery by providing on-demand access to current health status. Sensors will also enable service innovation by enabling access to new personal modes of care and services that until now have been the preserve of the privileged few.

Uncovering the Mysteries of Life

The mysteries of life are right under our noses and biosensors will provide new ways to look around and feel reality. In the era of "biosensing in everyday life," we'll be exposed to new data every day, lots of it; it will be ours to own, and ours to utilize and share in whatever manner we deem fit. Our sensors will be always on and always connected; they will work in unison with other biosensors and other crowdsourced data to generate new meanings and extract new patterns of occurrence and reoccurrence in time, space, and among various populations. This will enable increased introspection and greater learning about ourselves; it will also allow for more intimate interaction with loved ones and increase our awareness of the world around us.

Heart rate and steps taken, UV exposure from sunlight, ambient pollution, brain activity, bacteria—all will be available to a new generation of sensing consumers, one that will surpass the mobile generation in its race to exploit emerging capabilities.

As technology shrinks and becomes more mobile and accessible, the price of generating these signals will decrease even further. Data will become much easier to acquire. No longer will it be necessary for us to invade our bodies to extract blood or other bodily fluids; instead, we will employ noninvasive methods—sound, light, electricity, breath-sniffing, and clothing that senses our tiniest motions. The ancients contemplated an aura surrounding our bodies; biosensors will prove they were right, albeit in a different and much more useful sense.

This book is an introduction to sensors and to their applications that allow us to take greater personal ownership in monitoring our own health, wellness and the environments we live in. We are introduced to a future that will let each of us peer with unprecedented clarity into the complexities of the human body, to see our own aura and tap into it for data that can be processed into personal or public knowledge bases. The authors provide exciting insights into the pipeline of capabilities and usages, while looking beyond the hype and calibrating expectations.

Biosensors are upon us—welcome to the definitive technology handbook of yet another age of wonder, empowerment, and mysteries unfolded.

David Gordo
Strategic Planning Directo
Intel Corporatio

Preface

The groundwork of all happiness is health.

Leigh Hunt, 19th-century English po

When we first decided to write a book on sensors and their applications, we had little doubt about the theme or type of book we wanted to write. Though there are some excellent books on sensors and how they function, we felt this could be an opportunity to provide some practical insights into sensor application development, deployment, and evaluation. Having worked together in Intel's Digital Health Group and the Technology Research for Independent Living (TRIL) Centre for over six years, we were involved in developing and deploying healthcare technology to the homes of hundreds of older Irish adults. During that time, we worked in various multidisciplinary teams and collected insights from patients and clinical professionals, learning many valuable lessons along the way. These experiences have hopefully allowed us to gain a greater understanding of how sensor technology can be successfully applied and how external factors influence real-world sensor applications. In this book, we share much of what we've learned in a practical and easy-to-understand manner. We cover topics such as device regulation, managing sensor deployments, data visualization, and societal considerations, which are fundamental to all modern sensor-based applications, but are rarely described in sensor- or domain-specific books. We also examine how recent technology trends, such as mass adoption of smartphones and tablets, are affecting the proliferation of sensors applications into the consumer market.

We focus on the domains of healthcare, wellness, and environmental monitoring as they present some of the largest global challenges affecting us in the 21st century. Sensing plays an important role in these domains to help us to learn about the factors that influence our well-being, including our health status, our lifestyles, the food and water we consume, the air we breathe, and the quality of the environments in which we live. In a world that is becoming increasingly sensorized, we wanted to write an accessible book for anyone who wants to understand sensors and the technical and non-technical challenges in developing sensor applications, including clinical and technical researchers, engineers, students, and those who are simply curious about sensors. We hope this book will also help domain experts, such as clinicians or engineers, to understand the sensor applications in a more holistic manner.

This book is split into three sections: Chapters 2 to 5 describe sensors and the various hardware and software components required to create an end-to-end smart-sensor application; Chapters 6 to 8 describe the non-technical factors that must be considered for a successful sensor application; Chapters 9 to 11 describe sensor applications for health, wellness, and environmental monitoring. The chapters can be read sequentially or readers can dip in and out of the chapters that interest them. Throughout the book, we were mindful to reference links between chapters or to external material, to allow the reader to get more in-depth information on a topic, if they wish. Although we discuss sensing from a health, wellness, and environmental monitoring perspective, we believe that the core content of this book is applicable to any sensing domain.

We encourage people to download a copy of the ebook and to share it among their colleagues, friends, and families. We only ask that you follow the license on the copyright page.

We hope after reading this book, you will not only share our knowledge of sensing and sensor

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