# Virtual and Mobile Healthcare:

## Breakthroughs in Research and Practice

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# Preface

Today's society is continually becoming more fast-paced than ever before with our business, social, and even fitness needs available at the touch of our fingertips. Because more of our lives are becoming easily accessible, healthcare and medical advice must also follow this trend. Through mobile applications (apps) and user-friendly websites, insurance companies and medical providers are reaching patients via a more convenient medium in smartphones while also providing care to those who may otherwise be disinclined or too busy for an in-office appointment. Online applications and mHealth opportunities also give patients the option of making appointments electronically to assist in streamlining the communication between them and the medical provider and then providing reminders directly to their phones of any upcoming appointments.

Mobile health—the use of smartphones and other mobile technologies to support healthcare—offers various conveniences to patients such as setting appointments and medication management while encouraging users to become more engaged in their care. Beyond the individual patient using mobile and virtual health apps to assist their own needs, hospitals, doctors' offices, and other medical providers can use their apps to support public health and often forgotten preventative measures. For example, one health network may use texting to remind users to wear sunscreen and stay hydrated on hot, sunny days. Non-medical health apps such as FitBit and MyFitnessPal send reminder notifications to users' smartphones to get up from desks and stay active during the workday.

Beyond the patient's advantages of virtual and mobile healthcare, hospitals and practitioners also experience great benefits from it such as its cost effectiveness and time efficiency. Recent studies by the American Association of Medical Colleges show a projected shortage of family physicians in the upcoming years, and a crisis as such in the medical field makes it even more imperative for the physician's time to be used efficiently and effectively (Safavi & Dare, 2018). mHealth provides practitioners with the option of utilizing digital technologies to collect symptoms, medical history, and other information from the patient prior to the appointment as this data collection is typically the most time-consuming aspect of a visit. By receiving this information digitally beforehand, the primary care physician may review the history and have potential treatment options researched and ready for the patient at the time of their appointment. This application can save care providers a substantial amount of time over the course of the year. Digital triage and telemedicine for self-care of chronic conditions, such as diabetes, still allow the physicians to effectively treat their patients but in a manner that is much more conducive for them, their office, and their patients, sometimes not even requiring an in-office visit.

Although virtual and mobile healthcare is still on the rise, researchers, physicians, patients, and hospitals are already experiencing the numerous benefits to be had through digital medical care. Patients become more engaged in their health through mobile visits, visual representations of test results,

treatments, and care plans, and have their medical needs tended to without the need to make a formal in-office appointment. Physicians meanwhile benefit from having their time more effectively managed, are prepared with medical history and treatment options before going into an appointment, and can spend more time with other patients that require more personal interaction. Finally, hospitals can present patients with visual charts and text explaining test results and treatments allowing them to more coherently explain these to non-medical professionals and patients. Unfortunately, however, the lack of integration in offices and hospitals along with state regulations on mHealth are negatively impacting the potential virtual healthcare can have on the medical community at large.

The everchanging landscape surrounding the diverse applications of different scientific areas can make it very challenging to stay on the forefront of innovative research trends. That is why IGI Global is pleased to offer this two-volume comprehensive reference that will empower physicians, medical researchers, healthcare administrators and professionals, students, researchers, practitioners, and academicians with a stronger understanding of virtual and mobile healthcare.

This compilation is designed to act as a single reference source on conceptual, methodological, and technical aspects, and will provide insight into emerging topics including but not limited to eHealth, virtual healthcare, clinical decision-support systems, telemedicine, patient engagement, data security and protection, and mobile health commitment. The chapters within this publication are sure to provide readers the tools necessary for further research and discovery in their respective industries and/or fields.

*Virtual and Mobile Healthcare: Breakthroughs in Research and Practice* is organized into nine sections that provide comprehensive coverage of important topics. The sections are:

1. Cloud-Based Healthcare;
2. Data Mining, Big Data, and Analytics;
3. Electronic Health Records and Information Exchange;
4. Health Information Technology;
5. Health Monitoring Systems;
6. Internet of Things;
7. mHealth and eHealth;
8. Telehealth; and
9. Virtual Health Training.

The following paragraphs provide a summary of what to expect from this invaluable reference source:

Section 1, "Cloud-Based Healthcare," opens this extensive reference source by highlighting the latest trends in smart healthcare applications in the cloud. In the first chapter of this section, "Service Level Agreements for Smart Healthcare in Cloud," the authors, Prof. Mridul Paul and Prof. Ajanta Das from Birla Institute of Technology Mesra, India, describe their design for a cloud-based smart service for patient diagnostics through functional and non-functional requirements of Service Level Agreements (SLA) to ensure guaranteed services to patients. In the second chapter, "Cloud Computing as the Useful Resource for Application of the Medical Information System for Quality Assurance Purposes," Prof. Ekaterina Kldiashvili from the Georgian Telemedicine Union (Association), Georgia defines cloud computing as a flexible, secure, coordinated resource for data sharing among dynamic collections of individuals and institutions and argues in her paper the potential practical uses of cloud computing in health care services. In a noteworthy chapter, "Cloud Based Wireless Infrastructure for Health Monitoring," the authors, Prof. Ajay Chaudhary and Prof. Sateesh Kumar Peddoju from the Indian Institute of

Technology Roorkee, India; and Prof. Suresh Kumar Peddoju from Kakatiya Institute of Technology and Science, India, review complete state-of-the-art cases related to healthcare monitoring using wireless infrastructure and adapting cloud-based technologies in providing healthcare services. In the following chapter, "Secure Health Monitoring in the Cloud Using Homomorphic Encryption: A Branching-Program Formulation," the authors, Prof. Scott Ames, Prof. Muthuramakrishnan Venkitasubramaniam, Prof. Alex Page, Prof. Ovunc Kocabas, and Prof. Tolga Soyata from the University of Rochester, USA, apply fully homomorphic encryption (FHE) into the healthcare and patient data that is stored in the cloud to improve processing speeds while protecting sensitive patient information from misuse. In the final chapter of this section, "Towards Privacy-Preserving Medical Cloud Computing Using Homomorphic Encryption," the authors, Prof. Ovunc Kocabas and Prof. Tolga Soyata from the University of Rochester, USA, present a novel medical cloud computing approach that eliminates privacy concerns associated with the cloud provider that capitalizes on FHE potential. The authors present their FHE approach by displaying its implementation in a long-term cardiac health monitoring study.

Section 2, "Data Mining, Big Data, and Analytics," includes chapters on emerging innovations for optimized data mining techniques and intelligence applications in modern healthcare. In the first chapter of this section, "A Method for Classification Using Data Mining Technique for Diabetes: A Study of Health Care Information System," Prof. Ahmad Al-Khasawneh from Hashemite University, Jordan reviews four predictive data mining approaches that are being used to diagnose diabetes—k-nearest neighbor, support vector machine, multilayer perceptron neural network, and naive Bayesian network—to find the most effective method. In the following chapter, "Application of Complex Event Processing Techniques to Big Data Related to Healthcare: A Systematic Literature Review of Case Studies," the authors, Prof. Fehmida Mohamedali and Prof. Samia Oussena from the University of West London, UK, provide an overview of where in the health sector complex event processing (CEP) is most used, the data sources that contribute to it, and the types of event processing languages and techniques implemented to combat the slow progress of healthcare delivery systems in the United Kingdom. In the third chapter of this section, "Concoction of Ambient Intelligence and Big Data for Better Patient Ministration Services," the authors, Prof. Arushi Jain and Prof. Vishal Bhatnagar from the Ambedkar Institute of Advanced Communication Technology and Research, India, implement an ambient intelligence-based algorithm to a specific hospital environment to monitor patient health arguing the algorithm works to alert the patients' assistants if any unwanted variations occur in the patients' health parameters. In the concluding chapter of this section, "Towards Clinical and Operational Efficiency Through Healthcare Process Analytics," the authors, Prof. Vassiliki Koufi, Prof. Flora Malamateniou, and Prof. George Vassilacopoulos from the University of Piraeus, Greece, present a framework for optimizing healthcare procedures by analyzing process-related data to ensure that they meet the stated operational and performance objectives. The framework is built on top of a data infrastructure that integrates process-related data from various sources into a structured view suitable for analytics and decision support while it emphasizes security and patient privacy during healthcare processes.

Section 3, "Electronic Health Records and Information Exchange," presents coverage on novel strategies and innovative applications to modernize health records and patient information. In the first chapter in this section, "Hierarchy Similarity Analyser: An Approach to Securely Share Electronic Health Records," the authors, Prof. Shalini Bhartiya from IITM, India; Prof. Deepti Mehrotra from Amity University, India; and Prof. Anup Grdhar from Sedulity Groups, India, describe a proposed framework which would permit interoperable electronic health records (EHR) sharing while restricting access to unauthorized individuals using access control policy testing (ACPT). In the second chapter, "Biometric Secured Electronic Health

Record," the authors, Prof. Suresh Sankaranarayanan and Prof. Vigneshwaran Udayasuriyan from SRM University, India, investigate methods to reduce the false rejection ratio (FRR) and false acceptance ratio (FAR) in biometric-based access systems in care facilities. Within the following chapter, "EEMI – An Electronic Health Record for Pediatricians: Adoption Barriers, Services and Use in Mexico," the authors, Prof. Juan C. Lavariega, Prof. Roberto Garza, Prof. Lorena G. Gómez, Prof. Victor J. Lara-Diaz, and Prof. Manuel J. Silva-Cavazos from Tecnologico de Monterrey, Mexico, investigate the advantages of EEMI, a child-focused EHR, in modern pediatric offices to keep the relationships among diagnosis, treatment, and medications for patients compact and easily accessible furthering EEMI's standardization in Mexico. In a noteworthy chapter, "Critical Success Factors in Electronic Health Records (EHR) Implementation: An Exploratory Study in North India," the authors, Prof. Navneet Kaur Bajwa and Prof. Harjot Singh from Thapar University, India and Prof. Kalyan Kumar De from Amity University, India, investigate the role of critical success factors (CSF) in implementation processes of EHR systems in northern Indian multispecialty hospitals through a questionnaire distributed among those hospitals using EHR technology and surveying how impactful the CSFs are in the overall function of the office. In one of the concluding chapters, "An Architectural Solution for Health Information Exchange," the authors, Prof. Timoteus B. Ziminski, Prof. Steven A. Demurjian, Prof. Eugene Sanzi, Prof. Mohammed Baihan from the University of Connecticut, USA and Prof. Thomas Agresta from the University of Connecticut Health Center, USA, propose an architectural solution for health information exchanges (HIE) that leverage established software architectural styles in conjunction with the emergent HL7 standard fast healthcare interoperability resources (FHIR). FHIR models healthcare data with XML or JSON schemas using a set of 93 resources to track a patient's clinical findings, problems, allergies, adverse events, history, suggested physician orders, care planning, etc. Within another noteworthy chapter, "Barriers to Successful Health Information Exchange Systems in Canada and the USA: A Systematic Review," the authors, Prof. Basmah Almoaber from King Khalid University, Saudi Arabia & the University of Ottawa, Canada and Prof. Daniel Amyot from the University of Ottawa, Canada, study the barriers influencing the adoption and implementation of inter-organization HIE systems in Canada and the USA that are currently preventing health exchange projects between the two countries while citing privacy concerns and low stakeholder buy-in in the USA and low electronic records adoption in Canada as possible culprits. In the final chapter of this section, "Inter-Organizational Knowledge Sharing System in the Health Sector: Physicians' Perspective," Prof. Kamla Ali Al-Busaidi from Sultan Qaboos University, Oman, explores physicians' attitudes toward inter-organizational knowledge sharing system (IOKSS) deployment in the health sector in Oman showing results that are valuable for organizational designing, planning, and decision-making regarding their adoption of IOKSS in the health sector.

Section 4, "Health Information Technology," discusses coverage and research perspectives on innovative approaches to information technology application in medical environments. In the first chapter in the section, "The Process of Strategic, Agile, Innovation Development: A Healthcare Systems Implementation Case Study," the authors, Prof. Say Yen Teoh from RMIT University, Australia and Prof. Shun Cai from Xiamen University, China, aim to understand how agility and innovation capabilities can be strategically nurtured, developed, and managed to upgrade the quality of healthcare services. In the following chapter, "Towards the Development of Smart Spaces-Based Socio-Cyber-Medicine Systems," Prof. Yulia V. Zavyalova, Prof. Dmitry G. Korzun, Prof. Alexander Yu Meigal, and Prof. Alexander V. Borodin from Petrozavodsk State University, Russia explore Cyber-Medicine System (CMS) applications in medical information systems using the internet to integrate the data into medical devices and services to connect patients and professionals fusing the cyber and physical worlds. Within the third

chapter of this section, "Physician Engagement With Health Information Technology: Implications for Practice and Professionalism," the three authors, Prof. Erik L. Carlton from the University of Memphis, USA; Prof. James W. Holsinger Jr. from the University of Kentucky, USA; and Prof. Nnamdi Anunobi from the University of Memphis, USA, investigate the advantages and practicality of integrating health information technology (HIT) into 21st century physicians' offices. The advantages include enhancing the medical practice, reducing office costs, and improving patient experience while allowing for new approaches and higher professional standards. In a noteworthy chapter, "Adoption of ICT in Implementing Primary Health Care: Achievements of the Twenty-First Century," Prof. Quazi Omar Faruq and Prof. Arthur Tatnall from Victoria University, Australia discuss the introduction and use of information and communication technologies in primary healthcare and investigates reasons for adoption, or non-adoption, of these technologies. In particular, the authors investigate ICT use among general practitioners, eHealth, and the virtual doctor program in Australian offices. In the next chapter, "General Practitioners' Adoption and Use of ICT," Prof. Quazi Omar Faruq from Victoria University, Australia discusses the historical impact of implementing ICTs into general practitioner offices while he also investigates the evolving role of ICT in practices moving forward. In another noteworthy chapter, "ICTs, E-Health, and Multidisciplinary Healthcare Teams: Promises and Challenges," Prof. Bolanle A. Olaniran from Texas Tech University, USA explores the role ICTs play in the multidisciplinary teams (MDTMs) in healthcare settings while he also addresses the benefits and challenges ICTs may have in MDTMs such as privacy concerns. Within the following chapter, "Steps Towards Interoperability in Healthcare Environment," the authors, Prof. Hugo Peixoto from Centro Hospitalar do Tâmega e Sousa E.P.E., Portugal and Prof. Andréa Domingues and Prof. Bruno Fernandes from the University of Minho, Portugal, present a set of case studies from Centro Hospitalar do Tâmega e Sousa in which electronic semantic health record is implemented through various intelligent agents to strengthen the relationship between a patient and hospital. The goal of the electronic semantic health record is to support an appointment alert system, reduce non-programmed medical misses, and decrease costs to promote a streamline healthcare service for both the hospital and the patient. In a significant chapter of this section, "Semantic Interoperability-Enabled Architecture for Connected Health Services," Prof. Adel Taweel of King's College London, UK and Birzeit University, Palestine, presents a service-based approach that utilizes domain models combined with extensible problem models, enriched with domain terminology and knowledge services to enable autonomous data governance and semantic interoperability. In another important chapter, "Medical Case Based Reasoning Frameworks: Current Developments and Future Directions," the two authors, Prof. Shaker El-Sappagh from Minia University, Egypt and Prof. Mahfouz Elmogy from Mansoura University, Egypt, examine the current state of case-based reasoning (CBR) and its limitations in the medical domain, especially for diabetes mellitus, and evaluate the status of diabetes CBR systems for improvement. In one of the final chapters of this section, "Methodologies of Legacy Clinical Decision Support System: A Review," the authors, Prof. Meenakshi Sharmi from G.I.M.E.T., India and Prof. Himanshu Aggarwal from Punjabi University, India, explain clinical decision support along with the gateway to physicians and to policymakers to develop and deploy decision support systems as a healthcare service to make the quick, agile, and right decision for patients and healthcare. Within the concluding chapter, "A Multiplatform Decision Support Tool in Neonatology and Pediatric Care," the authors, Prof. Tiago Guimarães and Prof. Ana Coimbra from the University of Minho, Portugal; Prof. Simão Frutuoso from Centro Hospitalar do Porto, Portugal; and Prof. António Abelha from the University of Minho, Portugal, develop a framework to include tools that can help in the preparation of total parenteral nutrition prescriptions, table pediatric and neonatal emergency drugs, medical scales

of morbidity and mortality, anthropometry percentiles (weight, length/height, head circumference, and BMI), utilities for supporting medical decision on the treatment of neonatal jaundice and anemia, and other calculators in pediatric offices.

Section 5, "Health Monitoring Systems," explores coverage and applications of emerging technologies to support patient monitoring in medical environments. In the first chapter in this section, "A Trusted Ubiquitous Healthcare Monitoring System for Hospital Environment," the authors, Prof. Durga Prasad and Prof. Niranjan N. Chiplunkar from NMAM Institute of Technology, India and Prof. K. Prabhakar Nayak from Manipal Institute of Technology, India, focus on creating an android-based application for monitoring patients in a hospital environment through sensors that forward physiological data to the personnel at the hospital, doctor, or caretaker. In the second chapter, "Recent Advances in Minimally-Obtrusive Monitoring of People's Health," Prof. Amol D. Mali from the University of Wisconsin-Milwaukee, USA surveys the latest research on monitoring parameters that indicate a person's current health, or having potential to affect the person's health in future, using various physical sensors such as accelerometers, gyroscopes, electromyography sensors, fiber optic sensors, textile electrodes, thermistors, infrared sensors, force sensors, and photo diodes. In the following chapter, "Designing Smart Home Environments for Unobtrusive Monitoring for Independent Living: The Use Case of USEFIL," Prof. Homer Papadopoulos from the National Center for Scientific Research (NCSR) "Demokritos," Greece demonstrates the use of the design science research methodology (DSRM) process to design an ICT solution for the case study of ICT technologies for assistive living environments for elderly people specifically using the theoretical lens of the DSRM theory. Within a noteworthy chapter in this section, "Design and Development of Real Time Patient Monitoring System With GSM Technology," the authors, Prof. Sindhu Suryanarayanan, Prof. Sreekala Manmadhan, and Prof. N. Rakesh from Amrita Vishwa Vidyapeetham, India, explore patient monitoring systems in real-time and the common applications of these systems in hospitals and other medical environments. In another noteworthy chapter, "Design of WSN in Real Time Application of Health Monitoring System," the authors, Prof. Srinivas Sethi and Prof. Ramesh K. Sahoo from IGIT Sarang, India, describe the parameter values of the body that can be transmitted to remote data center with reliability, simplicity, low power, low bandwidth, and low cost in lightweight wireless networks to be used in real-time for items such as emotion and stress analysis, psychological study, physiological study, health condition, etc. In the next chapter, "New Features for Damage Detection and Their Temperature Stability," the authors, Prof. Fahit Gharibnezhad, Prof. Luis Eduardo Mujica Delgado, and Prof. Jose Rodellar from Universitat Politècnica de Catalunya, Spain, present novel techniques in structural health monitoring (SHM) based on different statistical and signal processing methods that are used in other fields but their performance and capability in SHM is presented and tested for the first time in this work. In one of the final chapters, "Nonlinear Ultrasonics for Early Damage Detection," the authors, Prof. Rafael Munoz, Prof. Guillermo Rus, Prof. Nicolas Bochud from the University of Granada, Spain; Prof. Daniel J. Barnard from Iowa State University, USA; Prof. Juan Melchor, Prof. Juan Chiachío Ruano, Prof. Manuel Chiachío, Prof. Sergio Cantero, Prof. Antonio M. Callejas, Prof. Laura M. Peralta from the University of Granada, Spain; and Prof. Leonard J. Bond from Iowa State University, USA, explore the integration of nonlinear ultrasonics with the Bayesian inverse problem as an appropriate tool to estimate the updated health state of a component taking into account the associated uncertainties. Within the following chapter, "Butterworth Filter Application for Structural Health Monitoring," the three authors, Prof. Ahmed Abdelgawad, Prof. Md Anam Mahud, and Prof. Kumar Yelamarthi from Central Michigan University, USA, propose a mathematical model to detect the size and location of damages in physical structures using the piezoelectric sensor. In an-

other concluding chapter, "Parallel and Distributed Population Based Feature Selection Framework for Health Monitoring," the authors, Prof. Naoual El Aboudi and Prof. Laila Benhlima from Mohammed V University, Morocco, provide an overview of existing feature selection methods especially those used in the context of big data, pointing out their advantages and drawbacks and proposes a parallel population based feature selection framework for health monitoring. In the final chapter of this section, "A Low Cost Pupillometry Approach," the three authors, Prof. Sergio Petridis, Prof. Theodoros Giannakopoulos, Prof. Constantine D. Spyropoulos from the National Center for Scientific Research "Demokritos," Greece, describe a method for monitoring pupil sizes using a common, low-cost web camera in real time in which the proposed approach detects the face and the eyes area at first stage before moving towards the pupil center and radius.

Section 6, "Internet of Things" covers innovative approaches to modern integration of the internet of things in healthcare environments and technologies. In the first chapter, "Thing Theory: Connecting Humans to Smart Healthcare," the authors, Prof. Sally A. Applin and Prof. Michael D. Fischer from the University of Kent – Canterbury, UK, explore how PolySocial Reality (PoSR), a framework for representing how people, devices and communication technologies interact, can be applied to developing use cases combining IoT and smart environment paradigms, giving special consideration to the nature of location-aware messaging from sensors and the resultant data collection in a healthcare environment. Within the final chapter of this section, "Reliability of IoT-Aware BPMN Healthcare Processes," the three authors, Prof. Dulce Domingos from the Universidade de Lisboa, Portugal; Prof. Ana Respício from the Operations Research Center/GUESS/Universidade de Lisboa, Portugal; and Prof. Ricardo Martinho from the Polytechnic Institute of Leiria, Portugal, focus on reliability and proposes to use the stochastic workflow reduction (SWR) method to calculate the reliability of IoT-aware BPMN healthcare processes as well as a BPMN language extension to provide processes with reliability information.

Section 7, "mHealth and eHealth," highlights the latest research in electronic and mobile health applications in diverse uses. Within the first chapter of this section, "A Taxonomy for mHealth," the authors, Prof. Ruwini Edirisinghe from RMIT University, Australia; Prof. Andrew Stanieri from Federation University, Australia; and Prof. Nilmini Wickramasinghe from Epworth HealthCare and Deakin University, Australia, offer a suitable taxonomy to systematically analyze and evaluate the existing solutions based on a number of dimensions including technological, clinical, social, and economic. In the following chapter, "M-Health in Prehospital Emergency Medicine: Experiences from the EU funded Project LiveCity," the two authors, Prof. Bibiana Metelmann and Prof. Camilla Metelmann from Greifswald University, Germany, display different approaches to provide prehospital emergency medicine using mHealth, such as smart phone applications for high definition video communication, to treat life-threatening conditions as soon as possible. In the third chapter of this section, "Mobile Healthcare in an Increasingly Connected Developing World," the authors, Prof. Nikhil Yadav from St. John's University, USA; Prof. Mehrdad Aliasgari from California State University, USA; and Prof. Christian Poellabauer from the University of Notre Dame, USA, discuss mHealth use, challenges, and solutions suitable for the developing world, highlighting existing problems and risks in realizing secure mHealth applications and services. In a significant chapter in this section, "Factors Influencing Physicians' Acceptance of e-Health in Developing Country: An Empirical Study," the three authors, Prof. Md. Rakibul Hoque from the University of Dhaka, Bangladesh; Prof. Adnan Albar from King Abdulaziz University, Saudi Arabia; and Prof. Jahangir Alam from the Bangladesh University of Business and Technology (BUBT), Bangladesh, aim to identify the critical factors affecting e-Health adoption among physicians in Bangladesh through a cross-sectional survey. In the concluding chapter, "eHealth Service Modeling for Developing

Country: A Case of Emergency Medical Service for Elderly in Asia," the authors, Prof. Vatcharapong Sukkird from Japan Advanced Institute of Science and Technology, Japan & Thammasat University, Thailand and Prof. Kunio Shirahada from Japan Advanced Institute of Science and Technology, Japan, look to develop an eHealth service model through mobile technology for developing countries to face with elderly patient demands in aging societies.

Section 8, "Telehealth," explores the emerging trends in telemedicine technologies that allow for fewer in office visits and stronger patient-doctor communication. In the opening chapter of this section, "Working Anywhere for Telehealth," Prof. Yvette Blount from Macquarie University, Australia and Prof. Marianne Gloet from the University of Melbourne, Australia examine telehealth adoption from clinicians' perspective through 44 in-depth interviews with Australian clinicians highlighting the benefits and drawbacks of telehealth use in their offices. In the second chapter, "The Influence of National Factors on Transferring and Adopting Telemedicine Technology: Perspectives of Chief Information Officers," Prof. Fariba Latifi from Lakehead University, Canada and Prof. Somayeh Alizadeh from Macquarie University, Australia investigate the national factors influencing the adoption of telemedicine technology in Iran, as a less developed country, through a self-administered questionnaire collected from Chief Information Officers of numerous Iranian healthcare systems. The findings indicate that political factors such as information and communication technology (ICT) policies, national data security policies, national e-health policies, national ICT infrastructures and rational decision-making, along with organizational factors such as organizational readiness and implementation effectiveness, are positively associated with telemedicine capability in Iran though no cultural factors impacted transferring to telemedicine in the country. In a noteworthy chapter, "A Proxy-Based Solution for Asynchronous Telemedical Systems," the authors, Prof. Sampsa Rauti, Prof. Janne Lahtiranta, Prof. Heidi Parisod from the Univesity of Turku, Finland; Prof. Sami Hyrynsalmi from Tampere University of Technology, Finland; Prof. Sanna Salanterä, Prof. Minna Elisabeth Aromaa, Prof. Jouni Smed, and Prof. Ville Leppänen from the University of Turku, Finland, present a proxy-based solution against data modification and spying attacks in web-based telemedical applications by obfuscating the executable code of a web application and by continuously dynamically changing obfuscation. In one of the final chapters of this section, "M-Health Telemedicine and Telepresence in Oral and Maxillofacial Surgery: An Innovative Prehospital Healthcare Concept in Structurally Weak Areas," the two authors, Prof. Katharina Witzke from General Dental Practice Bernd Hagen, Germany and Prof. Olaf Specht from the Institute for Implant Technology and Biomaterials e.V., Germany, present a comprehensive mHealth concept for oral and maxillofacial surgery as well as for dentistry in the context of emergencies that would open up a new perspective of patient-centered care. In the following chapter, "Mobile Telemedicine Systems for Remote Patient's Chronic Wound Monitoring," the three authors, Prof. Chinmay Chakraborty and Prof. Bharat Gupta from BIT Mesra, India and Prof. Soumya K. Ghosh from the Indian Institute of Technology Kharagpur, India, describes the implementation of a mobile telemedicine system for patient's chronic wound (CW) monitoring using a smartphone that has proven to be quick and reliable for providing healthcare at the door step. In the concluding chapter of this section, "Medco: An Emergency Tele-Medicine System for Ambulance," the authors, Prof. Anurag Anil Saikar from Smt. Kashibai Navale College of Engineering, India & Savtribai Phule Pune University, India; Prof. Aditya Badve, Prof. Mihir Pradeep Parulekar, Prof. Ishan Patil, Prof. Sahil Shirish Belsare, and Prof. Aaradhana Arvind Deshmukh from Smt. Kashibai Navale College of Engineering, India, propose a portable system which transmits the vital parameters to the healthcare center along with the images of the patient, also availing the patient's personal health record to the doc-

tor, thus bridging the gap between the hospital and the ambulance and "virtually" bringing the doctor to the ambulance, thereby allowing him to diagnose the patient remotely and as accurately as possible.

Section 9, "Virtual Health Training," focuses on the opportunities available for practitioners and hospitals in adopting virtual health and the necessary information needed to effectively implement it in their institutions. In the first chapter, "Who Am I as a Healthcare Provider? Identity and Transformative Learning in Virtual Environments," Prof. Rachel Umoren from the University of Washington, USA and Prof. Natalia Rybas from Indiana University East, USA explore the role of training healthcare professional students using virtual simulations and the emerging potential of virtual and augmented reality for health professional education. In the final chapter of this section and reference work, "Using Simulation to Teach Security and Encryption to Non-Technical Healthcare Professionals," the authors, Prof. Mark Gaynor, Prof. Tracy Omer, and Prof. Jason S. Turner from Saint Louis University, USA, intend to simplify challenging concepts through role-play demonstrations and serve as a foundation for understanding the basis of securing healthcare data. The authors review the benefits of simulation learning and outline a workshop and simulation game developed in response to difficulties teaching the technology of encryption and validate their results with anecdotal and indirect statistical evidence.

Research and implementation strategies of virtual and mobile healthcare are continually updating and advancing although current research shows a continual progression of usage and the advantages it brings to health centers, clinics, doctors' offices, and to individual patients. It shows to be cost-effective, time-efficient, and more conducive to all parties.

Although the primary organization of the contents in this work is based on its nine sections, offering a progression of coverage of the important concepts, methodologies, technologies, applications, social issues, and emerging trends, the reader can also identify specific contents by utilizing the extensive indexing system listed at the end.

## REFERENCES

Safavi, K., & Dare, F. (2018). Virtual health care could save the U.S. billions each year. *Harvard Business Review*. Retrieved from https://hbr.org/2018/04/virtual-health-care-could-save-the-u-s-billions-each-year

# Chapter 34
# Nonlinear Ultrasonics for Early Damage Detection

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## ABSTRACT

*Structural Health Monitoring (SHM) is an emerging discipline that aims at improving the management of the life cycle of industrial components. The scope of this chapter is to present the integration of nonlinear ultrasonics with the Bayesian inverse problem as an appropriate tool to estimate the updated health state of a component taking into account the associated uncertainties. This updated information can be further used by prognostics algorithms to estimate the future damage stages. Nonlinear ultrasonics allows an early detection of damage moving forward the achievement of reliable predictions, while the inverse problem emerges as a rigorous method to extract the slight signature of early damage inside the experimental signals using theoretical models. The Bayesian version of the inverse problem allows measuring the underlying uncertainties, improving the prediction process. This chapter presents the fundamentals of nonlinear ultrasonics, their practical application for SHM, and the Bayesian inverse problem as a method to unveil damage and manage uncertainty.*

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## INTRODUCTION

Nonlinear ultrasonics can play a major role in industrial structural health monitoring, since one of its main features is the capability to detect early damage manifestations. The nonlinear constitutive properties of a material, in the sense of deviation from Hooke's law, are recently being shown to be orders of magnitude more sensitive to micro-damage than the linear ones. As a consequence, a number of effects arise in the propagation of the ultrasonic waves as they interact with the material nonlinearity (Ostrovsky & Johnson, 2001; Broda, Staszewski, Martowicz, & Silberschmidt, 2014), namely,

- **Higher Harmonics Generation:** When a sinusoidal wave is emitted, a signal with additional harmonics, multiples of the fundamental, is received.
- Hysteretic mechanical behavior, in the stress-strain relationship.
- Wave modulations:
  - In amplitude and phase when two sinusoidal frequencies are propagated.
  - **Cross-Modulation of Waves (Luxemburg-Gorky Effect):** Passing modulation from an amplitude modulated excitation to a simultaneous and initially pure sinusoidal excitation.
- Amplitude dependent resonant frequency shifts when the material is insonified.
- Attenuation that depends on the excitation amplitude.
- **Acoustic Conditioning:** An immediate offset on material property values when insonification is active. The initial transient period time is also referred as fast dynamics.
- **Relaxation Effects or Fast and Slow Dynamics:** When excitation vanishes, material properties has a partial fast recovery and a slow final recovery that last minutes to achieve the original values, before excitation.
- Subharmonic generation.

These nonlinear effects, which are originated in the materials' microscopic and mesoscopic structures, are separable from the linear propagation in the frequency domain by a variety of experimental configurations (Ostrovsky & Johnson, 2001; Zheng, Maev, & Solodov, 1999; Jhang, 2009). Mesoscopic size is the scale of early damage manifestations, and micro-damage has also been shown to be particularly invisible to linear techniques (Nicholson & Bouxsein, 2000). Some recent experimental observations suggest that hysteretic and/or *nonlinear mechanical properties* may be a key factor to quantify changes and could unveil details of the micro- and meso-structure; both the intrinsic nonlinearity in the material or that of an induced damage. In practice, micro-damage modes such as micro-cracks behave as ultrasonic sources at frequencies different from the excitation, making it a promising tool to clearly locate and quantify damage (Matikas T., 2010). Nonetheless, few studies have been performed on the relationship between crack density and level of nonlinearity (Haupert, et al., 2014; Renaud, Callé, Remenieras, & Defontaine, 2008).

Industry will always quest for an as early as possible detection of damage. The increasing complexity of materials and damage modes, along with early detection needs, is leading to a cutting-edge development and usage of nondestructive techniques. The challenge is the extraction of a weak damage signature within the received signals. This demanding evaluation of the material integrity is one of the drivers on the incorporation of theoretical models to discriminate these weak damage signatures, by means of solving a model-based inverse problem. The aim is to reproduce, by modeled simulations, the acquired signals of the test, using an iterative procedure, which progressively adjusts the values of the model parameters,

1. Obtain robust predictions,
2. Scrutinize the behavior of a model to reproduce the SHM measurements, and finally
3. Rank the best-suited class of models.

Based on the inverse problem procedure, a real-time diagnostic tool using ultrasound-based SHM data would contribute to achieve condition-based maintenance technologies, which are fully impacting on critical engineering systems like nuclear engineering and aerospace, among others.

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## KEY TERMS AND DEFINITIONS

**Computational Model Uncertainty:** Computational models introduce new errors and assumptions on the digitalized calculation method, so that simulated signals accumulate theoretical and computational uncertainties.

**Data Uncertainty:** The test is subject to generate signals with noise and all kind of uncontrolled oscillations originated in test instrumentation, materials and performance. They could lead to misinterpretations, especially when looking for early and weak defects.

**Material Nonlinearity:** The fact that the internal structure of the material behaves as a nonlinear mechanical system, being stress the input and strain the output. In a linear material, the strain is directly proportional to the applied stress.

**Mesoscale Level:** The size scale level between $10^{-8}$-$10^{-9}$m and $10^{-6}$m, above atomic and molecule size, where matter discontinuity and aggregation generates local fluctuations on the parameters around an average value.

**Nonlinear System:** Given two possible inputs $A$ and $B$ on a system which lead to the respective outputs $a$ and $b$, the system is linear if an input, that is a linear combination of $A$ and $B$, $mA+nB$, yields to an output that is the same linear combination of the individual outputs $ma+nb$. Otherwise, nonlinear.

**Theoretical Model Uncertainty:** Theoretical models are not complete. They are based on assumptions and simplifications that can lead to failures in their predicting behavior capacity.

**Theoretical vs. Computational Model:** The same theoretical model can be implemented by different computational models, introducing different calculation strategy, assumptions, discretization modes, errors, etc.

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