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Preface

When I recall my first memories of kindergarten, I remember the drawing competition about Poland and the world in the year 2000. Because the date seemed so far away, the expectation of substantial change was evident. To be honest, some people were wearing antennas on their heads, but almost all our sketches were about space conquest and not about human life.

Now this magic date is behind us, and we—the children of the '60s—were right in having predicted the communication era for the year 2000; but we are not children anymore. Now, as engineers, we are responsible for the communication era. It manifests itself by the numerous applications of communication technology that exist, first in military and then in civilian life. Digital television and voice telecommunication, the Internet, global positioning systems, and global reference of time are the most common examples. We, the consumers of the early 21st century, are witnesses of the communication era.

Once more we—the children of the '60s—were right...unfortunately. In the communication era there is much attention on entertainment, on commerce and publicity, but still there is very little concern about human life. Who are we? The civilization that cares more about the primitive shows and worldwide games than about our health? Are we really responsible or are we still in our childhood?

Fortunately, the communication era already made its first marks in healthcare as well. We are witness to the triumphal spread of the idea of telemedicine all around
the world. The use of modern technology for medical applications is a domain of fascination for both young engineers and young doctors; moreover it conquers little by little the buildings of old hospitals and the minds of traditionally educated physicians. Each year, computers and digital information-based solutions are more present in healthcare institutions and become more usable to doctors, who no longer must provide health using their own hands. Getting familiar with a computer considered as a diagnostic or surgical tool of the 21st century is not easy for doctors. In fact it is difficult from the technological point of view, because the service and maintenance of modern electronic and computer-powered medical devices demands education in information technologies. But more difficult is the adaptation of the traditional medical point of view and traditional habits of physicians to the new role of distribution between doctors, patient, and technical devices. We, the engineers, really appreciate the effort of medics, as we share their sense of responsibility. It is surely not the business of entertainment anymore.

Computers are also present in our homes. Surprisingly they are similar machines based on the von Neuman scheme, as used 30 years ago in military or civil calculation centers. In a common belief they are associated with serious things only, like scientific research, economical forecasting, and development of new technologies. In the ’60s of the last century, everybody could imagine a spaceship with computers on board, but nobody could imagine a refrigerator with a computer build in. Nevertheless at the beginning of 21st century, advanced electronic devices and computers became general-purpose equipment of everyday use. The owner of a computer is currently not necessarily a scientist or a business analyst. Computers are very common as entertainment centers, home information resources, and communication tools. A simple reason for this comes from the fact that computers became available and acceptable during the past two decades. The secret of availability has its explanation in mass production and low price. What other smart device can be so cheap at the same time? Mass production achieved success thanks to the deep software customization of personal computers. And thanks to proper computer software development, this general-purpose device is a typewriter for a literate, an encyclopedia for an adolescent, a sampler for a music composer, a home studio for a digital videographer or photographer, and finally a newspaper or a means of communication for a bored housewife.

Acceptability is historically linked to ease of operation. Console-based operating systems are now reserved for professional computer systems administrators, while a significant majority of users prefer graphical interfaces designed with respect to human performance. Engineers adopt their design for merit correctness and technical effectiveness, but usability is a second important prerequisite.

This book is about medical devices, not about computers—though to tell the truth, almost every modern medical device today includes a build-in computer.
Nevertheless, the authors’ wish is to follow the example of computers, which come from temple-like computational centers to the kitchen. Computers, originally used for very serious problems only (like designing new rockets or calculating bank accounts) and now available to help children with their homework and to help home cooks collect recipes, smoothed the way for home care devices.

With the progress of medical education in societies, people need medical devices designed with regard to patient performance—the devices must be cheap and commonly available. Today, cardiology monitors are symbols of restricted-to-professional intensive care units and their use is commonly associated with serious, even life-threatening situations. In the future, we believe a small cardiological recorder may be worn as a watch, but instead of speeding up our heart, it will make it safe. The authors’ intention is that the new generation electrocardiographic device, described in this book under the name of PED (patient electronic device), will provide essential information and warnings about the most crucial cardiovascular system of our organism and will be commonly accepted in every house, even for personal use. The PED is intended to be used as an individual patient’s heart signal acquisition kit integrated with a communication device, which can automatically call an emergency service in case of patient heart failure. Therefore it must be as cheap and as easy to operate as the mobile phones of today. The user in pain does not have to be concerned with the details of the recorder’s operation, but instead must be provided with fast and reliable help.

THE CHALLENGE

The ubiquitous cardiology system is expected to be with a patient continuously and simulate the presence of his or her doctor, even during a trip far away from home. Fulfilling this task requires the personal recorder PED to be mobile and integrated as a part of a network. This seems difficult, but the example of mobile phones shows that it is possible. However, the medical knowledge embedded as ECG interpretation software demands much more computational power than voice processing performed by handsets. This limits the autonomous (performed by the PED itself) applications of personal cardio-monitors. With the use of wireless communication, the performance of the PED can be supported at any time with the data analysis performed by the SuSe (supervising server)—a large and powerful computer in the Central Station, which is a kernel element of the whole system’s architecture. In most difficult cases, the distant care of the patient can be provided by the doctors employed at the Central Station as consultants. In the case of emergency, the appropriate service can be called automatically for direct help to the patient.
Another limitation for the ubiquitous cardiology system is the availability of the wireless connection. The data transmission is highly dependant on atmospheric or terrain conditions, and in remote areas the link quality may be very weak. In such cases the device must rely on the embedded intelligence, and therefore simple ECG recorders transmitting the unprocessed ECG over a digital link are not applicable.

Doctors are our natural choice as colleagues, as we work on the frontier between medicine and technology. Inspired by the relations between the doctors we took on the challenge to design and partly prototype a system intended to resemble the cardiologist or the cardiologists’ group behavior much more than contemporary systems do. We believe that these relations, established through the history of medicine, are optimal and worth investigating and implementing into an automatic network-based surveillance system.

These investigations are addressed in this book. As a consequence of our early results, we designed and prototyped a limited-scale surveillance system that demonstrates the technical feasibility of a global scale cardiac surveillance network. The advantage of the prototype is the use of emerging but already matured technologies. We strongly hope that our findings will inspire other engineers to search for more human-oriented designs and also convince medical scientists to accept a new approach to diagnostic data considering reliability, uncertainty, and risk management issues.

PURPOSE OF THE BOOK

The authors of this book are scientists and engineers with some medical background working in biomedical engineering. Therefore we hope to find a common language with four groups of prospective readers:

- technology researchers and manufacturers working in the area of medical applications;
- medical doctors, in particular cardiologists involved in telemedicine;
- managers of caregiving institutions seeking future development of home care systems; and
- students of biomedical engineering, in particular those interested in electronic systems, telecommunication solutions in biomedicine, and dedicated information systems.

The book may be useful for experts aiming to predict the scenarios of development in the area of telemedicine in the near future, with applications extending
beyond the medical aspects, intended for everyday personal use. Medical devices are currently considered high-tech, requiring highly qualified operators. Such opinion assumes the equipment is restricted to use in hospitals or doctors’ offices, hindering the widespread use of artificial intelligence and telemedicine in home care. Though the devices are not reserved for outpatient use—or for use with impaired and elderly patients—these do seem to be quite a significant target group and therefore constitute a promising market. But our aim is to stimulate growth of common interest in general personal health, which would open up a nationwide market for personal health monitors responding to both needs: owner curiosity and personal safety. Healthy people could also be a target market for dedicated medical products in the future, as they are for entertainment products today.

In our opinion this book should stimulate some medical research and normalization in the field of diagnostics. Several drawbacks of methods currently in use are pointed out thanks to our metrological aspects. The conformance of the software and expert-derived diagnosis is judged from the results, instead of the similarity of data processing. This approach needs huge databases of human-annotated examples to provide the reasonable reliability of the software. For some rare diseases, the collection of a sufficient number of samples is difficult, making progress very expensive. The second issue is the absence in medical data of attributes commonly used in metrology to assess the data reliability in the value (e.g., amplitude) and time domains. We therefore seek to investigate the variability of the diagnostic parameters over time, and consequently to set the validity period for each parameter type. This would be the analogy of a Shannon theorem in medical measurements.

This book may also be useful for engineers as inspiration for their research on non-uniform systems. In electrical engineering and metrology, the assumption of data uniformity is a kind of sacrifice and thus is very rarely challenged. This can be partially explained, but not justified by the reason of commodity, since the theory of uniform data processing was established a century ago, and its counterpart concerning non-uniform data involves some modern mathematics. Our application shows that the non-uniform approach better simulates human behavior and due to the flexibility is much more suitable for adaptive systems. We are certain that this remark holds far beyond the cardiology for other automatic systems that are expected to replace and mimic human organs.

After introductory chapters presenting some known issues, we turn to more complicated matters. Therefore our primary reader is expected to be the technical and medical scientist or the advanced student. The authors hope, however, that this will not narrow the audience and that the future-oriented reader will also find this book interesting.
ORGANIZATION OF THE BOOK

The book is organized into two sections. Section I (Chapters II, III, and IV) presents the current state of the art in selected domains connected to telemedicine and computerized cardiology. Section II (Chapters VI, VII, VIII, IX, X, and XI) presents original achievements of the authors: the investigation of data uniformity and priority, the design and prototyping of system elements, and the validation of results. The remaining chapters (I, V, and XII) play the role of braces, justifying the research, and explaining the results applicability and the social impact of the proposed solutions. A brief description of each chapter follows.

Chapter I presents new needs, new opportunities, new challenges, and new fields for development of innovative IT methods for permanent and ubiquitous cardiologic monitoring. The authors present the general idea of an ECG recording device that is mobile and safe, thanks to the use of soft computing featuring high adaptability to the patient and to diagnostic needs.

Chapter II introduces basic concepts of electrocardiography—the anatomy and physiology of the heart, highlighting electrophysiological phenomena. This chapter also reviews computer procedures used to interpret the signal, and it presents basic regulation and example requirements on testing the performance of medical devices and software.

Chapter III presents the cardiovascular system as complicated, vulnerable, and very important to the organism, and it introduces the cardiovascular disease as the primary cause of mortality in developed countries. (In some counties, it is secondary only to cancer). The current state of the art of long-term monitoring is presented, followed by a short review of contemporary computer networking and digital communication technologies.

Chapter IV reviews the current issues concerning databases as reservoirs of data storage, retrieval, and interchange systems. The specificity of medical applications of the databases is highlighted as a result of the multitude of data modalities and the role the databases play in current information technology-based societies.

Chapter V stresses the need for an alternative approach to home care, personalized healthcare, and prevention in cardiology, and defines main postulates for the intelligent distributed surveillance system. Such a system benefits from current communication technology, agile software engineering, control theory, and from the observation of interpersonal relations. Three main aspects of novelty highlighted are:

- the experimental derivation of cardiologists’ knowledge,
- the use of dynamic re-programmability, and
- the definition of additional data attributes setting their medical relevance.
The authors reveal differences in data handling between technical and medical measurements, and point out some areas for medical research concerning data quality and uncertainty.

Chapter VI presents investigations and results concerning the distribution of medical information in the ECG signal. Following a common belief in the medical relevance aspect, certain signal parts are more informative than others. We propose several methodological variants for quantitative measurement of the local signal relevance. The chapter ends with a proposal of application of the scan-path analysis for objective assessment of personal interpretation skills.

Chapter VII addresses various aspects of improvements in a typical ECG processing chain. Particular procedures designed for the computation of specified diagnostic results are usually developed as a result of long research projects and are rarely disclosed as a source code. Without challenging well-established methods, we tried to optimize the data flow and minimize the propagation of computational errors.

Chapter VII presents the idea of medical information interchange networks providing the signal and possibly image interpretation services. The proposal of distributed interpretation challenges the current definition of telemedicine because the software, instead of the human, is supposed to be the main agent in the network. The prototype of QT dispersion analysis service is presented as an example, with all the related technical issues.

Chapter IX presents new solutions for dynamic task distribution in a mobile client-server cooperation. The authors present the prototype PDA-based ECG-oriented recorder supporting the agile interpretation software and the adaptive reporting format. The optimization of the patient description is an issue of particular concern, since it drives the interpretive software adaptation. The chapter also provides results for detailed analysis of technical conditions of task relocating, as well as for the analysis of erroneous decisions and their consequences.

Chapter X discusses various forms of adaptive ECG reporting, which is a consequence of the modulated software functionality and variable status of the patient. The authors postulate a new approach to the diagnostic parameters time series and consequently investigate the validity time for main components of the ECG diagnostic report. The concept of non-uniform reporting is presented with the concern of regularization of the reports.

Chapter XI presents the concept of “on request” ECG interpretation. This idea assumes the data recipient calls for new measurement results at the end of current data validity. The request is propagated backwards to the front-end procedures, but considerable calculation and transmission savings are made on the metadata of long validity. This concept defines several unexploited concepts for further research, but is the closest to human reasoning when a doctor is giving the care to his or her patient.
Chapter XII concludes and presents principles of the Emerging Wireless Telemedical Applications used for ubiquitous cardiology in home care, risk assessment, and cardiovascular prevention. The authors consider issues of acceptance, availability, and social impact of the system and network, simulating the continuous presence of medics with the patient in motion.