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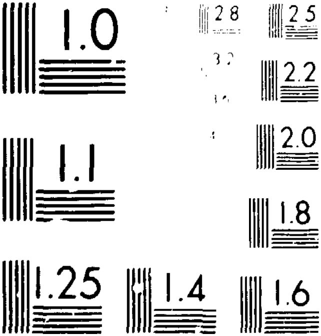

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12676

Distr.
LIMITED

UNIDO/IS.392
17 June 1983

ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

THE IMPACT OF MICROELECTRONICS ON BIOMEDICAL APPLICATIONS IN DEVELOPING COUNTRIES*

by

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V.83 57316

Contents

INTRODUCTION

A part of the Fourth Brazilian Workshop on Microelectronics held at Campinas, São Paulo, from 21 February to 4 March 1983, centred on "Biomedical Applications of Integrated Circuits". Several invited specialists discussed the international research work being carried out and exchanged some ideas on the implications of biomedical engineering for Brazil. Although the discussions held at the Workshop form the basis for this paper, the paper is intended to be more universal and applicable to developing countries generally.

The main objectives of this paper are:

(a) to review the state of the art and some new trends in biomedical engineering, based on the papers presented at the Fourth Brazilian Workshop on Microelectronics;

(b) to consider the relevance of biomedical engineering for developing countries;

(c) to identify requirements for the introduction of biomedical engineering in developing countries;

(d) to point out the basic requirements for co-operation between the medical profession and the electronics industry;

(e) to discuss special biomedical engineering applications for developing countries;

(f) to formulate some possible action programmes for introducing biomedical engineering.

This paper should not be considered as a complete study ... itself but rather as a preliminary outline. Only generally applicable ideas are expressed; in each developing country a detailed analysis of the local situation should be carried out first, however.

I. STATE OF THE ART AND NEW TRENDS

As already pointed out in the introduction, this section is based mainly on the papers which were given at the Fourth Brazilian Workshop on Microelectronics. Most of the ideas expressed relate to developed countries. Their relevance to developing countries is discussed in later sections.

The breakthrough of Very Large Scale Integration (VLSI) in biomedical applications is due to the fact that this technology makes it feasible to develop highly versatile, low cost, portable computerized systems with a high biofeedback capability, which could be programmed by less skilled people in the field, so that medical doctors and practitioners could optimize their diagnostics and their treatments. The storage in a central computer system of information on the medical history of the patient, the so-called "patient data base acquisition", has the great advantage that it afterwards could be used as an input for a diagnostic support system. Although most of the systems that are available on the market today are to a great extent restricted to clinical environments, the low cost and miniaturized systems at present under development should be conveniently portable and fully appropriate for use either in a remote area or at home. In general it could be said that the reduction in time and cost in developing software and systems by using VLSI in biomedical applications will bring more sophisticated medical systems closer to physicians and the patients. In this way health care will be available to a much larger section of the population.

Examples of computerized systems that are under development are Computerized Axial Tomography (CAT) scanners and closed-loop electronically controlled artificial organs like limb protheses and artificial kidneys. [1] Whereas for the CAT application very high speed devices are needed, the artificial kidney hemodialysis process requires circuits that can measure, adjust and control a large variety of parameters simultaneously.

Also the evolution in medical instrumentation depends to some extent on the evolution of integrated circuit technology. There is only a small time lag between the availability of new or improved electronic devices and their introduction and acceptance in the medical market. A large variety of patient monitoring instrumentation such as blood pressure and blood flow devices, electrocardiograms, defibrillators, electrosurgery instrumentation, anaesthesia apparatus, implantable transducers and biotelemetry systems are already available today. However, as integrated circuit technology changes, new prototypes are developed. By analyzing three different types of cardiac diagnostic instruments, the Vector cardiograph, the Holter scanner and a stress tester, which appeared on the market in 1970, 1975 and 1980 respectively, Baule [2] has demonstrated that nowadays product development is more software-intensive than hardware-intensive. This means that to develop new equipment, a better understanding and a greater availability of software tools are needed. The evolution of microcomputer-based systems has the great advantage that the system can expand without requiring a total redesign. There is also a very strong impact of digital technology on medical instrumentation, with more emphasis on the software aspects.

An important barrier to progress in biomedical applications is the lack of reliable and sophisticated input sensors and output actuators which match perfectly the VLSI circuits used for signal handling and computing facilities. The different biomedical measurements for diagnostic and therapeutic purposes are based on the monitoring of some physical and/or chemical parameters related to the human body. Depending on the parameters that one wants to measure, there are several principles or devices that can be used for monitoring these parameters. This is feasible only when suitable input sensors and output actuators are available for a particular parameter. Then a certain biomedical application can be worked out. This is illustrated by the following example:

> Suppose one wants to measure body fluid pressures. Direct methods to determine this parameter include measuring mechanical elastic properties of diaphragms or tubes using piezoresistive, capacitive and optical methods to convert mechanical deformations into electrical signals related to the pressure. As miniature pressure transducers have been fabricated for each of these techniques, it is possible to work out a biomedical application such as measuring the blood flow pressure.

A summary of the biomedical applications using either physical or chemical transducers has been discussed by Ko. [3] To illustrate the complexity of the problem, his summary is reproduced in table 1. As soon as the appropriate transducers can be fabricated, a huge amount of biomedical applications can be worked out. A lot of research is going on in order to integrate several transducers on a single chip, so that more parameters can be monitored simultaneously. It should be remembered, however, that a lot of research is needed still on the packaging of the biomedical transducers. Most of the conventional packaging materials are not compatible with the human body and cause immune and other reactions. In the case of the blood pressure transducer mentioned earlier, there are serious problems to protect the packaging from body fluid seepage.

A huge amount of investigation is under way to develop implantable instrumentation as there is a strong need for instrumentation that can measure the required parameters without restricting the normal activities of the patient. For patients who require long-term monitoring and/or treatment this aspect especially becomes very important. In some cases implantable instrumentation is less expensive (in comparison with a long stay in hospital) or is even the only possible solution (e.g. pacemakers). Such instruments can have a telemetric function, when the implanted transmitting unit measures the required parameter and converts it into a format which can be transmitted through a wireless media; or a stimulation function, when the implanted unit receives an external signal through a wireless media and converts it into a stimulating signal. It is also possible to design a closed-loop control system which combines telemetry and stimulation systems. A lot of research is going on in this field. The stringent requirements for implantable instrumentation concern: small size and light weight, low power consumption, stability during long-term operation, the noise and cross-talk insensibility, the system performance, and the packaging biocompatibility. Examples of such closed-loop systems being investigated in several research laboratories are a prosthetic application for telemetering and controlling the parts of the body that are under the voluntary control of a quadriplegic, an automatic drug delivery system for diabetics and certain cancer patients or others who require frequent infusions of insulin, drugs or hormones, and cardiac pacemakers. [3]

A lot of research is also being done in order to develop special processing technologies which can be used to fabricate integrated sensors. [4] Examples of this are silicon micromachining based on the use of special chemical etchants,

Table 1. Sensors and transducers for biomedical applications based on physical or chemical parameters, after Ko. [3]

A. Physical Parameters

Measured Quantity	Principle or Devices Used	Biomedical Applications
Electrical Potential	Voltage	Nerve and muscle activity, ECG, EEG, EMG, EOG, etc.
Impedance	Z-Bridge	Skin condition, respiration rate, peripheral blood flow
Temperature	Thermistor, pn junction, infrared	Inflammation, cancer location, blocked circulation
Sound & Vibration	Microphones	Heart and breathing sounds, blood pressure measurement, fluid flow
Light	Transmission, refraction, absorption	Physiology research, clinical laboratory, gas and ion sensors
Magnetic	Permeability, field	Blood flow, heart activity, proximity
Force and Pressure	Piezoresistance, capacitance, deformation	Pressure of blood, CSF, urine, etc., locomotion
Displacement, Velocity, Acceleration	Capacitive, magnetic, laser, ultrasonic, optical, ultrasound, acceleration force	Body movement, physiology research, orthopaedics
Flow - (blood, fluid, air)	Electromagnetic, optical and ultrasonic Doppler, pressure drop, streaming potential	Blood, air, body fluid flow, heart, lung, kidney functions
Volume	Displaced volume, dye dilation	Physiology research, cardiac output
Imaging - (shape, surface, 3-D structure)	X-ray, ultrasound, microwave, nuclear isotope	Shape and motion of the organs: heart, brain, eye, teeth, etc.
Time	Delay, response time	Alertness, nerve signal transmission, signal transmission in heart and other organs

B. Chemical Parameters

Measured Quantity	Principle or Devices Used	Biomedical Applications
Gas concentration	Gas-sensitive electrodes, chromatography, chemical analysis	Blood gas (H^+, O_2, CO_2, O_2 saturation) respiration, perfusion, anaesthesia, hospital operations, clinical laboratory
Humidity	Dew-point temperature, resistance and capacitance change due to condensation or absorption	Pediatric, respiratory research, intensive care
Ions	Ion selective electrodes ISFET, chemical analysis	Clinical laboratory, intensive care unit, acid-base balance
Biomolecules	Enzyme electrodes, chemical analysis	Clinical laboratory, research laboratory, patient monitoring

C. Behaviour Parameters

New sensors to be developed (in addition to those listed in A and B).

the development of electrostatic bonding techniques, and improved thin-film deposition techniques. These techniques have already been used to make monolithic capacitative pressure sensors with on-chip circuitry, and monolithic silicon thermopile infrared detectors.

The biomedical applications of microelectronics also impose certain hazards on the patients and the medical staff operating them. Safety standards have to be defined and maintained.

II. RELEVANCE TO DEVELOPING COUNTRIES

Before discussing the relevance of biomedical engineering in developing countries, it is better to identify and to analyse in a little more detail the different aspects of biomedical applications. Bioengineering is very often correlated with the development of a bionic person. Although this might be the end result of a very advanced research programme in the future, it is first necessary to think about more immediate and practical applications. It is impossible to run before learning how to walk. There are a large variety of very simple and straightforward biomedical applications, which would be very useful for the immediate needs of the population. This point will be clarified in the next sections.

A. Aspects of Biomedical Engineering

The following aspects can be distinguished:

(a) Development of diagnostic tools

These can be either a rather simple piece of equipment like a blood pressure monitor or a more sophisticated fully computerized system such as CAT scanners. It is important to differentiate between the environments where the diagnostic equipment will be used.

(i) Clinical environments

In these environments the equipment may be rather complex, but only a limited amount of people will have access to it. In hospitals complexity, maintenance and the availability of skilled technical and medical manpower is usually no serious limitation. For very special and less common ailments it is likely that only a few hospitals will have the appropriate equipment for diagnostic analyses and special treatment. In this case there is no real need to expand the number of centres or to simplify the equipment, unless the analysis can be improved and the overall cost reduced. However, if the application field is rather limited, the equipment cost can be so high that a lot of the people who really need the treatment cannot afford it. For such situations, special health care provisions (e.g. refunding most of the costs) have to be worked out.

On the other hand, there is also a large variety of diagnostic analyses, which should be available to most medical practitioners so that the turnround time is very short. In developed countries the situation is different, as only a few specialized centres can perform the analysis. The situation becomes even worse if one takes into account the large distance between the centres and the increasing number of patients requiring analyses every day. This example shows that some of the equipment used in a clinical environment in developed countries should be modified or even simplified for operation in developing countries. As will be discussed later, the real needs of the country involved and the local situation should be studied.

(ii) Remote areas

The biomedical diagnostic equipment suitable for outlying areas should be very flexible (enabling several types of analyses to be performed with the same tool), easy to transport or even portable and requiring almost no service or maintenance. The reliability of the equipment is a very important factor. In contrast to most developed countries, the environment should be studied in great detail for the developing countries. Very often the doctor's office is the only health care place that can be reached by patients in a reasonable amount of time. In addition to the remoteness of the area,transportation and mail services are poor or sometimes even non-existent, so that the doctors or their assistants must be able to carry out the more common and most urgent analyses. It is only feasible to have a large number of small-scale laboratories, when the installation cost is low enough and the equipment easy to operate and to maintain. In many cases only a few people are available to operate and maintain the equipment and to perform the diagnosis. This means that even if the financial support were available to buy more sophisticated diagnostic tools, they would be out of use after a short time.

(iii) Home-based health care

The home is the most attractive place for health care, especially for common, mild and moderate illnesses which do not require much professional treatment. Many patients do not need immediate access to highly trained personnel or sophisticated equipment. Often patients have to go to the clinic daily for a routine check, which easily could be done at home if the required diagnostic tools were available. A straightforward example of this is checking the temperature and blood pressure. Most patients feel much more comfortable and secure in familiar surroundings, so that home-based health care also has a psychological effect. Home care is also important for handicapped and bedridden patients many of whom at present reside in various types of institutions. By improving the availability of diagnostic equipment, and access to a telephone and modern communications systems, and forming so-called self-help groups of individuals with common social, physical and emotional problems, home-based health care seems to be feasible in the future. The main advantage of such a system is that one doctor can help a larger number of patients. However, at present this system of health care would be hard to introduce in developing countries. Therefore, a complete infrastructure has to be worked out. Even if all the technical restrictions were removed, it would require a partial re-education of both doctors and patients to convince them of the inherent benefits of an alternative mode of medical management.

(b) Development of artificial organs

As pointed out in section 1, microelectronics play an important role in the development of artificial organs. In contrast to the field of diagnostic tools, which are mainly used to monitor patients' health these applications are intended to cure the illness or the malfunction of living organs or, when necessary, to replace them. This field of bioengineering is certainly more spectacular, but also much more sophisticated. Examples of such biomedical applications are artificial kidneys, hearing aids for the partially deaf, limb protheses, reading aids for blind people, pacemakers. The microelectronic systems used can be (a) supercutaneous, situated on the outer surface of the skin; (b) subcutaneous, implanted under the skin; (c) percutaneous, going through the skin, such as catheters; (d) or any combination of these three. In order to develop artificial organs, a lot of research has to be carried out in different fields and on different levels. These are:

(a) Design of integrated systems

Depending on the approach to be taken, the design has to be done for different categories:

(i) Custom-built circuits. It is possible to work out a completely new concept, design it and process the required integrated circuits; thus it is possible to optimize the required electrical specifications and to adjust the processing technology. For this approach, however, full semiconductor manufacturing must be available. In general, this is only possible at high-level research institutes;

(ii) Semi-custom approach. It is possible to design the system in such a way that the processing can be done by a silicon foundry, situated either in the developing country itself or in a developed country. In most cases the design rules and the process specifications will be restricted or determined by the foundry;

(iii) Standard component approach. It is possible to design a biomedical system based on standard components available on the open market.

(b) Periphery circuitry

Once the required integrated circuits are built, several input sensors and output transducers are also needed. If they are not standard or unavailable on the market, they should be developed. This is a very important aspect which still requires a lot of research.

(c) Assembly and testing

The different individual circuits together with the I/O periphery have to be assembled in either a monolithic or a hybrid system. In most cases this also means that several thin- and thick-film deposition techniques have to be used. The testing of the systems is also not always straightforward, so that sometimes special test systems must be used. Generally, testing on animals is done for a long time before implementing the system in human livings. During the test period, a close collaboration between the physicians and the electrical engineers is required. This collaboration is discussed further in section IV.

(d) Packaging and encapsulation

Although this topic can be considered a part of assembly and testing, it is still a very troublesome area which requires special attention. The main barrier to the practical use and success of several existing biomedical systems is packaging. Only a limited amount of materials are suitable for use in biological systems. The drawbacks of the material mostly relate to their toxicity to biological tissue, their poor stability in biological fluids, their antithrombogenic characteristics and their electrochemical interfacial characteristics.

(e) Implantation techniques for subcutaneous systems

Although this field belongs more to the medical than to the electronical sector, it is important to bear in mind that the practical implementation of a biomedical system is rather complex and not without difficulties.

B. Situation in Developing Countries

Most of the work on microelectronics and their biomedical applications that is going on in developed countries has already been successful and will in the future certainly lead to a completely different health care service and management. However, it would be a completely wrong approach if the developing countries tried to catch up by simply duplicating what is available on the market. The investigations and the research done in developed countries is not always relevant to the developing countries. Before trying to develop or to buy the right know-how to produce biomedical systems, the developing countries should investigate in detail which are the required applications for their immediate needs. The diagnostic capabilities should not expand much faster than their therapeutic effectiveness. The overall health care situation is completely different in developing countries compared to developed countries. This can be illustrated by the following example:

Table 2 gives an overview, after R. Rushmer, [5] of the major medical successes and the medical enigmas in the United States, where some important dangerous diseases such as plague, cholera, smallpox, beriberi have been eliminated completely. This means that no great effort is being made to develop biomedical applications to heal these ailments, because they can be prevented. A similar table for a developing country would be completely different. Several developing countries are not very successful in eliminating or even preventing some of these diseases. This means that their research should be more oriented towards these problems.

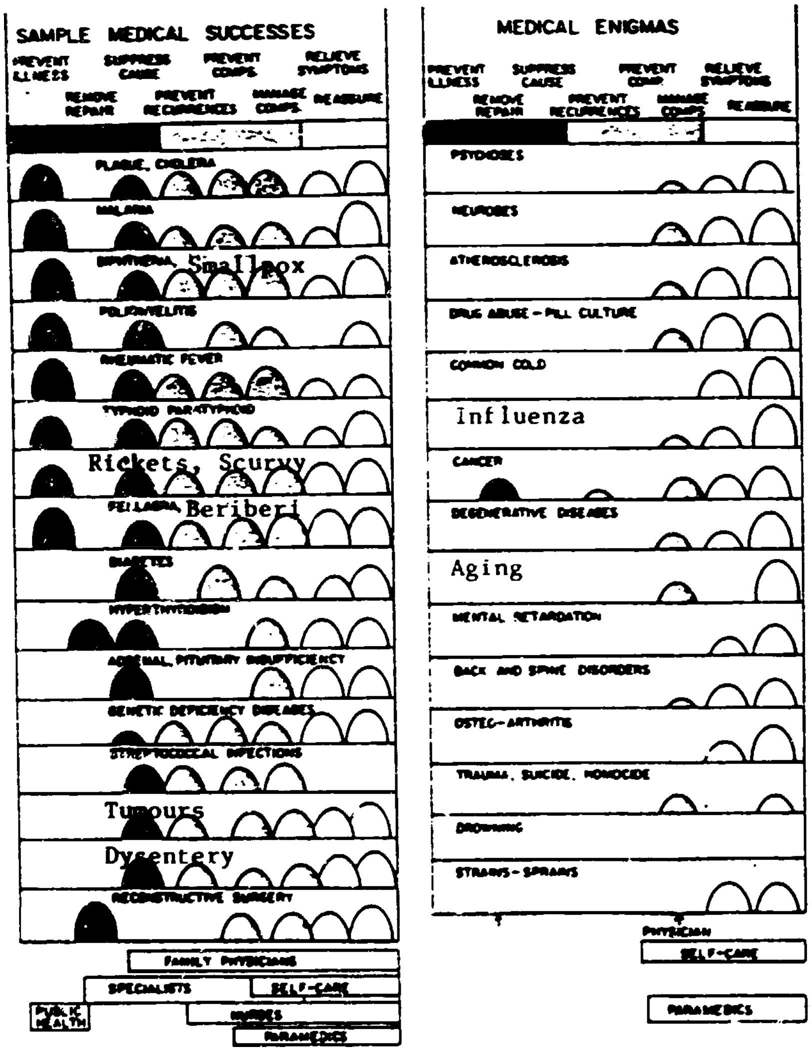
Secondly, in developing countries there exist a completely different organization of the medical health services in relation to:

(a) hospital density (number of hospitals per rural district). There are fewer hospitals and the distance between them is much greater, which means that patients need longer to get to the clinic (in some countries it can even take several days). Therefore the role played by the doctor's office and home-based health care (with medical practitioners visiting frequently) is very important;

(b) the total medical staff operating the hospital. Although many hospitals in developed countries lack sufficient medical staff, this is certainly true of developing countries;

(c) the total number of medical doctors in the country. In some developed countries there is an average of one doctor for less than 200 inhabitants. For developing countries this figure has to be multiplied by ten.

Table 2. Overview of some major medical successes and medical enigmas in the United States, after Rushmer. [5]



(d) the equipment available at both the hospital and the doctor's office. Some doctors in developed countries have their own small-scale laboratory. In developing countries, most doctors working in remote areas have no easy access to the equipment available in hospitals. Thus, at the very least,a long wait before the results of the required analyses are available must be taken into consideration;

(e) the number of specialized medical research centres existing in the entire country is rather limited.

In sum, although the medical needs in developing countries are much greater, the existing medical health care system is poorer.

There is certainly a pressing need for several biomedical applications. However, before entering this field each country should make detailed studies of the local situation and try to answer some of the following questions:

- What are the really urgent medical needs?
- What biomedical equipment is available in the country?
- What should be the minimum complexity of the equipment needed?
- Is the diagnostic equipment required available on the market and, if so, are the specifications given appropriate for the specific appl
- If the equipment is not available on the local market, should it be acquired abroad or manufactured locally?
- Which biomedical applications systems can be designed easily locally?

III. REQUIREMENTS FOR INTRODUCTION IN DEVELOPING COUNTRIES

There are several requirements of conditions which should be fulfilled before a developing country decides to enter the new and challenging field of biomedical electronics. Some of these conditions are discussed below.

(a) A core group of experts should be formed in each developing country to study the biomedical needs and to investigate which applications could meet them. The group should consist of both medical practitioners and engineers, and the applications should be relevant to the country concerned;

(b) The internal and external market situation should be studied in detail. Even though developing countries often want to develop their own products in order to become more independent, it is important for many biomedical applications to be competitive in the world market in such matters as performance and manufacturing costs. Developing countries should be aware of their strengths and weaknesses and try to benefit from their strengths and eliminate existing weaknesses;

(c) Existing potential has to be exploited. When a developing country is competent in a certain area, all the applications should be oriented towards this direction. In many cases it is more beneficial to use an existing technology (e.g. small to medium-scale integration) than to install a new technology (VLSI). For a large number of applications advanced technology is not required;

(d) The human resources and skills requirement must be determined. The training of the two groups of people, those who are going to develop the applications and those who will be using the applications has to be considered;

(e) Considerable attention has to be given to both the technical requirements and the environmental conditions that will be encountered by the application to be developed. Therefore the perception of the application by representatives of both the public and private sectors should be taken into account.

This general list of requirements is not exhaustive. For each developing country, the several subtopics related to biomedical engineering have to be treated as separate case studies.

IV. RELATION BETWEEN THE MEDICAL AND ELECTRONIC PROFESSIONS

Work on biomedical applications is only possible when there is a close and well-defined relationship between the medical practitioners and the electronic engineers. To establish this relationship, a strategy has to be worked out which takes into account the following two difficulties:

(1) technical engineers in both the public and private sectors have little or no awareness of the requirements of the health care service;

(2) The medical sector has little or no awareness of the potential of micro-electronics for biomedical applications.

There should be an open discussion between the developers and the users of the applications, although both groups often speak a different language. In general, it takes a very long time before a certain application is accepted for practical use. The doctors have to define the problems which have to be solved by the engineers. A good collaboration between the two groups is only possible when each is aware of the other's capabilities and limitations. Therefore the definition of a "product" and its specifications can take a very long time. It should always be borne in mind that microelectronics is not going to solve everything and that medical experiments are not done by trial and error.

Solutions to problems have to be considered in their proper context and afterwards translated into a more general format. The sometimes poor contacts and low level of mutual understanding is not typical of developing countries only but also of developed countries. Very often, highly skilled people are trained in a relatively narrow field only, and are strongly biased in certain directions. It could be said that nowadays this is a more general barrier to the progress of the society.

The introduction of microelectronics in non-technical areas is sometimes very revolutionary and requires some adjustment on the part of those concerned. However, the main question is no longer "should" they be introduced, but how can they be utilized under optimum conditions.

V. EXAMPLES OF PRACTICAL APPLICATIONS

This section discusses ideas and concepts for biomedical applications which are potentially interesting for developing countries. The needs of one country may be completely different from those of another country. As very scarce resources - qualified medical personnel, infrastructure of the health care system - should be utilized to the maximum extent possible, the main effort should be in the field of instrumentation and diagnostic tools. The few available skilled staff has to be freed of performing time-consuming daily routine analyses, so that they can concentrate on the areas which require their expertise. The overall management of the health care system has already been discussed briefly in section II. Some examples of biomedical applications, which give an idea of what can be done, are:

(a) Blood pressure monitors

It is very important to develop simple methods which give accurate blood pressure data in a short time. There are already controllers on the market which can be used easily by untrained and unskilled people, so that the medical practitioners no longer lose time in collecting data. As a large-scale screening is required in developing countries, this becomes a large volume market. It is necessary to investigate whether or not these monitors can be manufactured in the country itself at a price which is competitive with the world market.

(b) Blood gas analyses

The gases of the blood of particular interest to doctors are oxygen and carbon dioxide. The measurement of these gases is complicated by the fact that oxygen and carbon dioxide can be present in both dissolved and combined form.

(c) Applications in urology

There is great need for diagnostic tools for urine analysis. The analysis of the urine is very important as it often reveals information required to identify certain diseases (e.g. sugar in the urine is an indication of diabetes). Some of the analyses have to be done in a short period of time (on fresh samples). Although mostly chemical analysis techniques are used, microelectronics is very useful for data handling and control functions.

(d) Instrumentation for pulmonary systems

These applications can be either spirometers to measure respiratory volumes or pneumotachograph transducer systems to monitor respiratory flows. This field of application can even be extended to different anaesthesiological applications. Microcomputer-based systems are very suitable for automatic monitoring and adjusting several functions.

(e) Pulse counting and monitoring

Very often it is important to count the pulse rate and to determine exactly the shape of the pulse. Once again, the equipment should be as simple as possible and able to give a very accurate reading without the assistance of skilled people. When used to screen a large group of the population, and sold as a mass product, the fabrication cost per unit should be very low. A straightforward application of such systems is encountered in electrocardiography.

Besides this field of biomedical instrumentation, urgent needs are also found in the telemetry and stimulation systems. Normally these systems are used to monitor and/or improve the function of living organs, although some systems are replacing the functions of organs completely. Important applications for developing countries are:

(a) Pacemakers

Many people suffer from heart problems. In a lot of cases an artificial heart stimulator, or so-called pacemaker, is required. Although it is possible to buy pacemakers on the market, their performance can still be improved and the price is relatively high. In developing countries especially, most patients who really need a pacemaker cannot afford to buy one. Therefore it is necessary to give more attention to this device. However, before trying to develop a pacemaker, the technological infrastructure existing in the country has to be investigated.

(b) Hearing aids for the sensorial deaf

Many people are to some extent sensorially deaf. The perception of speech can be improved by the use of a neural stimulator. The implantable system should be placed as close as possible to the entrance of the cochlea in order to reduce the number of wires required. The power for the integrated system is supplied by a portable battery unit.

(c) Telemetry system for cystometry

Cystometry is a diagnostic procedure in which patients with bladder malfunctions such as incontinence or myoturation disorders are examined. To overcome the drawbacks of catheter systems, it is possible to develop telemetry systems which record the bladder pressure.

This list is far from complete and only gives some possible applications. Others include reading aids for blind people, speech analysis systems for patients who have had surgery on their vocal cords, implantable control systems for patients who regularly need the injection of a well controlled amount of drugs.

A more detailed overview of the field of medical engineering can be found in the book edited by Ray. [6]

It is very important to stress once again that the type of biomedical application which should be developed strongly depends on the local situation in the developing country, taking into account the urgent needs and the technological infrastructure and skills available.

VI. FUTURE ACTIONS AND CONCLUSIONS

It can be concluded that it is necessary for the developing countries to enter the field of biomedical electronics. The health care system has to be organized in such a way that it is beneficial to a greater part of the population. Immediate action points, if they have not started already, could be:

(a) the forming of a core group of experts to determine the urgent needs and to analyse the local situation;

(b) the making of an inventory of the biomedical systems and devices already used today, and summarizing their main limitations;

(c) the investigating of the existing potential (technological and skill base) which can be used to develop biomedical systems. The strengths and weaknesses in the different areas have to be defined;

(d) the definition of the "products" that are to be improved or developed;

(e) the training of the people needed to achieve the defined targets;

(f) the definition of medium and long-term action programmes.

Any improvement to health care delivery for the majority of the population is so important that it should be treated with the highest priority.

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