USING OF EMBEDDED SYSTEMS IN BIOMEDICAL APPLICATIONS

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Abstract: This paper describes principles of embedded systems and their role in medicine applications. Embedded system is combination of hardware and software which together form a component of a larger machine. An embedded system is designed to run on its own without human intervention, and may be required to respond to events in real time. Biomedical researchers, clinicians, computer scientists, engineers and anyone interested in learning about what embedded computing is and how it can be applied to make biomedical instruments more capable, easier to use, and easier to integrate into systems.

Introduction

To most people, *embedded systems* are not recognizable as computers. Instead, they are hidden inside everyday objects that surround us and help us in our lives. Embedded systems typically do not interface with the outside world through familiar personal computer interface devices such as a mouse, keyboard and graphic user interface. Instead, they interface with the outside world through unusual interfaces such as sensors, actuators and specialized communication links. Embedded system is combination of hardware and software which together form a component of a larger machine. These embedded systems have the potential to change radically the way people interact with their environment by linking together a range of devices and sensors that will allow information to be collected, shared, and processed in unprecedented ways.

Embedded systems are combination of processors, sensors, actuators, "intelligence", "hidden computers" and massive deployment, intensive interaction with uncertain environment. Real-time and embedded systems operate in constrained environments in which computer memory and processing power are limited. They often need to provide their services within strict time deadlines to their users and to the surrounding world. It is these memory, speed and timing constraints that dictate the use of real-time operating systems in embedded software [1], [3]. An embedded system is designed to run on its own without human intervention, and may be required to respond to events in real time.

Embedded systems may be used in many different types of applications, including transport (avionics, space, automotive, trains), electrical and electronic appliances (cameras, toys, television, washers, dryers, audio systems, and cellular phones), *medical equipment*, power distribution, factory automation systems, etc. Their extensive use and integration in everyday products marks a significant evolution in information science and technology.

A main trend is the proliferation of embedded systems, which should work in seamless interaction while respecting real-world constraints. Embedded systems have a number of *specific characteristics*:

- *Criticality:* The degree of embedded system criticality depends on the consequences of deviation from a nominal behavior that can impact safety, security and mission completion.
- *Reactivity*: Embedded systems are deployed in the physical environment, and as such they have a continuous interaction with it. Embedded systems are subject to real-time constraints relating their execution speed to that of their environment.
- *Autonomy*: Embedded systems need to be autonomous, that is, to fulfill their functions without human intervention for extended periods of time. Autonomy is needed, especially where human reactions may be too slow or insufficiently predictable.

Most of embedded computing concepts are the same as in conventional computing, but they are applied in ways that are unfamiliar to many. Resources are more constrained, temporal issues are often complex, and reliability is much more vital. Embedded computing requires much greater interaction with the system's hardware elements. Recently, there has been synergy among several key technical areas [2]. This synergy has lead to formidable growth in embedded computing power. With this growth, embedded tasks are faster and cheaper. In many domains (biomedicine among them), embedded computing is no longer the main limiting factor.

Biomedical researchers, clinicians, computer scientists, engineers and anyone interested in learning about what embedded computing is and how it can be applied to make biomedical instruments more capable, easier to use, and easier to integrate into systems.

Trends in Medical Systems

Trends in Medical Systems are following [10]:

- Direct face-to-face medical support to remote supervision and monitoring automated devices for control of long-term medication and treatment

ISSN: 1727-1983

- New means of interaction and surgery by new medical devices (MEMS, nanodevices)
- Smarter healthcare systems: automated "error-free" provision and protection of medicine, data/critical assets and support (critical clinical processes) in hospitals
- Components of healthcare systems as technology drivers (Fig. 1 and 2).

a) b)

Figure 1: a) Transducer that uses pulsed doppler ultrasound to measure fetal heart rate, b) Continuous arterial blood gas monitor.

Figure 2: Continuous, noninvasive blood pressure monitor.

All these areas will be impacted by interactions with ambient intelligence (AmI) in terms of the ability to sense environmental changes in much more detail and automatically acquire data from AmI sensors.
Systems will be developed that rest on the integration of a number of component systems that fit a specialized role within healthcare. Each of these component areas provides drivers on and needs for research and development in healthcare systems. The main areas are:

- Hybrid computer/drug systems, involving complex biological and computing interaction.
- Information infrastructure e.g. electronic health record, electronic patient record
- Management and control of procedures: e.g. drug administration, therapy management
- Assistive technologies for procedures: e.g. surgical robots, therapeutic nanomachines
- In-body devices: e.g. pacemakers, defibrillators, infusers for drug management
- Advisory systems: e.g. radiology prompting systems, drug expert systems
- Treatment machines: e.g. linacs, ventilators
- Monitoring/Imaging systems: e.g. scanners, x-ray, blood gas
- Modeling to support procedures: e.g. joint replacement
- VR/Enhanced reality systems: e.g. joint replacement, micro-surgery
- Training systems, simulation systems
- Telemedicine systems, including telesurgery, teleconsultation, telesupervision

Medical Application of Embedded Systems

Healthcare systems **-** Regarding health care systems and devices, cost and the need for more care and monitoring of the growing group of elderly people will involve ICT technologies and especially embedded systems of different kind, with soft to hard safety criticality to people. *Healthcare systems* can be decomposed into three broad categories. These categories are:

- Managing unwell patients (with particular emphasis on managing chronic conditions, implants, embedded medication)
- Managing the health of well patients ("wellness management").
- Clinical support (from primary to acute service and managing the interface with other support services, social services, accommodation, education).

The integration of *embedded healthcare devices and systems* into a global context involves local and large scale infrastructures with many dependencies affecting the dependable function of the system.

Furthermore, a positive influence on the broad area of telemedicine is envisaged. Healthcare applications offer distinctive challenges for embedded systems over the next ten years for the following reasons:

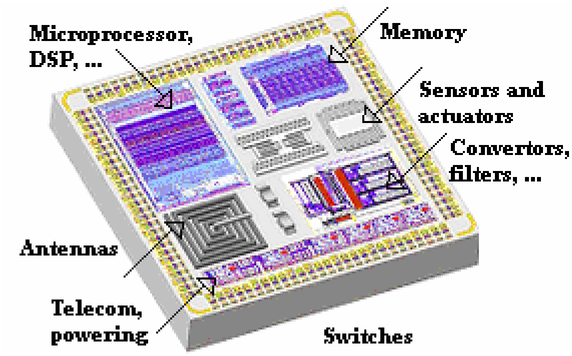

Figure 3: New conception of wireless sensors and actuators-embedded systems on the chip.

- The fundamental change offered by ambient intelligence is the ability to assist in a wide range of tasks by mapping more of the human actors work process into the environment. This allows systems to provide deeper interpretation of sensed data and allows control of local actuators to take account of more global context for the activity. Embedded systems are essential for the implementation of the reliable infrastructure to support AmI and *wireless sensors and actuators* (Fig. 3). In other proposed embedded systems application areas e.g. avionics, automotive, the processes are relatively short-lived and are focused on individual or small group process handling modest data volumes. By contrast deploying AmI in support of *medical processes* we see long-lived process (possibly over years) requiring the coordination of many actors with distinctive roles and the need to integrate massive amounts of data from highly diverse sources covering a range of modalities. All this provides a qualitatively different scale of challenge by contrast with the more constrained environments considered in the other application areas.

- Although many of these challenges will remain open new projects they will help guide the longer-term development of embedded systems in the provision of a knowledge-based infrastructure in support of complex organizational processes.
- Healthcare applications make massive demands on data capacity because of the extensive use of imaging and other data intensive monitoring technologies. They are also knowledge intensive, increasingly demanding prompt delivery of knowledge resources abstracted from large knowledge bases at the point of delivery of care. These characteristics pose a range of questions concerning the articulation of ambient, pervasive, embedded systems with the high performance, data intensive facilities provided by e-Science facilities. In the first instance this involves matching application-specific embedded architectures with the emerging grid service architectures. To summarize, the knowledge needed in health care systems draws on complex data sources, links to long term work processes and is required to be delivered at the point of treatment. This necessitates articulation with grid-like knowledge infrastructures.
- Health systems also involve complex ethical, privacy and security issues because they involve sensitive personal data related to health status, are embedded in long-lived processes and span many different organizational groups that have different needs, access rights and control over the data .
- Increasingly, healthcare technologies in the treatment and devices area involve hybrid electronic/biological systems that are both informatically and biologically active. This may also lead to personalization via augmentation with genetic data.
- Finally, healthcare systems is an interesting domain because it has the potential to provide the kind of universal need for ambient intelligence that could lead to the effective deployment of the technologies coupled to an environment where it is possible to experiment on a relatively small scale with professionals who are interested in the deployment of the technology and its effects on clinical practice.

This set of technologies that will benefit the elderly by improving the overall standard of the healthcare system and reducing the costs of in house monitoring and hospitalization.

Intelligent home healthcare embedded system - In the past, patients with chronic diseases often have to spend precious time and pay inconvenient visits to have health checking at either hospitals or clinics. As our life quality is being improved, any telemedicine systems and monitoring devices are developed. To reduce the inconvenience, was proposed an intelligent home health care embedded system which can provide diagnosis about health status for patients directly at home.

During recent years, there was a rapid growth in the development of telemedicine systems and monitoring devices for patients with chronic diseases and requiring continuous telemonitoring treatment. However, most of these systems only provide telemonitoring services or basic information about the health condition of the patients. For this reason, an intelligent home health care embedded system, which can provide patients with diagnosis about their health status at home, is developed. As a result, different types of pluggable medical transducers (e.g. electrocardiograph, sphygmomanometer, and blood glucose meter) for patients with different illnesses can be flexibly connected to the interface of the embedded system.

Patients can have health checking by themselves easily and advices about their health status are displayed to them immediately. According to the type of biomedical signals that needs to be obtained from the patients, different types of pluggable medical transducers will be connected to the embedded system for signal acquisition. By feeding the digitized biomedical signals to our novel embedded medical transducer parameter detector/extractor, relevant parameters will be extracted out by using promising techniques like wavelet transforms.

Finally, these parameters will be sent to our expert system with updatable knowledge base for diagnosis of the health status. Primary diagnosis results directly related to discomfort possibly occurred or disease likely to encounter, will be displayed as a preliminary advice to the patients. Patients will have a clearer idea about their health and can pay visits to their physicians only if their problem gets necessary.

Heart, which controls the life of every human being, is an important organ in our body. By studying the electrocardiogram (ECG), valuable information about the health status of the patient can be obtained. Other analyses, like blood pressure and blood glucose which require fewer parameters (e.g. systolic and diastolic for blood pressure, glucose level for blood glucose), can be treated similarly to our treatment on ECG signal as long as the transducers are well-designed [9].

The next example is *fall detection system* for the elderly. Falls are common in the elderly and constitute a major health burden. It is well known that the incidence of falls rises with increasing age. Prototype is wearable accelerometer for fall detection (Analog Devices ADXL105 – Fig 4.) [11].

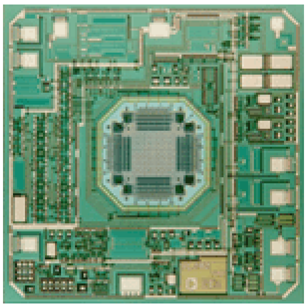

Figure 4: Analog Devices' two axis accelerometer

Telemedicine - Diagnosis of problems in embedded systems by remote means has been an interesting idea for the medicine. This is expected to bring about remarkable changes in the quality and speed of service, and consequent benefits to the health centers in terms of reduced costs and better image [4], [5], [6], [7].

All these will help in higher quality of remote diagnosis in terms of speed, correctness and cost-effectiveness. Another dimension to adaptability is added by the fact that if the firmware in the embedded system is also adaptable, then greater adaptability in remote diagnosis is available and all this eases the job of the remote diagnoser to that extent. An adaptable software agent combined with an adaptable embedded system together comprises what we call adaptable remote diagnosis system.

One of the easiest ways to accomplish remote diagnosis of embedded systems is to have a web-based access to field equipments (Fig. 5). This will let technical people use easy to available browsers to maintain the remote systems and learning curve on tools is considerably reduced.

The expert diagnoser is the person who will run a series of tests on the embedded system. She will be running a series of tests on the embedded system to confirm its normal working or to diagnose any problems with it. The expert diagnoser will be accessing the central server over the internet. The central server houses the software agents that will be running the various diagnostic tests on the embedded system.

The software agents are programs that will run the diagnostics on the embedded system and retrieve results. These results are then displayed to the expert diagnoser by the central server. The embedded system is connected to the central server over a LAN (it could be internet as well, since the embedded system has an assigned IP address).

Human - Biology Systems - The approach and the application out of the result can be understood from the perspective of biological system. It is worked at molecular level for pharmacophore findings and structure-based drug discovery, so as to develop Biological Medical Devices of molecular-based diagnostics and therapeutics. This approach is involved in conducting signaling pathways proteins, pharmacogenomics, pharmacokinetics, hemodynamics, pharmacodynamics, biorheology, and biodistribution studies in the early stage of drug development, in order to support rational design of dosing regimens for preclinical efficacy, toxicology studies, and clinical trials. It integrates the physiological and molecular understanding of the role of cellular processes and cytothesis during the maintenance of the state of health, and the treatment of diseases, respectively. As molecular medicine holds the promise of checking the progress of disease, regenerative medicine seeks to restore body function to normal physiology as far as possible [10].

The *embedded bioscience* together with bioengineering into the R&D milestone for four major programs: fundamental research, applied research, biopharmaceuticals, and group medicine. Life science has made it successful to bring human beings a total solution of tailored healthcare: it is tailored biopharmaceuticals that consists of BioMedical PolyPeptide GlycoProteins & botanical/herbal glycosides MediFormula as human biological response modifiers & rectifiers. Successful development of Life MediFormula involves achievement of GTP-binding proteins: regulatory proteins act as molecular switches and G-protein-couple receptors (GPCRS) are the largest group of cellular targets for conventional therapeutics.

Biomedical feedback control systems - Feedback control systems are widely used in bio-medical systems. It plays a key role for maintaining efficiency, reliability and profitability for the health care industry. In response to the demands of the medical industry, control systems are being required to deliver more accurate and better overall performance in the face of difficult and changing patient physiological conditions. Biomedical processes presents challenging problems to the control engineer.

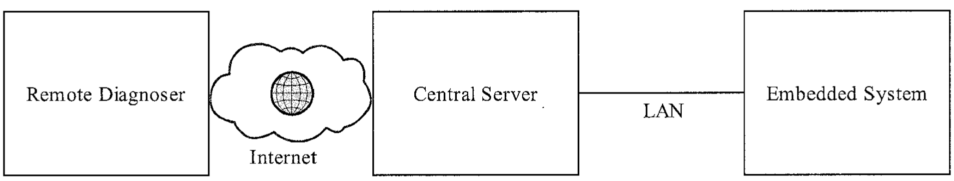

Figure 5: General Configuration of remote diagnose

Biomedical systems are complicated, models are nonlinear and there are many uncertainties surrounding the models. Control of such systems demands a high level theoretical knowledge, understanding of robustness issues, handling of unmodeled dynamics and system nonlinearities. Therefore they form an ideal test bed to apply fundamental and new theoretical developments in soft computing and control theory. Examples of some biomedical control systems include *control of blood glucose level in diabetics, control of arterial carbon dioxide tension and oxygen tension of mechanically ventilated patients, pain management of postoperative patients, blood pressure control of critically ill patients* etc. Automatic blood carbon dioxide tension regulator, blood sugar level regulator and pain management devices are systems, which were developed over the years.

Another area of research is in the development of *sensors* to estimate *key physiological parameters* that would enable the development of biomedical control systems. For example there are no commercial sensors that allow:

- Continuous monitoring of arterial carbon dioxide tension
- Arterial oxygen tension
- Blood sugar level
- Intensity of pain perceived under certain medical conditions

However it is well known that there are other indirect physiological parameters that can be measured which provides an indirect indication of the key parameters that require close monitoring or regulation. Examples of such indirect parameters include *end tidal carbon dioxide tension, oxygen saturation in blood* [8], *glucose concentration in interstitial fluid* etc. Methods of soft computing can be applied to combine continuous measurement of indirect parameters to produce sensors that can provide continuous estimation of the key physiological parameters:

- Closed loop control of blood carbon dioxide and oxygen tension
- Blood glucose regulation in diabetics
- Pain management of postoperative patients - patient controlled analgesia

Conclusions

Embedded systems will have a more important role in biomedical applications in the following period. The main areas of applications are i*ntelligent home healthcare embedded system* and *telemedicine.* There are used *wireless sensors and actuators* with *ambient intelligence.*

Global innovative ideas on embedded systems in biomedicine:

- Exploring and exploiting new opportunities in the emerging interface between computer and biology/healthcare, by developing smart applications that improves productivity and quality in the bio-laboratories.
- Evaluating emerging technologies such as pervasive and embedded hybrid computing. Use the new user needs and requirements in this novel application domain to direct research for breakthrough technologies in embedded hybrid computing.
- Introduce the use of pervasive embedded computing technologies to promote research productivity in biomedical laboratories, propelling computing in the biomedical domain beyond traditional bioinformatics;
- Design and develop a generic plug-and-play reconfigurable embedded middleware component for pervasive interface between heterogeneous lab appliances, laying a foundation for biomedical applications;
- Multimodal mobile communication for geographically-independent remote access, monitoring, and controlling of medical appliances and experiments;
- *Design a remote monitoring and controlling* a biomedical laboratory environment. Create a *Virtual Lab*, where scientists can access, monitor, and even control lab equipments when they are physically away from their laboratories, via multi-modal means (e.g. on their office computer, with their PDA, or even via a mobile phone). The design and development of a generic, reconfigurable, plug-and-play embedded system to plug diverse collections of machines in a biomedical laboratory into a smart communication network.
- Remote user authentication and control, robust wireless computing, and multi-modal access of the virtual lab for diverse collections of lab equipment. Design the remote controlling of home appliances, to the remote monitoring of transportation with trains, planes, ships, and automobiles.

Acknowledgement: The work and the contribution were supported by the project Grant Agency of Czech Republic – Architectures of embedded system networks, No. 102/65/0571.

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