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Enhanced power management unit for the Artificial Accommodation System

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Abstract: *The Artificial Accommodation System is a micro mechatronic device which will replace the lens inside the human eye to restore the accommodation ability after cataract. In such battery powered systems only a limited amount of energy is available. Therefore an intelligent power management is obligatory. Due to the restricted space of the Artificial Accommodation System it will be advantageous to combine all power management functions into one integrated circuit. For simpler implementation and better controllability, a mostly digital design is preferred. The proposed power management unit includes necessary features of an intelligent power supply, battery monitoring and a detection of the wearers sleep phases.*

Keywords: *Artificial Accommodation System, active medical implant, intraocular lens, power management*

Introduction

There are two cases in which the human eye loses its ability to focus on objects at varying distances (accommodation). With age the human lens becomes more and more rigid until no accommodation is possible anymore (Presbyopia). When treating cataract the human lens is replaced by a rigid intraocular lens which also results in the loss of the accommodation ability.

To overcome this disadvantage the Artificial Accommodation System is being developed [1]. It is a tiny, mechatronic lens implant which will be implanted inside the capsular bag like a standard intraocular lens. It contains several subsystems:

An optical element which can adapt its refraction by means of a micro actuator, a sensor system which measures the accommodation demand, a communication system which allows the communication between two implants and with an external monitoring device. Furthermore a control unit for the purpose of controlling the interactions between the subsystems is needed. All these subsystem have to be supplied with energy. In a first step an inductive charging system is developed which can recharge a micro battery within one hour [2]. To extend the autonomous period of operation, it is essential to use all subsystems in an optimal operating point with the lowest energy consumption. Previous investigations [3] showed that there is a trade-off between efficiency and available space in the implant. The use of several voltage converters reduces the energy consumption of the subsystems by providing optimal voltage levels. The drawback is that these components claim a large volume. The efficiency of the voltage conversion depends on the current consumption of the Artificial Accommodation System. The current consumption in turn depends on the actual operating state of each subsystem. It could be shown that an intelligent power supply consisting of a linear converter and a switching converter with adaptive voltage scaling meets the requirements best (Fig. 1). An additional approach to save energy is, driving the implant in an ultra-low power mode while the wearer of the system is sleeping. The intelligent power supply, the sleeping detection and a state of charge monitoring altogether compose the power management unit for the Artificial Accommodation System.

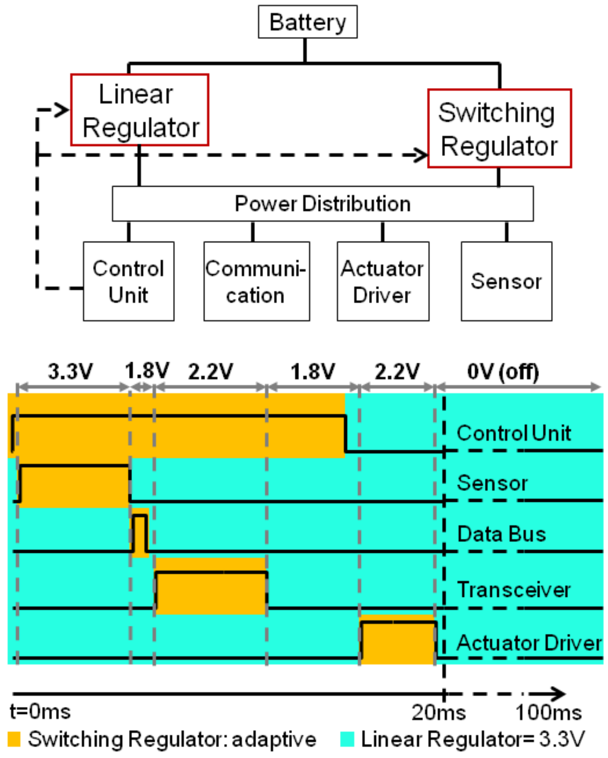

Figure 1: Topology (top) and transient behavior (bottom) of the power supply according to the operating mode.

Methods

Intelligent power supply:

As shown in Fig. 1 both voltage converters have to have the ability to supply each subsystem. This problem is solved by a switching matrix shown in Fig. 2. The assignment of subsystems is executed by the control unit. The switches will be realized with MOS-transistors. Information which voltage converter should supply which subsystem is transferred from the control unit to the switching matrix. The signals from the control unit can also be used to completely shut down a voltage converter. In case none of the outputs uses one of the converters, it can be switched off by a simple logical AND-/ NOR-gate.

By using a digital controller the reference input variable can be indicated as a digital value, modern control algorithms, like a state space controller, can be used and the controller can be optimized for all current characteristics the system exhibits.

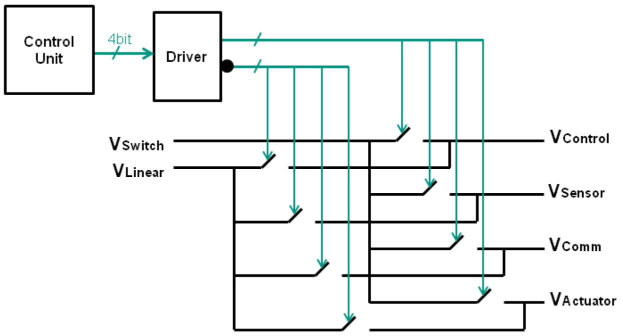

Figure 2: Switching matrix for dynamic assignment of the subsystems.

Battery state of charge (SOC) monitor:
Monitoring the state of charge of the battery is very important. The system has to be transferred into a fail-safe state safely before battery drainage. The main indicator of the SOC is the battery voltage. But this is not sufficient for precise calculation of the SOC [4]. Additionally the information about the load current of the system and the inductance current of the switching regulator can be used to enhance the estimation.

Sleeping detection:
An adult is sleeping about six to eight hours a day. So there will be a huge energy-saving potential, if the system operates in an ultra-low power mode during sleep. A sensor consisting of a photo diode, a transimpedance amplifier and an analog-digital converter (ADC) is measuring the incident light on the eye. If it is dark or the eyes are closed the output value of the sensor is low. Fig. 3 shows the schematic diagram of the sleeping detection. The first step is to compare the digital data with a threshold. To eliminate measurement errors and blinking, a serial-in, parallel-out shift register holds several results of the comparison. In every new sampling interval, the oldest value is shifted out. The length of the register and sample rate defines the delay until the system state changes to ultra-low power mode. In the ultra-low power mode, the actuator moves in fail-safe position, all subsystems except the photo sensor are transferred into sleep mode. The switching converter, the communication subsystem and actuator driver are shut down. The sensor sampling time is reduced from 100ms to 10s. As soon as one photo sensor value is above the threshold, an interrupt on the control unit is triggered and the system wakes up.

Results

Fig. 4 shows the block diagram of the whole power management unit. The only analog parts are the switching transistors, their corresponding drivers and the analog parts of the ADCs. All the other parts can be realized completely within the digital domain.

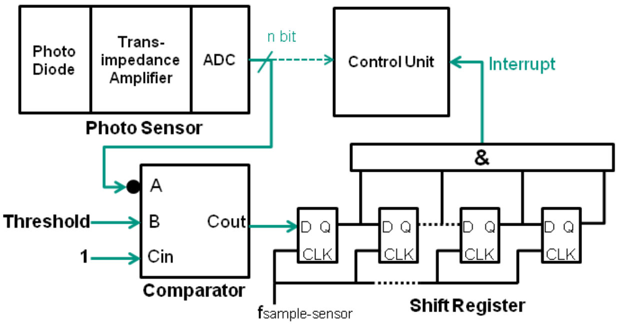

Figure 3: Sleeping detection

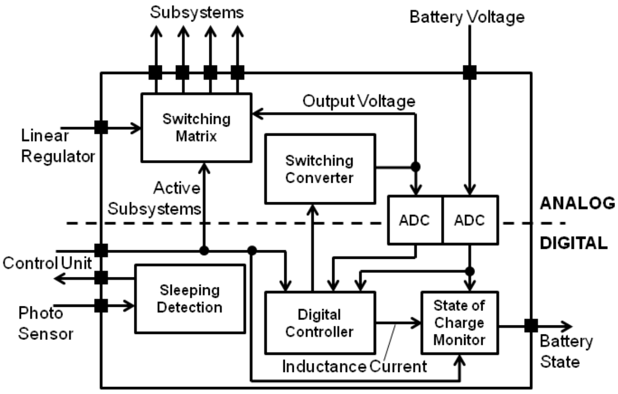

Figure 4: Power Management Unit

Discussion

To improve the efficiency of the Artificial Accommodation System, an advanced power management unit was designed. The main focus was to design the functionalities in digital logic for a simple hardware implementation. A prototype implementation of the digital part is currently under development. The analog circuits are composed of standard components. In future a mixed-signal integrated circuit (IC) can be designed, but it is also possible to design a pure digital IC and combine it with an analog IC to achieve higher efficiency and smaller outlines by using smaller manufacturing processes.

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