3.3 System Concept

The designed fNIRS instrument is based on a modular design (see fig. 3.2). The main development is a 4-channel Continuous Wave NIRS module that provides full stand-alone functionality.
Up to four of these modules can be connected to a mainboard that provides a simple parallel $4\,Bit$ control interface, the power supply rails and converts the analog signals. This modular design has the advantage of being adaptive to the requirements of future applications and research, it enables spatial distribution of the hardware (and weight), it allows direct hardware signal processing (thus minimizing noise and interferences) and it was premise for a much more efficient debugging and development process.

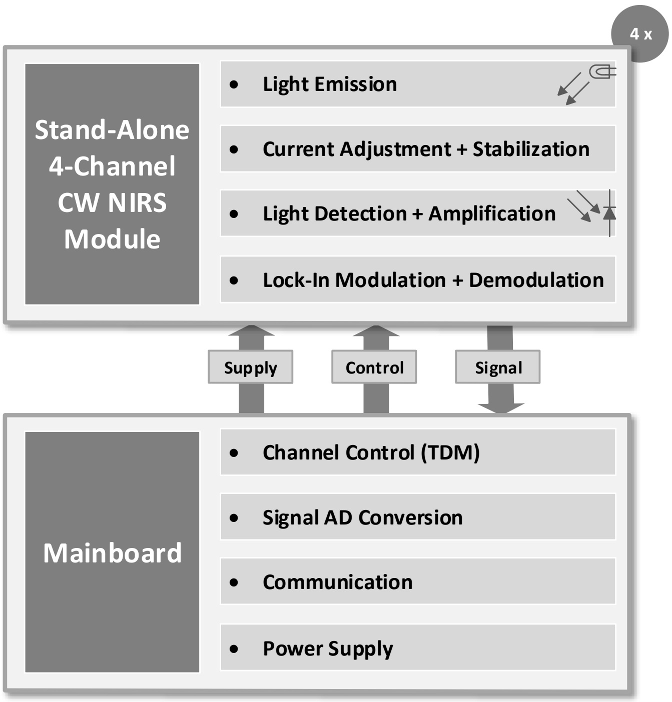

Figure 3.2: Modular system concept of the developed CW fNIRS system.

Each module provides four complete NIRS channels with two wavelengths each, consisting of four dual-wavelength light emitters, eight adjustable current regulators, one central light detector and lock-in modulation and demodulation of the light signals, as well as pre- and post-amplification of the detected signals.
The system uses Time-Division Multiplexing (TDM) for the NIRS channels. This is a trade off between preventing inter-channel crosstalk and sacrificing SNR, which is limited by the width of the applied time windows. The modules work stand-alone, with the interface requiring only the power supply, the above-mentioned parallel control signals for the activation of one of the module's four NIRS channels and providing the associated outgoing analog NIRS signal. Hence, any customization is possible and the NIRS module can also be used stand-alone, e.g. with NI DAQ equipment or any customizable hardware. As one objective of this work was to provide CW NIRS instrumentation for mobile applica-

tions, a controller mainboard was developed for this purpose. The heart of the mainboard is a microcontroller unit that

- adaptively controls the NIRS modules
- enables communication with the user via the UART protocol using a RS232 cable or the onboard Bluetooth wireless controller
- and supervises the analog-to-digital conversion of the incoming analog NIRS signals.

The board is designed for the connection of up to four NIRS modules, allowing up to 16 channels to be individually addressed and activated. The number of active NIRS modules can be configured at any time, enabling the adaption of the instrument to the needs of the experimental protocol and allowing to reduce the amount of active hardware and thus power consumption.

Figure 3.3 depicts a more detailed version of the above-introduced system concept for further commentary.
The upper part of the NIRS module shows the basic elements of NIR light modulation, current regulation and adjustment. Each of the four NIR light sources supplies two wavelengths, resulting in 8 channels that are controlled individually.
Each channel's current is regulated by a separate current regulator circuit consisting, among others, of a high-precision operational amplifier and a FET transistor. The activation and modulation of each of the channels for lock-in amplification is done by analog switches that are controlled by a 1:8 demultiplexer.
Heart of the NIRS module is a microcontroller that controls all functional units on the board. For NIR light lock-in modulation and demodulation, it supplies a $3.125\,kHz$ pulse width modulation (PWM) signal that is fed into the 1:8 demultiplexer. By choosing the demultiplexer channel, the controller activates one of the 8 NIR light channels and the PWM signal is fed through to the corresponding current regulator, where it modulates the analog switch and with that the current regulator input.
The current value that is the command variable for the current regulator is adjusted by a voltage at the current regulator inputs. This voltage is produced by a 1 channel $8\,Bit$ digital-to-analog converter (DAC) circuit controlled by the microcontroller.

The elements for light detection and amplification are depicted in the lower part of the NIRS module.
A light detector with integrated trans-impedance amplifier (TIA) converts the incoming optical signal into a voltage signal, which is then amplified by a programmable gain amplifier (PGA). The PGA is controlled by the microcontroller using a signal monitor line. This way, the maximum possible gain can be applied without reaching the dynamic range limit of the amplifier.
The amplified signal is then demodulated by a lock-in amplifier circuit using the same PWM signal reference that is used for the modulation of the light sources. After demodulation, the signal is filtered by a 3rd-order Butterworth low-pass and is then again amplified and stabilized before it leaves the NIRS module for analog-to-digital conversion on the mainboard.

In the lower part of the figure, the mainboard unit is depicted. A microcontroller unit administrates the operation of the instrument corresponding to the user inputs. It sends the control signals for up to four NIRS modules and reads the corresponding digitized values via SPI interface from a $16\,Bit$ 4-channel analog-to-digital converter (ADC).

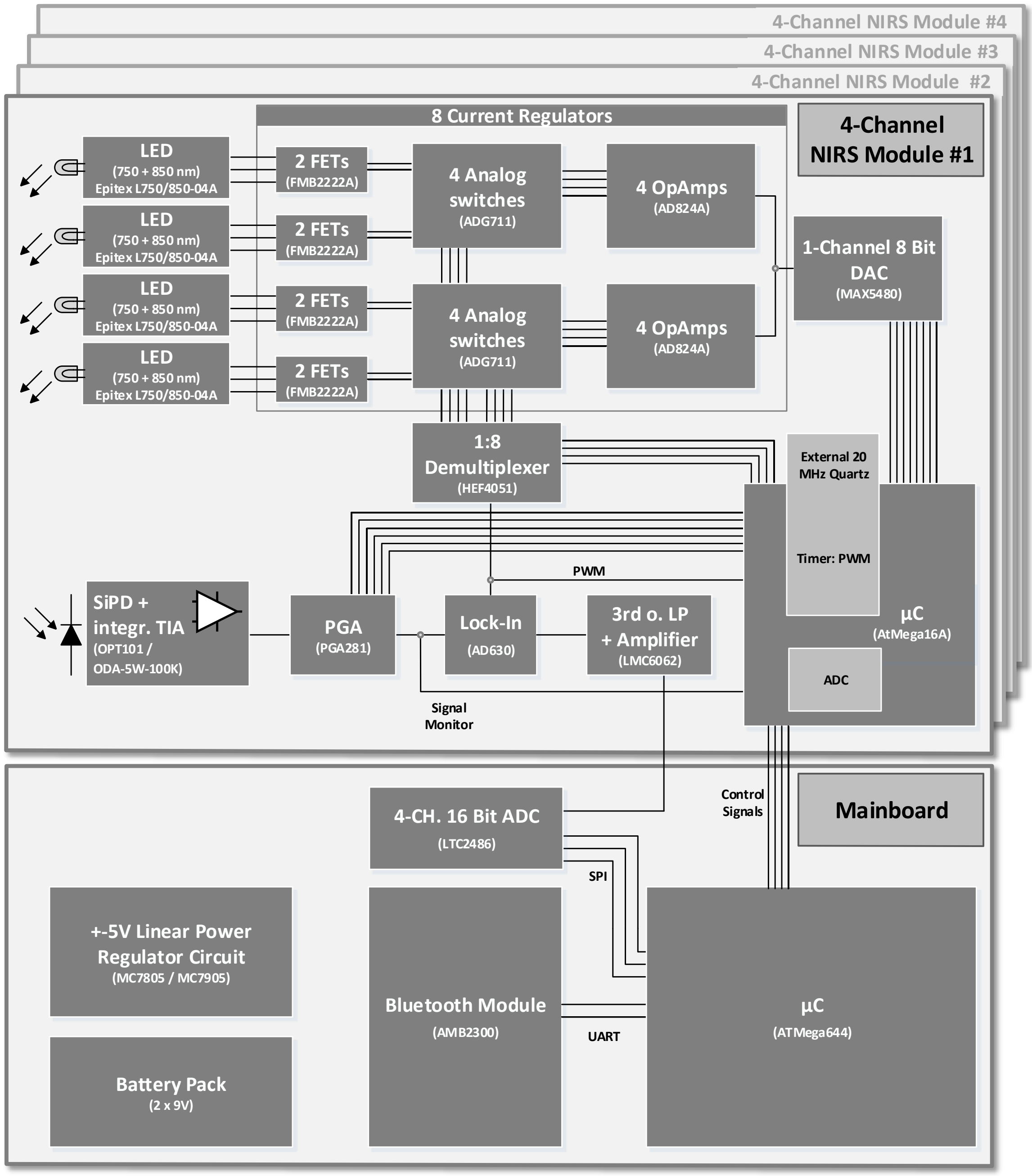

Figure 3.3: Detailed system concept of the developed CW fNIRS system.

The digitized values are then assigned to their correct channel and wavelength, further operational information is added and the complete data block is sent via UART to a Bluetooth module. The Bluetooth module works in transparent mode and simulates a common RS232 interface, sending the data to the PC where it can be saved and evaluated. Also on the mainboard, a stabilized linear power regulator circuit provides a $\pm 5\,V$ power rail for the NIRS modules. The two $9\,V$ (at least $7.5\,V$) inputs for the power regulator circuit come from battery packs that can be chosen at will.