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Design of a Real-time Signal Processing System for LIF Sensor

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Abstract: Laser Induced Fluorescence (LIF) sensor is one of the most sensitive approaches available for a variety of analytical applications, such as determination of nitrogen content of plant leaves, detection of chlorophyll content in water, etc. As a core instrumental requirement of real-time LIF sensor, signal processing system is used to store effective processing and identification algorithms in a short time. By analyzing the working principle of LIF sensor in detail, a novel platform of signal processing system used in LIF sensor is proposed in this paper. The design solutions and hardware architecture of the system are described in this paper, include Digital Signal Processor (DSP), data transmission block, and memory block. Several steps of signal processing methods are proposed, according to the characteristic of LIF sensor. At last, an application of using the signal processing system designed in this paper for measuring chlorophyll content in plant leaves is shown.

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1. INTRODUCTION

As a powerful spectroscopic technique, Laser Induced Fluorescence (LIF) is more and more commonly used for probing gas-phase atomic or molecular species, even in minute amounts, and determining their internal states distribution\(^{[1]}\).

The basic principle of LIF is shown in Figure 1. The species to be examined is excited with a laser. The wavelength is often selected to be the one at which the species has its largest cross section. The excited species will after some time, usually in the order of few nanoseconds to microseconds, de-excite and emit light at a wavelength larger than the excitation wavelength.

The relationship between fluorescence intensity and the material concentration can be described in following equation.

\[
F = k \times QE \times Po \times (1 - 10^{-\alpha L c})
\]  

\(F\) is measure of the fluorescence intensity, \(k\) is geometrical parameters of the instrument. \(QE\) is quantum efficiency (emission of photons / absorbtion of photons), \(Po\) is illuminant power, \(\alpha\) is absorbed section associated with wavelength, \(L\) is wavelength, \(c\) is concentration. (the physics meaning of \(\alpha\), \(L\), and \(c\) is same as the law of Beer-Lambert.)

Fluorescence analysis is a good method with the advantage of high selectivity, good reproducibility, simple, rapid, and easy sampling\(^{[2,3]}\).

The essence of signal processing is to extract information from the signal source with various noise and interference, and transform the extraction to a form which can be used by a man or a machine. High-speed and real-time signal processing is a special branch of signal processing which is important to realization of real-time data processing and rapid response to get results and widely used in industrial and military, such as radar signal processing and communication signal processing, etc\(^{[4]}\).

In this paper, a real-time signal processing for LIF sensor is designed. A new kind of spectral signal processing module, which uses a Digital Signal Processor (DSP) as its central processing unit, is designed for this system. Details on hardware and software design solutions of this module are discussed in later sections.
2. HARDWARE PART

The signal processing system designed for LIF sensor includes signal processing block, data transmission block, memory block and other devices. The hardware architecture is illustrated in Figure 2.

![Figure 2. The hardware architecture of the signal processing system](image)

2.1 Signal Processing Block

The basic electronic module is based on a central processor, TMS320LF2812, a kind of digital signal processor made by Texas Instruments company. This chip is an advanced fixed-point 32-bit digital signal processor. It is based on 32-bit fixed-point DSPTMS320C28x CPU kernel and its working frequency is as high as 150MHz, very well suited for numerically intensive algorithms. On the chip, 128K \( \times 16 \) Flash and 56 independent programmable general-purpose input output interface (GPIO) are integrated. It has powerful capabilities of digital signal processing and event management, and embedded control function. It can be used in many fields such as industrial automation and control, application of power electronics technology, intelligent instrument and motor servo control system, etc.\(^5\).

TMS320LF2812 consists of a 12-bit analog-to-digital converter (ADC) to capture an input signal which is output from LIF sensor. The resulting digital representation of the captured signal is then processed by spectral signal processing software. All of the process above is implemented by the software. The software is running on DSP processor which is the central device of signal processing block.

2.2 Data Transmission Block

In spite of being almost completely physically embedded in the DSP, special reference should be made to the interface capabilities of the module. In this paper, two kinds of communication modes, Universal Serial Bus (USB) and the Universal Asynchronous Receiver/Transmitter (UART), are designed for the communication with the host computer.

In this design, serial communication based on RS-485 between the host PC and the slave device is realized. The product of MAXIM LLC, MAX485, is used to complete the standard interfaces of RS-485 communication between PC and TMS320LF2812. The method is shown in Figure 3.
The ability to serial communication of TMS320F2812 is strong. Because relating to more control class registers, it makes system design more flexible. When design, firstly the control class registers are initialized, including data format definition, interrupt enable, interrupt priority, the baud rate setting and other parameters. After the initialization, sending or receiving data can be start. For sending data, the data should be written into SCITXBUF and then the SCI serial communication module will send the data automatically. For receiving data, the information from the pin SCIRXD / IO is automatically removed start bit, stop bit and parity bit by the SCI serial communication module and the data is written into SCIRXBUF.

AN2131Q is used for the USB interface which is a product of Cypress. There are four wires on the interface between the USB transceiver and PC: +5V, GND, D+, D-. Data is differential transmitted in the lines of D+ and D- as full-speed of 12Mb/s or low-speed of 1.5Mb/s. Transceiver is embedded in the chip, and there are not external circuits, but the pull-up resistor which used to distinguish the working mode of low-speed or full-speed are need to selected. The functional block diagram of AN2131Q is illustrated in figure4.

Two pieces of 8-bit FIFO (First in First out SRAM) chips are used to realize the two-way communication between the DSP and the USB interface. By this way, the data exchange between USB interface chip and DSP can be maximum faster than the speed of USB bus, so that the speed of data transfer between DSP and host PC is only limited by the USB protocol. Two pieces of IDT72V02 whose memory is 1K×9bit are used as the FIFO chips. If there is information to exchange between DSP and PC, the data is stored in FIFO, and then read by DSP or AN2131Q, in order to avoid data transmission congestion. The diagram of hardware connection is shown in Figure5.
2.3 Memory Block

In some embedded applications based on DSP architectures, the limited on-chip memory capacity is often insufficient to meet the requirements of mass data throughput. So the strong support of high-speed and large-capacity storage space is needed. In this design, a high-speed synchronous dynamic RAM (SDRAM) chip, IS42S16400, is selected to expand the storage space of embedded DSP systems. IS42S16400 is a kind of high-speed SDRAM chip launched by the company of ISSI whose single-chip storage capacity is up to 64M bits.

TMS320LF2812 provides up to 1MB of external memory interface to access the external memory. The SDRAM must be initialized when it is powered. First every storage unit is charged, then SDRAM automatically enters idle state (IDLE). In this state, the SDRAM may enter auto-refresh state or access operation state. Once the refresh is executed, the control program will write the read/write parameter into register. If access to read or write operation, the controller will executes the command of ACTIVEROW, and writes the address line. When BANK is valid, according to the parameters in mode register, the command of READ/WRITE or READAP/WRITEAP is executed. If the operation is completed, the SDRAM automatically enters the idle state. Figure 6 describes the SDRAM status of metastasis.

2.4 Other Devices

The system operates from a single +5V external power supply connected to the main power input. Internally, the +5V input is converted to +1.8V and +3.3V using separate voltage regulators. The +1.8V supply is used for the DSP core while the +3.3V supply is used for the I/O buffers of DSP and all other chips on the board.
A Complex Programmable Logic Device (CPLD) is used to implement functionality specific to the system. The CPLD has a register based user interface that lets the user configure the board by reading and writing to its registers.

3. SOFTWARE PART

3.1 Software Architecture

The majority of the software is written in C, using Code Composer Studio (CCS), which provides an integrated development environment to incorporate the software tools. CCS includes tools for code generation, such as a C compiler, an assembler, and a linker. For optimum performance, it is necessary to write some of the code in assembly language.

The C source program includes six modules shown in the figure8. The signal from LIF sensor is firstly acquired and digitized by the signal acquisition module. Then the digital signal is clean though the digital filter, and normalized by the software. After the processing of artificial neural network algorithm, the target signal is analyzed by the principal component analysis module, then the result is got and transmitted by the data transmission module.

3.2 Software Implementation

The software mixed use of C language and Assembly Language, C language code is more easily and quickly achieved while Assembly Language has higher performance advantages. In certain cases, mainly control applications, C language code is sufficient. However, in most cases, the initial application written in C language can not meet the requirements of one or more goals. This usually means some assembly codes are needed. In this design, to improve the executive efficiency in the limited resources, and meet the real-time requirements, some steps are taken to ensure the program codes are efficient.

In this design, there are two kinds of communication port. They are used for the communication between this slave and host computer. A protocol is designed to ensure the data communication traffic effective and reliable. Figure9 illustrates the data frame structure of the protocol.
4. IMPLEMENTATION

The signal processing system for LIF sensor is suit to real-time systems which need high-speed signal processing. It can be used to detect the existence of the target material and its concentration. An application for chlorophyll fluorescence sensor is implemented\(^7\), and experiments were done with the algae artificially propagated. The experiments showed that the minimum detectable concentration of chlorophyll a is \(1\mu g/l\), and the signal processing system has good linearity, which prove that the design of the system is reasonable, feasible and practical.

5. CONCLUSION

In this paper, the design and implementation of a novel LIF sensor signal processing system is proposed. Both hardware and software are designed. The hardware is based on DSP TMS320LF2812, and expanded peripheral circuits, which to give it powerful capability of data processing and analysis. The Software is efficient and the algorithm is optimized. The applications show that the proposed signal processing system works quite well for LIF sensor.

REFERENCES