Zeng-Rong Zhao, Shi-Lei Cai, Tian-Xiang Li and Li-Wei Pang

The Design of Laser Liquid Level Measurement System Based on FPGA and MCU

Abstract: The paper studies on an intelligent, real-time laser liquid level measurement system which is based on FPGA as the core unit and AVR MCU as aided processing unit. It realizes to measure the liquid level according to the control signal and the information can be shown in field or in remote site or on the mobile phone at the same time. The experiment result shows that this system achieves to high measurement accuracy, which meets to the requirement of measuring the actual level of liquid petroleum, liquid glass etc. in industry.

Keywords: FPGA AVR MCU Laser liquid level measurement

1 Introduction

Liquid level is a very common index in industrial measurement system. The early liquid level measuring instruments required to contact with liquid level measurement directly, which has the disadvantages of slow measurement speed and large error, and not suit in these occasions with high temperature and high pressure that is inconvenient to contact with sensor directly such as metallurgy, petroleum and chemical industry. But the laser liquid level measurement system adapts the method of non-contact level measurement, which achieves the accurate measurement of liquid level by using laser’s characteristics such as high precision, high speed, wide range and strong anti-interference ability to convey the level signal accurately. Through the subsequent information processing system, the level signal can be displayed in field, in remote control room or on the mobile phone, and the system can be controlled to measure or not which solves the problem of the non-contact measurement in long-distance [1].

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2 System Composition and Working Principle

The hardware components of laser liquid level measurement system is shown as Figure 1-1, which including FPGA core board, MCU core board, laser measuring range module, Bluetooth module, VGA interface, Android mobile phone, computer monitor and the measured liquid device.

In this system, FPGA is used as the main chip, MCU as the aided design to realize the complex logical circuit and drive the VGA display in high speed. Standard SPI interface is used to realize the communication between the MCU and FPGA. After the level information is converted and processed by the MCU which obtains from the laser ranging module, on the one hand the data is transferred to FPGA to calculate and drive VGA to display the liquid level data by the SPI bus, on the other hand, it establishes Bluetooth communication network to communicate with the mobile phone through the Bluetooth module, so the information of measured liquid level will be displayed on the mobile phone client via Bluetooth serial port. So the system realizes the intelligent liquid level monitoring and meets the requirement in petrochemical industry [3].

3 Major Modules and Technologies Related

3.1 Laser Ranging Module

In this design, the laser range sensor HJ-40A is adopted because of the high performance-price ratio. It uses the visible red light of 635 nm wave length, which belongs to the two level security laser and is not harmful to person, and its measuring range is 0.03–40 meters. Its detailed parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Technology parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>range</td>
<td>0.03–40m</td>
</tr>
<tr>
<td>2</td>
<td>Baud rate</td>
<td>19200bps</td>
</tr>
<tr>
<td>3</td>
<td>Power Consumption</td>
<td>&lt;1mw</td>
</tr>
<tr>
<td>4</td>
<td>Measurement accuracy</td>
<td>±1mm</td>
</tr>
</tbody>
</table>

In theory, there are two main methods to calculate the distance by laser: phase method and pulse method.
Firstly, the principle of phase method is to calculate the phase difference between the received laser signal and the continuous emission signal. The formula is:

$$D = \frac{c}{2} \left( \frac{\Phi}{2\pi f} \right)$$  \hspace{1cm} (1)$$

Where, $D$ is the distance measured, $c$ is the wave length, $\Phi$ is the phase difference and $f$ is the laser modulation frequency.

By this measurement method, the distance $D$ can be concluded from the formula as long as the phase difference between the received signal and the transmitted signal is obtained. But it has a drawback that the laser must be continuous, and also need the technology of difference frequency and modulation. Because it requires that the signal must be very accurate and strict, which makes it is not easy to achieve and is not adopted widely.

Secondly, the principle of laser ranging is that the laser is emitted out and reflected back when it meets the obstacle, the round trip time is obtained by a counter to calculate the distance. The formula is:

$$D = \frac{C \cdot T}{2}$$  \hspace{1cm} (2)$$

Where, $D$ is the distance measure, $C$ is the light speed, $T$ is the laser trip time. In this design, we adopted the pulse method to measure liquid level [4].

### 3.2 Bluetooth Serial Port Module

Bluetooth is a wireless communication technology standard, the wireless wave works at short baud and high frequency, the radio frequency range is from 2.4 to 2.485GHz. In a short range, data can be achieved interaction with mobile devices, such as the mobile phones, tablet PCs, desktop computers etc.

There are many Bluetooth serial modules in market; here the HC05 Bluetooth serial module is selected because of its good stability and compatibility. This module uses the TTL serial port, which is convenient to connect with MCU interface. Its parameters are listed in Table 2.

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Technology parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Communication distance</td>
<td>10m</td>
</tr>
<tr>
<td>2</td>
<td>Baud rate</td>
<td>9600bps</td>
</tr>
<tr>
<td>3</td>
<td>Current</td>
<td>&lt;5mA</td>
</tr>
<tr>
<td>4</td>
<td>Voltage</td>
<td>3.3V−3.6V</td>
</tr>
</tbody>
</table>
3.3 Micro Controller Unit Module

Micro controller unit (MCU) is mainly responsible for the communication between interfaces, after the serial port sends measurement command through the trigger button, the system begins to emit laser to access liquid level information, and this information is sent to the FPGA through the SPI bus and the Bluetooth module to process and display. The design flow is shown as in Figure 1.

![Design flow of MCU module.](image)

3.4 FPGA Module

Field programmable logic gate array (FPGA) comes from CPLD, GAL, PAL and other programmable device through technology innovation and progress, which can use VHDL or Verilog-HDL hardware programmable language to design the logic circuit to realize required function. VHDL language syntax is rigorous, and relatively close to the hardware, but the program is cumbersome. Otherwise Verilog-HDL is easier, which likes the C language. In this design, Verilog-HDL is used to program, ISE software and the hardware chip on the core board of Xilinx is used as the development platform. The design flow of FPGA module is shown as in Figure 2.
3.5 VGA Display Realization

There are 15 pins in VGA interface, 9 pins are used in general. The driving principle of FPGA is shown as follows: a line synchronization signal is loaded at pin 13-HSYNC, while a field synchronizing signal at the pin 14-VSYNC, so the VGA signal begins to scan from the first pixel of the first row to the last line of the last pixel, and the scan cycle is repeated. However, if when a certain pixel is scanned, such as the VGA interface pins 1, 2, and 3, which corresponds to the RED, GREEN and BLUE respectively, if the appropriate analogy voltage is loaded, the screen will display different colours corresponding to the analogy voltage. But the FPGA output signals are digital signals, how to generate the analogy signal of 0-0.714V? In this design a simple and ingenious method is used to solve this problem which is a simple DAC circuit consisting of a resistor divider array to matching different analogy voltage, as shown in the figure 1–4. It is not accurate as dedicated DAC conversion chip, but
meets the speed requirement because only measurement data is displayed only not the colour in this design, so the colour requirements is not high therefore, and the accuracy of required voltage signal is not high, while FPGA uses parallel mode, which meets the speed requirements completely [5].

4 Multi-Serial Communication Circuit Design

Serial communication is the communication protocol of general computer, equipped with RS232 interface in the old desktop computer. Because USB is more and more popularity now and professional USB serial communication chip can be used to convert the USB interface into the serial port of TTL directly, such as CH340, PL2303 chip, so the computer can realize serial transmission only equipped with the USB interface.

4.1 Serial Communication

In this design, AVR's ATmega2560 chip is adopted which contains 4 serial ports, serial port 0 contains pin 2 and pin 3, serial port 1 contains pin 45 and pin 46, serial port 2 contains pin 12 and pin 13, serial port 3 contains pin 63 and pin 64, and it can meet the system design requirements. Each serial port’s baud rate can choose from 2400 to 115200, which is convenient to different rate serial device. In this design, the laser ranging module uses the serial port 1 and 19200 baud rate, and Bluetooth module uses the serial port 0 and 9600 baud rate. In the connection of laser ranging module and the microcontroller, series resistors are used to achieve the voltage conversion, so the power supply voltage is compatible from single-chip’s 5V to laser ranging module’s 3.3V.

4.2 MCU and FPGA Communication Design

SPI communication principle: Serial peripheral interface (SPI) is a kind of synchronous serial communication bus in short distance. SPI bus equipment direct communication works in full duplex mode, with high communication speed reaching to 1Mb/s in the ideal condition. Generally there are a host machine and one or more guest machine in SPI communication. Signals of frame data to wait writing and reading are generated by the host. If there is a few guest machines, the host machine will give the chip selected signal to choose one guest machine to response to the equipment’ request.

The design of SPI communication circuit based on FPGA and MCU: There are many ways of communication between MCU and FPGA, such as serial communica-
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tion, FSMC (flexible static memory controller) communication and SPI bus communication. The FSMC bus’s speed is very fast to achieve 16MHz in write speed because of communication with the internal memory. But the FSMC interface pins are more, and its timing is complex. In contrast, SPI serial communication is more simple and quick, so it is adopted in the design. The diagram of communication hardware connection between FPGA and MCU is shown as in Figure1-4. Here microcontroller is the main equipment and FPGA is the slave device. After MCU obtains data’s, they are transmitted to the FPGA through the SPI bus. In FPGA they are analysed and processed to display the liquid level information on screen through VGA interface.

Implementation of SPI communication program: SPI bus is a ring bus structure with data ports such as CS, CLK, MISO and MOSI. Under the CLK signal’s controlling, bidirectional data’s exchange is realized in two registers. Here SPI bus module is written by Verilog HDL in this design which realizes the real time communication between FPGA and SCM.

5 Conclusions

After the whole system is built, all programs are compiled and downloaded to the corresponding chip. When the start button is pressed, the liquid level measurement system begins to work: the laser ranging module emits and receives laser, MCU processes liquid level measurement information, on the one hand, the information is feedback to the mobile phone software to display the liquid level data via Bluetooth, on the other hand it is transmitted to the FPGA to process and drive the VGA interface to display the data on the remote screen. The mobile phone software results is shown as in Figure 4-1, computer display as in Figure 4-2, All the test data are shown in Table3.

<table>
<thead>
<tr>
<th></th>
<th>Measured Liquid Level (mm)</th>
<th>Real Liquid Level (mm)</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.05</td>
<td>5</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>10.1</td>
<td>10</td>
<td>1%</td>
</tr>
<tr>
<td>3</td>
<td>15.06</td>
<td>15</td>
<td>0.4%</td>
</tr>
<tr>
<td>4</td>
<td>16.2</td>
<td>16</td>
<td>0.125%</td>
</tr>
</tbody>
</table>

According to the test data, we found that the accuracy of the liquid level measurement system is high with the error is low to 0.125 % in mm. This error meets the actual requirement of liquid measurement system in industry. And the system real-
izes the intelligent measurement of the display and control on the mobile phone or in the remote controller room. Through further improvement, it is easy to realize the liquid data’s storage, statistics and comparison to the last data, which is more convenient to the management of the liquid level in the industrial production.

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References


