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The Application of Distance-Measuring by Ultrasonic Based on CPLD in the Field of Agriculture Robot

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Abstract: In order to further improve the accuracy of the distance measurement of agricultural robots and realize the precise delivery of crop feeds, thereby increasing the yield of crops, this paper proposed a ultrasonic distance measurement system for agricultural robots based on Complex Programmable Logic Device (CPLD). The system mainly included two parts: hardware and software. The hardware part mainly included CPLD control part, ultrasonic sensor and temperature sensor. The software part mainly included the identification and counting of ultrasonic signals, data processing and temperature compensation. The system performed accurate ultrasonic ranging based on the current temperature and ultrasonic echo measurement. In order to improve the degree of humanization of the system, the system used a high-brightness digital tube to display the measured data in real time. The part of hardware had been analyzed and designed, and the same time the part of software had been designed by the language of VHDL and simulated by wave in QUARTUSII platform. Finally the design was downloaded to a CPLD chip named EPM1270T144C5. The system was tested by measuring the distance of block range from 50mm to 5500mm in the temperature of 28°C. After actual system testing, we found that the precision of test could be controlled less than 0.1 mm as a result of temperature compensating and high-speed characteristic of CPLD.

Keywords: CPLD, High Precision, Distance-Measuring by Ultrasonic, Agriculture Robot

1. Introduction

Ultrasonic sensors were non-contact sensors. Due to the strong directivity of ultrasonic waves, slow energy consumption, and long distances in the medium, ultrasonic waves were often used for distance measurement [1-7]. Ultrasonic detection was often quick, convenient, simple to calculate, and easy to achieve real-time control. Ultrasonic ranging was achieved by CPLD.

MAXII series CPLD chip EPM1270T144C5 was used as the control core in the distance measuring system, and T/R40 piezoelectric ultrasonic sensor was used as the measuring tool in the system. The CPLD control chip worked at the nanosecond level, which was three orders of magnitude faster than the traditional single-chip microcomputer. Thus the system had high counting accuracy and measurement accuracy. Therefore, it had been widely used in the development of agricultural robots. CPLD adopt CMOS technology, and also had many advantages such as high integration, good stability and low power consumption, etc. In order to make better use of CPLD resources and improve the stability of the system, the system peripheral interfaces (display and temperature measurement parts) were all integrated in Inside the CPLD. Experiments showed that the system could achieve stable ranging within 6000mm, with a ranging accuracy of 0.1mm.

2. Method

Ultrasonic waves sensor sent ultrasonic waves regularly, and reflected when encountering obstacles [8-15]. The transmitted waves were received by the receiver and converted into electrical signals. In this way, once the time difference between sending and receiving was measured, the distance could be calculated according to formula 1.

$$L=(C \times t) / 2 \tag{1}$$

In the formula 1, C represented the propagation speed of ultrasonic waves in the air which was 331m/s at 0°C and 347m/s at 25°C. Lowercase t represented the time difference between sending and receiving ultrasonic signals. The relationship between C and the environment temperature T (°C) was as formula 2.

$$C=331.4+0.61\times T \quad (2)$$

It could be seen that the speed of sound was closely related to temperature. Firstly, the current outdoor temperature could be measured by the temperature sensor. The accurate sound velocity at that time was obtained by the look-up table method, and the distance value was obtained by accurate calculation. The use of CPLD for accurate counting to complete the ultrasonic distance measurement greatly improved the measurement accuracy of the system.

2.1. System Hardware Design

The system adopted MAXII series chip EPM1270T144C5 as the control core, which was convenient for control, good stability and high precision. The system circuit was mainly composed of CPLD control module, ultrasonic transmitter module, ultrasonic receiver module, temperature compensation module, LED display module, and keyboard acquisition module. The overall structure of the system was shown in Figure 1.

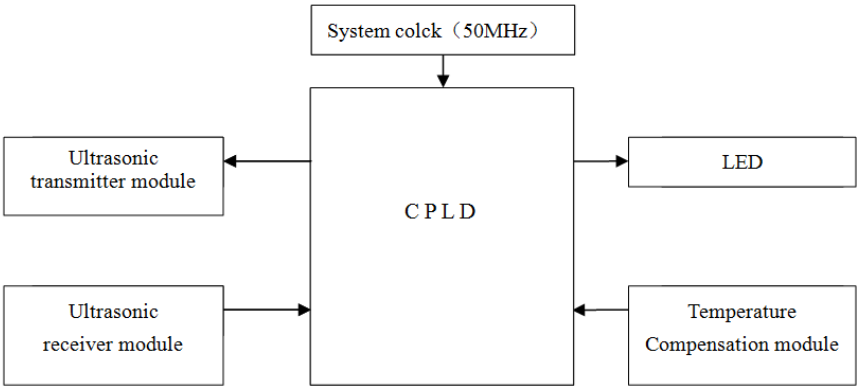

Figure 1. *System principle block diagram.*

2.1.1. The Circuit Design of the Ultrasonic Transmitter Module

The schematic diagram of the ultrasonic transmitter circuit was shown in Figure 2. The transmitting circuit was mainly composed of the inverter 74LS04 and the ultrasonic transmitting transducer T. The 40 kHz square wave signal come from the CPLD port was sent to one electrode of the ultrasonic transducer after passing through one inverter, and the same time the 40 kHz square wave signal also was sent to another electrode of the ultrasonic transducer passing through two inverters. Using this push-pull form to add a square wave signal to both ends of the ultrasonic transducer could increase the intensity of ultrasonic emission. Two inverters were adopted in parallel to improve the driving ability in the output terminal. On the one hand, the pull-up resistor could improve the high-level drive capability of the inverter 74LS04, and on the other hand, it could increase the damping effect of the ultrasonic transducer and shorten its free oscillation time.

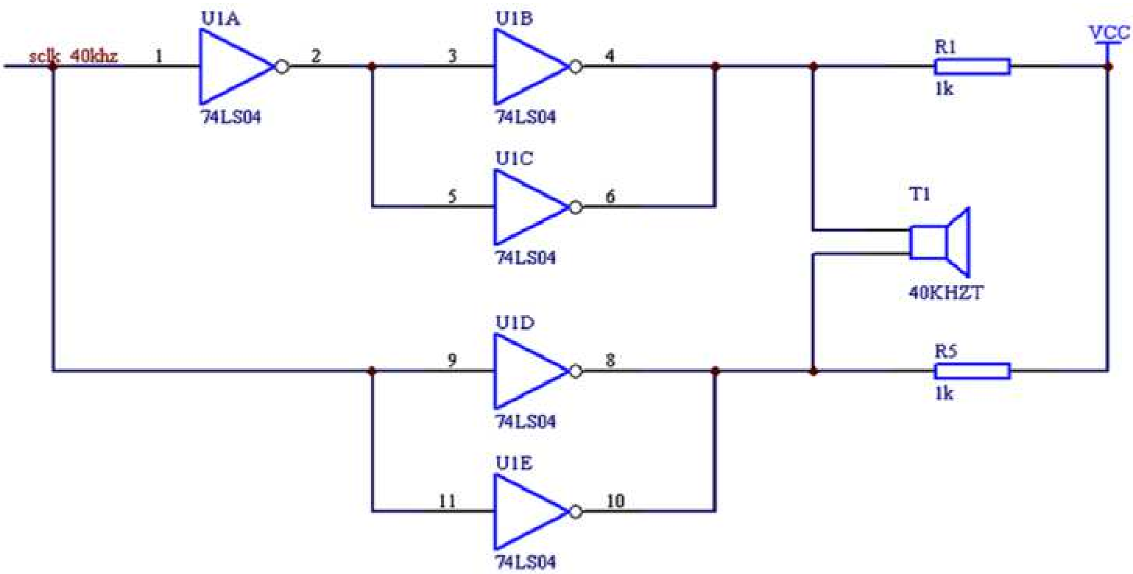

Figure 2. *Schematic diagram of ultrasonic transmission circuit.*

2.1.2. Circuit Design of Ultrasonic Receiving Module

The integrated circuit CX20106A [3] was a dedicated chip for infrared detection and reception, which was often used in infrared remote control receivers for televisions. Taking into account that the commonly used carrier frequency of infrared remote control 38 kHz was relatively close to the ultrasonic frequency of ranging 40 kHz, it could be used to make an ultrasonic detection receiving circuit (Figure 3). The experiment proved that ultrasonic wave (output high level when there is no signal) could be received by CX20106A which had high sensitivity and strong anti-interference ability. The high-level output voltage of CX20106A was 5V, and the working voltage of EPM1270T144C5 was 3.3V, so the voltage divider circuit was designed, with three 1K resistors connected in series, and then the voltage was divided and sent to the port of EPM1270T144C5 for counting.

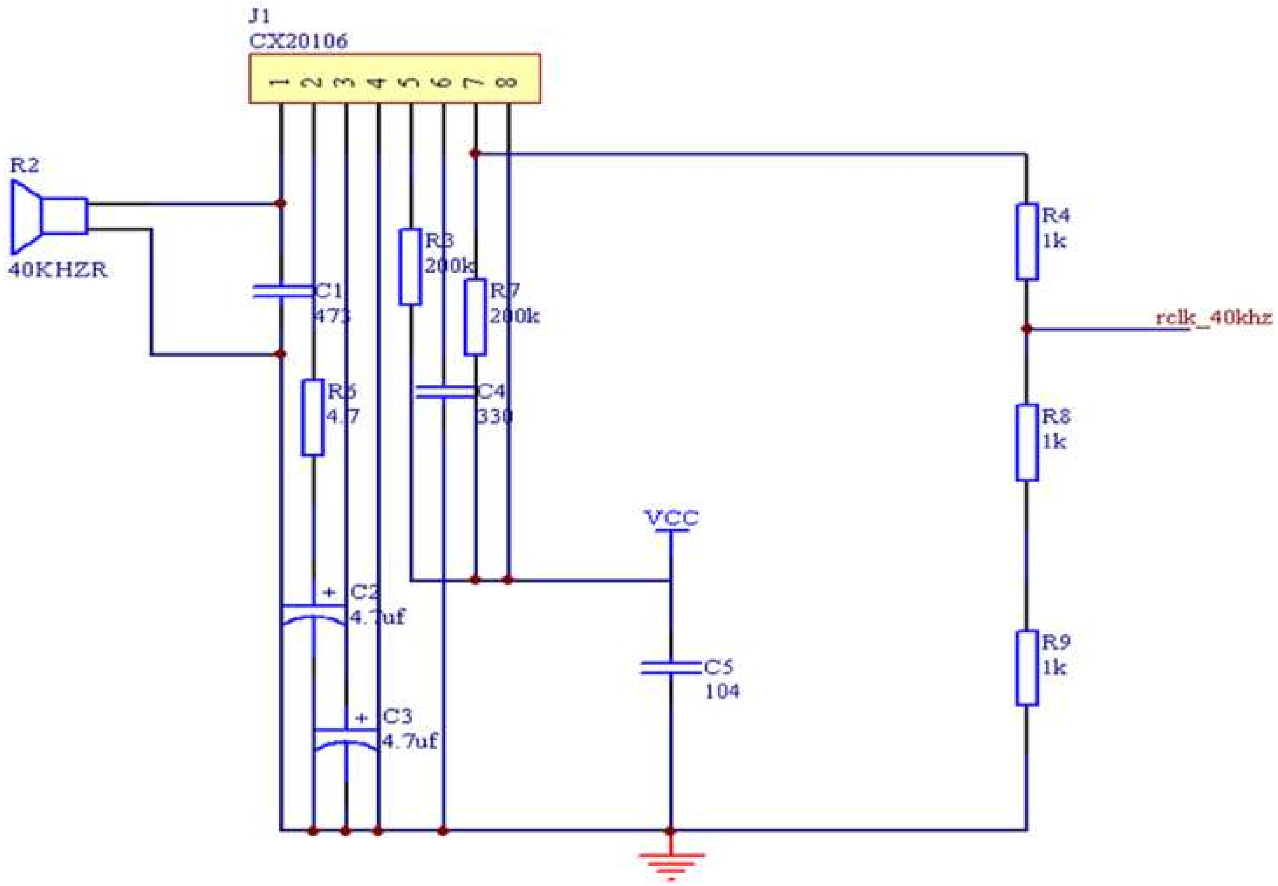

Figure 3. *Schematic diagram of ultrasonic receiving circuit.*

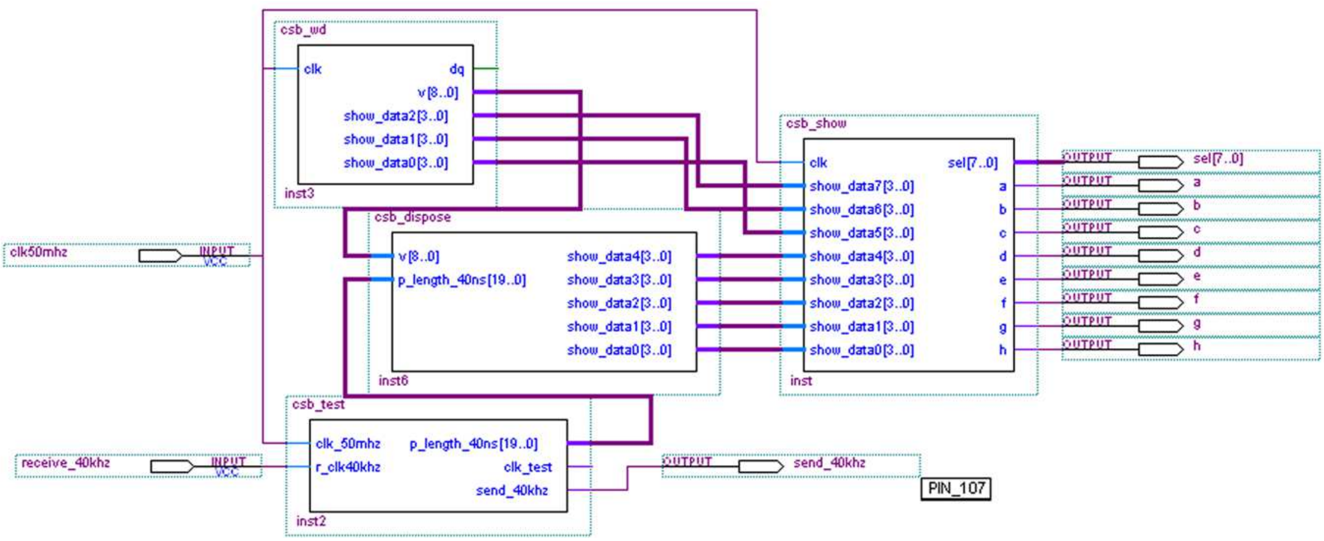

Figure 4. *The top-level design module diagram of the system.*

2.1.3. Design of Temperature Acquisition Module

For temperature acquisition, the DS18B20 digital temperature sensor [4] from Dallas Company was used. The hardware circuit interface was simple. It only needed to connect a 4.7K pull-up resistor between the power cord and the sensor single bus, the power supply was connected to 3.3V, and the signal was directly connected to the CPLD port.

2.2. CPLD Module Design and Simulation

The system was mainly composed of ultrasonic transmitter and receiver module, temperature acquisition module, data processing module, digital tube display module, etc. The system design adopted a modular design scheme. The top-level design module diagram of the system was shown in Figure 4.

2.2.1. Software Design of Ultrasonic Sending and Receiving Part

(i). Design of Ultrasonic Signal Generation Module

The system clock selected 50MHz to generate 40KHz ultrasonic signal, the signal period was 25 microseconds, and the test distance set by the system was 5 meters. According to the requirements, a control signal with a period of 50 milliseconds and a duty ratio of 1:1000 would be designed. Then, the control signal and the standard square wave signal of 40KHz could be Multiplied to obtain the ultrasonic transmission signal. The specific design procedure is as follows:

```
---40KHZ signal generation module with equal --duty cycle
process (clk)
variable a:integer range 0 to 1250;--1250
begin
if rising_edge(clk) then a:=a+1;
if a<625 then clk40hz<='0';
elsif a<1250 then clk40hz<='1';
else a:=0;clk40hz<='0';
end if;
end if;
end process;
--control signal(clk2) generate
--module program
process(clk)
variable e:integer range 0 to 100000000;
begin
if rising_edge(clk) then e:=e+1;
ssignal<=(clk2 and clk40Hz);
if e<2497500 then clk2<='0';
elsif e<2500000 then clk2<='1';
else e:=0;clk2<='0';
end if;
end if;
end process;
```

(ii). Design of Ultrasonic Signal Receiving Module

The ultrasonic receiving module started the counter to count when the ultrasonic wave was sent out, and stopped counting when the echo was received, and then latched the data and sent it to the data processing module for data processing. The counting pulse period was 40ns which could be obtained by dividing the system reference clock by 2. Taking the sound speed of 340 m/s as an example, the maximum error of the count could be calculated as (340*40*10-9) m=0.0136 mm, which obviously meet the design requirements. In addition, in order to prevent the direct emission of ultrasound, the system had set a processing blind zone of 0.1 milliseconds, and no ultrasound would be received within 0.1 milliseconds from sending the ultrasound. The concrete simulation wave form is shown as in Figure 5.

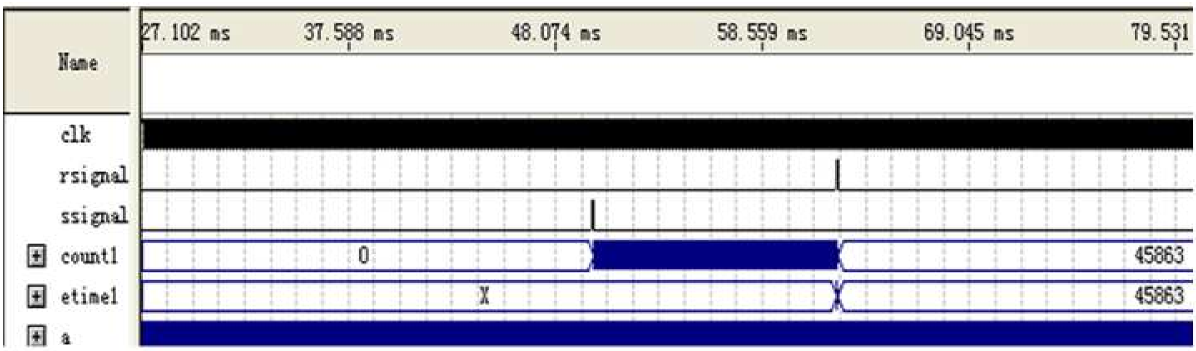

Figure 5. *Simulation waveform diagram of ultrasonic transceiver module.*

2.2.2. Software Design of Temperature Compensation Part

The digital temperature sensor DS18B20 was mainly used to realize temperature collection. First, the chip would be initialized, then a ROM command (0CCH—skip ROM) would be sent to the chip, and then a function command (44H—temperature conversion command) with a delay of 800 milliseconds would be sent. And then the chip would be re-initialized, then the ROM command (0CCH-skip ROM) would be sent, and finally 0BEH which was temperature read command would be sent to complete a temperature reading.

According to the above working sequence of the DS18B20 chip, the VHDL language state machine was used to design the reading sequence to complete the temperature conversion and reading. The high and low byte order of the temperature was read out and converted, and then the data processing module was sent to the data processing module for data processing to realize the temperature. Compensation and display.

2.2.3. Software Design of Data Processing Part

The ultrasonic speed v would be determined according to the temperature of the temperature acquisition module (in millimeters/milliseconds), the number of pulses received by the ultrasonic receiving module was p_length_40ns, and the maximum allowable reception was 1000000 pulses (the maximum distance measured was about 6 meters), and pulse cycle was 40 nanoseconds, so distance= p_length_40ns*40*v*10-6 /2= p_length_40ns*v/50000 (in millimeters). As we know that multi-byte data multiplication and division in CPLD would be occupied a lot of LE resources of the system. Therefore, the rationality of the program design must be considered. The multiplication of multiple data should use the iterative method as much as possible, reuse resources, and do not define signals where variables could be defined. In this idea, the resource utilization rate had been reduced from the original 123% to 57%, which greatly saved resources for other design modules (the overall download resource utilization rate of the final system was 97%).

The specific design part is as follows:

```
if en='0' then
--Data processing permission signal,
--valid at high level
distance<=0;
else
tmp:=p_length_40ns;
tmp:=tmp/5000;
tmp:=tmp*v;
distance<=tmp;
---test distance whose unit was 0.1mm
-- Guaranteed display accuracy of 0.1 mm
end if;
--- Decomposed data sent to digital
--tube display
x1:=distance/100000;
---x1was iterative variable
show_data4<=x1;
x1:=x1*100000;
new_distance:=distance-x1;
x1:=new_distance/10000;
show_data3<=x1;
x1:=x1*10000;
new_distance:=new_distance-x1;
x1:=new_distance/1000;
show_data2<=x1;
x1:=x1*1000;
new_distance:=new_distance-x1;
x1:=new_distance/100;
show_data1<=x1;
x1:=x1*100;
new_distance:=new_distance-x1;
x1:=new_distance/10;
show_data0<=x1;
end process;
```

2.2.4. LED Display Part Software Part

Taking into account that the amount of data to be displayed was not large and required high definition, the display part adopted digital tube dynamic display. A total of 8 digital tube would be used to display. The first 3 digits were used to display real-time temperature, and the last 5 digits were used to display the test distance (40mm-6000mm). And the measurement was displayed to one decimal place. First, the system's reference clock 50MHz would be divided by 50000 to obtain a 1KHz signal as the dynamic scanning clock of the nixie tube. After the 8 data to be displayed were decoded, they would be sent to the nixie tube one by one under the action of the clock to realize the lighting one by one.

3. Discussion

According to the design requirements, firstly, the ultrasonic transmitter transducer and receiver transducer would be installed on the circuit board. And require the center lines would be required to be horizontal and 4-8 cm apart. Then the hardware part of the system would be preliminary debugged. Secondly, all software modular would be simulated. After the output signal waveform and the waveform of the input signal met the requirements, the software system would be debugged together with the hardware system. After the software simulation was completed, the *.POF file would be compiled and downloaded to the EPM1270T144C5 chip through the parallel download port in JTAG mode. Ten times tests under the condition of 25 degrees Celsius at room temperature were finished, and the test results showed that the test error could be controlled within 0.1 mm.

4. Conclusion

The ultrasonic distance measurement system was applied to agricultural robots, with high system integration, simple peripheral circuits, fast response speed, high test accuracy, and the test accuracy was 1-2 orders of magnitude higher than that of the ultrasonic distance measurement realized by ordinary single-chip microcomputers. And after actual system testing, the precision of test could be controlled less than 0.1 mm. The main control chip of the system adopts CMOS structure, and the system had many advantages such as low power consumption and high stability, and has a wide development prospect.

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Biography

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