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Application of cross correlation algorithm in micro sensor detection

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Abstract. With the increasingly widespread application of micro sensors in daily life, how to give better play to the role of micro sensors in various fields has become the focus of attention. In order to better promote the development of micro sensors in detection, the cross correlation algorithm was applied to the digital closed-loop control system of micro sensors in this paper, and the adjustment test of language coding, simulation software, and development boards was carried out. The results show that the fusion application of cross correlation algorithm in the micro sensor industry can help to achieve detection function and improve performance standards, and can also provide effective experience for the application of cross-correlation algorithms in other fields.

Key words. Cross-correlation algorithm, micro sensor, detection, application.

1. Introduction

Micro sensors have been widely used electronic devices in recent years, the principle of which is the sensors that consist of physical and chemical reactions and mechanisms and microfabrication techniques on the basis of semiconductor material [1]. Micro sensors are divided into different species according to different attributes. For example, according to whether there is energy, they are divided into source micro sensors and passive micro sensors [2]. According to the factors of sound, they can be divided into phase micro sensors, acoustic harmonic sensors and amplitude micro sensors [3]. In addition, micro sensors can be divided into antigen micro sensors, biological micro sensors, hormone micro sensors and biomass micro sensors according to their uses [4]. Moreover, there are many classifications, such as optics, electricity, chemistry and so on, which are not discussed below. Micro sensors have been developing rapidly in recent years because of intelligence, low loss, simple synthesis and small size. The smallest size of the microsensor is up to a few millimeters [5].

However, for the rapid development of micro sensors, the research on its principle, technology and application is far from enough. Nowadays, the micro sensor is developing toward digital, scientific and technological, high security, high accuracy,

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intelligence, automation, miniaturization, low loss, energy saving and environmental protection [6]. Since micro sensors are fabricated by micro mechanical technology, the size of micro components can reach sub-micron size, and so it is called "micro scale effect" [7]. However, there are also many problems such as severe signal attenuation, large amount of loss and interference of external factors, which set many obstacles for the reception and transmission of signals [8].

Based on the related basic theories, the problems and difficulties existing in the application of micro sensors were discussed in this paper. Through field programmable gate array, cross correlation algorithm was integrated into the application of micro sensors. The non-interfering signals in all the signals received by the micro sensor were detected and effectively selected. And some references were provided for the application of cross-correlation operation and the function of micro sensor.

2. State of the art

According to the literature, the so-called micro sensors can be divided into chemical micro sensors, physical micro sensors and biological micro sensors on the basis of their different measurement objects [9]. Chemical micro sensors are generally based on the charged nature of ions. At present, the application of ion sensors in the fields of medicine, chemistry and biological products has become more mature [10]. The physical micro sensor transmits the physical information of the object through the frequency of the sound wave, such as magnetic field, amplitude, angular velocity, temperature, and other factors [11]. But its application scope is not very extensive, and the specific application methods need further exploration and research. Biological micro sensor is the process of mapping DNA probes to target DNA by using changes in physical properties such as light waves and sound waves. In this way, the process of synthesis and the process of polymerization of nucleotides are clearly displayed, which solves many problems for the biological community and even the medical community [12]. Some studies have shown that the application of micro sensors has become the most mature, stable and practical microelectromechanical devices [13].

The cross-correlation method can reflect the correlation of two random variables at different times, which can describe the relation between the variable A in time T_1 and the variable B in time T_2, so as to facilitate the transmission and acquisition of information. At present, the cross correlation operations play an important role in the following aspects: first of all, the cross-correlation calculation can be used to determine the delay time and improve the efficiency of the industry [14]. Moreover, the cross correlation operations can identify transmission paths, and a number of peaks in the function are analyzed and identified synthetically [15]. Third, the cross-correlation operation can detect any interference signal, which can select the target signal among many signals, so as to eliminate the external interference and provide the accuracy of detection. Fourth, the micro sensor pulse system always maps the measurement results, and for the interference signal, the system will eliminate all the interference signals. In this way, it is not difficult to find that cross correlation algorithm can be used in micro sensor applications with a multiplier effect. Therefore, how to apply cross-correlation algorithm to micro sensors is the most important aspect of our research.

3. Methodology

Taking silicon micro sensor as an example, the application of cross-correlation algorithm to detect weak signals in micro sensors was described in this paper.

3.1. 3.1 Design of correlation system detection module

First of all, in order to find the resonant point of an electric thermal shock sensor, a closed electrical loop system was designed in this paper, as shown in Fig. 1. The output signal of the micro sensor was formed by the signal to be measured, the interference signal whose frequency is 50 % of the signal to be measured and the interference noise of an electric thermal shock micro-sensor. The method of detecting the measured signals by cross-correlation algorithm is as follows:

The input signal of the micro sensor is $X(t)$. Its components include noise signal $N(t)$, same frequency coupling sine interference signal $S_{\mathrm{w}}(t)$ and sine noninterference signal $S_{2\mathrm{w}}(t)$. Thus, it can be expressed by the formula

$$X(t) = S_{\mathrm{w}}(t) + S_{2\mathrm{w}}(t) + N(t)\,. \tag{1}$$

The multifrequency control signal is $Y_{2\mathrm{w}}(t)$. According to the formula (1), the relation between the input signal of the micro sensor and multifrequency control signal is

$$\begin{aligned} R_{xy}(n) &= X(t) \times Y(t+n) \\ &= [S_{2\mathrm{w}}(t) + S_{\mathrm{w}}(t) + N(t)] \times Y_{2\mathrm{w}}(t+n) \\ &= S_{2\mathrm{w}}(t) \times Y_{2\mathrm{w}}(t+n) + S_{\mathrm{w}}(t) \times Y_{2\mathrm{w}}(t+n) + N(t) \times Y_{2\mathrm{w}}(t+n) \\ &= R_{s_{2\mathrm{w}}Y_{2\mathrm{w}}} + R_{s_{\mathrm{w}}Y_{2\mathrm{w}}} + R_{NY_{2\mathrm{w}}}\,. \end{aligned} \tag{2}$$

The multifrequency control signal in the formula is the sine signal $S_{2\mathrm{w}}(t)$. There is no cross correlation between the multifrequency control signal $Y_{2\mathrm{w}}(t)$ and the noise signal $N(t)$. So when n is infinite, $R_{S_{\mathrm{w}}Y_{2\mathrm{w}}}$ is viewed as approximately equal to 0, and $R_{xy}(n) \approx R_{S_{2\mathrm{w}}Y_{2\mathrm{w}}}$. In this way, the extracted functions are represented by programming:

$$R_{xy}(m) = \frac{1}{N} \sum_{n=0}^{N-1} x(n)y(n-m)\,, \tag{3}$$

where m is an infinite integer. The function $R_{xy}(M)$ is converted to a sine function with the same period as the sampled signal. Thus, the resonant point of the micro

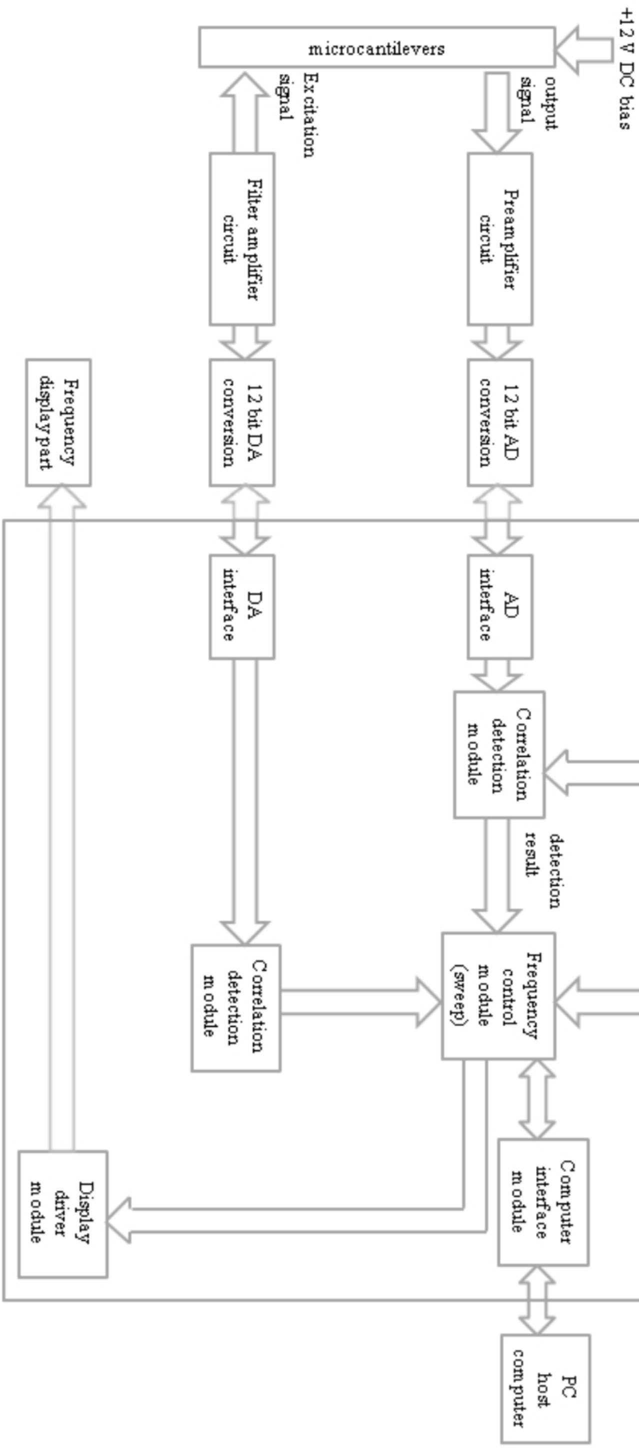

Fig. 1. Closed-loop electric system of sensor

sensor is obtained. The smaller is the mean absolute value of the autocorrelation function, and the smaller is the absolute value, the smaller is the output intensity of the sensor. Then, when the absolute value is the maximum, the corresponding frequency point is the resonance point.

The above design was simulated and analyzed by Matalab software. The start time was $t = 5e - 6$, the end time was $t = 12.8e - 4$, and the time interval was consistent with the start time. 240 points were set as detection points, and according to multi frequency contrast signals $Y_{2\mathrm{w}}(t) = \cos(2\pi \times \omega t)$, all selected signals in the input signals were as follows $S_{2\mathrm{w}}(t) = \cos(2\pi\omega t)$. The same frequency coupling sine interference signal was $S_{\mathrm{w}}(t) = \cos(\pi\omega t)$. In the formula $\omega = 14000$, and simulation charts can be obtained.

3.2. Implementation of cross-correlation operations by the use of FPGA

The purpose of this paper is to extract the target signal mixed in the noise without being affected by the same frequency coupling interference signal. The FPGA can only handle digital signals. Therefore, firstly, the signals collected by micro sensors were converted into digital signals. And FPGA was used to control the collected signals. The converted digital input signal and the multifrequency control signal were passed to the RAM of the FPGA corresponding address until a sufficient amount of data information was obtained.

In cross correlation operation, the following formula was used

$$\underset{xy}{\hat{R}}(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)y(n-k)\,. \tag{4}$$

It is known that the cross-correlation operations of digital signals follow the rules: multiplication first, followed by the addition. Then, by using the nature of the real time signals of the target signals, each operation only selects half of the data for cross-correlation calculation, thus ensuring that the number of data information for each cross-correlation operation is equal. In doing division, FPGA is prone to greater errors. Therefore, in order to get the maximum value for each section, the operation divided by N was canceled in this paper, and then the formula was converted to

$$\underset{xy}{\hat{R}}(k) = \sum_{n=0}^{N/2} x(n)y(n-k)\,. \tag{5}$$

However, in practice, there was a problem that time could not be delayed. In order to solve this problem, the cross-correlation operation was used to read the corresponding data. When reading the data, the RAM address bar of the stored data was changed. Finally, the result data were compared and analyzed. The larger the target signal in the micro sensor output signal was, the greater the calculated result was, the two showed the proportional relation. When the maximum corresponding frequency point was the resonant point of the micro sensor, the maximum value of

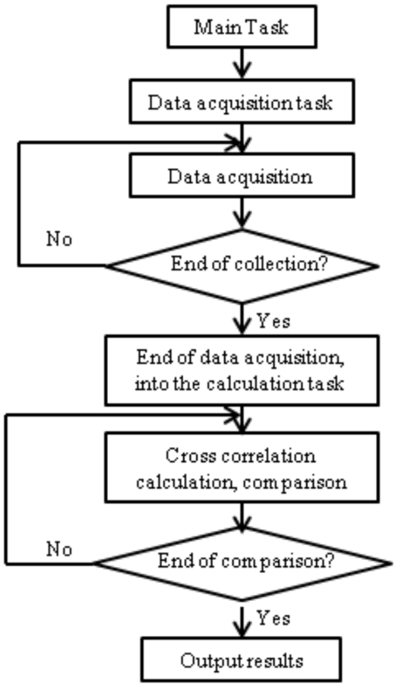

Fig. 2. Closed-loop electric system of sensor

the operation result and the corresponding n were recorded simultaneously. The experimental technical route is shown in Fig. 2.

4. Result analysis and discussion

4.1. Design results of the relevant system detection module

The simulation diagram is shown in Figs. 3–6. Figure 3 shows the correlation between the multi frequency control signal and the preset detected signal. Figure 4 shows a case where multiple frequency contrast signals are correlated with the same frequency coupled sinusoidal interference signals. Figure 5 shows the correlation between the multi frequency control signal and the interference input signal. Figure 6 is the comparison of the results in Figs. 3, 4, and 5. From the results of Fig. 3, when the input signal contained only interference signals, the results of cross-correlation operations were smaller. The results of cross-correlation calculation of the same frequency coupling sinusoidal interference signal and multi frequency control signal were very close to that of the multi frequency control signal and the preset detection signal. It can be seen, that at the theoretical design level, the detection of the micro sensor input signals with the same frequency coupling interference can be effectively extracted by cross-correlation calculation. And there is some theoretical support for this method.

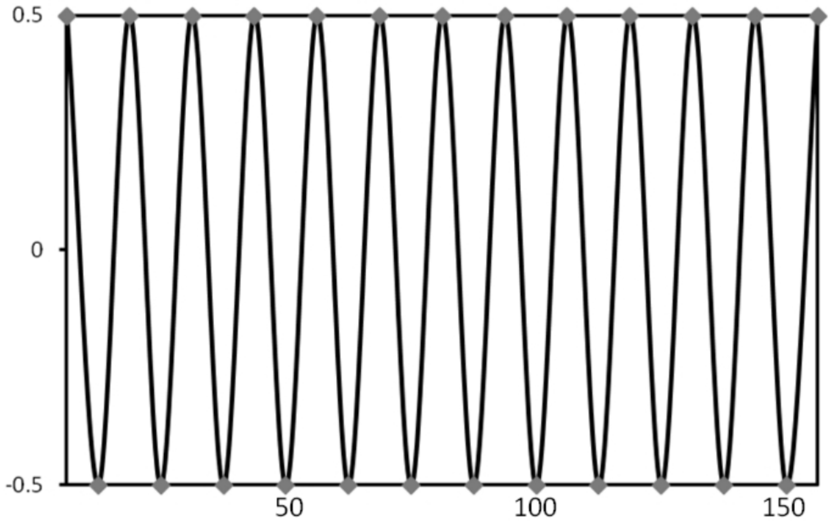

Fig. 3. Cross-correlation between multi frequency control signal and preset detected signal

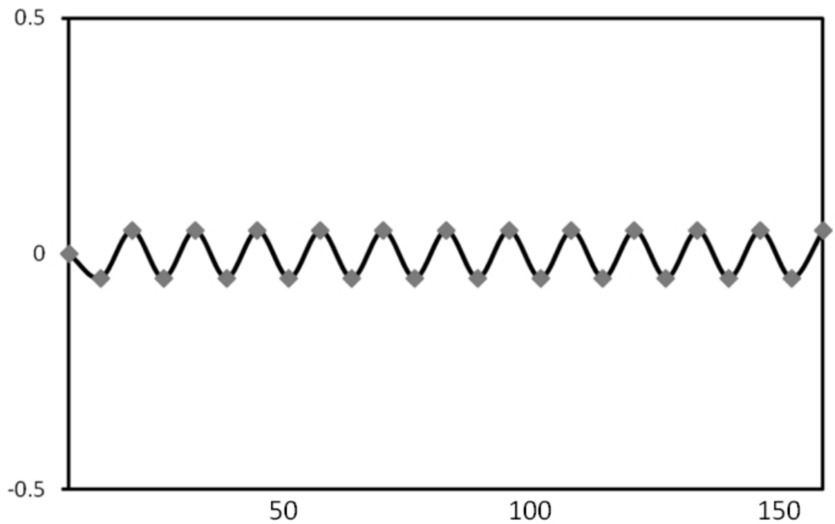

Fig. 4. Cross correlation operation of multi frequency control signal and sinusoidal interference signal with same frequency coupling

4.2. Using FPGA to achieve cross-correlation results

The object of this experiment was the sine wave band of 13.5 kHz. A total of 16 data was obtained at the frequency of 200 kHz, as shown in Table 1. The cross correlation operation was carried out on two groups of data, and the results showed that $n = 2$, Max = 1676267.

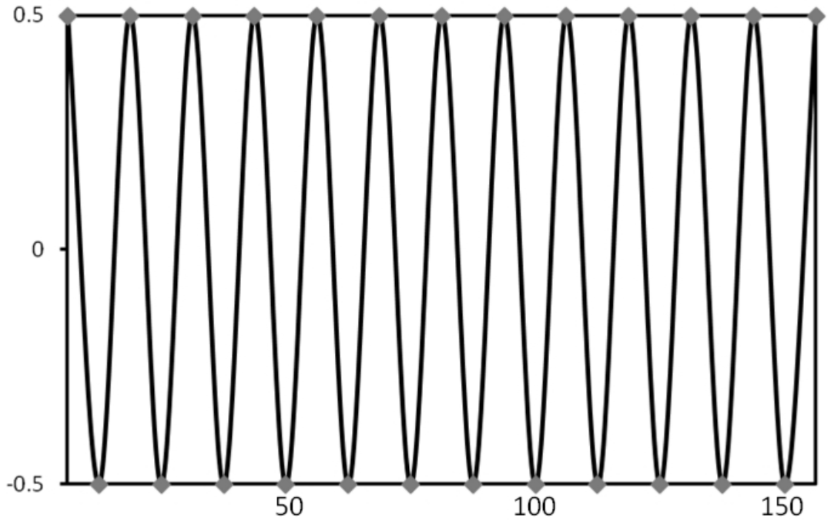

Fig. 5. Cross-correlation computation between multifrequency control signals and interference input signals

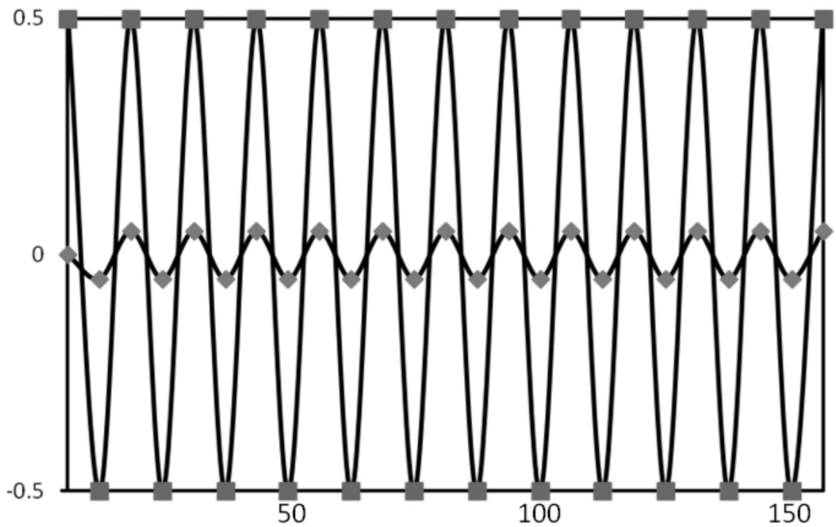

Fig. 6. Unified results

Table 1. Two sets of input signal data

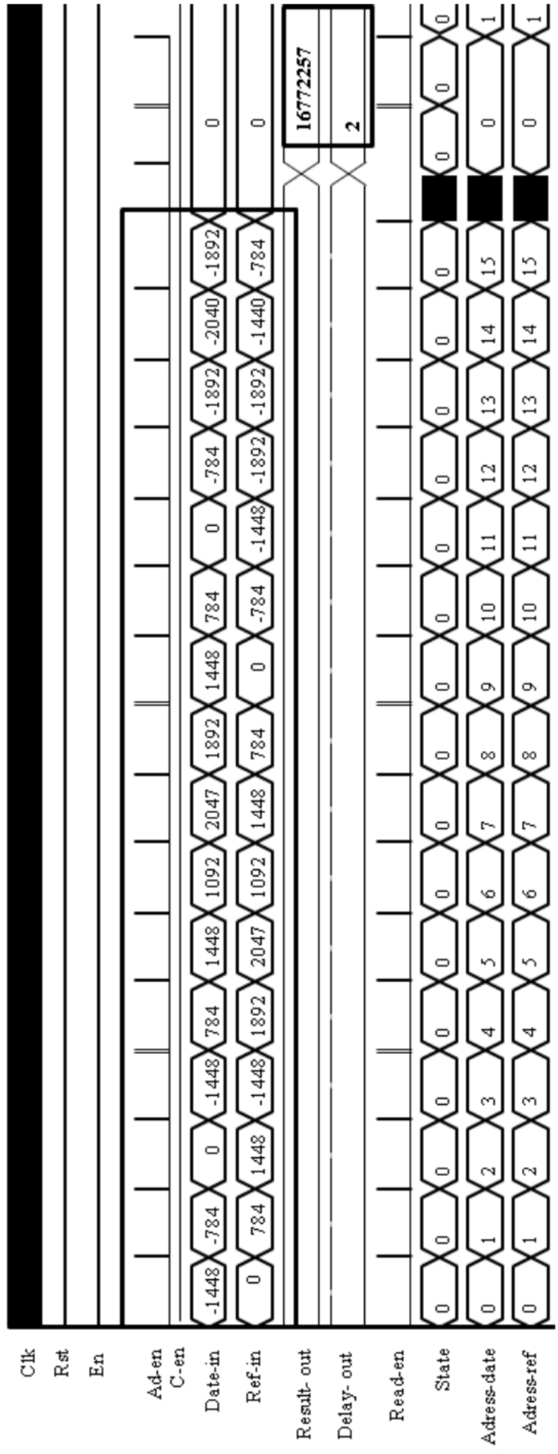

Fig. 7. Simulation results

Address	Data in	Ref in	Address	Data in	Ref in	Address	Data in	Ref in
0	-1445	0	6	2024	1445	12	-1445	-2024
1	-739	739	7	1887	739	13	-1887	-1887
2	0	1445	8	1445	0	14	-2024	-1445
3	739	1887	9	739	-739	15	-1887	-739
4	1445	2024	10	0	-1445			
5	1887	1887	11	-739	-1887			

Quartus II software was used to carry out simulation experiments, as shown in Fig. 7. The upper two sets of data were input data, and the two party data was the simulation data for application. It can be seen that the theoretical value is consistent with the simulation results.

After the system was debugged, the system was applied to the control system of the silicon resonant micro sensor. After open loop detection, scanning was performed, but the signal was not locked and thus re detected.

5. Conclusion

In order to study the application of the cross-correlation algorithm in the detection of micro sensors, this paper takes silicon micro sensors as an example. Firstly, the feasibility of cross-correlation computation applied to micro sensors is analyzed and verified theoretically. Then, the design and application of cross correlation operation in silicon micro sensor is realized by FPGA. Through Verilog programming language code, and the use of Quartus II software simulation experiments and debugging, and finally obtained the frequency characteristic curve. The conclusion of the study are as follows: through the cross-correlation algorithm can be extracted in the mixed noise signal, which is not affected by the same frequency coupling interference signal. The frequency and number of samples are in line with the corresponding standards. However, the application of the cross-correlation algorithm in the detection of micro sensors is still in the initial stage, and the distance to create products that are really applied in military and other fields still needs further research and demonstration. But the conclusions and results obtained in this paper can provide some reference for future research.

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