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Design of a New Metal Detector Based on Single-Chip Microcomputer

Zihao Peng
School of Electronic Information and Electrical Engineering
Yangtze University
Jingzhou, China

Abstract: To address the deficiencies of existing metal detectors in accuracy and sensitivity, this paper presents a portable metal detector based on the STM32 microcontroller. The system adopts an RC oscillation circuit as the signal transmitter and an LM324-based circuit for signal reception and processing. A combined amplitude and phase detection method is proposed to accurately identify metal types and locations. An adaptive filtering algorithm is applied to suppress environmental noise and improve detection precision. The optimized coil with high-permeability material and a multi-layer winding structure enhances sensitivity and anti-interference performance. A low-power power management module extends working time, making the device suitable for field and mobile applications. The main innovations include intelligent metal identification, optimized coil design and signal processing, as well as user-friendly human-computer interaction. Compared with conventional detectors, the proposed system exhibits significant advantages in precision, sensitivity and intelligence, providing an efficient and reliable solution for related applications.

Keywords: STM32 Microcontroller; Metal Detector; Amplitude and Phase Detection; Adaptive Filtering; Portable Detection

1. INTRODUCTION

As a device for detecting metallic objects, metal detectors play an important role in industrial production, security inspection, archaeological excavation, environmental protection and other fields[1]. However, with continuous technological advancement, the limitations of conventional metal detectors have become increasingly prominent, such as single function, limited detection accuracy and high power consumption[2]. In recent years, the rapid development of microcontroller technology has provided new opportunities for the intelligent and digital upgrading of metal detectors. With the powerful processing capability of microcontrollers, new-generation metal detectors can not only achieve high-precision metal detection, but also integrate diversified functions through software programming, such as alarm threshold setting, detection data storage and remote communication[3].

This study develops a novel microcontroller-based metal detector. Based on the principle of electromagnetic induction and combined with the digital signal processing capability of the microcontroller, the detector achieves high-precision detection and intelligent management of metallic objects[4]. In hardware design, the STM32 microcontroller is adopted as the core controller, equipped with inductive sensors, an LCD display, a key input module and a buzzer alarm module. Through the coordinated operation of these modules, the detector can display detection data in real time and trigger sound-light alarms when metallic objects are detected, providing users with intuitive detection results and timely warning information[5].

2. Hardware Design of a Novel Metal Detector Based on Single-Chip Microcomputer

2.1 Overall Design Scheme of Hardware Circuit

The novel metal detector based on single-chip microcomputer is composed of the following functional modules: signal transmitting module, signal receiving and processing module, signal detection module, system control module, and human-computer interaction and alarm module. The hardware design block diagram of the novel metal detector based on single-chip microcomputer is shown in Figure 1.

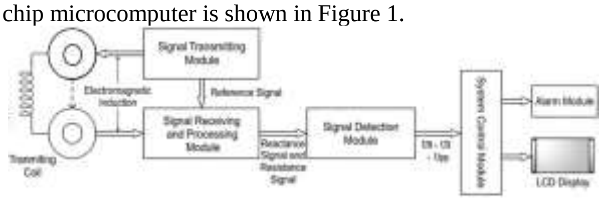

Figure. 1 Hardware Block Diagram of a Novel Metal Detector Based on Single-Chip Microcomputer

The signal transmitting module generates a sinusoidal signal with a specific frequency and voltage through an oscillating circuit as the input signal. The input signal passes through a wound transmitting coil, and propagates electrical signals by means of electromagnetic induction and eddy current effect, thereby generating a received signal in the receiving coil. The received signal is transmitted to the signal receiving and processing module, where the amplitude signal is extracted, filtered, amplified, and subjected to quadrature decomposition, so that the signal is decomposed into a resistance signal and a reactance signal. In the signal detection module, the reactance signal, resistance signal and amplitude signal are transmitted to the single-chip microcomputer respectively according to the current operating mode of the metal detector. In the system control module, the single-chip microcomputer is used for key scanning, alarm triggering and other operations, and low-power operation is realized throughout the whole process.

System design requirements:(1) Realize the function of metal type identification;(2) Realize the function of metal intensity discrimination;(3) Reduce power consumption and simplify the circuit structure;(4) Realize the LCD display function;(5) Realize human-computer interaction and alarm functions.

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2.2 STM32 Microcontroller Minimum System Design

As the system control module of the hardware circuit, the microcontroller (MCU) system is connected to the signal detection module and the human-computer interaction and alarm module. This system is mainly composed of the STM32F103C8T6 microcontroller, power supply circuit, Bootloader startup configuration circuit, and in-circuit programming (ICSP) circuit. In this circuit architecture, the STM32 microcontroller acts as the core component. To guarantee its functional implementation, it must be interfaced with other related peripherals. It is required not only to ensure the normal enabling of all peripheral devices, but also to achieve reliable communication between each functional module and the microcontroller, thereby processing the collected data and transmitting the processed information to the corresponding modules. The STM32F103C8T6 microcontroller is shown in Figure 2.

Figure. 2 STM32F103C8T6 Microcontroller

2.3 Signal Transmitting Module Circuit Design

This paper designs an RC sine-wave oscillator using the LM324 quad op-amp to generate a 53 kHz sinusoidal signal, which serves as a stable signal source for subsequent circuits and the hardware's signal transmitting module. The LM324 is suitable for this application due to its low power consumption, low input bias current, single-supply operation, ~1 MHz bandwidth and ~0.5 V/μs slew rate, which meet 53 kHz oscillation requirements with cost efficiency[6].

The RC oscillator converts DC power into a stable 53 kHz sinusoid, with adjustable frequency via resistance and capacitance modification. This paper uses this circuit to drive specific loads/devices; proper op-amp-RC connection and rational PCB layout reduce parasitic inductance/capacitance impacts, and high-precision 53 kHz output is achieved through debugging and optimization.

An active filter at the oscillator output suppresses high-frequency spurs and noise, yielding a clean, stable 53 kHz sinusoid that meets the signal transmitting module's requirements. The module's schematic is shown in Figure 3.

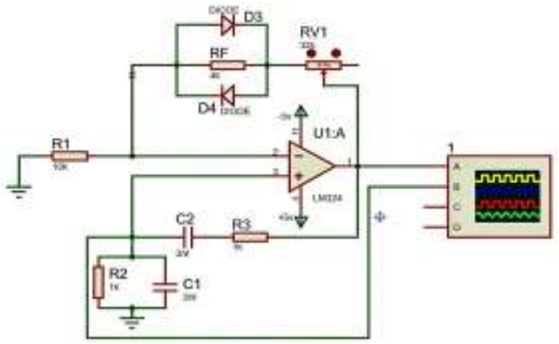

Figure. 3 Schematic Wiring Diagram of the Signal Transmitting Module

3. Software Design of a Novel Metal Detector Based on Single-Chip Microcomputer

3.1 Software Flow Structure

The software structure of the novel MCU-based metal detector includes four major modules: initialization program, key scanning program, threshold discrimination program, and human-machine interaction and alarm program. The flow structure of the module design is shown in Figure 4.

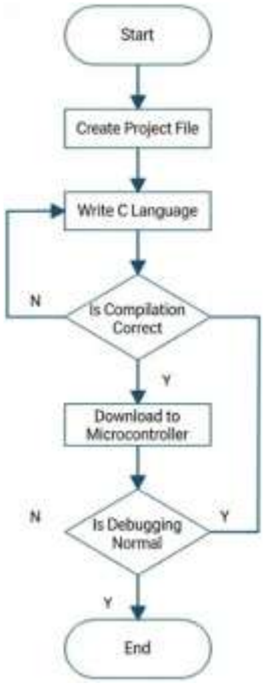

Figure. 4 Fundamental Development Flow of Microcontrollers

3.2 Initialization Program

Software initialization of an STM32 microcontroller refers to configuring the microcontroller's various peripherals and functional modules through programming code, transforming it from the default state after power-on or reset into a state suitable for the execution of the application program. The detailed initialization steps are as follows:

(1) System Clock Initialization Configure the system clock source (such as the High-Speed External crystal oscillator HSE, High-Speed Internal RC oscillator HSI, etc.), set the frequency division coefficients of the clock tree, and determine the system clock frequency. This ensures the

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microcontroller operates at the correct clock frequency, provides stable clock signals for subsequent peripherals, and affects system performance and power consumption.

(2) GPIO Initialization Configure GPIO pin modes (input/output/analog/alternate function), output types (push-pull/open-drain), speed, pull-up and pull-down resistors, etc. This enables GPIO pins to function according to application requirements, such as controlling peripheral power supplies and communication signals.

(3) Peripheral Initialization: Configure peripherals including UART, timers, ADC, and others, setting parameters such as baud rate, counting frequency, and sampling time. Peripherals are enabled and configured to meet specific application requirements, such as data transmission, timing control, and analog signal acquisition.

(4) Interrupt and DMA Initialization. Configure interrupt priorities and enable interrupt sources; initialize the DMA controller and set parameters including transfer direction and data width. This enables fast responses to external events, improves data transfer efficiency, and reduces the CPU load.

Microcontroller initialization ensures stable software operation. Through proper clock configuration and peripheral initialization, all modules of the microcontroller operate under appropriate conditions, avoiding instability or abnormal behavior. It fulfills functional requirements by configuring GPIO and peripherals, allowing the microcontroller to cooperate with peripheral hardware. It optimizes system performance: reasonable clock settings and peripheral configurations can improve operating speed and reduce power consumption. Furthermore, once initialization is complete, the application program can run in the configured environment without manual hardware configuration modifications, simplifying subsequent development.

3.3 Mode Discrimination Program

Compared with traditional metal detectors, the novel metal detector based on microcontroller has three selectable modes: off mode, metal type discrimination mode, and metal intensity discrimination mode. The basic discrimination principle has been introduced in the hardware section, where data is transmitted through a binary method to reduce the usage of external pins.

(1) Define the mode selection and update function.(2) Read the pin states: use the GPIO_ReadInputDataBit function to read the states of PA12 and PA13 pins, and determine the current mode by combining the states of these two pins.(3) Anti-debounce processing: use static variables last_pa12 and last_pa13 to store the pin states read last time. The pin states are considered valid only when they are consistent twice consecutively, so as to prevent mode misjudgment caused by pin jitter.

Mode judgment: update the current mode according to the state combination of PA12 and PA13. This function is called in the main loop, and the corresponding logic is executed according to current_mode. In the software implementation part, the microcontroller reads the binary values of PA12 and PA13 pins, and the mode discrimination function can be realized through simple anti-debounce processing and discrimination code. Then, according to the current mode, the signals received by PB0 and PB1 are processed with different algorithms and transmitted to the subsequent threshold discrimination program.

3.4 Threshold Discrimination Program

Before performing threshold discrimination in the software, it is necessary to perform arithmetic processing on the signals read by the ADC, and calculate their amplitude and phase respectively. By cyclically calling the function Calculate A in the main function, the relationship between the amplitude and phase of the received signal and the transmitted signal can be calculated and stored in the result variable A.

The threshold discrimination program needs to perform threshold judgment on the pre-calculated result variable A according to the current operating mode. Both the metal type discrimination mode and the metal intensity discrimination mode have five different discrimination thresholds. In the threshold discrimination program, threshold comparison is carried out according to the current mode and the calculated value of A.

In the metal type discrimination mode, the value of A is compared with five thresholds to determine the result level. Similarly, in the metal intensity discrimination mode, the value of A is also compared with five corresponding thresholds to determine the result level. The result is stored in threshold result for subsequent display and alarm operations. The flow of the threshold discrimination program is shown in Figure 5.

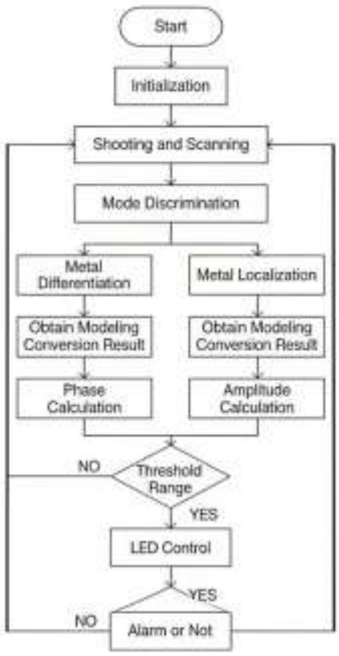

Figure. 5 Threshold Discrimination Flow

3.5 Human-Machine Interaction and Alarm Program

The human-machine interaction and alarm module can be implemented in two aspects: LCD display and buzzer alarm.

Software design concept:The STM32 microcontroller is used to drive the LCD screen and output the results.When the metal detector is in the off state, the LCD displays "Not Activated".In the metal type discrimination mode, levels 1–3 are displayed as "Ferromagnetic Metal", and levels 4–5 as "Non-ferromagnetic Metal".In the metal intensity discrimination mode, level 1 displays "Intensity 1", level 2 "Intensity 2", level 3 "Intensity 3", level 4 "Intensity 4", and level 5 "Intensity 5".

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In both metal type discrimination mode and metal intensity discrimination mode, if metal is detected, a high level is output through pin PB15 to activate the buzzer alarm.

4. Low-Power Design of a Novel Metal Detector Based on Microcontroller

4.1 Hardware Selection and Configuration Optimization

The clock circuit is one of the main power consumption sources in a microcontroller system. Selecting a low-power external crystal oscillator can effectively reduce the power consumption of the clock circuit. For example, a low-power 12MHz crystal oscillator can be used, which features relatively low power consumption and can provide a stable clock signal[7].

When designing the circuit, unnecessary components should be minimized to reduce the static power consumption of the circuit. For instance, a simple RC filter circuit can be adopted instead of a complex active filter circuit, reducing the use of active devices such as operational amplifiers. In addition, reasonable PCB layout, shortening wiring lengths and reducing crossings to lower parasitic capacitance and resistance, also helps decrease power consumption.

4.2 Hardware Selection and Configuration Optimization

4.2.1 Power Management Optimization

(1) Dynamic Voltage Scaling

Dynamically adjust the operating voltage of the CPU according to the actual workload of the metal detector. Under light load conditions, reducing the CPU operating voltage can significantly reduce power consumption. When the metal detector is in an idle state or only performing simple data processing, the CPU operating voltage can be lowered. When complex data analysis or processing is required, the CPU operating voltage is increased accordingly[8].

(2) Peripheral Power Management

Turning off the power supply to unused peripherals can effectively reduce power consumption. In a metal detector, not all peripherals need to be operational at all times. For example, the power supply to the ADC module can be turned off when data acquisition is not in progress, and the power supply to the LCD driver module can be shut down when the LCD screen is not in use. Reasonable management of peripheral power can significantly reduce the overall power consumption of the metal detector.

4.2.2 Peripheral Control Optimization

(1) Display Device Control

The LCD screen is one of the main power consumers in the metal detector. Turning off the LCD backlight or reducing its brightness when display is not required can effectively reduce power consumption. When the metal detector is in an off or idle state, the LCD backlight can be turned off. When detection results need to be displayed, the backlight is turned on and adjusted to an appropriate brightness.

This project uses the LCD1602 liquid crystal display, a dot-matrix liquid crystal display module specifically designed for displaying letters, numbers, symbols, etc., which features low power consumption. The LCD1602 liquid crystal display is shown in Figure 6.

Figure. 6 LCD1602 Liquid Crystal Display

(2) Buzzer Control

The buzzer consumes a certain amount of current during alarm operation. Turning off the buzzer's power supply when no alarm is required reduces power consumption. When the metal detector does not detect metal or is in an off state, the buzzer is kept silent and its power supply is cut off. When metal is detected and an alarm is needed, the buzzer's power supply is turned on to emit an alarm sound. The low-power high-level triggered buzzer is shown in Figure 7.

Figure. 7 Low-power high-level triggered buzzer

5. Conclusion and Future Work

In terms of hardware design, this thesis develops a novel metal detector based on the STM32F103C8T6 microcontroller. The STM32F103C8T6 is adopted as the core controller, and the signal transmission, reception, processing and detection are realized by integrating the corresponding peripheral circuits.

In terms of software design, the system initialization configuration, mode discrimination, threshold discrimination, as well as human-machine interaction and alarm functions are implemented. The software design covers the entire process from system startup to signal processing, ensuring the accurate and efficient operation of the metal detector.

In terms of low-power design, the overall power consumption of the system is successfully reduced by optimizing hardware selection and configuration, software algorithms, power management, and peripheral control. By adopting low-power components and implementing optimized hardware and software designs, the metal detector is ensured to operate stably in a low-power state.

In conclusion, the novel metal detector based on the STM32F103C8T6 microcontroller designed in this thesis features rigorous hardware circuit and software program design, and a multi-functional metal detector with high efficiency and low power consumption is successfully developed.

6. ACKNOWLEDGMENTS
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