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# A Design of Water Cannon Control System with Remote Control Function and Automatic Mode

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# A Design of Water Cannon Control System with Remote Control Function and Automatic Mode

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**Abstract**. Traditional manual fire-fighting water cannons cost much physical strength to operate due to its own weight and lasting fire-fighting process. In order to reduce the physical stress of firefighters and ensure their safety, a remote control system for water cannons based on STM32 using freeRTOS is introduced in this paper. It has both manual mode and automatic mode with distance of remote control over 250 meters. Power consumption performance has been additionally optimized to extend the standby time considering it's battery-powered.

## 1. Introduction

The development history of human society is also the history of confrontation with different natural forces, among which fire is a focus. On the one hand fire offers us light and warmth, on the other hand it can be disaster. Statistics published by Chinese government shows that up to 237 thousand fires occurred in 2018, causing property loss more than 3.6 billion RMB as well as countless deaths[1].

Water cannon could be an advisable choice to combat large fire due to its efficiency[2]. Although its range is usually up to 60m, firemen are still at risk of suffering from explosion. Additionally, long-time operation is exhausting, especially when oil depot is on fire where fire-fighting process lasts for several days. Actually, firemen urgently demand a water cannon that is able to sweep automatically and be controlled at a distance[3].

In this paper, a remote controlling system for water cannon is designed to solve the above problem, which is a typical embedded system with FreeRTOS, a real-time operation system, and it is established based on microcontroller. The system realizes distant wireless control reaching up to 250 meters based on 433MHz radio frequency as well as wired control based on CAN bus, with manual mode or automatic mode, where track is set by firemen. It's worth noting that the system is powered by battery, so power consumption is specially optimized. The whole system is established and tested. Results prove the integrity and practicability of the designed system.

## 2. Design of Hardware Platform and Module Selection

### 2.1. Overall Design

The proposed system is generally divided into two parts in the design stage: the main controller module and the remote controller module. The core function of the main controller is to drive the corresponding motors according to the received command, to change the spraying direction, to choose column mode or mist mode for spraying, set movement route and ensure the safe direction range. While the remote controller just sends correct commands to main controller. Realization of these

functions calls for real-time processing but doesn't require too much capacity of calculation, so an MCU (Microcontroller Unit) is extremely suitable as the core processing unit[4].

The block diagram of the proposed system is given below in figure 1 and figure 2. The remote controller is powered by 3.7V Lithium battery and main controller is powered by 24V Lithium battery pack. Mutual communication is based on a pair of 433MHz wireless modules and CAN bus. Additionally, RS485 interface and motor interface are included in main controller.
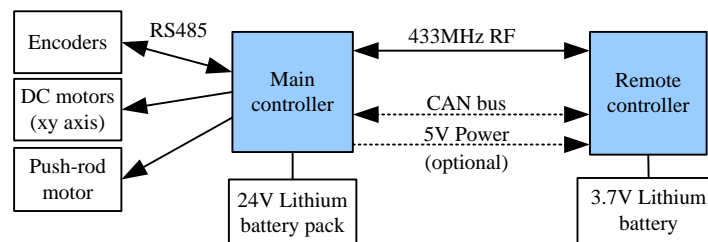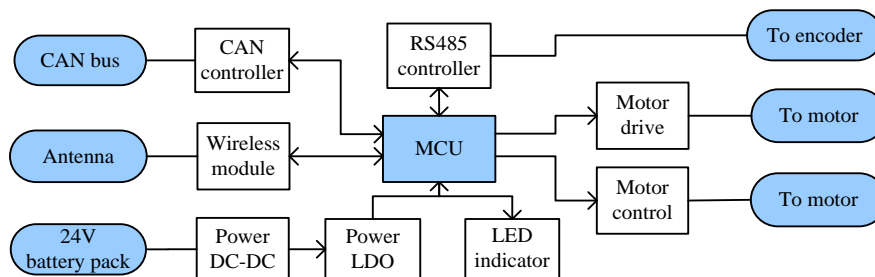


Figure 1. Overall system scheme



Figure 2. block diagram of main controller

### 2.2. Microcontroller Unit
It's noted that, in recent years, ARM Cortex-M series core has become one of the most popular cores for MCU. It's definitely much powerful than classical 51 series. Semiconductor giants have launched MCU based on Cortex-M core one after another, with improved performance, various peripherals and feature of low power.

In this design, selected MCU is from STM32 series launched by ST Microelectronics. The STM32 is a family of 32-bit microcontrollers based on the ARM Cortex-M core, featuring high performance and low power consumption. In addition it works with a frequency of up to tens or even hundreds of MHz with first-class on-chip resources. On-chip CAN controller involved in STM32F1 family even simplifies the design of the system[5]. Finally, the STM32F103 chip is chosen.

### 2.3. External Communication
This system requires wireless communication with communication distance of over 200 meters and wired communication of tens of meters as a backup.

The most essential parameters for wireless communication are reliable communication distance and power consumption. Here the proposed system uses LoRa spread spectrum communication module based on SX1278 chip. It does not need any base station and is very resistant to external interference, so signal cover or multiple devices will not be a problem[6]. Communication distance between two wireless modules is tested using small-sized glue stick antenna with 1.5dB gain. The result shows that reliable two-way transfer is ensured more than 250 meters away with transmission power of 1W.

In the proposed system, CAN bus is preferred instead of RS-232 and RS-485. These two common serial ports only specify the physical layer, but the CAN bus comes with a protocol additionally, which ensures the reliability[7]. The mature CAN controller chip also eases the application of the CAN bus.

## 3.  Overall Software Design

### 3.1. Functions Analysis and Tasks Division

In this part, functions are discussed again in detail. Then these functions will be realized by several tasks with FreeRTOS, which provides tasks management, signal & message and dynamic memory management[8].

The remote controller is mainly responsible for sending commands, which is realized without operation system. Now pay attention to the main controller.

The automatic mode will be one used most often in practice because in this mode system can automatically control the water cannon to cover an area without human intervention, as long as the track is set. However, traditional manual control is also in need when fire is changed rapidly. In order to facilitate the water gun pointing and spraying mode at a certain fixed state at the beginning of using, a reset function is required. In addition, the system itself also includes some passive functions, including rotation limit security, battery monitoring, error processing and so on. The error task is executed to store the error information and try to restart the MCU when unexpected conditions occurred. The error task and the hardware watchdog work together to make sure the system is always available. According to the function description above, major tasks of the system are arranged as Figure 3 shows.
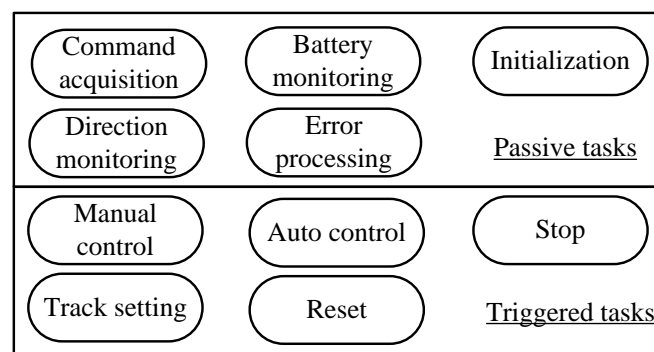


Figure 3. Tasks designed in the proposed system

### 3.2. Overall Working States

In order to better illustrate the relationship between these tasks and how they work, a simple state diagram of the main controller is given in Figure 4.

After the initialization where basic tasks are created and all peripherals are configured, the system enters the idle state. The idle state can be transferred to another state when receiving the corresponding valid command. An operation timeout or a stop command reception leads to the stop state, where the system clears the temporary data and flags and stop all the motors. Then it returns to the idle state. It's remarkable that the stop command has the highest priority and can be immediately executed, so the system can recover from some errors manually and prevent potential dangers.
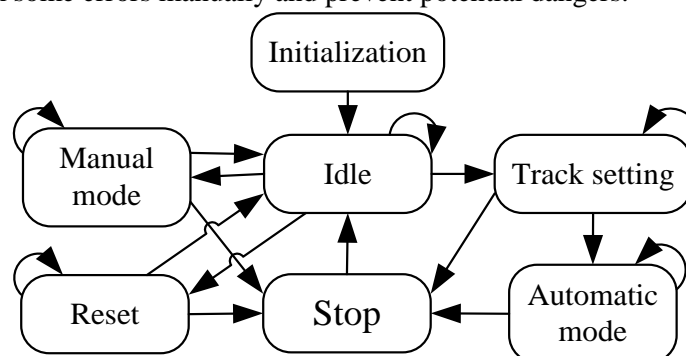


Figure 4. State diagram of the proposed system

### 3.3. Implement of Direction Monitoring and Track Setting

The direction monitoring task gets the number of turns and current angle from both vertical and horizontal encoders, which are coaxial with corresponding motors. Then convert them into actual direction through gear ratio and initial direction. It can be expressed by the formula followed.

$$A_r = \frac{360 \times N + A_c}{k} + A_i \tag{1}$$

Where $A_r$ is the actual direction angle of the cannon, $A_c$ is the current angle of the encoder, $A_i$ is the initial angle as the benchmark. These three parameters use degree as a unit. N is the number of turns of the encoder and k is the gear ratio between the motor and the rotatable pedestal of the water cannon.

Once actual direction is acquired, it's easy to specify the movement boundary is reached or not.
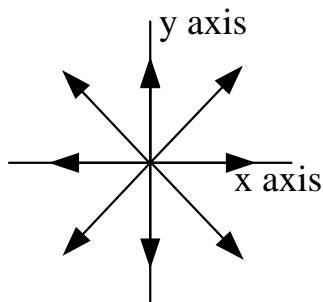


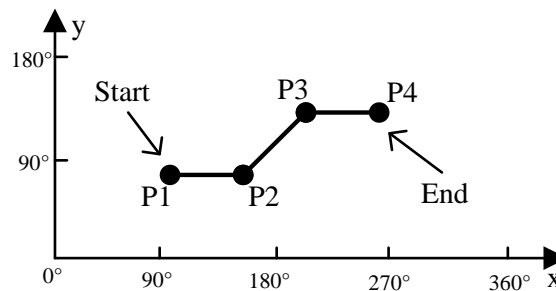Figure 5. Eight possible directions          Figure 6. Track and four turning points, P1 to P4

Then we'll introduce how the track setting is realized. To simplify the description, all the rotation is regarded as the movement in a two-dimensional coordinate system. X axis represents horizontal rotation and Y axis represents vertical rotation. In the proposed system, when entering the track setting mode, user control the water cannon manually to sweep the wanted area once, during which the system will record the movement track. Actually, not every point on the track is recorded, the system just records turning points. Since the speed of motor is fixed regardless of starting and stopping, possible movement directions are shown in Figure 5, along the axis or 45 degrees angle with axis. Here a linked list is used to describe turning points and their connection as shown in Figure 7. It is worth noting that necessary information about turning points is stored compactly in binary form to save memory space. When automatic control is enabled, *X_Pos* and *Y_Pos* indicate position of the current point and *Movement* instructs motors to stop, rotate positively or negatively heading to the next or the last point.
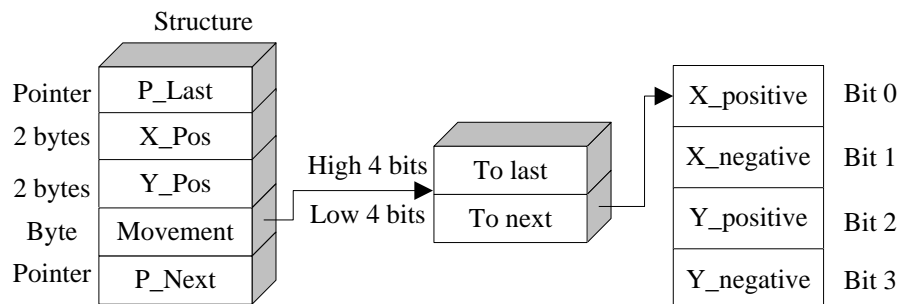


Figure 7. Data structure of members from linked list

## 4. Testing and Low Power Optimization

### 4.1. Testing and Power Consumption Analysis

The whole electronic system is constructed and tested in the lab. The remote controller sends commands to the main controller and the main controller executes them. They're all powered by battery.
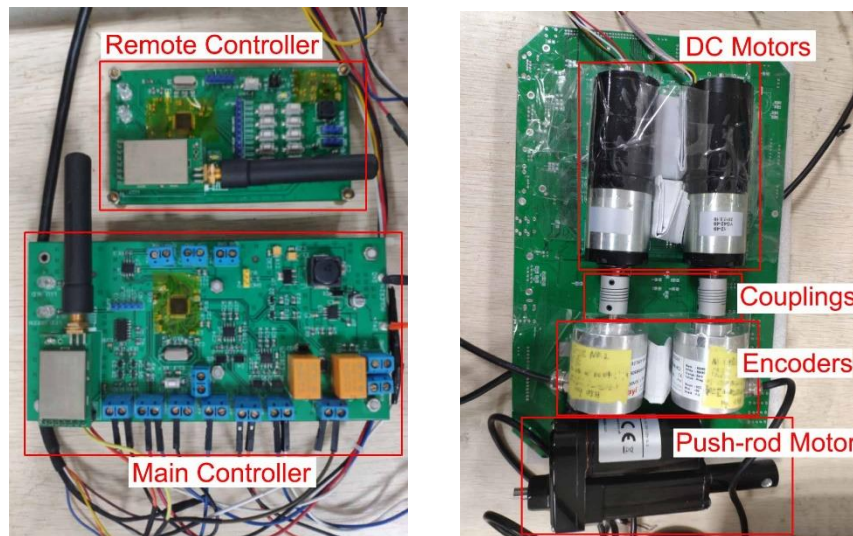
Figure 8. Controllers, motors and encoders under test

During the first test, all the function works well as designed. High-capacity Lithium battery pack can support at least 6 hours full-speed working of the main controller and motors when motors take up most of the consumption, but it is disappointing on that of the remote controller, where's no power button due to waterproof design requirement. Therefore, the performance of power consumption in remote controller is analyzed.

The wireless remote controller is tested alone, with supply voltage of 3.7V same as that of Lithium battery. It is found that its idle state consumes more than 100mA. The continuous command transmission state consumes more than 400mA.

The difference of power consumption between standby state and continuous transmission state is caused by wireless module, so analysis of power consumption of the standby state is enough. The power distribution pie chart is shown below by opening the test jumper between parts separately. It can be seen that the MCU consumes most of the power. The second is the power consumption of the wireless module, because the wireless module keeps ready to receive messages although it does not send any information. In addition, the CAN circuit consumes negligible power of 12%. Finally, the static power consumption of low dropout regulator (LDO) contributes to the power consumption too.
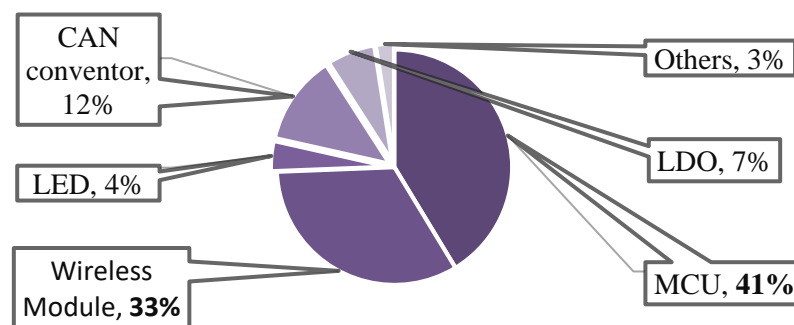


Figure 9. Pie chart of power consumption analysis of remote controller

*4.2. Hardware Optimization*

Based on the above analysis, a hardware optimization scheme is obtained. The first step is to deal with the CAN bus, because a 120 ohms match resistor is connected across two differential lines to match the impedance of the shielded twisted pair. Together with pull-up and pull-down resisters of 360 ohms, there forms a path from power to ground with impedance of hundreds of ohms. Due to relatively short communication distance, it's acceptable to increase the impedance of two pull-up and pull-down resistors. Also, many other pull-up resistors are modified with allowable range or removed if not

necessary. The CAN converter chip itself has no independent enable pin, so the power of the CAN converter is controlled by the MOS tube to eliminate power consumption during idle state. The 5V to 3.3V LDO is re-selected resulting in a decrease in static power consumption from 6mA down to 50uA.

### 4.3. Software Optimization

The optimization on the software is mainly to take advantage of the low power mode of STM32. The STM32F103 series has three low-power modes: sleep mode, stop mode, and standby mode. The latter two consume power at the microampere level. The sleep mode only shuts down the core, while the peripherals work normally, while other two can't. The first two modes can maintain the IO state and respond to most of interrupts. But in the standby mode, IOs all keep in high-resistance state and MCU can only be woken up by the wake-up pin.

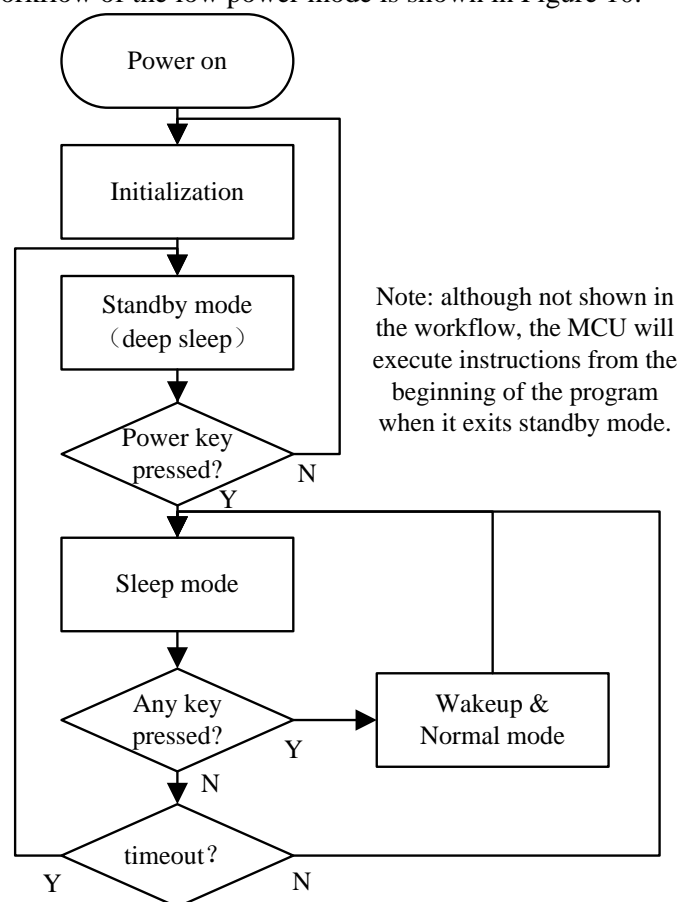The switching and workflow of the low power mode is shown in Figure 10.



Figure 10. Workflow and transition among three working states

The working state is re-divided into three basic states: shutdown state, standby state and working state. The sleep mode can quickly response and get back to normal mode and is applied to the standby state. At the same time, wireless module enters its sleep mode. It still consumes 20mA in this state during the first test. Therefore, the flexible frequency reduction is introduced to reduce the STM32 main frequency from 72MHz to a minimum of 8MHz. Shutdown state doesn't mean remote controller is power off. In this state, MCU enters standby mode and only response to the interrupt on wake-up pin, while nearly all other peripherals on board are powered off.

### 4.4. Optimization Result

After optimization on hardware and software, the power consumption performance of the proposed remote controller has greatly improved as result shows in Figure 11. The power consumption in

shutdown state is reduced to less than 80 uA, supporting long-time storage without charging. Standby state with consumption of less than 6 mA helps to improve power consumption performance while working between two operations with long interval.
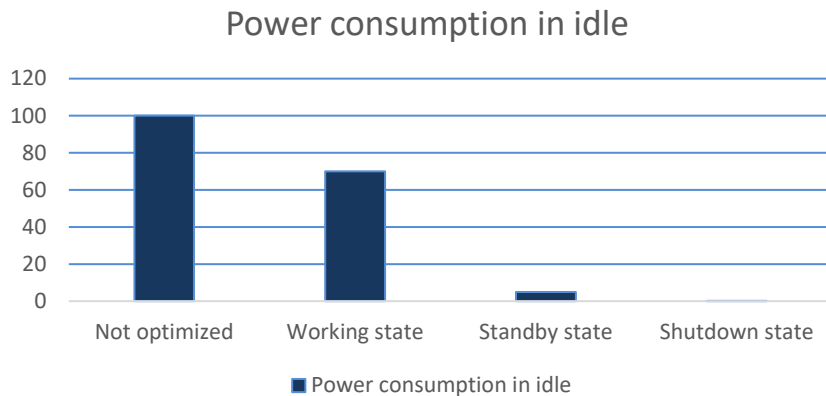


Figure 11. Power consumption comparison among different states

## 5. Conclusion

This paper focuses on a water cannon remote control system with remote controller available 250m away and manual mode as well as automatic mode, introducing the requirements analysis and solution design process including both hardware and software. Moreover, additional low power optimization is conducted for it is powered by battery especially for the remote controller. In conclusion, the system can effectively reduce the physical exertion of firefighters and is easy to maintain and use. Its wireless communication scheme and MCU performance have a large margin, so there is considerable room for development.

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