Wasted mask collection robot [version 1; peer review: awaiting peer review]

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Abstract
With the spread of major respiratory infectious diseases such as the new coronavirus pneumonia on a large scale worldwide, various countries and regions have taken medical supplies such as disposable medical masks (DMMs, mainly composed of a large variety of polymer material polypropylene PP). The demand is constantly rising. A large number of discarded masks are mixed in the streets and alleys, and the recycling process is extremely risky. In this era, it is particularly important to realize manual remote control of the collection of discarded masks. The waste mask collection robot mentioned in this article adopts a modular design method and carries out the system design, control system design, and hardware structure design for each part of the waste mask collection. In terms of the hardware system, a detailed analysis has been made on the chip model and the specifications of each application device and a reasonable design have been carried out. The design requirements of various parts are introduced, and their structure and function in the device are described in detail. Related hardware circuits are designed, such as the manipulator motor drive circuit and its control circuit. In terms of the software system, the driver program, the function program of the host computer, and the STM32 single-chip microcomputer, such as PWM motor driver and serial port communication, are designed. In terms of control system design, based on the Robot-link Wi-Fi wireless data transmission module, a set of information interaction codes between the host computer and the STM32 single-chip microcomputer is designed, which can realize ultra-low delay control. The PWM motor drive and serial communication were tested for the function. After the program was burned, the expected function was completed, and the actual product was finally assembled and tested to achieve the expected function.

Keywords
STM32, Modular design, Mask, The robot
Introduction
Status and problems of mask recycling

The special era background of masks. With the spread of major respiratory infectious diseases such as New Coronavirus pneumonia in the whole world, the demand for medical materials such as disposable medical masks (DMMs), a large variety of polymer materials, polypropylene PP and so on in various countries and regions has been increasing. By the end of April 2020, the average daily output of DMMs in China reached 200 million, each weighing about 5g, with about 1000 tons of abandoned DMMs every day. How to deal with covid-19 DMMs produced in and after the epidemic is fully understood. The full understanding of the necessity of waste DMMs recycling and accelerating the development of technologies for the recycling of DMMs has become an important topic for Corona Virus Disease 2019 (COVID-19) and other respiratory infectious diseases, while also an urgent requirement for protecting the ecological environment.

The current problems of mask recycling. DMMs are composed of a waterproof layer (spunbonded non-woven fabric), filter layer (melt-blown non-woven fabric), ear straps, nose bridge, and other components. Both the waterproof layer and the filter layer use PP non-woven superfine fibers as the core material, accounting for more than 90%, and are the main material of DMMs; the ear straps are often made of polyethylene terephthalate (PET) and polyurethane (PU); and the nose strips are usually made of polypropylene (PP)/galvanized iron wire, polyethylene (PE)/galvanized iron wire, or aluminum strips. The diameter of the PP ultra-fine fibers used in the filter layer is about 2μm. The filter layer is generally prepared by the melt-blowing process in the factory, that is, the PP is melt-extruded by the screw is sprayed with high-speed and high-temperature airflow to make the melt flow stretch at a higher speed to form ultra-fine short fibers, and then stacked on the mesh curtain to form a continuous short fiber mesh, which is then prepared by self-adhesive or other reinforcement processes.

First, the ultrafine fiber has a small diameter and a very high specific surface area; secondly, the surface resistance of PP material is high (10^{16} - 10^{18}Ω), which easily generates a large amount of static charge on the surface of the ultrafine fiber. Therefore, when the droplets with bacteria or viruses are close to the ultrafine fibers, they will be adsorbed by the electrostatic charge on the surface of the ultrafine fibers, thereby achieving the purpose of blocking bacteria or viruses. Due to the strong electrostatic force on the surface of the ultrafine fibers, it is impossible to remove bacteria or viruses with simple water washing, and water washing will also greatly reduce the electrostatic force on the surface of ultrafine fibers, so most of these masks are disposable. Although bacteria or viruses are adsorbed on the surface of the mask, they are not killed. This feature also brings special inconvenience to the recycling process of discarded DMMs.

The necessity of using smart robots for recycling

Used masks are often thrown into ordinary household waste at will, but they are full of threats, especially to the workers in the garbage collection process. In the garbage collection process, workers often lack protection and come into contact with masks with a large number of active viruses. It is very dangerous, but it is difficult to ensure that all recycling personnel wear protective clothing and implement a strict disinfection system. At the same time, because masks are randomly discarded in the streets, alleys and outdoors, the existing fixed sorting devices cannot be used.

Innovation of this paper

Therefore, our team developed a waste mask collection robot. The robot can recognize and pick up discarded masks on extreme roads and send them to the designated recycling area. The robot has a mechanical arm with 4 degrees of freedom and 180 ° rotation, can clamp 500g articles, and can easily collect waste masks without contact. The robot chassis is a crawler structure, with strong trafficability and climbing ability, and can pass through the complex outdoor environment. After the work, the robot only needs to be disinfected, which is convenient and safe.

Component selection and robot build

The structure of the waste mask collection robot

The robot (Figure 1) uses an STM32 (STM32F105RBT6) as the mainboard, with PWR(power), AVR(Automatic Voltage Regulator), and power supply voltage regulator and motor drive modules to drive the robot. The following table (Table 1) lists the functional modules and their components.

Introduction to the principle of each component

STM32 development motherboard. The model of the STM32 motherboard used in this article is STM32F105RBT6, and the specific meaning of each part is shown in Table 2. The reason we choose this motherboard is that it is relatively cheap after ensuring that all aspects of performance are up to standard.
Figure 1. Dimension of each part of the robot.

Table 1. Function module and its component.

<table>
<thead>
<tr>
<th>Function module</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU (microcontroller unit)</td>
<td>Single-chip microcomputer(STM32F105RBT6)</td>
</tr>
<tr>
<td>Drive module</td>
<td>PWR (power), AVR (automatic voltage regulator), and power supply voltage regulator and motor drive modules(L298N)</td>
</tr>
<tr>
<td>Camera module</td>
<td>The 720p HD (high definition) camera</td>
</tr>
<tr>
<td>Yuntai module</td>
<td>The 2-degree-of-freedom video pan/tilt</td>
</tr>
<tr>
<td>Battery module</td>
<td>Lithium battery(2200mAh 8A 12V)</td>
</tr>
<tr>
<td>Robotic arm module</td>
<td>Four degrees of freedom robotic arm</td>
</tr>
<tr>
<td>Obstacle avoidance module</td>
<td>Ultrasonic sensor</td>
</tr>
<tr>
<td>Tracking module</td>
<td>Infrared sensor</td>
</tr>
</tbody>
</table>

Table 2. Description of STM32 model.

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Letters</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STM32</td>
<td>STM32 stands for ARM Cortex-M 32-bit microcontroller</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>F for chip sub-series</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>105 stands for Enhanced Series</td>
</tr>
<tr>
<td>4</td>
<td>R</td>
<td>The item R represents the number of pins, where T stands for 36 pins, C for 48 pins, R for 64 pins, V for 100 pins, Z for 144 pins, and I for 176 pins.</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>Item B represents the embedded Flash volume, where 6 represents 32K bytes of Flash, 8 represents 64K bytes of Flash, 128K bytes of Flash, and so on.</td>
</tr>
<tr>
<td>6</td>
<td>T</td>
<td>The item T stands for the package, where H stands for the BGA package, T for the LQFP package, and U for the VFQFPN package.</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>Item 6 represents the operating temperature range, where 6 stands for -40-85°C and 7 for -40-105°C.</td>
</tr>
</tbody>
</table>
The chip used by the robot designed by the team is STM32F105RBT6. STM32F105RBT6 devices use Cortex-M3 cores, with a maximum CPU speed of 72 MHz. This series has 128KB on-chip flash memory, 64KB SRAM (static random-access memory), and 14 communication interfaces (Table 2). The performance of the motherboard is sufficient to support the realization of various functions of the waste mask collection robot.

**Infrared sensor with tracking function.** An infrared sensor is a kind of sensor that can sense the infrared radiation of a target and measure it by using the physical properties of infrared. According to the detection mechanism, it can be divided into photon detector and thermal detector. Infrared sensing technology has been widely used in modern science and technology, national defense, industry, and agriculture.

The infrared detection method is to use the characteristics that infrared has different reflection intensity on the surface of objects with different colors, the sensor continuously emits infrared light to the ground during driving the car. When the infrared light meets the white paper floor, it occurs diffuse reflection, and the reflected light is received by the receiving pipe installed on the car; If a black line is encountered, the infrared light is absorbed and the receiving tube on the trolley cannot receive the infrared light. The single-chip microcomputer determines the position of the black line and the walking route of the car based on whether it receives the reflected infrared light. The walking route of the car is to follow the black line. An implementation of this function is shown in Figure 2. According to the program we burned into the STM32 main control board, the car will automatically recognize the black path and travel on it. We use this technical means to accomplish the ‘Line patrol’ function. The infrared sensor model we use is E18-D80NK (Shenzhen Shenmingyang Electronics Co., Ltd.). However, any infrared sensor module with (voltage current condenser) VCC, ground (GND), and signal line (IO interface) can be used to realize this function.

**Ultrasonic sensor that realizes automatic obstacle avoidance function.** Ultrasonic sensors are sensors that convert ultrasonic signals into other energy signals (usually electrical signals). Ultrasound is a mechanical wave with a vibration frequency higher than 20kHz. It has the characteristics of high frequency, short wavelength, small diffraction phenomenon, especially good directivity, which can become rays and propagate directionally. Ultrasound has a great ability to penetrate liquids and solids, especially solids that are opaque to sunlight. When the ultrasonic wave encounters impurities or interfaces, it will produce significant reflections to form reflected echoes, and when it encounters moving objects, it the Doppler effect can produce be produced.

The basic structure of ultrasonic sensors: There are two main types of ultrasonic sensors, one is that the receiving end and the transmitting end are separated, and the other is the transceiver type. The current positioning system mainly uses the transceiver type ultrasonic sensor. The structure is shown in Figure 3.
The energy of ultrasonic waves is reduced and attenuated due to the propagation in the air. The attenuation rate depends on the vibration frequency; the higher the vibration frequency, the higher the attenuation rate, and the shorter the distance that it can be transmitted. However, the resolution of the measured distance is inversely proportional to the vibration frequency. The higher the vibration frequency, the better the resolution. That is, if the vibration frequency is high, the vibration distance is short, but the resolution is good; conversely, if the vibration frequency is low, the vibration distance is long, but the distance resolution decreases; therefore, the propagation effect of the ultrasonic sensor is very good in the short distance, and the long-distance effect is very poor.

The reflected ultrasonic signal is converted into an electrical signal (40kHz: a sine wave with a period of 25μs) through an ultrasonic sensor (Nanjing Kaijit Electric Co., Ltd.), amplified by an analog circuit, adjusted for the DC (Direct Current) component, and input to the A/D (analog to digital) conversion circuit of the STM32. The pre-designed signal processing program is used to control the robot to avoid obstacles by turning left, turning right, and moving backward.

### Four degrees of freedom robotic arm

An industrial robot arm replaces part of the functions of the arm with a machine and these have been widely used in various industrial production fields such as transportation. In some special high-risk environments, the industrial robot arm plays an irreplaceable role. Industrial robots are playing an increasingly important role in the field of industrial automation products, and have now become high-tech with important significance for emerging industries in the future.

The manipulator used in this paper has four degrees of freedom, which is realized by two longitudinal and two lateral servos, among which the No. 1 steering gear realizes the bionic elbow function, the No. 2 steering gear and the No. 3 steering gear realize the wrist function, and the No. 4 servo is used to realize the grab function. The structure diagram of the robotic arm is shown in Figure 4.

**Robot-link Wi-Fi wireless data transmission module**

The Wi-Fi module used adopts the Qualcomm AR9331 chip, which is a highly integrated WLAN (wireless local area network) solution. The module conforms to the international standard 802.11 b/g/n protocol, adopts DSSS (direct sequence spread spectrum) baseband modulation technology, and can adapt to the wireless hotspots of routers and other devices, with a maximum connection rate of up to 150Mbps.

Figure 5 shows the system structure of the Wi-Fi wireless data transmission module. Robot-link Wi-Fi wireless data transmission module (AR9331), the external STM32 motherboard is transmitted to the voltage conversion module through Microusb and converted to a 5V power supply; the data interaction between AR9331 and the STM32 motherboard is completed through UART (universal asynchronous receiver/transmitter); The data exchange between them is completed through the ANT (antenna) through the conversion circuit; RJ45 is a reserved network cable interface, which can be communicated with the outside world through the network cable.

**Robot module integration scheme**

The robot system integration is shown in Figure 6. The four-degree-of-freedom robotic arm of the discarded mask collection robot is connected to the 5V3pin interface on the STM32 motherboard through the 3pin cables on the
four servos; the camera is connected to the Robot-link Wi-Fi module through the usb data cable to transmit image data to the host computer. Both the infrared sensor and the ultrasonic sensor are connected to the 5V3pin interface on the STM32 mainboard through a 3pin cable. The two motors of the PWR(power), AVR(Automatic Voltage Regulator), power supply voltage regulator and motor drive module (L298N) are connected on the same side on the M1 and M2 interfaces reserved on the STM32 motherboard.

Notice: The positive and negative poles of the motors need to be reversed on the opposite side.

Real robot
The real robot is shown in Figure 7. It mainly includes the main board, power supply voltage regulator and motor drive module, infrared sensor for tracking function, ultrasonic sensor for automatic obstacle avoidance function, 2-degree-of-freedom video pan/tilt for mask identification, four degrees of freedom robotic arm, robot-Link Wi-Fi wireless data transmission module, etc. The chassis consists of an alloy structure with tracks and can realize real-time operation on special road surface.
Software design
Robot electronic system model
The simulation flowchart of robot electronic system is shown in Figure 8. The video transmission of the camera is independent and can be completed only by the Wi-Fi module, and the single-chip microcomputer does not participate in any link of the video transmission. The upper computer software transmits the control instructions to the Wi-Fi module, and the vehicle-mounted Wi-Fi module transmits the instructions to the single-chip microcomputer through the serial port.

Robot program running process
The operation flow chart of robot program is shown in Figure 9. The PC sends instructions to the MCU, which receives the instructions and controls the robot to run the corresponding operations. After running the

Figure 7. Physical assembly diagram.

Figure 8. Simulation flowchart of robot electronic system.

Figure 9. Flowchart of robot program operation. PC (personal computer) MCU (micro-controller unit) PTZ (pan/tilt/zoom).
corresponding operation, it starts waiting for a new instruction. Among the commands that can be operated are PTZ (pan/tilt/zoom) control, Manual control, Line patrol, Ultrasonic obstacle avoidance, Follow master, Steering gear control, etc.

**Robot control instructions**

The microcontroller stores the received control commands into the buffer[] array. Using the instruction example above, the result stored in buffer[] is buffer[0]=00, buffer[1]=01, buffer[2]=02. The storage of a set of instructions is complete. The Communication_Decode() function parses the data stored in buffer[].

For example manual control. If the above instructions are parsed. Then the car will execute a manual control forward instruction (MOTOR_GO_FORWARD).

The following is part of the code for manual control:

```c
void Communication_Decode(void)
{
    if(buffer[0]==0x00) //Manual control
    {
        GPIOB->ODR ^= GPIO_Pin_5; //Motor indicator
        switch(buffer[1])
        {
            case 0x01:MOTOR_GO_FORWARD;return; //Moving forward
            case 0x02:MOTOR_GO_BACK;return; //Backwards
            case 0x03:MOTOR_GO_LEFT;return; //Turn left
            case 0x04:MOTOR_GO_RIGHT;return; //Turn right
            default:MOTOR_GO_STOP; //Stop
        }
    }
}
```

So we can see that buffer[0] selects the Manual control of the robot. Buffer[1] is the content of the specific sport. Buffer[2] is a reserved instruction location (not used for the time being). It should be pointed out that there are many modes of the car. The actual meaning represented by the buffer[x] needs to be found in the Communication_Decode() function.

**Robot driver**

1. Serial port driver
   Mainly use serial port 1 to receive instructions and upload data. The main functions can be found in usart1.c. For example, initialization, sending string, etc.

2. Robot motor drive
   Mainly use timer 5 to provide L298N with two PWM waves to control the motor speed, and the forward and reverse of the motor are directly controlled by IO high and low levels.

3. 12864 LCD driver
   It is mainly used to display some selection menus. You can find some of its commonly used driver functions in 12864.c, and you can directly call related functions with slight changes.

4. Servo drive
   Use timing 2 to generate 8 PWM waves with an adjustable duty cycle to realize the control of 8 steering gears. The code of the servo driver can be found in the interrupt function of timer 2 (Interrupt.c).
5. Infrared sensor driver

The infrared sensor only needs to read the high and low levels of the corresponding IO port to drive the infrared sensor.

6. Ultrasonic sensor drive

Timer 4 is used to measure the duration of the high level to achieve the purpose of measuring distance. Its measurement function is found in the Ultrasonic.c file, and the function in this file can be directly called if necessary.

7. Various mode function functions

Functional mode functions such as manual control, line tracing and avoidance, ultrasonic barriers, and following the master are all based on the above-mentioned simple drive-by adding simple logic functions to realize the functions of various mode functions.

**System test**

**PWM motor drive test**

*PWM motor speed regulation principle.* An L298N motor driver is integrated into our power board (Figure 10). This motor drive controls a motor that needs to give three signals, namely EN (enable) (PWM (pulse width modulation)), IN1 (input1), and IN2 (input2). EN is the motor enable. The PWM wave generated by the single-chip microcomputer is given to the EN pin of the motor drive to control the motor speed (the higher the proportion of the high-level duration in one cycle of the PWM wave, the higher the motor speed). IN1 and IN2 control the forward and reverse rotation of the motor (1, 0 forward, 0, 1 reverse, 00 or 11 does not rotate).

* Burning code.* The PWM motor speed control code (my_stm32.hex) was burned into the microcontroller using ST-LINK. Scilab (RRID:SCR_014258) is a free alternative to this software, that can perform the same function.

*Figure 10. Motor drive.*
void main(void)
{
    SystemInit(); /* Set the system clock to 72M */
    SysTick_Configuration(); // SysTick interrupt configuration, mainly used for timing
    MOTOR_GPIO_Config(); // Motor pin initialization
    TIM5_PWM_Init(); // Timer 5 (motor speed PWM initialization)
    Set_Left_Speed(300); // Set left wheel speed
    Set_Right_Speed(300); // Set right wheel speed
    MOTOR_GO_FORWARD; // forward
    while (1);
}

Wiring. The motor is connected to the position of the motor terminal M1+, M1- (or M2+, M2-).

Test phenomenon. The battery was then connected to the STM32 board and turn on the power switch to see the effect of Figure 11.

Serial communication test
Introduction to serial port code. The serial port was initialized, and the MCU stores the received serial port numbers in a buff [] array. Then the printf function was used to display the numbers in the buff [] array to the serial port tool. This array is unsigned integer data, so when sending data, it is necessary to send hexadecimal numbers in theHEX format.

Main program. Refer to reference for this part of the code.

void main(void)
{
    SystemInit(); /* Set the system clock to 72M */
    SysTick_Configuration(); //SysTick interrupt configuration, mainly used for timing
    USART1_Config(); // Serial port initialization
    while (1)
    {
        if(Send_flag==1){printf("Recieve_data=%d\n",buffer[0]);Send_flag=0;}
    }
}
This code is the main program, the main function is to set the system clock to 72M and initialize the serial port.

**Serial port interrupt function.** Refer to reference 30 for this part of the code.

```c
void USART1_IRQHandler(void) // Serial port 1 interrupt service routine
{
    if(USART_GetFlagStatus(USART1, USART_FLAG_RXNE)==1)
    {
        USART_ClearFlag(USART1,USART_FLAG_RXNE);
        buffer[0]=USART_ReceiveData(USART1); // After receiving the data, store the data in the buff
        Send_flag=1;
    }
    else
    {
        USART_ClearFlag(USART1,USART_FLAG_LBD);
    }
}
```

This code initializes the serial port, and the MCU stores the received serial port number into a buff [] array. We then use printf to display the numbers in the buff [] array to the serial port tool. This array is unsigned integer data, so we need to send hexadecimal numbers in HEX format when sending data.

**Burning code.** The serial port interrupt function my_stm32.hex file was then burned into the microcontroller.

**Wiring.** The power board was then connected via a USB communication cable into the computer, the battery was installed, and the power switch was used to power on the board.

**Serial communication test phenomenon.** The robot was connected to serial port number on a computer, then the serial port number, baud rate and hex mode transmission were set as per Figure 12. The connection was tested using SSCOM 3.3 by sending the hexadecimal number “FF”, and the microcontroller sends the received “FF” back to the computer. What we show here is 255. (The hexadecimal number “FF” is converted to decimal number 255)

![Figure 12](image-url)
Summary
The tests for PWM motor drive and serial communication were successful. After the program was programmed, the expected functions were all successfully completed. Tests for other basic function modules were also completed. To keep this article succinct, only two are listed here. We have included all data from tests performed in the repository found in the data availability section\(^\text{32}\) and a demonstration of the robot working is provided\(^\text{33}\).

Conclusions
Due to the rapid increase in demand, the recycling-related industries of discarded masks are entering a period of vigorous development\(^\text{34}\). In this paper, due to actual needs, a waste mask collection robot is developed based on an STM32 single-chip microcomputer. The robot adopts an alloy chassis with a double track structure, which not only ensures the durability of the robot, but also allows for the collection of masks on various road surfaces. Ultrasonic sensors are used to achieve automatic obstacle avoidance; infrared sensors are used to achieve tracking; a two-degree-of-freedom video gimbal is used to achieve mask recognition; a four-degree-of-freedom robotic arm is used to pick up and collect masks. Finally, the STM32F105RBT6 is used as the main board, and the Robot-link Wi-Fi wireless data transmission module is used to realize the complete function of the whole robot. The robot can realize the function of automatic line patrol or manual remote operation, which can solve the safety problems of practitioners in the process of recycling waste masks. It can also solve the economic and environmental problems in the recycling process of waste masks: it consumes a lot of energy to develop and invest in the sorting equipment for waste masks in large garbage dumps, and the robot used in this paper can solve this problem appropriately.

This research proposes the design of a waste mask collection robot, completes the design and assembly of the overall mechanical structure of the robot, and the system design of the control part. Limited by my research ability and experience, as well as time and energy factors, there are some areas that would benefit from improvements. I hope that future research can further improve the waste mask collection robot, such as how to use intelligent new technology to make the robot. While maintaining efficient operation, improve operation accuracy and work efficiency, among other issues.

The waste mask collection robot proposed in this article, could be used for remote and non-contact processing of waste medical supplies, such as masks, protective clothing, medical waste and so on. Through the application of this robot, it may be possible to reduce the risk of virus infection for front-line workers and clean up highly polluted garbage that people cannot directly touch, which has broad application prospects.

Data availability
Extended data
Figshare: The data of paper ‘Wasted Mask Collection Robot’. https://doi.org/10.6084/m9.figshare.19517317.v1\(^\text{32}\)

This project contains the following extended data:
- Robot serial communication protocol.xls (Commands used to control robot)

Zenodo: attachment 3 Yihan Zhao. https://doi.org/10.5281/zenodo.6337118\(^\text{33}\)

This project contains the following extended data:
- attachment3.mp4 (Competition video showing final robot in operation)

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Software availability
PWM control

Archived source code at the time of publication: https://doi.org/10.5281/zenodo.6214402\(^\text{28}\)

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Serial communication
Source code available from: https://github.com/572735583/Serial-communication.git
Archived source code at the time of publication: https://doi.org/10.5281/zenodo.6214557

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Full source code
Source code available from: https://github.com/572735583/code-collection.git

Archived source code at the time of publication: https://doi.org/10.5281/zenodo.6336979

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Robotic arm simulation working range
Source code available from: https://github.com/572735583/Robotic-arm-simulation-working-range.git

Archived source code at the time of publication: https://doi.org/10.5281/zenodo.6540767

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Compatible with all C++ code
Source code available from: https://github.com/572735583/Compatible-with-all-C-code.git

Archived source code at the time of publication: https://doi.org/10.5281/zenodo.6540792

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