IRSTI 55.30.03, 55.30.31, 55.30.13 DOI: https://doi.org/10.26577/JMMCS2023v120i4a8

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DESIGN OF CONTROL SYSTEMS FOR A ROBOT FOR CLEANING PUBLIC SPACES

The aim of this article is to examine the control mechanism for a cleaning robot employed in public areas, focusing on the development of a controller for the cleaning robot. The motor control system block diagram for the surface cleaning robot is created based on the principle of Pulse-Width Modulation (PWM) for speed control. Each module's functions in the control system are separated and elaborated. The article presents a proposal for software and hardware design, adopting a thinking model based on the AVR microprocessor. By using RS485 and PC communication, following an agreed protocol, the control system facilitates the robot's forward and backward movements, rotation, and operation with a DC or stepper motor. Consequently, it enables the surface cleaning robot to perform its work more effectively.
Key words: A robot designed for cleaning surfaces, The AVR Mega8535 microcontroller, control system, modular design.

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Қоғамдық кеңістіктерді тазалауға арналған роботтың басқару жүйелерін жобалау

Бұл мақаланың мақсаты – тазалау роботының контроллерін әзірлеуге назар аудара отырып, қоғамдық орындарда қолданылатын тазалау роботының басқару механизмін зерттеу. Бет тазалау роботының қозғалтқышты басқару жүйесінің құрылымдық схемасы жылдамдықты басқаруға арналған импульстік ен модуляциясы (PWM) принципіне негізделген. Басқару жүйесіндегі әрбір модульдің функциялары бөлініп, өңделеді. Мақалада AVR микропроцессоры негізіндегі ойлау моделін пайдалана отырып бағдарламалық және аппараттық құралдарды жобалау ұсынысы берілген. RS485 пайдалану және келісілген хаттамаға сәйкес ДК-мен байланыс орнату, басқару жүйесі роботтың алға және артқа қозғалысын, айналуын және тұрақты ток қозғалтқышымен немесе қадамдық қозғалтқышпен жұмысын жеңілдетеді. Сондықтан бұл бет тазалау роботына өз жұмысын тиімдірек орындауға мүмкіндік береді.
Түйін сөздер: Бет тазалау роботы, AVR Mega8535 микроконтроллері, басқару жүйесі, модульдік дизайн

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Проект системы управления роботом для уборки общественных помещений

Целью данной статьи является изучение механизма управления роботом-уборщиком, используемым в общественных местах, с упором на разработку контроллера для робота-уборщика. Блок-схема системы управления двигателем робота для очистки поверхностей создана на основе принципа широтно-импульсной модуляции (ШИМ) для управления скоростью. Функции каждого модуля в системе управления разделены и проработаны. В статье представлено предложение по проектированию программного и аппаратного обеспечения, использующее модель мышления на основе микропроцессора AVR. Используя RS485 и связь с ПК в соответствии с согласованным протоколом, система управления облегчает движения робота вперед и назад, вращение и работу с двигателем постоянного тока или шаговым двигателем. Следовательно, это позволяет роботу для очистки поверхностей выполнять свою работу более эффективно.

Ключевые слова: Робот для уборки поверхностей, микроконтроллер AVR Mega8535, система управления, модульная конструкция

1 Introduction

Surface cleaning robots are public space protection equipment, mainly used to collect garbage in the restroom. In addition to their primary function of collecting garbage in public spaces, surface cleaning robots offer several additional benefits. For instance, they can be used as tools for evaluating the quality of indoor air, which is critical for ensuring the health and safety of individuals who spend time in such spaces. Furthermore, they provide numerous societal benefits, such as reducing the workload of human cleaners and promoting a cleaner, more hygienic environment. Finally, the potential for promising applications of surface cleaning robots is vast, as they can be further developed and modified to serve other purposes beyond their current functions. These various benefits have been noted and supported by research in the field [1, 2, 3, 4, 5]. At present, the responsibility for cleaning public spaces falls upon human cleaners due to the absence of surface cleaning robot systems that possess flexibility, mobility and high intelligence. However, with recent advancements in robotics technology, the development of a control system for surface cleaning robots that can communicate with the main computer and control system has become increasingly feasible. Such a system would have theoretical significance by furthering our understanding of the capabilities and limitations of robotic systems. In addition, the development of such a control system would have significant applied value, as it would improve the efficiency and effectiveness of surface cleaning in public spaces, reduce the workload of human cleaners, and promote a cleaner, more hygienic environment. This potential has been recognized and supported by research in the field [5, 6, 7, 8, 9, 10].

2 Literature review

Robots are used in many areas, even in everyday life (22). Robots for home use are on the rise. Robot vacuum cleaners are especially known (23). Among the various robots that exist in the world, only some robots can be used specifically for human household chores. Among these robots, there is one particular type of robot that is very useful for everyone, and that is the cleaning robot (24). A simple automatic robot that uses some predefined algorithms and programs to clean a given area is called a cleaning robot. The main application of this robot is to reduce human intervention in the cleaning process, which can be time consuming. These robots can be used anywhere, i.e., in offices, homes, factories, etc. These robots can be activated with the push of a button or can be pre-configured to activate at a specific time (22).

As shown in Fig. 1, the whole system adopts a public space cleaning robot, previously developed in the laboratory, based on the SCARA system, as a carrier. SCARA robots are a new type of industrial robots that combine high precision and movement speed. The design of SCARA robots consists of two arms connected together, attached to the base. Thus, SCARA robots are four-axis robots with freedom of movement along the $X - Y - Z$ axes, rotational movement is also carried out along the Z axis. SCARA robots are ideal for moving loads from point A to point B in a horizontal plane, if little movement is required along the Z axis. Due to the rotational movement of the Z axis, SCARA robots can not only move objects, but also screw them, which makes these robots indispensable on assembly lines. The surface cleaning robot system is composed of three working motors, each serving a specific purpose. The front stepper motor is responsible for collecting debris, while the left and right rear DC motors control the $X - Y$ axes to enable movement and navigation. The control system receives information from the main computer, which it then processes and utilizes to execute commands that control the three motors, ultimately working to accomplish the desired objectives. The cleaning robots are also equipped to organize the information received in real-time, utilizing the user protocol to send data to the monitoring center via the RS485 serial port. Upon arrival at the host computer, the batch data is recovered and displayed on the control interface of the host computer, providing valuable information about the status and performance of the cleaning robot. This sophisticated system serves as a testament to the rapid advancements in robotics technology, making it possible to design and implement intelligent and efficient solutions to complex problems in a wide range of industries.

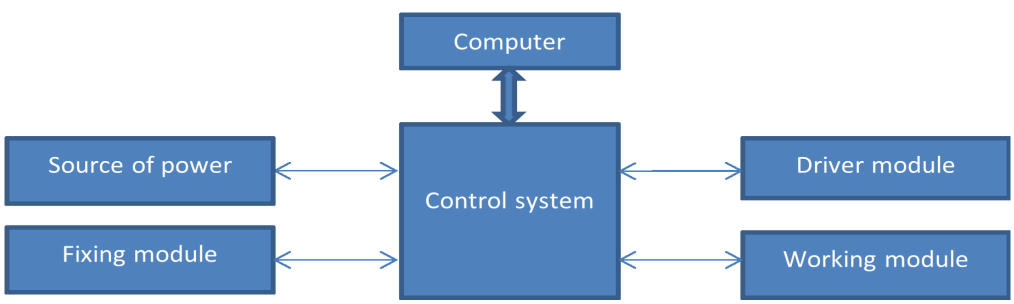
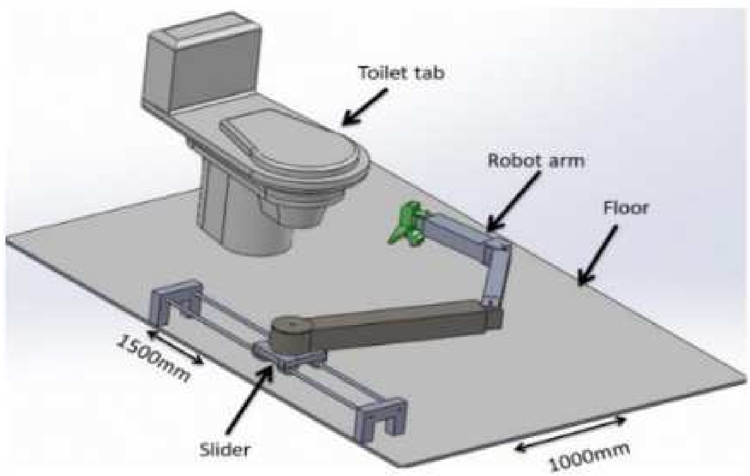


Figure 1: Block diagram of the robot control system

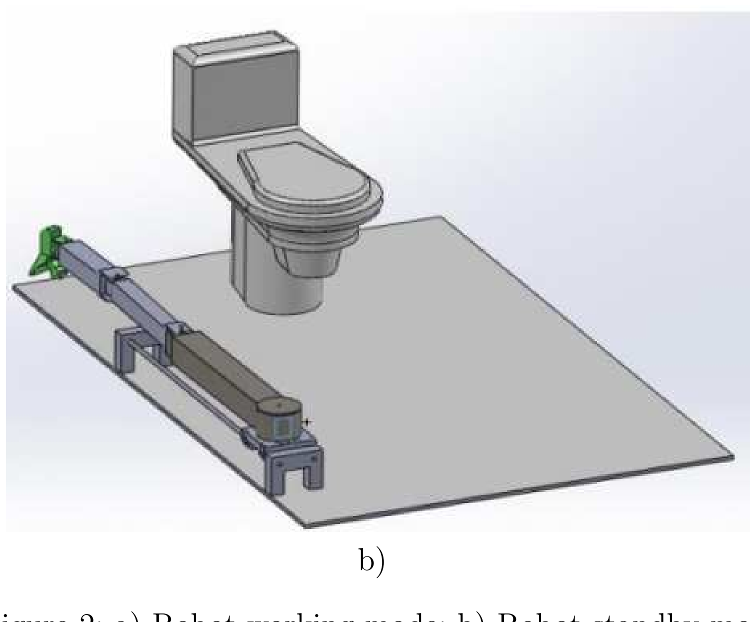
3 Robot design concept

The design of the robot is determined by the working environment and the task. The exploration robot comes with some limitations; the proposed robot can only work in a structured and predefined workspace. In this study, bathroom dimensions should be no more than 1000 mm wide and 1500 mm deep. According to the standard toilet cubicle systems in Western European countries, the dimensions of the public toilet cubicle should be 850 mm wide and 1500 mm deep.

Depending on the robot performing the task, the robot arm must be accessible anywhere in the workspace without blind spots and reasonably compact. Therefore, in this study, we proposed a multi-joint robotic arm with a similar structure to the SCARA robot (see Fig. 2. a, b). As shown in Figure 2b, the robot aligns itself along the slider guide after cleaning the surface. Traditionally, in such a tight workspace, continuum arms have an advantage due to their flexible structure. However, in this task, the Robot Manipulator must have a rigid link to control a heavy tool [21].



a)



b)

Figure 2: a) Robot working mode; b) Robot standby mode

4 Results and discussion

After analyzing the requirements for control systems of public area cleaning robots, it was determined that the control system's hardware circuit should consist of several important components, including the motor control circuit, external watchdog, simulation download module circuit, RS485 interface circuit, and power management circuit. The motor control circuit is responsible for driving both the DC and stepper motors, which are crucial for the robot's movement and cleaning capabilities. A leak detection circuit is also included to ensure the safe and proper operation of the robot. The general structure of the control system can be visualized in Figure 3, which provides an overview of the various components and their interconnectivity. By carefully designing and integrating these circuits, the control system can effectively control the movements and actions of the cleaning robot, ensuring its proper functioning and efficient operation.

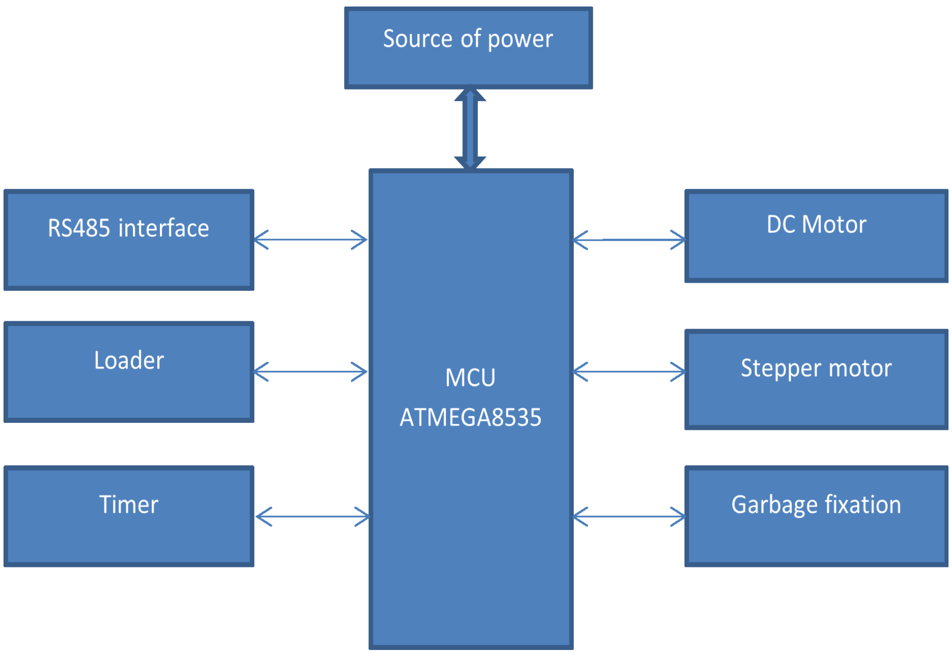


Figure 3: General scheme of building the control system hardware

4.1 Microprocessor

The ATmega8535 microprocessor serves as the fundamental component of the surface cleaning robot control system, providing a high throughput of up to 1 Million Instructions Per Second per Megahertz (MIPS/MHz). This ensures that the system can process data and execute commands quickly, without compromising on power consumption. By utilizing the ATmega8535 microprocessor, the surface cleaning robot control system is equipped with a reliable and efficient core that can effectively manage and execute the necessary tasks required for the proper functioning of the system.

4.2 DC motor drive module

In order to achieve the necessary movements of the surface cleaning robot, such as moving forward, backward, and turning, it is crucial to have precise control over the speed and direction of the motor's rotation. The speed control of a permanent magnet DC motor can be accomplished through two primary methods: armature series resistance and supply voltage reduction. However, using the armature series resistance method can result in instability at low speeds and discontinuous speed changes. Conversely, reducing the supply voltage can provide smoother speed control without altering the motor's mechanical characteristics [13]. During a single cycle of positive and negative changes in the PWM, the armature voltage at both ends of the motor experiences changes twice, which enables determining the average voltage through the following formula [14]:

$$U_0 = \left(\frac{t_1}{T} - \frac{T - t_1}{T}\right) U_s = \left(2\frac{t_1}{T-1}\right) U_s = (2\alpha - 1)U_s$$

α – duty cycle, $\alpha = t1/T$.

The duty cycle is a crucial parameter in the pulse-width modulation (PWM) technique that controls the speed of a motor by varying the conduction time of a switch in a periodic signal. In the given equation, the duty cycle represents the ratio of the switch's on-time to the period T, while the conversion range α lies between 0 and 1. In a bipolar reversing PWM drive, the average armature voltage of the motor is determined by the value of α. For instance, when $\alpha = 0$ and $U0 = -US$, the motor rotates in the reverse direction and achieves maximum speed; when $\alpha = 1$ and $U0 = US$, the motor rotates forward and attains the maximum speed; and when $\alpha = 1/2$ and $U0 = 0$, the motor comes to a halt. The duty cycle plays a crucial role in controlling the speed and direction of the motor, making it a vital parameter in motor control systems.

4.3 Stepper Motor Driver Module

A stepper motor is a type of actuator that can convert an electrical signal into precise angular movement. Unlike other types of motors, the stepper motor can be precisely controlled by varying the number of pulses it receives, allowing for highly accurate positioning. In addition, the speed and acceleration of the stepper motor can also be controlled by changing the frequency of the pulses, making it a versatile option for a wide range of applications. To drive a stepper motor, a square wave current is typically used, which is achieved through the use of a stepper motor drive. A breakdown driver is a type of stepper motor drive that employs electronic damping technology to reduce or eliminate low frequency vibrations that may affect the motor's performance. By minimizing vibrations, breakdown drivers can improve the motor's positioning accuracy, reduce operating noise, and ensure smooth operation [15].

Figure 4 illustrates that stepper drives are comprised of three signal ends: pulse signal (PUL), direction signal (DIR), and enable signal (ENA). These signal ends are connected to the MCU's PB3, PB1, and PB0, as well as the negative electrodes which are grounded. Through programming, the driver can be controlled to regulate the stepper motor's movements to achieve the desired outcome. With this method, precise control over the motor's speed, direction, and positioning can be obtained.

4.4 An overview of the program's control system structure

Based on the analysis of the system's functional requirements and the results of the hardware module design, the software for the control system of the surface cleaning robot

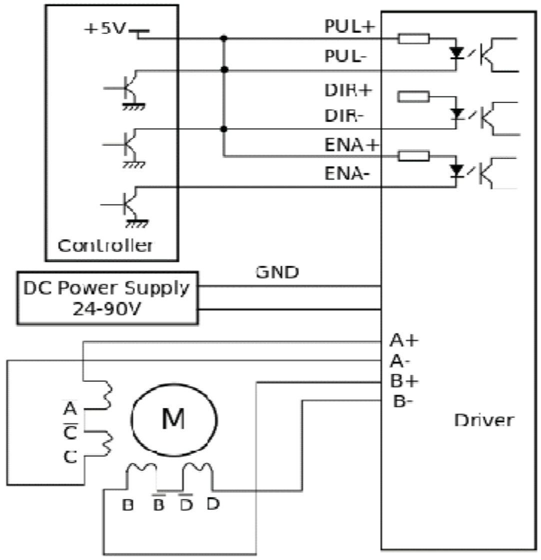


Figure 4: Stepper Motor Drive Interface Block

is composed of several subroutines in addition to the main module program. The general structure of this software is depicted in Figure 5. The software consists of several important components, including the main program, the internal initialization routine, the UART serial communication program, the DC motor control program, and the leakage detection interrupt program. These components have been developed based on a careful review of existing literature and established practices in the field of robotic control systems [16, 17, 18, 19, 20].

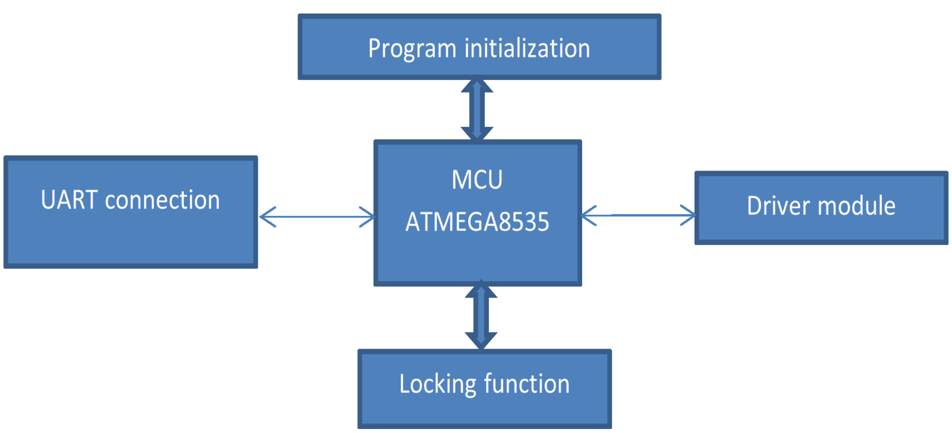


Figure 5: General structure of the system software

4.5 The process of creating software for the main controller module

Once the master device applies power to the system, the parameters are initialized and the port addresses are assigned. Additionally, two leakage detection signals are read, and the motor driver module routine is executed based on the instruction sent by the master to modify the speed and direction of the motor's rotation. This entire process results in the surface cleaning robot transitioning into the working state. If we take a closer look at the robotic surface cleaning system, we can see that the main program, as illustrated in figure 6, plays a crucial role in managing these tasks and ensuring the smooth functioning of the entire system.

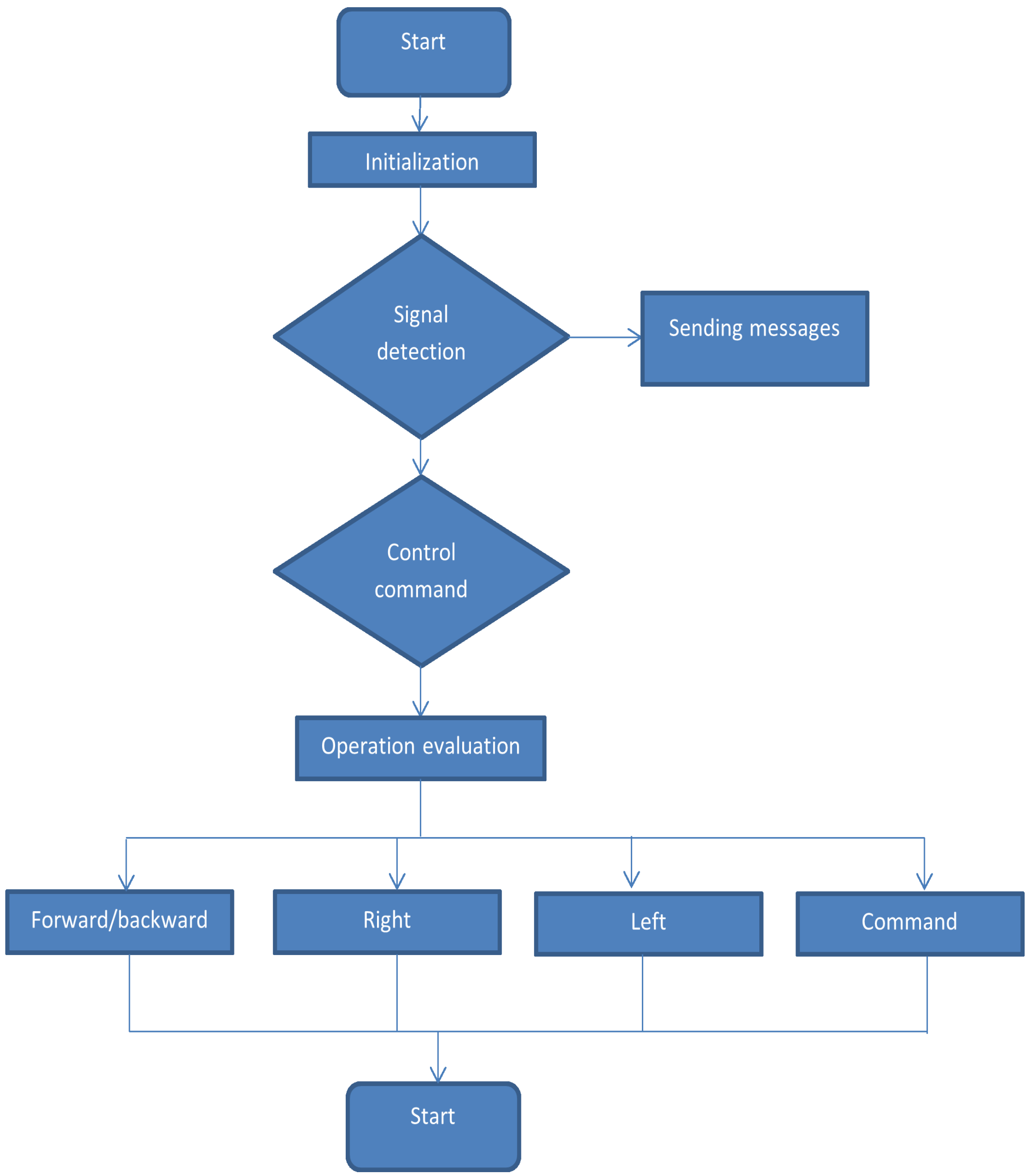


Figure 6: Scheme of the main operating mode of the system

5 Conclusion

The current study provides a comprehensive analysis of the public area cleaning robot control system design in both hardware and software aspects. It introduces an innovative control scheme that integrates a main computer and a microcontroller, which brings a series of benefits to the entire cleaning robot control system, such as fast response time, decreased power consumption, durability and real-time control capability. As a result, the overall system stability and reliability are significantly improved. With the aid of the main computer and the microcontroller, surface cleaning robots can be accurately controlled to perform their cleaning tasks with high precision and efficiency.

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