

# Study of Wearable Stealth Air Purifier

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**Abstract.** In view of the increasingly serious environmental pollution in the current urban modernization process, the working principle and operation mode of this intelligent air purification device for preventing pollution hazards such as smog are introduced. The air purifier adopts the principle of “human-machine-environment” coordination and high efficiency, and uses weak current technology to drive and PID algorithm to control gas flow as a technical means to complete the dynamic balance between the initial resistance and the final resistance of the filtered air, which can solve the general problem of the mask in the current market that the respiratory comfort is inversely proportional to the protective effect. At the same time, combined with ergonomics and environmental engineering principles, the filtered air is directly connected to the nostrils of the respiratory passage to form a dedicated closed airway, which solves the fatal problems that unpurified air is inhaled and exhaled carbon dioxide gas is repeatedly inhaled to form secondary pollution. The work has designed a new concept of air purifier from the direct connection of personal breathing passage, the one-time use of clean air, and the miniaturization and invisibility of functional structures. It has realized three major technological breakthroughs with its personalized, compatible and aesthetically pleasing design. The work allows more people to breathe freely with higher quality clean air in severe smog pollution, or to actively prevent respiratory diseases.

**Keywords:** air purification; miniaturization and invisibility of structures; secondary pollution; intelligent PID control.

## 1. The Background and Significance of the Research

Economic development and urban expansion are remarkable manifestations in the process of urban modernization. In this process, the living standards of urban residents are constantly improving, but they also bring about the discharge of various pollutants, environmental pollution and the intensification of severe weather conditions. The urban atmospheric environment is polluted and threatens people's health. Therefore, many people choose air purification devices, which become a necessity in our lives.

After market research, we found that air purification is mainly divided into two categories:

(1). When people are outdoors, they mainly rely on various types of masks. Currently, there are four kinds of masks in the market: cotton masks, medical non-woven masks, activated carbon masks, and KN90&KN95 masks. Table 1 compares the advantages and disadvantages of these kinds of masks. We found that the current air purification devices in the market generally have problems of inconsistency in comfort and protection, resulting in a lower overall evaluation. Although there are many kinds of products, but the breathing is stagnant, causing chest tightness and shortness of breath, so the long-term use is prone to lack of oxygen; and the mask covers the face, only revealing the eyes, restricting speech. Exhaled air with water vapor not only wets the mask but also easily breeds germs. In the high season of influenza such as autumn and winter, it is very susceptible to virus infection. And the exhaled carbon dioxide gas is re-inhaled to form secondary (circulating) pollution, and the amount of clean air or oxygen supply is insufficient, so it cannot be worn for a long time.

Table 1. Analysis of the advantages and disadvantages of masks in the market

Mask type	Characteristics	Advantage	Disadvantage
Cotton mask	With filter	Keep warm Repeatable cleaning	① Breathing is not very comfortable ② Easy to cause pollution or bacterial infection ③ Need to change the filter frequently
Fashion cotton mask	① personality ② good looking	① Keep warm ② Repeatable cleaning	① No protection against smog ② Prone to contamination or bacterial infection ③ Most printing materials contain heavy metals harmful to the human body.
Medical non-woven mask	Both haze and flu weather apply	① Good bacteria and virus filtration ② Breathable comfort ③ Clean and hygienic	① Poor sealing ② One-time use
Activated carbon mask	Suitable for places with odor or formaldehyde exceeding the standard	① Good bacteria and virus filtration ② Can absorb odor, formaldehyde, etc.	① Poor gas permeability ② Need to change activated carbon frequently
KN90&KN95 mask	① Not recommended for long wear ② Respiratory disease patients and the infirm is better not to use	① Fine dust filtration effect ② Good sealing effect	① Uncomfortable ② Easy to cause respiratory diseases, etc.

(2). In a specific indoor environment, air purifiers are mainly used. At present, the air purifier on the market mainly consists of four parts: wind grid, activated carbon, filter element and air outlet, which has high removal efficiency for indoor pollutants, but the instrument has problems such as limited adsorption capacity of activated carbon. And long-term use of the filter element will lead to a decrease in filtration capacity, resulting in frequent replacement of components and high maintenance costs. In the working environment with dust and odor, the air purifier is affected by indoor space, air flow, air medium, maintenance and repair, so the use efficiency is greatly reduced.

The team designed a new air purification device through experiments. While solving the above problems, the device adopts the principle of “human-machine-environment” coordination and high efficiency, and combines the principles of ergonomics, “weak power technology drive + PID control” and environmental engineering principles. A new concept of air purifier design is provided for the direct connection of the personal breathing channel, the one-time use of clean air, and the miniaturization and invisibility of structures.

## 2. Working Principle & Design

The wearable stealth air purifier is a personal wearable device specially designed to prevent air pollution, dust space, harmful gases, epidemic diseases or fire emergency. It consists of a filter element [1], a jacket [2] and a nasal mask [3]. The feature is: the HEPA filter of the filter element is built in the outer casing. The two nasal plugs at the head end of the trachea of the Y-shaped nasal mask are directly connected to the two nostrils of the person, and the truncated end of the trachea is connected to the filter element in a plug-and-pull manner, and the outer sleeve is a human wearable accessory.

The filter element consists of a HEPA [4] filter cover, a turbofan and an external power supply. The HEPA filter has a nested turbofan to form a micro-filter. The side of the filter is provided with a suction valve outlet and an external power connection. The turbofan and the external power supply are connected to form a split weak electric fan system. The external power supply is a current common weak level rechargeable battery. The built-in turbofan and external power supply form a split-type micro-fan with a power of less than 1W. When the fan is energized, the negative pressure of the turbofan draws in a proportional proportion of the air, and the oxygen concentration flow sensor

instantly feeds back the amount of gas required for the person to breathe, thereby PID control is performed on the air volume and wind speed drawn in the HEPA filter. So the dynamic balance of the initial and final resistance of the filtered air is completed, and the resistance difference is 0, achieving the balance of supply and demand and comfort of the normal breathing of the human body.

The jacket that is nested in the outer layer of the HEPA filter in the filter element is a wearable accessory for the human body. It allows the purifier to have the function of air purification and structural invisibility while highlighting the individual aesthetic design, making the overall structure of the purifier a miniature design element for various personal accessories such as head wear, hair accessories, collars, clothing and glasses frames.

The nasal mask consists of a Y-shaped structure consisting of an interface, a trachea, a left nasal plug, and a right nasal plug. The trachea is a medical transparent hose material that is easy to invisible and wearable. The tail end is a plug-in interface. The head end is two left and right nasal plugs of the same structure, and the plug of the nasal plug is a flexible hoist mouth shape with mesh to maintain air tightness and elastic connection with the nostrils. The upper end of the plug is provided with a safety barrier and an elastic plastic flap valve. When inhaling or deactivating, the plastic film valve is tightly sealed above the safety barrier due to its own elasticity, so that the unfiltered purified air cannot enter the nostrils through the safety barrier, that is, the valve ensures that the carbon dioxide gas exhaled is only unidirectional.

Note:

[1] Filter element:

The above filter element uses the weak electric technology drive and the PID control principle. The filtered air has three modes: human inhalation, fan inhalation, and man-machine and inhalation.

[2] Jacket:

Based on the aesthetic requirements of ergonomics, the above-mentioned jacket is designed to be worn on the outer layer of the filter element for the human body to wear, so that the overall structure of the purifier becomes a variety of personal accessories such as headwear, hair accessories, collars, clothing, glasses frames, and the like. And jackets are such personal accessories.

[3] nasal mask:

The above-mentioned nasal mask combines ergonomic principles and environmental engineering principles to liberate the face and mouth that are not related to breathing, and is convenient for invisibility and wearing. Y-type transparent one-way ventilation is made of medical grade PVC (polyvinyl chloride) material. The hose ensures that the filtered clean air flows unidirectionally from inhalation to exhalation. The exhaled carbon dioxide is not inhaled to form secondary air pollution due to the cover. The head end is two gourd mesh nasal plugs. The end is the air inlet interface, which is a special one-way closed channel connecting the nostrils and the filter HEPA filter.

[4] HEPA:

HEPA is a High Efficiency particulate air filter. The HEPA-compliant filter has an efficiency of 99.7% for 0.1 micron and 0.3 micron. It can remove more than 99.97% of the particles with a diameter of 0.3 micron (1/200 of the hair diameter), which is the most effective filter medium for pollutants such as smoke, dust and bacteria. According to the method specified in GB/T6165-1985 "High Efficiency Air Filter Performance Test Method, Transmission Rate and Resistance", a filter having a transmittance of  $\leq 0.1\%$  (i.e., efficiency  $\geq 99.9\%$ ) or a count transmittance of  $\geq 0.001\%$  (i.e., efficiency  $\geq 99.999\%$ ) for particles having a particle diameter of  $\geq 0.1 \mu\text{m}$  is a high efficiency air filter.

### **3. Innovation**

#### **3.1 Cleaner and Smoother Direct Connection**

The "point-to-point" type of closed airway between the filter element and the nostril liberates the face and mouth that are not related to breathing. It isolates the secondary pollution caused by repeated inhalation of unpurified air or exhaled carbon dioxide gas due to mask blockage during inhalation of filtered air, ensuring 100% inhalation of purified air and 100% elimination of exhaled gas.

### 3.2 More Scientific and Healthier One-time use

The invention adopts a one-way suction valve in the filter element and a one-way valve in the nasal plug to design a unidirectional flow of the filtered air from the inhalation to the exhalation. The filtered clean air is completely inhaled through the closed air tube for human inhalation. There is no mask blockage or gap to make the exhaled carbon dioxide and the unpurified air re-inhaled, and the breathing effect of exhaling exhaust gas and absorbing clean gas is truly achieved.

### 3.3 More Colorful and More Miniaturized Invisibility

The miniature filter body, the invisible wearable jacket and the simple and transparent Y-shaped nasal mask make the overall structure of the purifier a miniature design element for various personal accessories such as headwear, hair accessories, collars, clothing, glasses frames, etc. Invisible wearing, with the individual ‘aesthetic design + air purification + body invisibility’ multiple functions, the air purifier for the first time becomes the miniature design elements of the personal accessories, not only wearable and invisible, but also rich in form and variety.

## 4. Theoretical Design

Automatic control: Automatically using a device or device (control device) to automatically control a certain working state or parameter (controlled amount) of the machine, equipment or production process (control object) without any direct participation. scheduled to run regularly. Closed-loop control refers to the control method in which there is negative feedback between the controlled amount (output) of the system and the control action. This subject designed a self-adjusting nonlinear PID controller for variable speed fans. The control principle is shown in Figure 1.

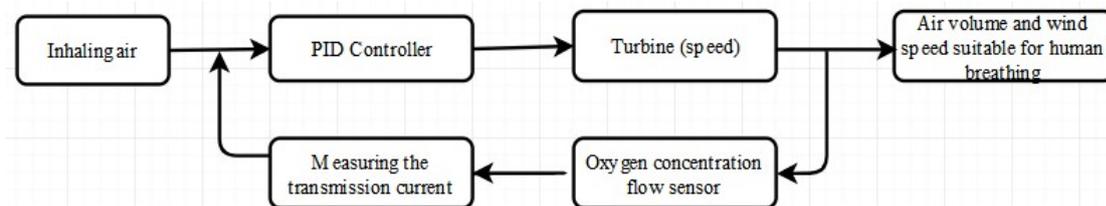


Figure 1. Schematic diagram of control

The air purification device communicates with the controller through the external environment to realize control of the controller. The controller receives the guidance information of the purification device, adjusts and outputs the feedback signal to realize direct control of the turbine, and also feeds relevant information to the Oxygen concentration flow sensor.

The controller has the characteristics of fast response and small overshoot, improves the dynamic process of the fan speed control and the accuracy of that. It has certain adaptability and robustness as well. On this basis, a complete self-regulating control strategy is proposed: the optimal wind speed can be directly set by human-computer interaction or by the fuzzy controller. Above and below the optimum wind speed of human breathing, the fuzzy PID-PID dual-mode controller based on fuzzy rule control controls the turbine angle to maintain optimum wind speed operation. Near the optimum wind speed, the system maintains constant speed operation.

The fan speed nonlinear PID controller consists of a nonlinear state error feedback control law and two nonlinear tracking-differentiators. Figure 2 shows the basic structure of a nonlinear PID controller. In the figure, the 2nd order TD realizes fast overshoot tracking of the input signal and gives its 1st order differential signal.

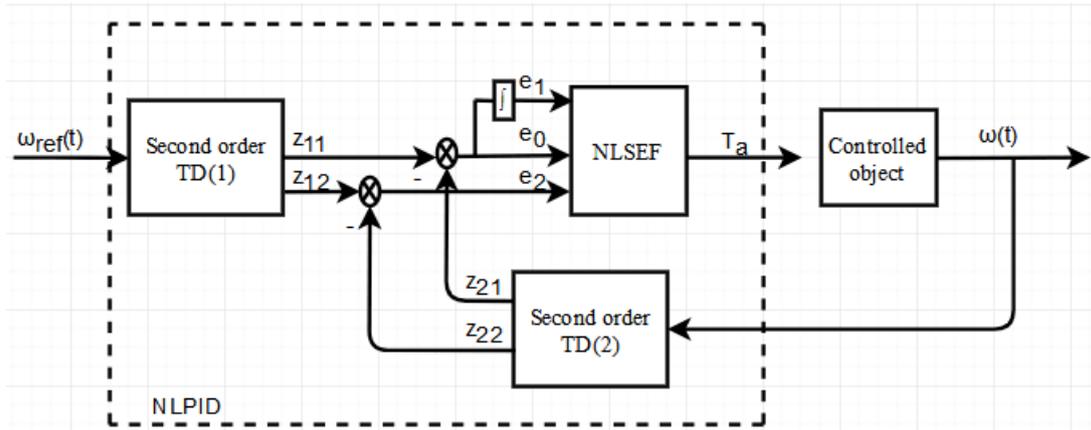


Figure 2. Basic structure of a nonlinear PID controller

$Z_{11}$ ,  $Z_{21}$  track the reference input  $\omega_{ref}(t)$  and system output  $\omega(t)$  respectively.  $Z_{12}$ ,  $Z_{22}$  are the differential signals of  $\omega_{ref}(t)$  and  $\omega(t)$ .  $e_0$ ,  $e_1$ ,  $e_2$  are the deviation between the reference input and the system output and its integral and micro-component. NLSEF through the non-linear combination of these signals forms a control amount.

According to the analysis, it is assumed that  $R_1$  and  $R_2$  are system parameters of 2nd order TD(1) and 2nd order TD(2) respectively. By adjusting  $R_1$  and  $R_2$ , the tracking transition process of the 2nd order TD output signal to the input signal can be changed. Small error, large gain, and strong ability to suppress error signals can be got.

## 5. Performance Testing and Analysis

For an air purification product, the purification effect is the key to the core technical strength of a product. We tested the purification effect through experiments:

**Indoor testing:** We ignited an ordinary sandalwood in a room about 10m<sup>2</sup> and tested it with an air detector with MC certification (national metrology certification). At the moment of igniting the incense, the detector showed PM2.5 of 123  $\mu\text{g}/\text{m}^3$  and PM10 of 197  $\mu\text{g}/\text{m}^3$ . In order to test the air purification effect of the work, we let the sandalwood burn for several minutes. The same air inlet position was connected to the purified air outlet, it can be seen that the PM2.5 and PM10 values were cleared when tested again.

**Outdoor test:** We conducted outdoor tests at the same time on the playground of North China Electric Power University. The ambient air was directly tested at the test site. The detector showed a PM2.5 of 113  $\mu\text{g}/\text{m}^3$  and a PM10 of 202  $\mu\text{g}/\text{m}^3$ . After the air inlet of the air detector was connected to our air purifier, PM2.5 and PM10 were cleared.

According to the test, our air purifier purification effect is very satisfactory. In the process of using, it can not only achieve invisible wear, but also the breathing effect is much higher than the anti-smashing mask. The reason why is because it has own air supply system which will not only make the breathing very smooth, but also avoids the negative impact on the body, especial poor breathing.

## 6. Analysis of Application Prospects

There are many kinds of air purifier equipments or masks supplied for preventing smog damage at home and abroad. There is still no air purifier that can truly adapt to personal freedom of movement, clear breathing passage, invisible wear, or complete use of clean air. The device addressed not only the above problems but also the problem of secondary pollution. What's more, the material does not have to be frequently replaced. Hence, it will have a good market prospect.

Its scope is mainly used for prevention:

(1). air pollution (haze weather), (2) influenza disease (popular infection), (3) poisonous gas (exhaust gas poisoning, etc.), (4) dust space (workshop, mine, etc.), (5) fire escape (drinking environment), (6) health care (inhalation therapy), etc.

The market case is as follows:

(1) Traffic police occupation class: Built-in air purification filter in the police cap and connected with transparent micro nose mask (or through the special hollow glasses frame), the traffic police on duty can avoid the harm of automobiles' poisoning and the professional image;

(2) Fire escape class: In the fire smoke environment, this common product has a unique one-way gas guiding performance which can effectively prevent the smoke from entering the nostrils and win the escape time.

(3) Commonly used by the public: Under the increasingly serious smog pollution, the demand for high-efficiency air purifiers is becoming more and more urgent. The purifier increases the health protection function of the respiratory system and becomes a modern form with a variety of personalized wearable.

## References

- [1]. ZHAO Yongxiang, XIA Changliang, SONG Zhanfeng, et al. Nonlinear PID control of fan speed in variable speed constant frequency wind power generation system[J]. Proceedings of the CSEE, 2008, 28(11): 133-138. DOI:10.3321/j.issn :0258-8013.2008.11.023.(in Chinese)
- [2]. Su Yuxin, Duan Baoyan. A Novel Nonlinear PID Controller[J]. Control and Decision, 2003, 18(1): 126-128. DOI: 10.3321/j.issn: 1001-0920.2003.01.031.(in Chinese)
- [3]. Zhang Lizhong, Ma Yongxiang. Research on Initialization of PID Fuzzy Controller[J]. Journal of Harbin University of Commerce(Natural Science Edition), 2018, 34(2): 205-208.(in Chinese)