Research Progress of STM32-Based Indoor Air Formaldehyde Detection Device

Chunxu Wang*

The High School Affiliated to Renmin University of China, Beijing, 100080, China

Abstract. The design trend of the formaldehyde detector system based on STM32 is analyzed, and it is emphasized that embedding technology enables portable detection, real-time operation and intelligence, breaking through the limitations of traditional detection methods. Using "STM32" and "formaldehyde detector" as key words, relevant literature information such as journals, patents and technical proposals in 10 years (2015~2025) was collected. The research results show that a general configuration composition of "ZE08-CH2O Formaldehyde sensor + other sensors + wireless communication module + local LCD display + buzzer alarm" has become the mainstream. Since these products use the same ARM core, most of them have selected Keil MDK under the Windows platform as development software; A representative firmware flowchart "Power-on initialization → Synchronous multi-sensor sampling → data processing & error analysis → threshold judgment → local display / buzzer alarm → wireless transmission" provides a useful reference for designers to develop the next generation's handheld formaldehyde detectors.

1. Introduction

With the introduction of "Dual Carbon" strategy and the new era Healthy China 2030 plan, indoor air quality issues have gradually gained attention. HCHO was listed by WHO as Group 1 carcinogen; it has a strong release cycle and is very easy to cause cancer [1]. When the indoor HCHO concentration exceeds 0.1 mg/m^3, it is easy to cause unbearable discomfort, and when the indoor content is higher than 0.6 mg/m^3, it will be fatal. The recently issued "Indoor Air Quality Standard" GB/T 18883-2022 limits the maximum value of one hour's average to 0.08 mg/m^3, but from the actual test data, it can be seen that in most cases, after six months, the new decoration house still has an exceedance rate of 42%. Spectrophotometer and gas chromatography are troublesome operations, require laboratory environment and high costs, cannot complete on-site detection and monitoring, let alone real-time monitoring, and there is also great dependence on other interfering gases or factors, including temperature, humidity, etc. For example, when using ethyl alcohol to assist in detecting formaldehyde indoors, not only does it not solve the interference between the two, but rather increases its measurement error. At present, there are few relevant results in the research on formaldehyde detectors based on microcontrollers such as STM32, and a detailed analysis and summary of the domestic and foreign application status of STM32 technology in indoor formaldehyde detection devices is rarely found. Therefore, we must dig deeper into “Full Hardware/Software Calibration, Low Power Consumption, and IoT Integrated Research Based on STM32”, deeply understand and summarize their latest development situation of hardware architecture, embedded software programs, carefully read and study and compare the performance characteristics of the mainstream commercial products and some of them, sort out and analyze their current technological levels and key technologies, clearly reveal its current critical technological bottlenecks and important breakthrough points in this direction of research, and provide corresponding reference ideas and guiding significance for the following and the whole industry later R&D, application and promotion in specific aspects: The focus of our work here is to deeply summarize the research achievements and development trends of formaldehyde portable measuring instruments with STM32 as a key point in the main hardware and software structure aspect, further verify and compare the mainstream commercialized products Performance through comparative experiments, clearly display the level status of mainstream commercial products' productization process, sort out key technical problems in each part of core technology and components design and use, find the best future breakthrough points in research in related fields, make corresponding suggestions for deepening the next generation research in depth for all researchers, which provides good theoretical support for realizing mass production and popularization of low-cost, high-performance, low-power, scalable portable formaldehyde detectors for indoor space.

*Corresponding author's e-mail: BulldozerWang@outlook.com

2. Review of Formaldehyde Detection Technology

Mainstream formaldehyde sensors work on 3 principles: spectrophotometry, electrochemistry, and semiconductor.

In 1996, Vianello et al. proposed a formaldehyde sensor based on an ion-selective field-effect transistor. The concentration of formaldehyde in the air was recorded by measuring the output voltage change of the field-effect transistor. The field-effect transistor can sense the change in the electric field at its gate and output an electrical signal. Formaldehyde can be separated into hydrogen ions under the action of dehydrogenase and then detected by the field-effect transistor. This sensor has high sensitivity and can measure formaldehyde gas with a minimum concentration of 0.1 ppm [2].

In 1999, Nakano and Nagashima designed a formaldehyde sensor based on the reaction between hydroxyl groups of sulfuric acid and formaldehyde to release hydrogen ions, which causes a color change in the dimethyl indicator. This sensor uses the color change of a paper strip to record the continuously changing formaldehyde concentration over a period of time. Considering the instability of formaldehyde concentration in a short period, this design is more helpful for indoor environment detection compared to general one-time detection devices. This design can show relatively accurate formaldehyde concentration (error ±0.02ppm) within a 20-hour period, but it is affected by air humidity, and gases such as hydrogen chloride, acetone, and acetaldehyde can also interfere with the device readings [3].

In 2003, Suzuki et al. developed a portable (19 cm * 8 cm) formaldehyde sensor based on spectrophotometry and colorimetric chemical reactions. The reactants used were formaldehyde probes KD-XA01 and KD-XA02. The concentration of formaldehyde was determined by distinguishing the color change of the reflected light from the blue LED light shining on the formaldehyde and its reactants (from white to yellow) [4].

In 2007, Yamazoe and the Shimano team developed a formaldehyde sensor based on tungsten oxide (WO_3) nanoparticles. This device utilizes the adsorption of formaldehyde gas on the heated semiconductor surface and the subsequent oxidation reaction, which causes a change in the material's electrical conductivity. By monitoring the resistance value, the sensor can quantitatively detect the concentration of formaldehyde. This sensor can operate at 350°C and has a good linear response within the range of 0.1 - 5 ppm for formaldehyde. It has high sensitivity and good recovery performance, but is susceptible to cross-interference from volatile organic compounds such as ethanol and acetone. Moreover, it may experience baseline drift during long-term operation [5].

3. Progress in Hardware Research

Figure 1 is the overall hardware schematic diagram of the system. The sensor part, the STM32 microcontroller part, local alerting device, and wireless transmitter part are the main components of the hardware part. Among them, the sensor component acquires the observational data through formaldehyde sensors and temperature, humidity, and barometric pressure sensors; these acquired environmental parameters act as calibration inputs into the MCU for further increasing accuracy while the STM32 serves as the central processing hub. Specifically, the core of the STM32 series product features a powerful 32-bit ARM Cortex™-M3 RISC core with huge storage space, plenty of GPIO pins, many communication ports and other peripheral facilities and interfaces such as diverse protocol transmission modes, which are suitable according to the different applications using a variety of STM32 product lines (depending on the needs). It has a wide range of selections that fit different design projects: finally, its output values can be presented in situ using a small LCD screen along with a buzzer sound issued by pressing an audible button at hazardous level. Furthermore, it allows transmission wirelessly (using Bluetooth, WiFi or SMS) to PC computers or mobile phones as required to get timely information from afar.

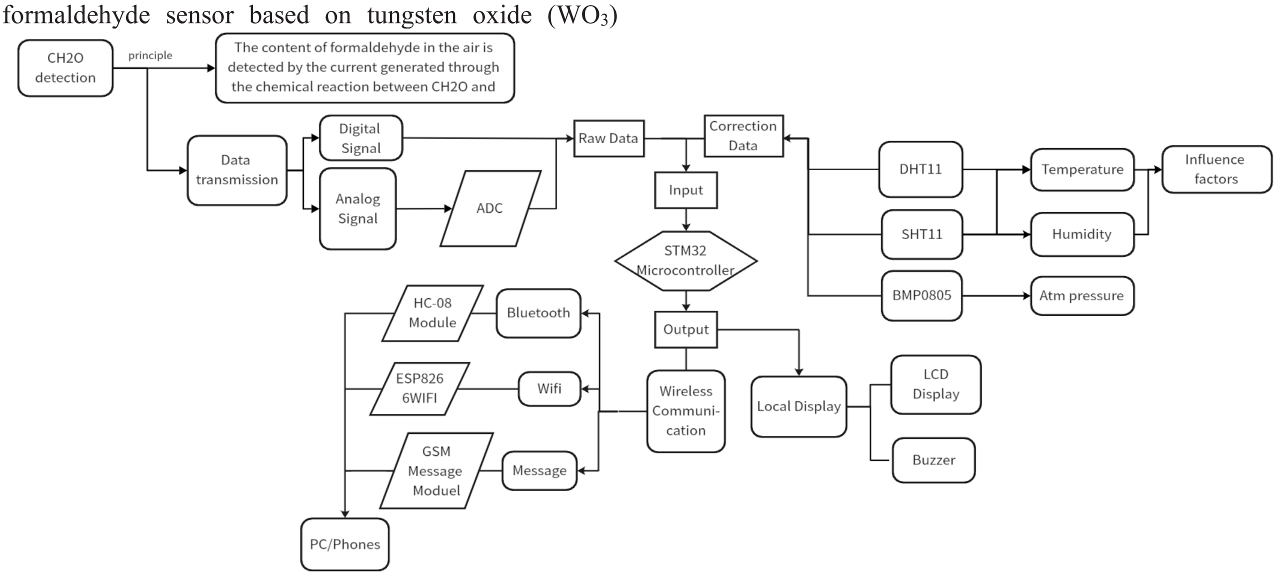

Figure 1. Overall hardware design schematic diagram

Table 1 lists the hardware module models of previous studies' STM32 indoor formaldehyde detection devices. In addition to the formaldehyde sensor, some have added a temperature and humidity sensor [6][7][8], particulate matter sensor [7][8], barometer sensor [8], and a few smoke and flammable gas sensors [7] because other factors in life such as temperature, humidity, and other gases will affect the formaldehyde detection results and require calibration.

Mainly used the formaldehyde sensor model: ZE08-CH2O[6][9], M-01[10], MQ138[7], MS1100[8]. Among them, ZE08-CH2O and M-01 have stronger selectivity for formaldehyde, better measurement precision; MS1100 and MQ138 can measure many harmful gases but are easily interfered by other gases. Among them, the resolution of ZE08-CH2O is the highest (0.01ppm) and MQ138 is the lowest (10ppm), not conducive to accurate measurements, only suitable for qualitative alarms. Due to the fact that the performance of this series of products produced domestically is unstable, M-01 and MS1100 are not recommended. In summary, choose the product ZE08-CH2O due to its high accuracy, stability, and high-resolution characteristics.

Temperature and humidity sensing modules adopt DHT11[6][7] and SHT11[8], where SHT11 has higher accuracy than DHT11, a larger measuring range, higher resolution and lower power consumption, although its response speed is slow and the price is relatively expensive. SHT11 uses I2C mode data acquisition method while DHT11 uses single-line digital signal output method. Two kinds of particulate matter sensors mainly adopted GP2Y1010AU0F[7]: Based on optical scattering principle with a measurement range of 0-0.5mg/m³ (PM2.5/PM10), an analog voltage signal is output, which requires additional ADC circuit. Its advantage is low cost ~ $5, but needs LED driving circuit, and is prone to data drifting caused by humidity. Sharp's second generation PM2.5 sensor[8]: Based on laser scattering principle with a measurement range of 0-1000μg/m³ and accuracy ±10%FS, it adopts fan design, which shows significantly better anti-interference ability compared with the former, although the cost is high $15-20.

The adopted communication protocol mainly includes two forms. Most of the formaldehyde sensor modules use UART serial interface because its transmission distance is far and the interference resistance is strong. Some adopt analog signal output for higher precision, lower energy consumption and higher cost. Wireless modules include esp8266 wifi module [10], gsm sending module [11], bluetooth serail module [6][7][8] and gprs module [9] to achieve real-time device-client information feedback.

Table 1. Hardware Modules

Sensor Type	Detection Principle	Purification Principle	STM32 Type	Display	Communication	Warning Module	CH2O concentration threshold	References
ZE08-CH2Ogas sensor	Electrochemistry	Reaction of O3 and CH2O molecules in a 1:1 molar ratio	STM32F103C8T6	LCD1602A	Integrated GPRS module Combining ATKSIM900C Wireless communication + High performance MCU + Embedded TCP	LED	0.1mg/m3	[9]Huang (2022)
M-01 CH2O Sensor	Electrochemistry	None	miniSTM32F103ZE-T6	LCD12864	ESP8266 WIFI network solution	Not specified	Not specified	[10] Li, et al., (2019)
DHT11+ZE08-CH20	Electrochemistry	None	STM32F103RCT6	Not specified	HC-08 Bluetooth-Uart module	Buzzer	Not specified	[6]Fang (2021)
GP2Y1010AU0F+DTH11+MQ138+MQ135, +MQ2	Semiconductor Sensor	None	STM32F103C8T6	Not specified	Bluetooth-Uart module	Not specified	Not specified	[7] Wang (2021)
Not specified	Electrochemistry	None	STM32	LCD1602	GSM message module	Buzzer	Not specified	[11]Yang (2023)
SHT11+BMP0805+MS1100+Sharp 2nd generation	Not specified	None	STM32F103RBT6	Not specified	CH340G; HC-08 Bluetooth	Uart or Bluetooth	Not specified	[8]Yang et al,.(2016)

The general method of detecting formaldehyde at present is based on electrochemical principle[7]. The principle is as follows: Formaldehyde is oxidized or reduced alternately on the two electrode plates, and the reaction equation is:

$$HCHO+O_2=CO_2+H_2O$$

As the electron migration of the reaction producing electricity, the strength of current could be used as a measurement of formaldehyde concentration. However, toluene and alcohol would affect this method. There was limited work that adopted formaldehyde's purification module. Only Huang Jiamin et al adopted a formaldehyde's purification module according to the stoichiometric chemical relationship between ozone and the formaldehyde [9], but there was no confirming whether it was safe in the experiment, nor gave the concrete need for using dosage of the ozone when they purified indoor air. According to my rough calculating, they have ensured that used for minimal purification effect the Ozone's content has been more than 0.128mg/m³; compared with upper limit value of the safety standard, the needed quantity of ozone amount is far above the upper limit value, which does harm to people under certain condition (especially in indoor situation). So as to whether ozone could be taken as an ideal thing for removing formaldehyde remains doubtful. We chose Keil MDK as the programming software because STM32 chip adopts ARM cores, and it would be more convenient to use the development tool from ARM Corporation rather than other IDE. This made library function programs easier to develop and operate at high level. Figure 2 represents a schematic picture showing a common way of developing a soft project [8] currently.

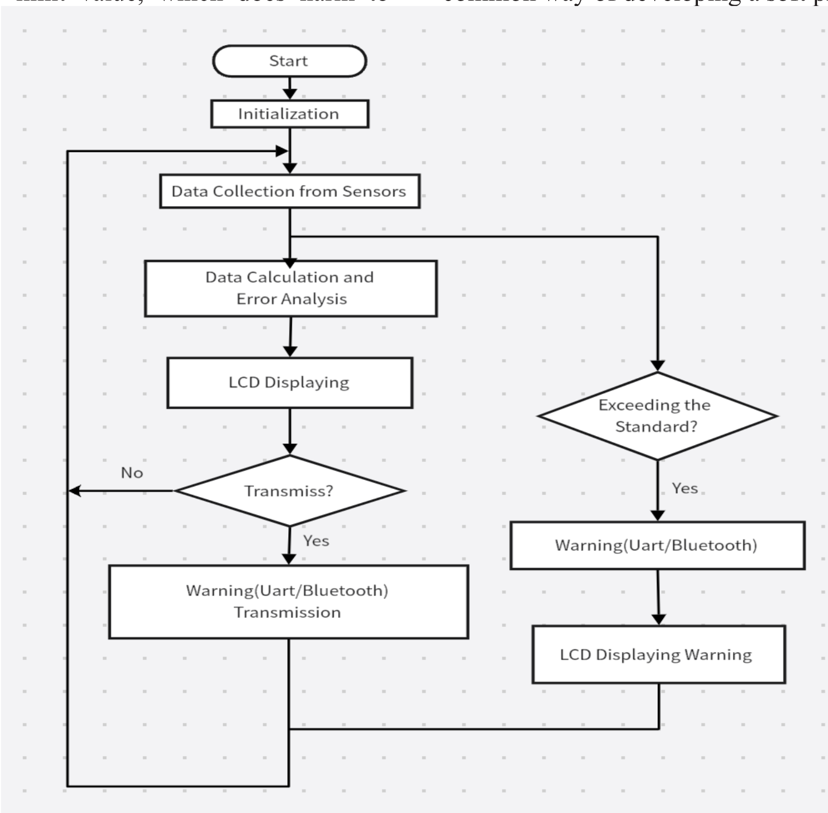

Figure 2. Overall Design Flow of the Software [8]

4. Research progress on Software

In most previous studies, Keil MDK was selected as the programming software [8][10], primarily because STM32 is based on ARM cores, and using Keil (developed by ARM Corporation) offers greater convenience for development. The library function programming approach has become the prevailing method in current applications [8][10]. Figure 2 presents a representative case of the software design workflow [8]. Compared to register-level development, this approach is simpler and operates at a higher system level.

When the system powers on, it runs an initializing program, configures MCU pins one by one and initializes peripheral devices; when all sensors enter ready states, data sampling begins: each sensor sends detecting signal to MCU; then through ADC module, analog signal is digitized and able to process. MCU calculates and converts raw data charactered of each sensor according to characteristic parameters, and conducts error compensating calculating then finishes correct result of measurement; after data being processed will be sent real-time into terminal LCD displaying device simultaneously MCUs does safety judgment between value of measured quantity and setting alarm limit, if exceeds alarm limit it forwards alarming instruction through Bluetooth modulator to on-site device, otherwise if within safe value scope, checking is conducted whether from PC or Mobile terminals sent request for data or not, upon receiving the command sending of data would be made toward PC serial interface while transmission of measuring results toward mobile equipment would be completed through wireless connection being established between both by Bluetooth[9].

Specifically, since most formaldehyde sensors operate on the principle of oxidation-reduction reactions, they are prone to be influenced by factors such as temperature, humidity, ethyl alcohol, etc. To improve the accuracy of formaldehyde sensors, compensating algorithm which takes the influence factors into account is crucial [12]. Take temperature: according to the study from Liu, the response value of formaldehyde sensor shows a strong positive correlation with temperature in Figure 3, indicating the necessity of introducing correction parameters [13].

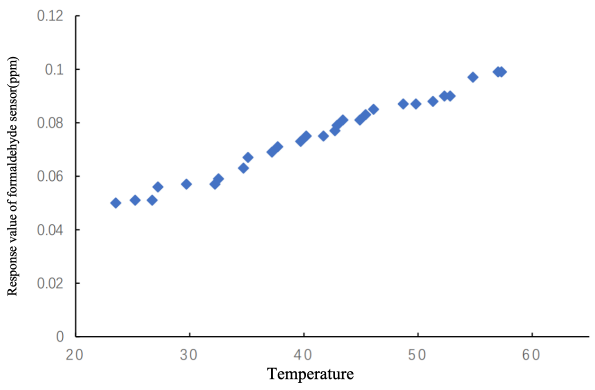

Figure 3. The influence of temperature on the concentration of formaldehyde [13]

5. Evaluation Results of Commercial Formaldehyde Detectors

Table 2 lists the detection accuracy of formaldehyde detectors, after reading data from the report issued by the Shanghai Consumer Council, tested by Shanghai Jianke Testing Co., Ltd. and Chemical Analysis Testing Center. The test results show that Honeywell type, Shanshan type, CEM type, FNIRSI type, Dingmeng type have relatively high detection accuracy compared with other types, the average deviation value between ±0.05; while for Telaire type, FreeLite type, Yisheng type, Blatn type instrument, the average deviation is more than ±0.1; Others' relative accuracy values are in between (±0.05 ~ ±0.1). Among the former's accurate value, CEM has the highest price, then followed by Honeywell and Shanshan, but sell better - better than Honeywell and CEM among all kinds; while in the latter low-price series, Blatn has the most expensive instrument, which falls in third place in terms of accurate readings, followed in terms of price by Yisheng and Telaire who also had record-high sales under such circumstances -- although Greenride was the top seller overall but performed mediocrely when compared to peers during lab testing, along with recording high sales at the same time--but the Blatn item number is rated very highly due to its hefty price tag, but it failed poorly when tested under the standard pressure [14]. A paradoxical conclusion appears: price does not seem related directly to how good one can detect indoor air Formaldehyde better, neither will popularity do that either!

After reviewing the major progress that research institutes made on the development of indoor formaldehyde detecting device powered by STM32 system through literature search available in domestic as well as world leading journals using our expertise, we reached several conclusions.

Table 2. Summary of Accuracy Evaluation of 15 Formaldehyde Detector on the Market

Type	Product	Price (yuan)	Monthly Sales	Concentration 1 (mg/m^3)	Difference with standard	Concentration 2 (mg/m^3)	Difference with standard	Concentration 3 (mg/m^3)	Difference with standard	Average absolute difference
1	Greensky	169.15	10w+	0.055	0.018	0.093	0.022	0.057	-0.045	0.055
2	Honeywel	359	1w+	0.04	0.003	0.06	-0.011	0.09	-0.012	0.018
3	House Dr	54	2w+	0.012	-0.025	0.037	-0.034	0.06	-0.042	0.073
4	Sensology	269	5k+	0.16	0.123	0.31	0.239	0.49	0.388	0.491
5	Essexbio	299	14k+	0.106	0.069	0.156	0.085	0.221	0.119	0.194
6	Smartsensor	928	22	0.02	-0.017	0.06	-0.011	0.09	-0.012	0.032
7	FNIRSI	189	110	0.043	0.006	0.085	0.014	0.131	0.029	0.030
8	Anxinbao	69	6.6w+	0.019	-0.018	0.025	-0.046	0.042	-0.06	0.084
Type	Product	Price (yuan)	Monthly Sales	Concentration 1(mg/m^3)	Difference with standard	Concentration 2(mg/m^3)	Difference with standard	Concentration 3 (mg/m^3)	Difference with standard	Average absolute difference
9	Pureair	887	154	0.063	0.026	0.116	0.045	0.177	0.075	0.096
10	Shanshan	164	3.7w+	0.022	-0.015	0.061	-0.01	0.087	-0.01	0.028
11	Ziyouguang	167	1	0.121	0.084	0.121	0.05	0.123	0.021	0.141
12	Dienmern	66.9	3k+	0.058	0.021	0.092	0.021	0.121	0.019	0.048
13	Trabon	69	6k+	0.034	-0.003	0.073	0.002	0.14	0.038	0.018
14	Bolangtong	998	500+	0.084	0.047	0.157	0.086	0.253	0.151	0.183
GB 50325-2020 AHMT				0.037	Standard	0.071	Standard	0.102	Standard	-

This study found that there is no significant positive correlation between the retail price of commercially available formaldehyde detectors and their detection accuracy. It is speculated that some manufacturers have excessively invested in non-core software functions, thereby weakening the contribution of hardware performance to overall accuracy. Under the constraint of limited research and development budgets, it remains a core challenge for both the academic and industrial sectors to determine which hardware bottleneck, if broken through, could lead to a "stepwise" improvement in the detection accuracy of formaldehyde sensors. Through a systematic review of the technical manuals of 15 mainstream products on e-commerce platforms, four hardware factors that have a decisive impact on detection accuracy can be identified: ① high-resolution formaldehyde sensing elements; ② constant-speed fans with stable flow (actively controlling the intake air flow to reduce the disturbance of external wind speed); ③ high-quality chip processors; ④ high-precision temperature and humidity sensors (used for temperature and humidity compensation and calibration). Notably, the Defeng formaldehyde detector, which performed best in terms of accuracy in the evaluation, did not use the mainstream electrochemical detection method but instead selected semiconductor gas-sensitive elements, preliminarily suggesting that the selection of sensing elements might be the primary breakthrough point for accuracy improvement. However, this inference still requires validation through larger sample sizes, double-blind controls, and third-party laboratory tests.

6. Conclusion

Through a systematic review of literature from prominent domestic and international journals, this study investigates the research progress of STM32-based indoor formaldehyde detection devices. The key conclusions are as follows:

Hardware Architecture Standardization: General hardware system: ZE08-CH2O formaldehyde sensor + (SHT11/DHT11 temperature-humidity sensor + BMP0805 barometer + GP2Y1010AU0F/Sharp second-generation PM sensor) + GSM / Bluetooth / WiFi wireless transmission + LCD display + buzzer alarm; where ZE08-CH2O is generally preferred, with a resolution of 0.01 ppm, factory-calibrated at 0.1 mg/m³, and industrial-level stability.

Software Design Paradigm: Keil MDK has an advantage in the programming software. The typical process is power-on initiation → multi-sensor synchronous sampling → calculation & error compensation of data → judgment of threshold value → local display/buzzer alarm → wireless transmission. Attention was paid to the raw data preprocessing program (different type sensors) and the MCU's error compensation algorithm running program during coding.

Market Product Evaluation Insights: Of the 15 commercial detectors we evaluated, we saw no positive correlation between price and accuracy: High accuracy tier (avg. error < ±0.05 mg/m³): Honeywell, Shanshan, FNIRSI, and Dingmeng are kings in this domain even though they are less than 400 CNY. Low accuracy outlier: Blatn (~1k CNY) is ranked 3rd lowest as its inaccurate reading of ±0.18 mg/m³ comes with a high price - expensive does not mean accurate. We found that our top-selling model (Greenride, 100k+ sold) had adequate results (error = 0.055 mg/m³), yet was purchased for only 169.15 CNY - more focus on bang-for-buck rather than ultra-fine precision. There's a huge opportunity for consumer-grade products under 200 CNY to hit errors ≤±0.05 mg/m³.

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