Response to reviewer comments

We are sincerely grateful to the editor and reviewers for their valuable time spent on reviewing our manuscript. The comments are very helpful and valuable, and we have addressed the issues raised by the reviewers in the revised manuscript. Please find our point-by-point response (in blue font) to the comments (in black font) raised by the editor and reviewers.

Referee: 2

COMMENTS TO THE AUTHOR(S)

In the introduction review of the different types of lidars, the discussion should be more open and not only discuss few particular studies. For instance, for airborne lidar, it seems as it only serves for marine aerosol measurement and the measurement of PM.

Response: Thank you for your valuable and professional feedback.

In the introduction, we extensively discuss three common LiDAR systems-spaceborne LiDAR, airborne LiDAR, and ground-based LiDAR. And thoroughly discusses their research applications. For the airborne LiDAR section, we have supplemented the manuscript with additional content regarding observation of air pollutants and desert dust aerosols.

"Airborne LiDAR is a LiDAR system mounted on aircraft or drones, capable of providing large-area coverage and highly mobile detection scanning. Some scholars employ airborne LiDAR to study the surface properties of desert aerosols, analyze marine aerosol concentration distributions, and the vertical distribution of urban pollution." (refer to lines 48-52 in the revised manuscript)

The introduction of mobile ground-based lidar lacks motivation with respect to the state of the art. Please, highlight which gap in the state of the art does it fill. Are the other existing moving ground-based lidars limited? In which manner?

Response: Thank you for your valuable and professional feedback.

In the Introduction, we supplemented the content on the gaps filled by mobile ground-based LiDAR and the limitations of existing mobile ground-based LiDAR technologies.

"Vertical detection and scanning detection can only achieve fixed-point detection within a specific area, resulting in limited detection coverage." (refer to lines 63-65 in the revised manuscript)

“However, the need for uninterrupted cruise detection during regional pollution prevention and control actions, which can lead to a significant loss of operator energy. This has resulted in a significant increase in labor costs for existing manned cruise detection systems. In addition, being in an environment with high concentrations of toxic pollutant emissions can cause irreversible damage to the bodies of researchers.” (refer to lines 70-74 in the revised manuscript)

System principles and methods: Please, provide which modules have been used: which hardware model for the controller, which lidar (if commercial), which router, etc.? Which type of OS is used? How are the communications between modules carried out? Are there not any sensors measuring velocity, wheel radial speed, etc.? Further details are required.

Response: Thank you for your valuable and professional feedback.

The LiDAR uses an embedded control board as the controller, with acquisition control software embedded in it.

The product name of the computing platform for the unmanned vehicle is IPC6000； the configuration is M219F-2C-4G-64G-WIFI.

The LiDAR is not a commercial LiDAR, and the system uses the Windows 10 operating system. The unmanned vehicle system uses the Ubuntu operating system. The router used is a home 4G router. The wire control chassis module communicates via CAN bus protocol. The wire control chassis module subsystem integrates the following sensors: Hall-effect wheel speed sensors, brake fluid pressure sensors, rotary encoders, absolute optical encoders (for angular position), and pedal travel sensors.

All modules within the LiDAR system communicate with the industrial control computer (IPC) via TCP/IP protocols over Ethernet/Wi-Fi networks. The environment and perception modules communicate with the computing platform via the Internet. We have also supplemented in the revised manuscript, which can be referred to lines 96-98 and lines 100-102.

Further details on the lidar are required. Is it a commercial lidar? Under which modes can it operate (vertical, conical)? Which temporal and spatial resolutions does it have? How has it been calibrated?

Response: Thank you for your valuable and professional feedback.

Detailed parameters (temporal and spatial resolution) of the LiDAR systems are tabulated in Table 1 (refer to line 108 in the revised manuscript). This is not a commercial LiDAR. It is capable of vertical and scanning detection. In the manuscript; we describe vertical and conical scanning detection experiments.

Implementation of horizontal scanning experiments was constrained by limitations of the experimental site. However, supplementary videos documenting the horizontal scanning tests are provided in the Attachment. LiDAR does not require calibration. The blind area of the lidar is relatively small, about 45 meters, and no calibration is required.

No explanation of Mie-scattering lidar measurement is provided. Please provide a paragraph explaining the measurement principle of lidars through Mie scattering.

Response: Thank you for your valuable and professional feedback.

We have supplemented the manuscript with the physical principles underlying Mie-scattering LiDAR measurements.

"Mie-scattering LiDAR is commonly used to measure aerosols, which refers to laser radar systems engineered based on Mie scattering principles. It quantifies the optical properties of aerosol particles and clouds by receiving Mie-scattering echoes from these atmospheric constituents." (refer to lines 110-112 in the revised manuscript)

Sect. 2.4.: This section is incomplete. The control of the unmanned vehicle should be described more in detail, thoroughly describing the methods used, and concretizing the resultant equations for the target system. The method should be reproducible. Further explanation of variables such as state and control variables, Lagrange interpolation polynomials, or Legendre-Gauss collocation point are required.

Response: Thank you for your valuable and professional feedback. This section has been revised in the revised manuscript to comprehensively describe the path planning methodology employed. Please refer to Sect. 2.4 in the revised manuscript.

Sect. 3.1.: Is it needed to prove that the lidar is able to capture the aerosols? If it is a commercial lidar, this could be addressed as a case example for the study scenario and not a proof of its capacity. Same for Sect. 3.2.

Response: Thank you for your valuable and professional feedback. In previous atmospheric pollution studies, LiDAR systems have been extensively utilized for aerosol studies. Our system employs Mie-scattering LiDAR for aerosol quantification based on Mie scattering theory (Mie scattering theory refer to lines 110-112 of the revised manuscript). The LiDAR system is a prototype developed by our team, not a commercial product.

Sect. 3.3.: This section is incomplete. No discussion of the results is provided. No plot of the results is neither provided. How can you assure that the system is able to provide accurate measurements of the aerosol profiles? Is there any calibration/validation? Which are the velocities that the vehicle can achieve? Which problems did it encounter? How do the results connect with the state of the art?

Response: Thank you for your valuable and professional feedback.

We have implemented revisions in response to your recommendations. We will combine the path planning simulation in Chapter 2 with the content of this section for explanation. Vehicle speed is controlled at a maximum of 1 m/s. We made the system operate stably at low speeds to increase the detection time, ensuring accurate detection of aerosol distribution. In the early stage of the experiment, when we encountered an obstacle, we would detect it and then stop. If it was a static obstacle, we would carry out obstacle avoidance. The results show that the system has the ability of unmanned cruise detection and real-time warning of regional pollution prevention and control.

We conducted an unmanned intelligent navigation experiment on February 26 (from 9 a.m. to 12 p.m.). The measurement results showed the detection of aerosol pollution. The revised manuscript also mentioned that the air quality index (AQI) in Hefei on the 26th was 115. We selected the hourly particulate matter concentrations in Hefei on the 26th for verification/calibration. The variation curve of particulate matter concentration is shown in Fig.1 below, the PM2.5 concentration from 9 to 12 o'clock is higher than 100 μg/m^3; and the PM10 concentration at 11 and 12 o'clock is higher than 150 μg/m^3; reaching the standard of light pollution. The results verify that the mobile detection process can accurately detect aerosol pollution.

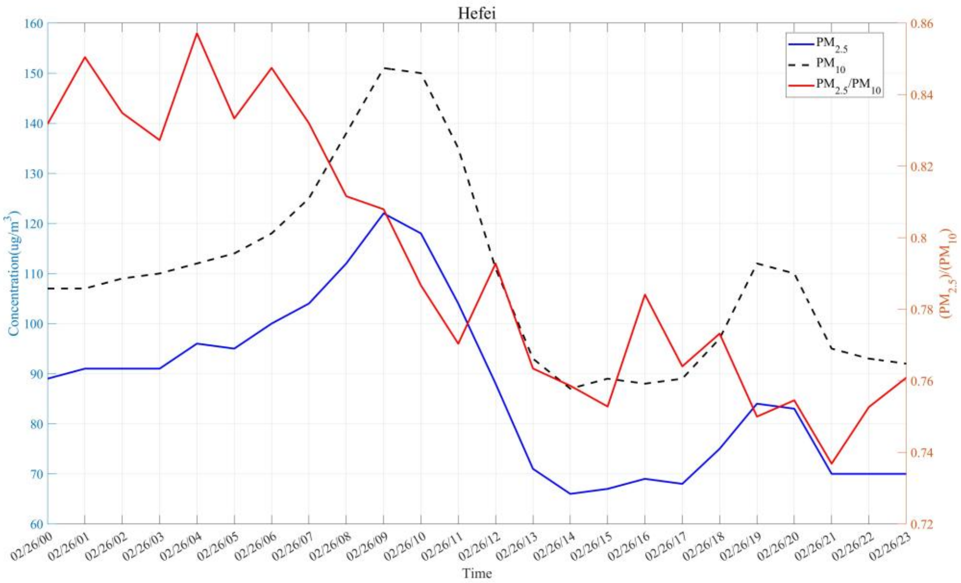

Fig.1

Why is it necessary to have in a single controller for both the lidar and the vehicle? Would not be easier to have separate controllers for each type of the system? Please comment on that.

Response: Thank you for your valuable and professional feedback.

These two systems each have their own control modules. The industrial computer includes both the industrial computer for the lidar system and the computing platform for the unmanned vehicle system, which may cause misunderstanding when presented in this way. In the revised version, we have made modifications, and the schematic diagram of the modification is as follows. The corresponding manuscript has also been revised. (refer to lines 84-85 in the revised manuscript)

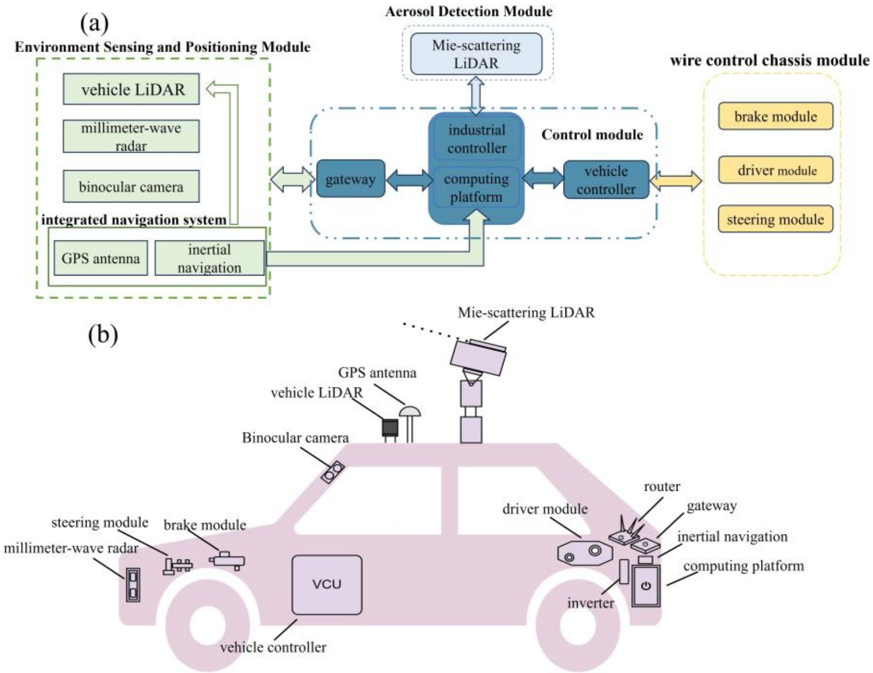

Fig.2

Lines 35/38: I suggest highlighting the adverse effects on health besides viruses and germs. For instance, reduced life-expectancy, higher cancer rates, etc.

Response: Thank you for your valuable and professional feedback. We have implemented revisions in response to your recommendations. (refer to lines 36-37 in the revised manuscript)

Lines 47-49: Regarding space lidar, once launched, the maintenance costs are virtually eliminated. Please, provide a reference for that.

Response: Thank you for your valuable and professional feedback. This was indeed a writing error caused by our carelessness in this regard. We have revised this part in the article. (refer to line 47 in the revised manuscript)

Line 54: “it’s” should be “it”.

Response: Thank you for your valuable and professional feedback. We have made revisions in the manuscript according to your comments. (refer to line 57 in the revised manuscript)

Line 70: “to addess the above issues. This paper […]” please remove the dot.

Response: Thank you for your valuable and professional feedback. We have made revisions in the revised manuscript according to your comments. (refer to line 74 in the revised manuscript)

Equation (1): write it with “e” instead of “exp”, remove “*” and/or change it to “·”.

Response: Thank you for your valuable and professional feedback. We have made revisions in the revised manuscript according to your comments. (refer to line 114 in the revised manuscript)

Please enunciate the value of the lidar constant C used.

Response: Thank you for your valuable and professional feedback. C is 19.

Lines 90-95: These sentences are written like a list. Please, rephrase them to provide better flow and readability for the text.

Response: Thank you for your valuable and professional feedback. We have made revisions in the revised manuscript according to your comments.

“A Mie scattering LiDAR is selected for the aerosol detection module, mounted on the roof of the unmanned vehicle. The LiDAR system and the industrial controller form an integrated system. All modules within the LiDAR system communicate with the industrial controller via TCP/IP protocols over Ethernet/Wi-Fi networks. The inverter provides a stable 220V power supply to the LiDAR and computing platform. Fig.1b is the module distribution of the detection system. The relevant technical parameters of the system can be seen in Table1.” (refer to lines 98-104 in the revised manuscript)

Line 110-111: “Previous studies […]”. Please provide references for the studies.

Response: Thank you for your valuable and professional feedback. Due to content changes, we have removed the narrative information about the depolarization ratio in the revised manuscript.

Equation (3): provide the value used for constant k.

Response: Thank you for your valuable and professional feedback. K is 0.4.

Line 120-123: Change dots to commas. Indicate what are t_0 and t_f.

Response: Thank you for your valuable and professional feedback. We have made corrections. And added explanations these two parameters in the revised manuscript.

"In the formula (3): t_0 and t_f are the initial and termination moments respectively of the unmanned vehicle respectively." (refer to lines 139-140 in the revised manuscript)

Equation (6): De-capitalize "OR" and separate them. It looks like "ORM" is written. What is theta?

Response: Thank you for your valuable and professional feedback.

We have made the change. (refer to line 161 in the revised manuscript)， Theta represents the movement direction of the unmanned vehicle relative to the obstacle.

Lines 139-140: Please rephrase. This sentence does not make sense.

Response: Thank you for your valuable and professional feedback. This sentence caused you a misunderstanding. We have rewritten it.

"For a line LAB that is neither parallel nor perpendicular to the X-axis, if point M lies outside the quadrilateral ABCD, the following conditions must hold:" (refer to lines 162- 164 in the revised manuscript)

Line 143: Please provide a reference for the Bolza problem.

Response: Thank you for your valuable and professional feedback. In the revised version, we have added a supplement on the Bolza problem.

"An optimal control problem typically comprises: the system dynamics differential equations, physical constraints, obstacle avoidance constraints, boundary constraints, and a performance index function. The optimal control parameters are obtained by minimizing the

performance index function while satisfying all constraints." (refer to lines 176-179 in the revised manuscript)

Lines 145-146: satisfy what? Sentence incomplete.

Response: Thank you for your valuable and professional feedback. R^n and R^m denote the n-dimensional and m-dimensional real number spaces, respectively. Additions were also made regarding control variables and state variables.

"In the formula (8): $\xi(t)$ and $\mu(t)$ are the state and control variables of the system, respectively. The state variables $\xi(t)$ encompass the vehicle's longitudinal displacement *x*, lateral displacement *y*, velocity v, acceleration a, heading angle θ, and wheel steering angle φ. The control variables include the wheel angular velocity ω and jerk. $\xi(t) \in R^n$ and $\mu(t) \in R^m$ satisfy." (refer to lines 182-185 in the revised manuscript)

Line 163-167: This should be moved to Sect. 3.

Response: Thank you for the suggestion. The revisions have been incorporated into the manuscript. (refer to lines 285-290 in the revised manuscript)

Lines 183-195: Please provide references.

Response: Thank you for the suggestion. We have added references in the revised manuscript.

"Many previous studies have correlated multi-source data with LiDAR data to investigate variations in aerosol concentration (Tu et al., 2022; Xiao et al., 2023)."(refer to lines 248-249 in the revised manuscript)

Fig. (6): Please provide a label for the colorbar.

Response: Thank you for the suggestion. The revisions have been incorporated into the manuscript.