Dear reviewer,

Thank you for your letter and for the reviewer's comments concerning our manuscript entitled "Research progress and challenges in laser-controlled cleaning of aluminum alloy surfaces" (ID:1765530). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our research. We have studied the comments carefully and made a correction which we hope to meet with approval. Revised portions are marked in red on the paper. The primary corrections in the paper and the responses to the reviewer's comments are as follows:

1. **It is problematic that the conclusions regarding the individual parameters influence on the cleaning process are based on specific but different processing conditions presented from different labs and research teams. The conclusions should be followed by a problematizing discussion that can convince the readers that the revealed trends are generic, not depending on the contamination at hand or the base alloy or something similar, if this now is true.**

Response: Thank you very much for your careful review.

Page 5, raw 158-161: “Studies have shown that the removal effect of oxide films and paint layers from the aluminum alloy surface gradually improves with increasing laser beam power. However, when the power increases to a certain extent, the oxide film and paint layer are removed, and the aluminum alloy substrate is ablated [12, 50–54, 62]. ”

Page 6, raw 196-199: “Many studies have shown that the removal effect of oxide film from an aluminum alloy surface initially increases and subsequently decreases with increasing energy density [13, 33, 55–59].”

Page 8, raw 242-244: “it was confirmed that with the increase in the pulse frequency, the cleaning effect of the aluminum alloy surface initially increased and subsequently decreased.”

Page 8, raw 248-250: “ The research results show that the laser cleaning effect of the oxide film on an aluminum alloy surface initially increases and subsequently decreases with the decrease in pulse width.”

Page 9, raw 272-274: “Studies have shown that the removal effect of oxide film from an aluminum alloy surface initially increases and subsequently decreases with the

decrease in laser cleaning speed."

Page 9-10, raw 300-302: "In other words, the cleaning effect of the oxide film on the surface of aluminum alloy initially increases and subsequently decreases with an increase in the scanning speed. "

Page 10-11, raw 336-342: "They observed the surface after laser cleaning and found that when the absolute value of the defocus distance is the same, the cleaning effect is the same. When the defocus distance is 0 mm, the energy density is the highest, and the heat absorbed by the paint layer is the largest, yielding the best cleaning results. The above findings confirm that variations in the removal mechanism and cleaning effect with concerning defocus distance are related to the energy density distribution, and the ideal defocus distance is within Rayleigh length. "

2. **The manuscript describes the following process parameters: laser power (total power), laser energy density (radiant exposure), laser repetition frequency (pulse frequency), laser cleaning speed (I assume travel speed), laser scanning speed (this is problematic! Is it a local scanning pattern in a global reference frame that travels with the cleaning speed? If so, it is more appropriate to define a velocity and scanning pattern, I assume it is a repetitive pattern), pulse width (temporal), and laser defocus. Since these parameters are coupled there is a need to also define the following: the laser power density distribution, beam Rayleigh length. A discussion about defocus and radiant exposure is not meaningful without this information for example. Other parameters that are relevant but not explained or defined are the laser interaction time (related to pulse duration/scanning- and travel speed) and if there occur multiple exposures on the same surface area during processing. I also think that laser wavelength is a relevant parameter but not discussed.**

Response:

(1) The concept of laser scanning speed and laser cleaning speed are distinct. During the laser cleaning procedure, the loading platform or the laser cleaning head's movement speed is called laser cleaning speed. Significantly, a laser cleaning device with a reciprocating swing of the scanning oscillator causes the laser output spot to move back and forth along a specific length range, becoming a linear spot. The spot-moving speed is called laser scanning speed. Since the laser scanning speed significantly influences the spot lap rate, it is not viable to specify the scanning mode to investigate how this parameter objectively affects cleaning performance.

(2) Different from laser welding and laser cladding, under the action of a scanning oscillator in laser cleaning equipment, the beam used for laser cleaning is generally a linear spot. In addition, to avoid damage to the substrate during the laser cleaning process, the laser used for cleaning is generally a pulsed laser. Based on the above two reasons, the literature currently studies the influence of laser energy density on the cleaning effect.

(3) The laser Rayleigh length has been increased in the study of the laser defocus distances.

(4) In the research on laser cleaning of paint and oxide layers on the surface of aluminum alloys, the wavelength of the laser used is a fixed value, 1064 nm, so there is no research on the influence of wavelength parameters on the effect of laser cleaning. I also think this will be a future research topic.

(5) The definition of laser interaction time has been added in the discussion of laser parameters.

3. It is obvious that the different parameters discussed are coupled. I lack a discussion about this issue since there are suggestions in the summary and outlook section that talks about optimization and feedback control. If there is no information about this coupling that can be complemented to the manuscript at least there should be a discussion about how to deal with this.

Response:

At the end of Section III, we add a discussion as follows：

We have gained a thorough understanding of the essence of laser cleaning by summarizing the influence of laser beam and space parameters on the cleaning effect: a laser irradiated on the object's surface, and a series of physical or chemical reactions occur to remove pollutants. Pollutant removal is affected by the energy and duration of laser irradiation. The laser process parameters, in particular, determine the irradiation energy and time. For example, the laser power, repetition frequency, and defocus amount all work together to determine the laser energy (energy density) received by the unit area pollutant. While the scanning speed, cleaning speed, and pulse width all work together to determine the action time between the laser and pollutant in the same area. In the laser cleaning process, these parameters are coupled, and the effects on the cleaning effect are related. When the pollutants are removed under the gasification mechanism, on the one hand, the energy density should be

appropriately reduced to avoid excessive irradiation energy; on the other hand, the scanning and cleaning speeds should be appropriately increased, and the pulse width should be decreased to avoid exposing pollutants to laser irradiation for an extended period of time and to avoid over-ablating the substrate. When the pollutants are removed under the peeling mechanism, on the one hand, the energy density should be appropriately increased to improve the peeling efficiency. On the other hand, the scanning and cleaning speed should be reduced, and the pulse width should be increased to prolong the irradiation time of pollutants in the same area and improve the cleaning efficiency to ensure the substrate's safety.

The formula of laser energy density ε is as follows:

$$\varepsilon = \frac{4P}{\pi D^2 f} \quad (1)$$

where ε is laser energy density, P is laser power, D is laser spot diameter and f is repetition frequency.

Laser energy density is a crucial laser coupling parameter. According to the above literature, the recommended energy density for using a laser to remove an oxide film from the surface of an aluminum alloy is 7.1-17.5 J/cm^2, and the recommended energy density for using a laser to remove paint layers from the surface of an aluminum alloy is 3.2-25 J/cm^2.

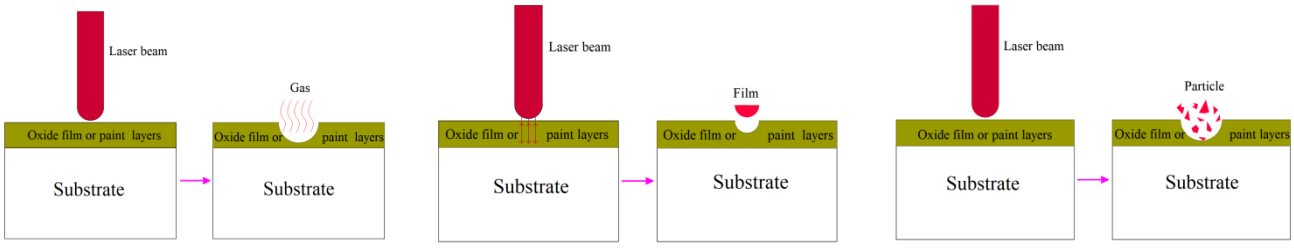
4. **Page 1, raw 29 Abstract: "This paper also identifies the real－time detection methods in the laser cleaning process and investigate the research and development direction of the laser cleaning technology." This sentence suggests that all possible real-time detection methods relevant for laser cleaning have been identified in this paper. This is likely not true. For example, in the outlook the authors suggest the use of infrared imaging. I suggest that this sentence should be rewritten.**

Response: This sentence have been rewritten. "This paper also introduces several real－time detection methods in the laser cleaning process."

5. **Page 2, Figure 1. The pictures in the centre of the illustration are too tiny to be recognized. Either remove or redo it.**

Response: According to the requirements of the journal, the Graphical Abstract cannot be directly added into the article, so we have deleted the Graphical Abstract and will submit it separately. In additon, the figure of the mechanism of laser cleaning has been

changed:



(a) (b) (c)

Figure 1. The mechanism of laser cleaning,(a) ablation gasification,(b) vibration stripping,(c) explosion stripping

6. **Page 3, raw 97 and 98: "controllable direction, and strong convergence ability" – replace with spatial coherence**

Response: "controllable direction, and strong convergence ability" has been replaced with spatial coherence.

7. **Page 3, raw 114: regarding evaporation (Evaporation is vaporization that happens at temperatures below the boiling point. Should be insignificant in laser cleaning) use the word vaporization only.**

Response: The changes have been finished in our manuscript.

8. **Page 12, raw 404-405: Give reference to what is meant by "welding grade III"**

Response: We have carefully checked the concept of welding grade III. It is related not only to the porosity after welding but also to undercut, slag inclusion, cracks, etc. In Zhou's research, only the porosity reduction showed that the weld reached grade III. We think it is not rigorous. Therefore, "welding grade III" has been deleted from our manuscript.

9. **Page 13, row 453-455 "As the coating on the aluminum alloy surface has a higher absorption coefficient for laser energy than the substrate, a microphone can be used to collect the acoustic signal from the cleaning surface when the paint layer is cleaned"- this claim is not logic. The acoustic emission is due to pressure waves and has nothing to do with different absorptivity in different materials. I suggest that this sentence should be rewritten.**

Response: This sentence has been rewritten in our manuscript as follows:

A laser irradiates the oxide film or paint layer on the aluminum alloy surface. The oxide film or paint layer on the aluminum alloy surface rapidly vaporizes and volatilizes when the energy received by the surface is greater than the material's vaporization point.

The vaporized particles continue to absorb energy. When the surface absorbs energy above the ionization energy, ionization will occur, creating a high temperature and high-pressure plasma cloud to produce shock waves [77]. When the surface absorbs ener-gy below the material's melting point, the material will expand due to the temperature in-crease. In this case, the periodic deformation of the surface layer by the laser pulses of na-ture will radiate periodic thermoelastic acoustic waves [78]. Whether a plasma acoustic wave or a thermoelastic acoustic wave, it is related to the material's thermal, optical prop-erties, and incident laser properties. During the laser cleaning process, the thermal and optical properties of the material change, resulting in changes in the acoustic signal. Therefore, the acoustic signal during laser cleaning can be detected to realize online cleaning process monitoring. Specifically, As the coating on the aluminum alloy surface has a higher absorption coefficient for laser energy than the substrate, a microphone can be used to collect the acoustic signal from the cleaning surface when the oxide film or paint layerthe paint layer is cleaned.

10. Pages 13 and 14, raws 446-477: is the acoustic emission airborne or waves in solid? This has very practical implications. Explain more in details.

Response: Raws 446-477 have changed as follows:

A laser irradiates the oxide film or paint layer on the aluminum alloy surface. The oxide film or paint layer on the aluminum alloy surface rapidly vaporizes and volatilizes when the energy received by the surface is greater than the material's vaporization point. The vaporized particles continue to absorb energy. When the surface absorbs energy above the ionization energy, ionization will occur, creating a high temperature and high-pressure plasma cloud to produce shock waves [77]. When the surface absorbs energy below the material's melting point, the material will expand due to the temperature increase. In this case, the periodic deformation of the surface layer by the laser pulses of nature will radiate periodic thermoelastic acoustic waves [78]. Whether a plasma acoustic wave or a thermoelastic acoustic wave, it is related to the material's thermal, optical properties, and incident laser properties. During the laser cleaning process, the thermal and optical properties of the material change, resulting in changes in the acoustic signal. Therefore, the acoustic signal during laser cleaning can be detected to realize online cleaning process monitoring. Specifically, a microphone can be used to collect the acoustic signal from the cleaning surface when the oxide film or paint layer is cleaned. An analog signal can be collected and converted into a digital signal using an audio card and sent to a computer for signal analysis. Studies have shown that the

amplitude of the acoustic signal varies with the paint thickness [79]. When the laser interacts with the paint layer, the amplitude of the acoustic signal is high and remains stable. However, when the paint layer is removed, the laser interacts with the aluminum alloy substrate with high reflectivity and low absorption and the amplitude of the acoustic signal decreases. Therefore, removing the paint layer from an aluminum alloy surface can be indirectly judged by the change in the amplitude of the acoustic signal during the cleaning process. Furthermore, the frequency of the acoustic signal can be used to determine the cleaning threshold when laser cleaning the paint layer on the aluminum alloy surface.

Zou [80] found that when the laser energy is below the cleaning threshold, the maximum amplitude frequency of the received acoustic signal is all above 0.04kHz. Once the laser energy density is equal to or above the cleaning threshold, the maximum amplitude frequency is always 0.04kHz. Figure 10 illustrates this phenomenon graphically. We define 0.04kHz as the characteristic frequency of acoustic signal monitoring in the laser cleaning process. Specifically, The characteristic frequency is relevant to the type of substrate. Therefore, by analyzing the acoustic signal, we can establish an acoustic monitoring method to assess whether the paint has been removed. Compared with other monitoring methods, acoustic monitoring has the advantages of a wide application range, high efficiency, and low operating cost. However, we should notice that audible frequencies could also carry lots of noise, which may limit the accuracy in the industry environment.

11. **Pages 14, raws 465-476: The reasoning about acoustic signals is not logic. The value 40 Hz that is mentioned in this context, is it a universal constant or is it application dependent? "Furthermore, time–amplitude, frequency–amplitude (FA), and time–frequency (TF) spectroscopies have different properties at varying laser fluences." – this sentence is problematic since at first, the time-amplitude representation is not a spectrum. Secondly what is meant by spectroscopies?**

Response: The content of this part has been completely modified, as shown above.

12. **Page 14, raw 492: replace "An optical signal collector" with for example "A collimating optics"**

Response: "An optical signal collector" has been replaced with"A collimating optics"in our manuscript.

13. **Page 15, raw 498-507: This paragraph is very problematic. Several algorithms are listed with no references. How can you segment an image accurately by combining Otsus method with morphology? What is the relevant information and what is quickly location? "Li et al. proposed an intelligent laser cleaning method based on machine vision, and after a series of tests, the accuracy of particle swarm optimization–reasoning or a support vector machine (PSO–SVM) reached 92.5% [82]." – I can not understand the message in this sentence. Please explain.**

Response: This paragraph has been rewritten as follows:

Machine vision technology also can realize real–time detection during the laser cleaning of oxide films on aluminum alloy surfaces. Shi et al. [83] used Visual Studio 2015 as the development platform, coupled a variety of machine vision detection algorithms, designed a real-time monitor system for laser cleaning aluminum alloy based on machine vision, and realized the accurate segmentation and rapid positioning of qualified and unqualified areas for cleaning, during the laser cleaning process of the oxide film on the aluminum alloy surface. The detection accuracy can reach 0.03 mm, and the total pro-cessing time of a single image is 400 ms. Specifically, Shi uses a CCD camera and an aux-iliary light source to synchronously collect the laser-cleaned image of the aluminum alloy surface and then import it into the machine vision-based real-time monitor system for la-ser cleaning aluminum alloy for subsequent image processing and calculation. First, the median filter method is used to filter the image. The Retinex single-scale algorithm [84] based on the color constancy perception theory is used to de-illuminate the image to re-store a more realistic original image. Then, to better distinguish the light and dark features of the image, the image, after being de-illuminated by the Retinex algorithm, is subjected to Gamma transformation to correct the grayscale of the image and enhance the contrast. Next, the maximum inter-class variance algorithm Otus [85] is used to dynamically seg-ment the light and dark areas in the image. After segmentation, the dilation algorithm is used to remove the over-segmented areas, and the parts with too small areas are removed to obtain the segmented image. The dark area is the nonconforming area. The Canny edge identification technique [86] and the connection threshold search algorithm [87] are used to identify the nonconforming area's size and precise position.The laser–cleaned image is processed using technology based on the Retinex algorithm, and the image is accurately segmented by combining the Otus algorithm and morphology. Finally, the Canny edge detection

and connected domain search algorithms are used to determine the relevant in-formation of the area that does not meet the cleaning requirements to accurately segment and quickly locate the qualified and unqualified surface areas of the aluminum alloy after laser cleaning [81]. Li et al. proposed an intelligent laser cleaning method based on ma-chine vision, and after a series of tests, the accuracy of particle swarm optimization–reasoning or a support vector machine(PSO–SVM) reached 92.5% [82].

14. **Page 16, raw 552-553: Here suggests some temperature monitoring. In general, it is a very complex task to measure temperatures by infrared thermography. Especially when you have metallic surfaces at different oxidation states. My question is why temperature is the most relevant quantity. I believe that thermograms can be used to get information related to heat radiation that can be linked to process deviations and relevant quality issues. I suggest that this sentence should be rewritten to better explain what the authors really mean.**

Response: This sentence has been rewritten. "For example, the use of high-speed cameras for dynamic monitoring of laser cleaning process, a pyrometer camera for temperature monitoring of the laser cleaning process."

15. **Page 16, raw 557-559: "For the online inspection of laser cleaning on complex parts and large components, the research and application of robot vision technology will be the focus of future laser cleaning."- How have the authors reached this conclusion? There is no motivation to that in the manuscript.**

Response: This paragraph has been rewritten as follows:

(3) Improvinge the applicability of online detection of laser cleaning. Currently, the online detection of laser cleaning focuses on acoustic signals, spectral signal detection, and robot vision. Acoustic signals have a wide range of applications and are inexpensive, but they are significantly affected by environmental noise. The detection efficiency of a spectral signal is high, but it requires plasma generation, which is inappropriate for low energy density. Robot vision is perfect for image processing, but there is still room for im-provement in processing speed. In order to further improve the applicability of real-time detection of laser cleaning, on the one hand, the advantages of acoustic monitoring meth-ods, spectral signal detection methods, and machine vision can be supplemented. On the other hand, more advanced detection methods should be explored.

16. **Page 16, raw 569: I suggest replacing "algorithm feedback" with "feedback**

algorithm"

Response: "algorithm feedback" has been replaced with "feedback algorithm" in our manuscript.

Special thanks to you for your comments.