

Dear Editors and Reviewers:

Thank you for your letter and for the reviewers' comments concerning our manuscript entitled "Design of UAV trajectory prediction system based on multi-flight modes" (Manuscript Number: drones-3011599). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and have made correction which we hope meet with approval.

Revised portion are marked in yellow in the paper. The main corrections in the paper and the responds to the reviewers' comments are as flowing:

Response to Reviewer #2:

[Comment 1] Abstract: needs improvement and expansion. The authors talk a lot about the formulation of the problem, but the novelty of the proposed model is missing. Please specify what are the main quantitative results that appeal to a general audience, and what are the main innovations of the article?

Reply: We are very grateful to the reviewers for pointing out that the unclear description in abstract. We have increased the description of the specific studies in the Abstract and further stated the conclusions of the studies.

How the paper is modified: The before and after revisions about Abstract of our latest manuscript submission are as follows:

Before modification	
Abstract: With the burgeoning impact of artificial intelligence on the traditional UAV industry, the pursuit of autonomous UAV flight has emerged as a focal point of contemporary research. Addressing the imperative for advancing critical technologies in autonomous flight, this paper delves into the realm of UAV flight state recognition and trajectory prediction. Presenting an innovative approach focused on improving the precision of Unmanned Aerial Vehicle (UAV) path forecasting via the identification of flight states, the study substantiates its efficacy through the implementation of two prediction models. Firstly, UAV flight data acquisition was realized in this paper by carrying multi-sensors. Subsequently, two different UAV flight trajectory prediction models were designed, and the trajectory prediction errors after UAV flight state recognition were comprehensively compared and analyzed. The empirical evidence unequivocally demonstrates that integrating UAV flight state recognition into the trajectory prediction model markedly decreases prediction errors compared to the original UAV flight trajectory prediction model.↵	7 8 9 10 11 12 13 14 15 16 17 18
After modification	
Abstract: With the burgeoning impact of artificial intelligence on the traditional UAV industry, the pursuit of autonomous UAV flight has emerged as a focal point of contemporary research. Addressing the imperative for advancing critical technologies in autonomous flight, this paper delves into the realm of UAV flight state recognition and trajectory prediction. Presenting an innovative approach focused on improving the precision of Unmanned Aerial Vehicle (UAV) path forecasting via the identification of flight states, the study substantiates its efficacy through the implementation of two prediction models. Firstly, UAV flight data acquisition was realized in this paper by carrying multi-sensors. Finally, two models for UAV trajectory prediction are designed based on machine learning methods and classical mathematical prediction methods, respectively, and the results before and after their flight pattern recognition are compared. The experimental results show that the prediction error of the UAV trajectory prediction method based on multiple flight modes is smaller than the traditional trajectory prediction method in different flight stages.↵	7 8 9 10 11 12 13 14 15 16 17 18

[Comment 2] The authors need to identify the gaps left by previous approaches and explain how their proposed framework addresses these gaps.

Reply: We are grateful to the reviewers for bringing up our lack of description of the inadequacies of the previous study, which we have re-described in the introduction section in that area.

How the paper is modified: We add a discussion of the shortcomings of traditional UAV trajectory prediction methods in the introduction and indicate how this paper addresses these issues, before and after the modification are shown below:

Before modification	
The above literature is a review of the current state of research by current scholars in the areas of pattern recognition and UAV trajectory prediction. Based on the need for re-	57
search in areas related to autonomous flying UAVs, this paper investigates the key areas	58
of autonomous flying UAVs: UAV trajectory prediction. [↵]	59
The main contributions and innovations are listed below: [↵]	60
	61
After modification	
The above literature is a review of the current state of research by current scholars in the areas of pattern recognition and UAV trajectory prediction. However, the UAV trajec-	57
tory prediction model based only on a certain kind of fixation has a flaw: it only predicts	58
future trajectories based on the UAV's trajectories in the past period of time, and it does	59
not take into account the situation where the UAV's maneuvering strategy has changed	60
in a short period of time. In other words, the traditional UAV trajectory prediction model	61
cannot comprehensively consider the flight posture of the UAV in its current state. Based	62
on the need for research in areas related to autonomous flying UAVs, this paper investi-	63
gates the key areas of autonomous flying UAVs: UAV trajectory prediction. [↵]	64
The main contributions and innovations are listed below: [↵]	65
	66

[Comment 3] Introduction is not up to the mark. Recent related studies and existing models should be added in the introduction.

* Prescribed Performance Fault-Tolerant Attitude Tracking Control for UAV with Actuator Faults. <https://doi.org/10.3390/drones8050204>

* Strategies for Optimized UAV Surveillance in Various Tasks and Scenarios: A Review. <https://doi.org/10.3390/drones8050193>

* Deep Reinforcement Learning-Based 3D Trajectory Planning for Cellular Connected UAV. <https://doi.org/10.3390/drones8050199>

* Effect of Control Parameters on Hybrid Electric Propulsion UAV Performance for Various Flight Conditions: Parametric Study. <https://doi.org/10.3390/applmech4020028>

Reply: We are very grateful to the reviewers for providing four classic literatures on the current state of UAV research, in which I have learnt and further improved our manuscript. Meanwhile, we have placed them in the introduction for discussion in the manuscript.

How the paper is modified: We discuss the four papers provided by the reviewers in the introductory of the manuscript, before and after the modification are shown below:

Before modification	
In trajectory prediction research, Kan-nan and colleagues [22] introduced a low-com-	42
plexity linear Kalman filter based on the differential state equation, enhancing trajectory	43
prediction accuracy and response time. Wang and co-authors [23] devised a multi-step	44

ballistic prediction method known as MUKF, achieving real-time dynamic target prediction with an average prediction time of 20.16 seconds. Zhang et al. [24] devised a trajectory prediction model spanning four dimensions by integrating historical flight data with UAV motion equations. They incorporated a genetic algorithm for dynamic weighting. Niu et al. [25] introduced a model predictive control (MPC)-based adjacent motion trajectory prediction algorithm that operates independently of communication requirements. Their method exhibited superior performance in simulation experiments compared to traditional distributed model predictive control (DMPC) algorithms. Meanwhile, Xie and colleagues [26] presented a framework for online UAV trajectory prediction using Gaussian process regression (GPR). Their methodology exhibited outstanding performance when compared to alternative approaches, as validated through simulation experiments and real-world data scenarios.

After modification

In trajectory prediction research, Kan-nan and colleagues [19] introduced a low-complexity linear Kalman filter based on the differential state equation, enhancing trajectory prediction accuracy and response time. Wu et al. [20] propose a fixed-time extended state

observer (FXTESO)-based preset performance fault-tolerant control method for handling the attitude tracking problem of UAVs under actuator failures, and the effectiveness of the proposed control strategy is verified through simulation results. Fan et al. [21] comprehensively evaluated optimisation strategies for UAVs in a number of key areas such as infrastructure inspection, security surveillance, and environmental monitoring, analysed the effectiveness of UAVs in specific tasks, and explored the challenges of operating in complex environments. Liu et al. [22] proposed a simultaneous path planning method based on an improved Deep Reinforcement Learning (DRL) algorithm, combined with radio mapping techniques, to optimise 3D trajectories for cellular-connected UAVs in order to improve system efficiency and reliability. Benmoussa et al. [23] conducted a parametric study to investigate the effects of control parameters on the performance of a UAV with a hybrid electric propulsion system under different flight conditions, aiming to provide guidance for the design and operation of UAVs. Zhang et al. [24] devised a trajectory prediction model spanning four dimensions by integrating historical flight data with UAV motion equations. They incorporated a genetic algorithm for dynamic weighting. Niu et al. [25] introduced a model predictive control (MPC)-based adjacent motion trajectory prediction algorithm that operates independently of communication requirements. Their method exhibited superior performance in simulation experiments compared to traditional distributed model predictive control (DMPC) algorithms. Meanwhile, Xie and colleagues [26] presented a framework for online UAV trajectory prediction using Gaussian process regression (GPR). Their methodology exhibited outstanding performance when compared to alternative approaches, as validated through simulation experiments and real-world data scenarios.

Meanwhile, the references section should be corrected as follows:

After modification

20. Wu, Q.; Zhu, Q. Prescribed Performance Fault-Tolerant Attitude Tracking Control for UAV with Actuator Faults. *Drones* 2024, 8, 204, doi:10.3390/drones8050204.
21. Fang, Z.; Savkin, A.V. Strategies for Optimized UAV Surveillance in Various Tasks and Scenarios: A Review. *Drones* 2024, 8, 193, doi:10.3390/drones8050193.

22.	Liu, X.; Zhong, W.; Wang, X.; Duan, H.; Fan, Z.; Jin, H.; Huang, Y.; Lin, Z. Deep Reinforcement Learning-Based 3D Trajectory Planning for Cellular Connected UAV. <i>Drones</i> 2024, 8, 199, doi:10.3390/drones8050199.	405 406
23.	Benmoussa, A.; Gamboa, P.V. Effect of Control Parameters on Hybrid Electric Propulsion UAV Performance for Various Flight Conditions: Parametric Study. <i>Applied Mechanics</i> 2023, 4, 493–513, doi:10.3390/applmech4020028.24. González-Arribas, D.; Soler, M.; Sanjurjo-Rivo, M. Robust Aircraft Trajectory Planning Under Wind Uncertainty Using Optimal Control. <i>Journal of Guidance, Control, and Dynamics</i> 2018, 41, 673–688, doi:10.2514/1.G002928.	407 408 409 410

[Comment 4] Please include the significance of this work.

Reply: We are very grateful to the reviewers for pointing out the shortcomings of our manuscript's discussion of the study's purpose, which we have improved in the abstract, introduction, and conclusion sections, respectively.

How the paper is modified: A description of the improvements in our abstract section follows:

Before modification	
Abstract: With the burgeoning impact of artificial intelligence on the traditional UAV industry, the pursuit of autonomous UAV flight has emerged as a focal point of contemporary research. Addressing the imperative for advancing critical technologies in autonomous flight, this paper delves into the realm of UAV flight state recognition and trajectory prediction. Presenting an innovative approach focused on improving the precision of Unmanned Aerial Vehicle (UAV) path forecasting via the identification of flight states, the study substantiates its efficacy through the implementation of two prediction models. Firstly, UAV flight data acquisition was realized in this paper by carrying multi-sensors. Subsequently, two different UAV flight trajectory prediction models were designed, and the trajectory prediction errors after UAV flight state recognition were comprehensively compared and analyzed. The empirical evidence unequivocally demonstrates that integrating UAV flight state recognition into the trajectory prediction model markedly decreases prediction errors compared to the original UAV flight trajectory prediction model.	7 8 9 10 11 12 13 14 15 16 17 18
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Abstract: With the burgeoning impact of artificial intelligence on the traditional UAV industry, the pursuit of autonomous UAV flight has emerged as a focal point of contemporary research. Addressing the imperative for advancing critical technologies in autonomous flight, this paper delves into the realm of UAV flight state recognition and trajectory prediction. Presenting an innovative approach focused on improving the precision of Unmanned Aerial Vehicle (UAV) path forecasting via the identification of flight states, the study substantiates its efficacy through the implementation of two prediction models. Firstly, UAV flight data acquisition was realized in this paper by carrying multi-sensors. Finally, two models for UAV trajectory prediction are designed based on machine learning methods and classical mathematical prediction methods, respectively, and the results before and after their flight pattern recognition are compared. The experimental results show that the prediction error of the UAV trajectory prediction method based on multiple flight modes is smaller than the traditional trajectory prediction method in different flight stages.	7 8 9 10 11 12 13 14 15 16 17 18

A description of the improvements in our introduction section follows:

Before modification	
The above literature is a review of the current state of research by current scholars in the areas of pattern recognition and UAV trajectory prediction. Based on the need for research in areas related to autonomous flying UAVs, this paper investigates the key areas of autonomous flying UAVs: UAV trajectory prediction.	57 58 59 60
The main contributions and innovations are listed below:	61
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The above literature is a review of the current state of research by current scholars in	57
the areas of pattern recognition and UAV trajectory prediction. However, the UAV trajec-	58
tory prediction model based only on a certain kind of fixation has a flaw: it only predicts	59
future trajectories based on the UAV's trajectories in the past period of time, and it does	60
not take into account the situation where the UAV's maneuvering strategy has changed	61
in a short period of time. In other words, the traditional UAV trajectory prediction model	62
cannot comprehensively consider the flight posture of the UAV in its current state. Based	63
on the need for research in areas related to autonomous flying UAVs, this paper investi-	64
gates the key areas of autonomous flying UAVs: UAV trajectory prediction.	65
The main contributions and innovations are listed below:	66

A description of the improvements in our conclusion section follows:

Before modification	
5. Conclusions	321
In this paper, two prediction models are devised to forecast UAV trajectories, with	322
and without flight state identification. The results suggest that the prediction accuracy of	323
the model incorporating flight state identification exceeds that of the model without this	324
identification.	325
The focus of this paper lies in demonstrating the effectiveness of utilizing UAV flight	326
state identification to enhance trajectory prediction models. This is supported by referenc-	327
ing relevant studies and proposed algorithms. Clear language and terminology are em-	328
ployed in describing the methodology and results to ensure readers' understanding and	329
reproducibility of the experiments. Subsequently, five flight state prediction models were	330
developed using BP neural network and Adams prediction model to forecast the trajecto-	331
ries.	332
After modification	
5. Conclusions	321
This study addresses the improvement of traditional UAV trajectory prediction	322
methods. Traditional UAV trajectory prediction only considers past UAV flight history	323
data, which is insufficient for the current UAV flight state. Based on this, this paper com-	324
prehensively considers the current UAV flight pattern and historical flight trajectory to	325
predict the UAV trajectory in the future period. In this paper, two prediction models are	326
devised to forecast UAV trajectories, with and without flight state identification. The re-	327
sults show that the prediction accuracy of the model incorporating flight state identifica-	328
tion exceeds that of the model without this identification.	329
The focus of this paper lies in demonstrating the effectiveness of utilizing UAV flight	330
state identification to enhance trajectory prediction models. Subsequently, five flight state	331
prediction models were developed using BP neural network and Adams prediction model	332
to forecast the trajectories. The prediction results show that the flight mode <u>recognition</u>	333
<u>based trajectory prediction system proposed in this paper has a much smaller prediction</u>	334
<u>error.</u>	335

[Comment 5] Many method improvements of the authors are the integration of a large number of existing methods. Are they simple system integration or have new features? How can the authors prove the effectiveness of the integration methods?

Reply: We are very grateful to the reviewers for suggesting shortcomings in our description of the innovations in this paper, and we have improved the description in the experimental results section of the manuscript.

How the paper is modified: In response to the reviewers' comments, we have made the following two improvements to the manuscript: 1) We have included images of the physical flight verification of the UAV in the experimental section of the manuscript. 2) We provide a more detailed

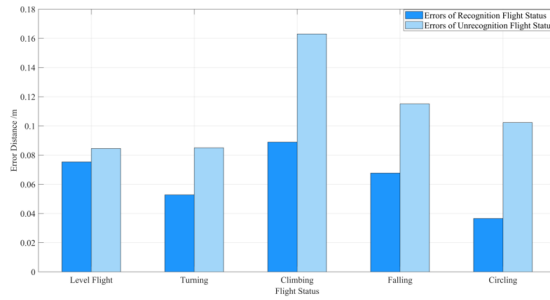
legend description of Fig. 7's in the Experimental Results section as well as a further explanation of the results of the graphical presentation later on.

1) physical flight verification:

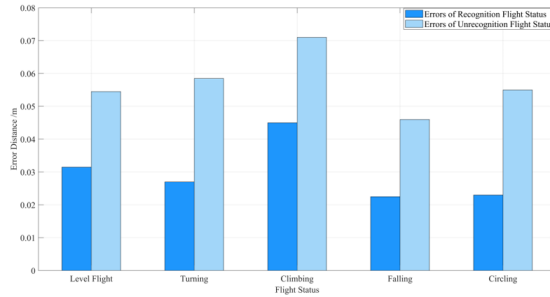
After modification	
4. UAV TRAJECTORY PREDICTION RESULTS AND ANALYSIS	276
4.1 Neural Network Model Prediction Results	277
In this research, we had used the device shown in Figure 1 to measure the flight information of the UAV. Meanwhile, we recorded the information of the UAV flight, the fight process of UAV is shown in Figure 5.	278
	279
	280
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a) UAV flight test figure (1)	282
	283
b) UAV flight test figure (2)	284
Figure 5. UAV flight information measurement pictures	285

2) In Figure 7:

Before modification



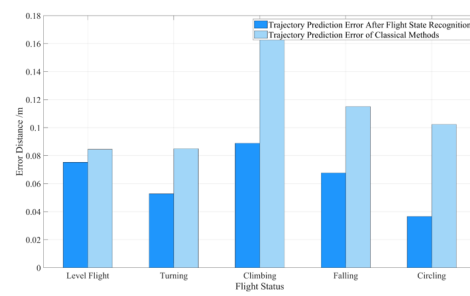
a) errors in neural network prediction models[↵]



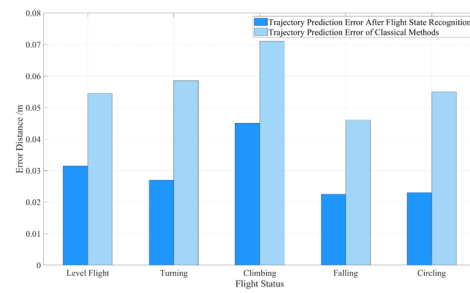
b) errors in Adams prediction models[↵]

Figure 7. Comparison of two trajectory prediction methods[↵]

After modification



a) Comparison of UAV trajectory prediction errors of machine learning methods before and after flight mode recognition[↵]



b) Comparison of UAV trajectory prediction errors of classical mathematical methods before and after flight mode recognition.[↵]

Figure 7. Comparison of two trajectory prediction methods[↵]

2) In results and analyses:

Before modification

Figure 7. Comparison of two trajectory prediction methods	□	287
In Figure 7, the a) picture depicts the error of the neural network prediction model and the b) picture depicts the error of the Adams prediction model. Upon comparing the two images, it's evident that after identifying the UAV flight states, the errors in both prediction models are markedly diminished. The test shows that the UAV flight state recognition-based trajectory prediction model can achieve better UAV trajectory prediction than the direct adoption of the prediction model for UAV trajectory prediction.		288 289 290 291 292 293
After modification		
Figure 7. Comparison of two trajectory prediction methods	□	287
In Fig. 7, figure a) depicts the error of the UAV trajectory prediction model based on the machine learning approach, and figure b) depicts the error of the classical mathematical approach for predicting the UAV trajectory. Comparison of the two figures shows that the errors of both prediction models are significantly reduced after identifying the UAV flight pattern. The experimental results show that the UAV trajectory prediction model based on flight pattern recognition can better achieve UAV trajectory prediction than directly using the prediction model for UAV trajectory prediction.		288 289 290 291 292 293 294

[Comment 6] All equations should be cited.

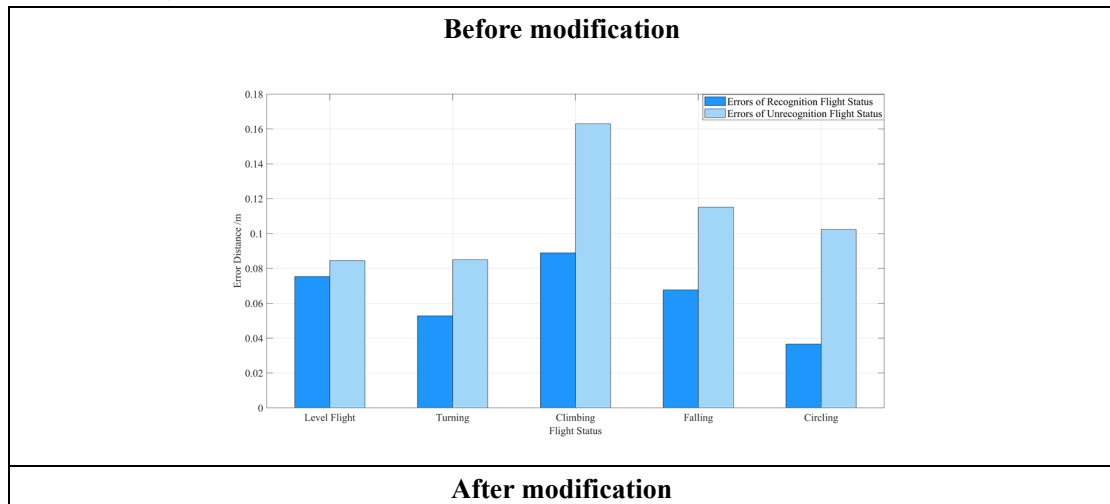
Reply: We are grateful to the reviewers for raising the issue of citation of our formulas, all of which have been cited in the latest submission of the manuscript.

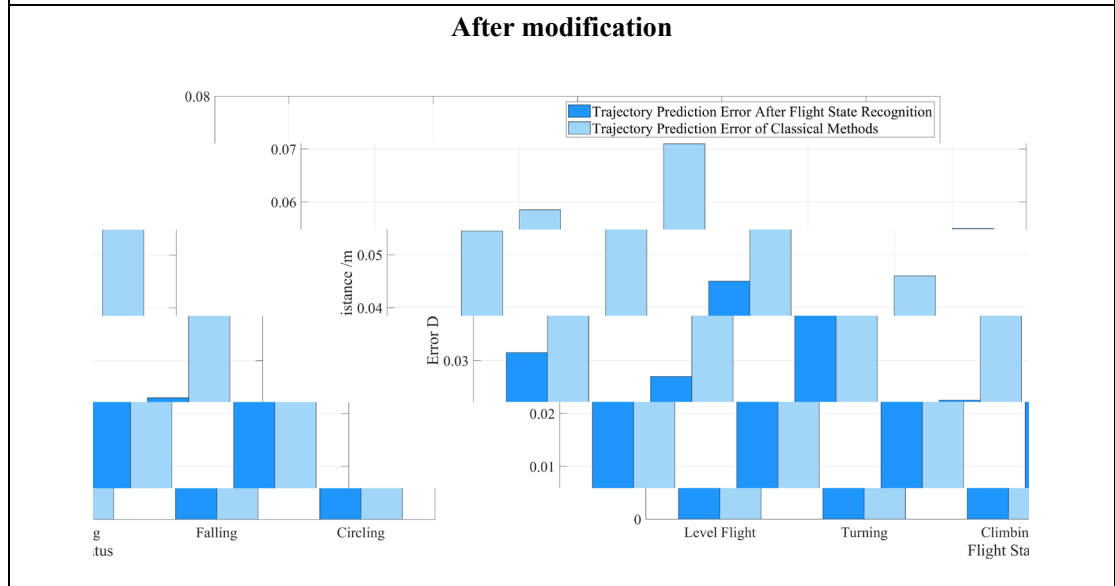
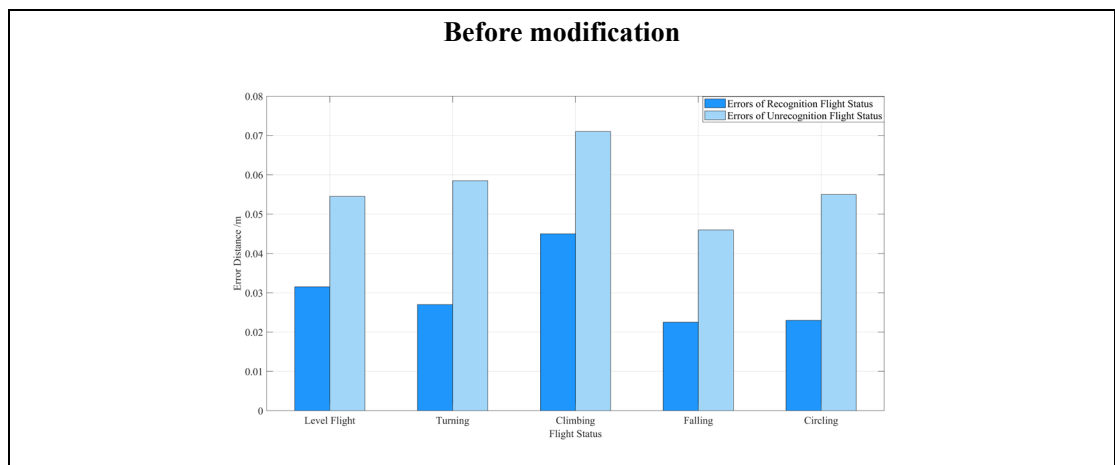
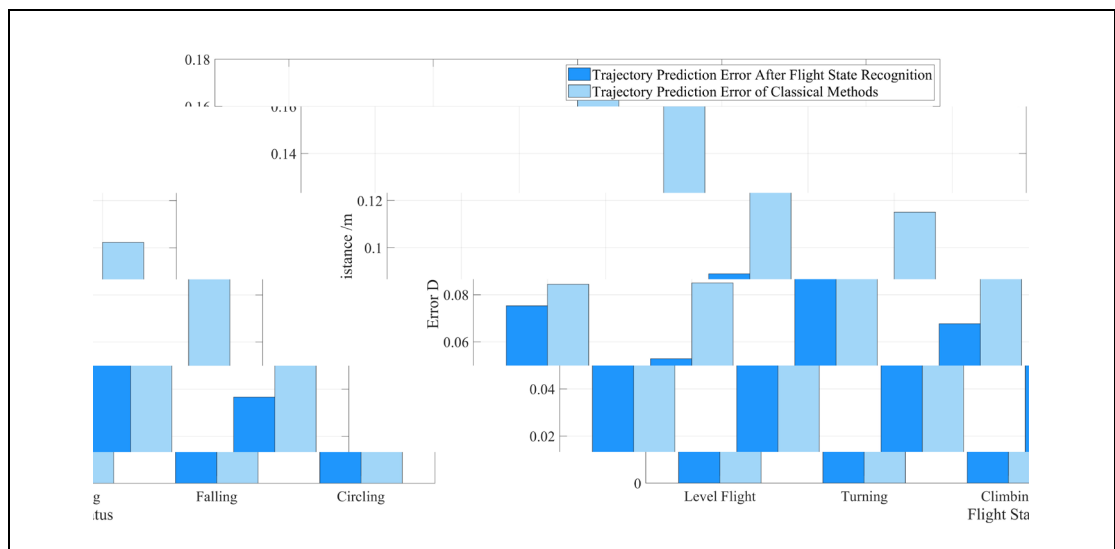
How the paper is modified: We have cited all the formulas in the manuscript and treated the altered parts in yellow in the manuscript.

[Comment 7] The authors must improve the clarity of the graphs by increasing the title size and enhancing the overall quality.

Reply: We are grateful to the reviewers for raising the issue of the size of the legends in our diagrams, and we have adjusted the unreasonable legends in the manuscript to increase the readability of the diagrams.

How the paper is modified: We adjusted some of the images in the manuscript to make them more readable, as follows.





According to the reviewers' comments, we have made extensive modifications to our manuscript and supplemented extra data to make our results convincing. Thank you again for your positive comments and valuable suggestions to improve the quality of our manuscript.

We appreciate for editors and reviewers' warm work earnestly, and hope that the correction will meet with approval.

Yours sincerely,

Zhuoyong Shi

May 21, 2024