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Geoscientific Instrumentation Methods and Data Systems Discussions

Interactive comment on "Experiments on magnetic interference for a portable airborne magnetometry system using a hybrid unmanned aerial vehicle (UAV)" *by* Jirigalatu Jirigalatu et al.

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We thank you very much for reading the manuscript and providing very helpful and constructive comments.

General Comments

1. **I would recommend shortening the abstract. About 60% of it is introductory information and could be reduced to a couple of sentences. The abstract should be a "brief introduction of the topic". Also the abstract should in-**

clude some specific results and should "mentions possible directions for prospective research."

   Response: We shortened the abstract to make it as concise as possible. Please see the new abstract in the manuscript.

2. **My largest issue is the paper needs to thorough rewrite; not for technical reasons as much as the English is poor. This gets increasingly apparent after the introduction. It is filled with colloquial language, "we" and "us", and an excessive amount of connective words like "Besides", "Nevertheless", "furthermore", "consequently", "in principle", "however", "hence", "again and again", "on the other hand". On many occasions I had to guess the interpretation of a sentence and it is difficult to follow the idea being developed in many paragraphs.**

   Response: Thank you for the advice. We tried to remove some unnecessary linking works to make the manuscript easier to understand.

3. **The conclusion were adequate but I would request further information in a couple of areas that would help the reader accept these conclusions. Unfortunately I may have missed this due to General comment 2.**

   (a) **I felt section 3.2 requires further information i. Where is the battery, ESCs, and other equipment located? Could this be incorporated into a Figure (Figure 3?) or added as a separate figure?**

   Response: We included a figure that shows the mentioned components in the manuscript.

   (b) **What dies the background look like? The structural beam in Figure 1 doesn't have any steel in it? There is no change of the background over time? Or how did you handle the background removal?**

   Response:

i. There isn't any steel in the structural pole because the room was general magnetic measurement, so only non-magnetic material was used.

ii. The background changed with time because the measurement was conducted on separate days. Therefore, the data shown in the manuscript have been diurnal-corrected and background corrected as it is stated in the caption of the figure.

iii. The process can be expressed as **Corrected magnetic signature** $=$ (**Raw magnetic signature** $-$ **Diurnal variations**) $-$ (**Raw background measurement** $-$ **Diurnal variations**).

(c) **You may want to add what gridding algorithm was used or if a filter was used. If an exact gridding algorithm was used without a filter, great job! iv. Why is there no signature from the motors? Or were they removed? v. What is the signature located in the tail seen in Figure 2b)**

Response: Yes, we clarified in the manuscript how we gridded the data in the manuscript. Only a simple linear interpolation that is a built-in function in Matlab was used to grid the data, no extra filtering was involved. There is the signature from the the motors, but the signature from the motors is masked by the magnetic signature from the highly magnetic servomotors. It is much easier to see in Figure 2c.

(d) **P6, line 122. I do not understand why the flexibility of the wing from Tuck et al. 2018 would provide a limit on the flexibility of the wing of this UAV?**

Response: We rephrased the sentence.

(e) **Could you use the same colour bar for a) b) and c) in Figure 2.**

Response: We tried to use the same color scale. But because the direction of the magnetic field was changed as the orientation of the UAV was changed, so if we use the same color scale for the three figures, the mag-

netic highs and lows you see in Figure 2 will not be as clear as they are now. For example, the magnitude in Figure 2a is from -200 nT to around +680 nT, whereas the magnitude in Figure 2c is from -730 nT to 160 nT.

(f) **Two reference that would be well suited for this section: 1. (Hansen, 2018) – magnetically modelled a fixed-wing VTOL UAV. 2. (Tuck, 2019) – magnetically characterized 4 different UAVs using a motor setup.**

Response: We referenced the two articles as suggested.

Specific comments

1. **The motors seem to have many names: "electric engines" (P1, line 10), "BLDC motor" (P4, table 1), "BLDC servomotor"(Figure 3 caption). Personally I prefer "BLDC motor" as I think of servo when I read servomotor and pistons (like a gasoline engine) when I read engine. As a result, I am confused whether 3b is the magnetic signature of a servo or the motor. As there are 4 of the former and 3 of the latter how does their signatures compare among each variant? (Forrester, 2011) suggest that the field produced by servos can vary significantly.**

   Response: We see the confusion. We use, therefore, servomotor and motor instead. In comparison with the original servomotors that came with the UAV, the new servomotor is 10 times less magnetic.

2. **I could not find a reference to figure 3**

   Response: Please see the reference of the figure at Line 103.

3. **Are there tail servos? Where are they in figure 3?**

   Response: Yes, there are three servomotors, two for the elevator and one for the rudder. In Fig 1 in the response, we can see three magnetic highs that should be associated with the back servomotors and the rear motor.

4. **P2. Line 38. Are traditional manned aeromagnetic surveys limited to above 80m? Can you provide a reference for this? I have seen helicopter mag surveys searching for UXO only a few metres off the ground. . .**

   Response: In *Aeromagnetic Surveys: Principles, Practices, and Interpretation* by Colin Reeves, on page 44, it states that conventional fixed-wing survey aircraft in terrain free of significant topography are routinely operated at terrain clearances of 100 m, 60 m, and even 30 me in some countries. However, in all EU member states, Visual Flight Rules set out a minimum altitude of 150 m (500 ft). We see the confusion, we rephrased the sentence.

5. **P2, Line 39. I would suggest adding something about the improvement of detectability by 1/distanceËĘ3. This is important!**

   Response: We rephrased the sentence.

6. **P3,line 61. Tuck et al propose a method for characterization that incorporates both static and dynamic interference together by powering the motors during measurement. The “interplay” is relevant to how a source can influence other sources and so all systems should be active during characterization. Could you be clearer as to why you claim this experiment is still not sufficient? Also, you do not do this for your characterization experiment and should be explained why you chose to ignore this “interplay”**

   Response: We agree with Tuck that measuring the magnetic signature of each component of a UAV is very helpful to understand the magnetic interference from a UAV. But the magnetic signature of a UAV can become rather complex and dynamic, especially when all electric motors and servomotors and electronic components switch on. As a result, the magnetic signature of a UAV can vary dramatically, which depends on a plethora of factors such as power consumption, throttling, attitude, and even on-site air density as well as air speed. Therefore, we recommend not only to measure the static magnetic signature of a UAV but

also to fly the UAV and collect in-flight magnetic data to analyze the real-time in-flight magnetic interference from a UAV.

7. **P3, line 71. Are the motor still powered during fixed-wing flight to keep the props from spinning? Or do they loosely spin during flight? Wouldn’t either scenario provide interference?**

   Response: The front motors are still powered in the cruise mode (or the fixed-wing mode) but should not rotate (please see the attached figure that shows the status of the two front motors). In principle, as long as a brushless DC motor rotates, there is an alternating magnetic field generated by the spinning rotor that includes a few permanent magnets.

8. **P5, line 106 you say “The UAV remained turned-off during the magnetic signature measurement”.**

   Response: We rephrased the sentence.

9. **Sentence on P5, line 114-116 is not true. The noise envelope is not a function of the efficiency of compensation.**

   Response: We agree that the noise envelop is not a function of the efficiency of compensation. We see the confusion, and we deleted the confusing part.

10. **P7, line 137. It should be noted that although increasing the boom length may not create additional significant aerodynamic forces, it does increase instability during flight. Also, one would expect larger amplitude vibrations with a longer boom (P7, line 141).**

    Response: Yes we agree. But as our aero-engineer (the second author) has pointed out that it should not increase instability as long as the center of gravity of the UAV stays where it is supposed to be by adjusting the battery’s position and the flight controller is able to handle the changes in the moment of inertia.

As for the in-flight vibrations, by using a strong rod or a rigid tube with a properly designed supporting structure, the vibrations can be kept to a minimum. Furthermore, the added length of the rod increases the arm of the aerodynamic forces. This does have a negative impact on the stability specially on pitch and yaw states, but the impact is kept within the controllable ranges of the flight controller and aerodynamic control surfaces (elevator and rudder).

11. **P9, line 179. Are you suggesting that the magnetic geology 12 km deep created a gradient of 225nT/m? Later you say otherwise (p10, line 187) so I think you just need to reword this sentence.**

    Response: We rephrased the sentence as suggested. The local geology should not create such strong gradient, which must be from the UAV.

12. **P10, line 180. You suggest the interference is "probably due to radio transmission and cultural noise". You could test this by turning your radio on and off. You can test for cultural noise by moving the UAV to another area.**

    Response: We agree with the reviewer that we could have done that. Because we are also new the development of a UAV-borne system, we didn't expect that the cultural noise in the vicinity of the test site and the radio transmission could be measured by the magnetometers.

13. **Figure 8. Why doesn't the 4th difference correlate between the two sensors if the source is mainly the UAV? Perhaps worthy of discussion?**

    Response: Because the attenuation due to distance is strong, that is why in the figure the the secondary magnetic profile is a lot noisier and the 4th difference of the primary magnetic profile is almost constant, which means that some of the interference that can be measured by the secondary sensor may be too small to be measured by the primary sensor. Therefore, the 4th difference of the two magnetic profiles may not necessarily be correlated.

14. **P13, line 2. Will adding 10 cm to L make much of a difference? This can be calculated easily once you identify your source (which you do in the previous section).**

    Response: Yes, the data that we show in the manuscript are the raw observations. We were surprised by the big difference due to the 10 cm difference as well. Since the major noise source is the output current, it is dependent on the magnitude of the output current from the battery, the shape of the current-carrying cable, and the orientation of the current-carrying cable, which make it difficult to calculate the resultant magnetic field.

15. **P13, line 231. Either use relative time or do the math. Relative time looks cleaner**

    Response: We re-plot the figures using relative timestamp as suggested.

16. **P17, line 251. Why is the gradient higher for the second dynamic experiment than the first?**

    Response: There are several reasons as we stated in the manuscript. First of all, the there were GNSS antenna and IMU in the cockpit in the first dynamic experiment. For the secondary experiment, the GNSS and IMU were removed after the timestamp was synchronised. Besides, due to the weight change, we had to re-adjust the location of the battery to make sure the CG stays where it should be so that the layout in the cockpit was changed and meanwhile the shape of the current-carrying cable and orientation of the current-carrying cable were alos changed. The main reason should be the changes made to the current-carrying cable.

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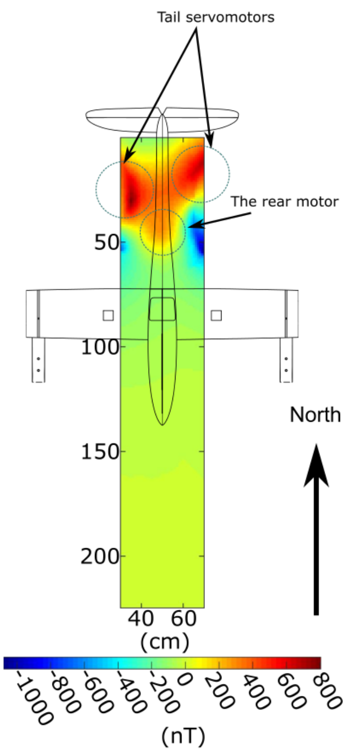

Fig. 1. Location of the tail servomotors and the rear motor

Fig. 2. Status of the front motors in the cruise mode. The figure is credited to Kapetair.