Dear editors,

The paper was previously submitted as Sensors-64105-2023, and was sent back for revisions. I have included detailed details on the specific changes made to address the reviewer's concerns. I have also uploaded separately comparisons of the previous and current versions for the main paper and supplement. Most of the comparison differences are due to changes in the reference numbering and Microsoft Word's inability to compare floating figures.

Reviewer #2 was understandably curious about aspects of the ILEMT hardware design and performance, and of EMT design tradeoffs in general, but this is unfortunately not the subject of the of this paper. Ref [2] has some information on ILEMT, and more papers are forthcoming.

The supplemental file is in effect part of the paper, and should be available online. It contains more detailed content that does not fit within the page limit, including information to address reviewer questions.

The supplement also has additional material added which is not directly in response to reviewer comments. This is in section II concerning the design constraints and implementation of the calibration stage and fixtures.

Thank you,

Robert A. MacLachlan

Reviewer: 1

Recommendation: Publish in Minor, Required Changes (as noted in the Comments section. This rating may not be assigned for Sensors Letters.)

Comments:

I believe that this paper should be of interest to researchers working on use of electromagnetics for tracking targets in visually impaired environments.

Following are questions and suggestions for modifications to your manuscript. These are in order of appearance in your manuscript.

On Page 1 of the review document, there is a diagram of the overall system. Is this diagram going to be included in the final manuscript?

- ⇨ Yes, added

page 3, 2nd column, line 26, what is meant by the term "combinational explosion"? Does this mean a rapid expansion of the number of calculations required to reach a solution?

- ⇨ Clarified, “This procedure is tedious, and rotation effects have often been ignored, perhaps in part because of the large number of poses that must be tested when rotation and translation are varied simultaneously.”

page 5, 1st column, eqn 3 - should there be a scaling factor?

- ⇨ Yes, added k_g and clarified “Where k_g is a gain constant that in practice we absorb into the calibrated source and sensor moments, §VI.”

page 8, 1st column, line 21 - what is meant by the term "is in common"? Are you indicating that, as there are mirror images of some of the combinations of rotations, only 1/2 the combinations are unique? If this is the case, why can the uncertainty in the positioning of the rotation be ignored?

- ⇨ Discussion of the rationale behind source and sensor fixturings has been expanded considerably in the supplement.

page 8, section E. You stated that, as the dimensions of the sensor are much less than those of the source, the source can be regarded as a dipole. This is only true if r >> 4 x diameter source as stated in Ref 25.

- ⇨ Clarified: “While this is a fairly large 17x15x14 mm sensor (which improves the signal-to-noise ratio) it is still much smaller than the source, so the sensor response is much closer to a dipole than the source field is.”

page 8, section F, the acronym DLT is undefined.

- ⇨ Fixed, this abbreviation is now defined as Direct Linear Transform in the cross-reference.

page 9, 2nd column, line 25, "model works has" do you mean "model has"

- ⇨ fixed

page 9, 2nd column, line 35, " paffle.

- ⇨ Fixed

page 10, Figure 10 comes before Figure 9. Looking at the captions for both figures, it appears as if the existing Figure 10 should be labelled Figure 9 and visa versa.

- ⇨ Yes, fixed. The cross references had not been updated.

The last sentence of the caption for the exiting Figure 10 appears to be missing some words. At present this sentence reads: "See instead Fig.10 which summarizes this data by the vector magnitudes of direct and cross"

⇨ fixed

If the Figures are relabelled, then the text will need to reflect these changes. For example, on page 10, 2nd column, line 12, Fig. 9 would become Fig 10.

⇨ fixed

In the existing Fig 9, there are plots of errors and non-linearities for the X, Y and Z axes. Reference is made to a plot of "The data in Fig. 9 is here reduced to two curves (see arrows)". These two plots appear to be missing.

⇨ Clarified that we referring to the other figure not this figure. This was extra confusing because of the mixed-up numbers. “In this figure the data in Fig. 9 has been reduced to two curves (see arrows):”

In your discussion section you report that your implementation will be freely available. Can you provide details of how to access your implementation?

⇨ Added “These are available under Apache License 2.0 on osf.io[3].”

[in supplemental material]

Page 12, 2nd column, line 55, there is a missing link to a reference.

⇨ fixed

Page 13, 1st column, line 13. You state that: "Fortunately, any metallic interference drops as r^6". Can you provide a reference that explains the mechanism for this level of fall off?

⇨ Added in supplemental material:
Fortunately, any metallic interference drops rapidly with distance. The dipole field of the source drops as $r-3$ of the source-to-metal distance, and the metal creates an interfering field proportional to this when must then reach the sensor. If the metal effect could also be modelled as a dipole then the disturbance would decrease as $r-6$, but empirically we have found the interference to be unmeasurable well before this asymptote is reached. That is, to have an effect the metal must be large enough that it can’t be approximated as a dipole. Using a more realistic $r-4$, f the closest interferer is at 3.2x the source/sensor distance, then the interference will be reduced by 100, which can usually be neglected

Reviewer: 2

Recommendation: Review Again After Resubmission (Paper is not acceptable in its current form, but has merit. A major rewrite is required. Author should be encouraged to resubmit a rewritten version after the changes suggested in the Comments section have been completed.)

Comments:

The Authors propose a suitable method for EMTS calibrating by investigating the effect of positioning error on calibration accuracy.

The paper is interesting and well structured. Some remarks should be addressed to improve the manuscript.

Please explain the meaning of ρ in first formula

- ⇨ Added forward reference to section V where specific dipole measurement model and parameters ρ are discussed. “Our specific measurement model and the structure of ρ is discussed later (§V.)”

Please enumerate all used formulas

- ⇨ Display formulas that are referenced elsewhere have been labeled.

In the section IV the authors introduce matrix multiplication T1 and T2 but these matrices are not used in the formulas

- ⇨ Clarified that these are arbitrary instances of a transform: “Let $\boldsymbol{T}1$, $\boldsymbol{T}2$ be arbitrary linear homogeneous transforms.”

In sub-section VIII.C the authors assert that “The stage position uncertainty is 107 μm,” , please explain how this value was calculated.

- ⇨ Clarified that this is discussed in the supplement: “For details of this uncertainty, the stage construction and characterization see supplement §II.”

Please justify the assertion “Non-repeatable variation in the coupling is dominated by drift.

- ⇨ Drift measurements added to supplement show that the drift is large enough to dominate other error sources.

the authors assert that “To minimize this drift, we powered up the tracker at least 2 hours prior to data collection”. Please explain how the authors have evaluated this time period. It should be useful to show the drift after both 2 hours and 8 hours.

- ⇨ Clarified that drift is only relevant to the scope of this paper insofar as it affects the calibration process. Added drift plot and further discussion in supplement section IV. “Drift over this time degrades calibration accuracy, so we powered up the tracker at least 2 hours prior to data collection (supplement §IV.)”
- ⇨ And in supplement: “The present concern for calibration procedures is that the calibration data collection takes a considerable amount of time. If there is any time-dependent error this will undermine the calibration process, so it is necessary for drift to be well less than the desired calibration accuracy. The tested ILEMT tracker (§VIII.E) shows noticeable warmup drift related to temperature rise in the source (Figure 1.) A warmup of 120 minutes is sufficient for the position to stabilize”

Please justify the selected frequencies values (7.5 kHz, 10.5 kHz and 13.5 kHz) used for sinusoidal signals of three different coils.

- ⇨ Clarified that hardware design decisions of the ILEMT tracker are outside the scope of this paper, which concerns EMT calibration in general. “While a detailed discussion of ILEMT design and performance is outside the scope of this paper”

Does the proposed algorithm take the non-orthogonality between source and sensor into account?

- ⇨ Clarified that both default and concentric methods include axis non-orthogonality “Both the default and concentric calibration methods model axis non-orthogonality.” This also implicit in the inclusion of the moment vectors in the §V.C measurement model.

The proposed algorithm was tested for small distance between source and sensor (200 mm). Normally the maximum distance for EMTS used in surgical environmental is 500 mm. Do the authors think their technique can be applied for distance close to 500 mm?

- ⇨ Expanded on the discussion of r/d workspace scaling: “The purpose of calibration is to model whatever combination of source and sensor is chosen. To operate at a longer range a proportionally larger source would be used, preserving the signal-to-noise, with the same r/d ratio giving similar accuracy to the dipole approximation.“

Additional Questions:

1. Is the topic appropriate for publication in these transactions?: Yes

2. Is the topic important to colleagues working in the field?: Yes

1. Is the paper technically sound? If no, why not?: Yes

2. Is the coverage of the topic sufficiently comprehensive and balanced?: Yes

3. How would you describe the technical depth of the paper?: Appropriate for the generally knowledgeable individual Working in the Field or a Related Field

4. How would you rate the technical novelty of the paper?: Somewhat novel

1. How would you rate the overall organization of the paper?: Satisfactory

2. Are the title and abstract satisfactory?: Yes

title and abstract explanation:

3. Is the length of the paper appropriate? If not, recommend how the length of the paper should be amended, including a possible target length for the final manuscript.: Yes

length of the paper recommendation:

4. Are symbols, terms, and concepts adequately defined?: Not always

5. How do you rate the English usage?: Satisfactory

6. Rate the Bibliography?: Satisfactory

1. How would you rate the technical contents of the paper?: good

2. How would you rate the novelty of the paper?: sufficiently novel

3. How would you rate the "literary" presentation of the paper?: mostly accessible

4. How would you rate the appropriateness of this paper for publication in this IEEE Transactions?: good match

If you are suggesting additional references they must be entered in the text box provided. All suggestions must include full bibliographic information plus a DOI.

: I don't suggest additional references

Would you recommend this paper for a Best Paper Award?: No

decision and recommendations