IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION

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January 19th, 1998

Mr. James English
2671 West Broadway, Apt. #8208
Tucson, AZ 85745

Dear Mr. English:

Re: *G97159 - "Measuring and Reducing the Euclidean-Space Effects of Robotic Joint Failures"*

The review of your paper is now complete. Based on the three reviews obtained, please ***Revise and Re-submit*** your paper for an additional round of reviews.

The reviewers made numerous comments. Firstly, all the reviewers share the concern as to how physically meaningful the failure situations considered might be in practice. Reviewer #1 questions how one would know which joint was going to fail (the paper presents algorithms to optimize configurations for the failure of a particular joint). Therefore, the reviewer expresses concerns about the usefulness of the approach in general, if one needs to know which joint would fail for the approach to be used.

Reviewer #4, while emphasizing the rigor of the analysis, raises serious concern about whether the premise of the paper (the type of joint failures in the problem statement) is realistic and whether these types of failures are likely to really occur in a practical system. The reviewer provides practical examples to support his objection. He also suggests that the paper would be more worthy of publication if you could provide practical evidence of the existence of the types of failures the analysis considers.

The revised version of the paper should be sent to me within two months from the day you receive this letter. The revision must be accompanied by a statement in reply to the reviewers' comments (specifically the concerns of Reviewer #4, regarding the practical existence of sensor faults of the type considered in the paper) that will indicate clearly, in point form, how each of the comments has been addressed. If you can not complete the revision within the time allocated, you may submit the revised paper to the Editor-in-Chief (7 copies) as a new submission indicating the previous number of the paper. The revised paper will be assigned a new number for a new cycle of reviews.

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G97159

Should you have any related concern, do not hesitate to contact me.

Sincerely,

Andrew Goldenberg
Editor

copy: Dr. Richard Volz, Editor-in-Chief
Associate Editor

encl. 3 reviews

MMENTS TO AUTHORS

Referee Code 1

Paper Number G97159

Author English

Title **Measuring and Reducing the Euclidean-Space Effects of Robotic Joint Failures**

Paper: G97159
Title: Measuring and Reducing the Euclidean-Space Effects of Robotic Joint Failures
Authors: English and Maciejewski

The authors present a Euclidean distance measure between two manipulator configurations, and propose to use this measure to minimize the possible damage due to joint failures.

comments:

- The authors spend a large amount of effort explaining how one can analytically compute the derivatives of the measure they introduced. However, in the examples, they do not indicate in any way why this derivative information is needed. Is it used to optimize the manipulator configuration using some kind of gradient descent method? If so, how does one deal with the local minima that exist?

- The authors suggest that one can optimize the configuration of a redundant manipulator to minimize the chance for damage after a joint failure occurs. However, they only provide examples in which the configuration is optimized for a failure in a *particular* joint. This seems to be an unlikely scenario; in general, one does not know in advance which joint is going to fail, so that one cannot optimize the configuration for a failure in the unknown joint either.

This raises some concern about the usefulness of the proposed approach. Can one globally optimize the configuration of the manipulator for arbitrary joint failures? That is, can one determine a configuration for which the post-failure configuration deviates minimally from the pre-failure configuration regardless of which joint fails? If so, how good is the performance under global optimization, i.e. how much deviation should one expect between the manipulator configuration before and after an arbitrary failure (worst case and average)? If not, is the proposed measure still useful then? (why would I want to optimize the failure tolerance of a particular joint if it is really detrimental to the failure tolerance of all the other joints?). I feel that this is a very important issue that is currently not addressed in the paper.

minor comments:

- define the convention of DH parameters before it is first used on page 3.

- Could the authors please give us an estimate of the computational cost of the proposed method?

COMMENTS TO AUTHORS

Referee Code 3

Paper Number G 97159

Author English

Title **Measuring and Reducing the Euclidean-Space Effects of Robotic Joint Failures**

1. Please do not leave significant information in the figure captions. If you need more space, reduce the SIZE of the figures (they do not need to be as large as they are now.) As an example, the first paragraph in the intro refers to Fig. 1 and only states that "the joint error is an imprecise measure of the effect of the failure..." the figure 1 caption adds that "the robot ... ... extensive arm and endeffector displacement..." after a failure. This information would be better placed in the text of the intro to explain why the joint error is imprecise. The statement in the figure 1 caption beginning with "This article presents...." should definitely go in the introduction (end of 1st paragraph?).
2. In the final configuration of your paper, make sure the figures are close to the references in the text.
3. In Section I, Para. 3, you have the phrase "...possibly in conjunction with other recovery methods." Do you have any suggestions for these methods or references? Please add references or an example method.
4. In Section VA, why is an L-shaped object used? Does this represent something or provide more useful information? Please explain briefly in the text.
5. In Section VA after eq. 37, what is the "gradient projection technique"? Are you referring to the calculation of the gradients discussed earlier in the paper or some other (common?) technique? If you are referring to Section IIC or Section IVC, please state that: "... the gradient projection technique presented earlier in Section __." If you are referring to some other method please add a reference.
6. In Section VA in the next paragraph after eq. 37, the wording in the sentences after the one beginning "The errors in the object..." becomes a little burdensome. Please reword. For example, "Figure 6 shows the errors in the object caused by a 0.1 radian error in joints two through five respectively using the best and worst robot configurations. The improvement, using the best configuration, for the joint two and joint five failures is especially substantial, but improvement is evident in all cases. If a calibration type failure was experienced in one of these joints,...."

Paper No: G97 159 Rev. #3.

Comments to Authors (p. 2)

7. At the end of the same paragraph referred to in #6, you state "as would be the case if the error value were not well known or not stable," what does it mean for a fixed $\tilde{q}_i$ (which you are assuming for this example) to be unstable? Your parenthetical comment was confusing. Perhaps it would be less so if you simply removed the "or not stable."

8. In the next paragraph of Section VA, you state "..., for static $\tilde{q}_i$, o_1 and o_n are static once the hand is fixed." First, is o_1 affected by the hand position at all? Second, instead of using "static" just state that "...o_1 and o_n do not change...." In the next sentence, what do you mean by "...where the focus is on a single object in the last frame"? Do you maybe mean "...where the focus is on the error induced on a single object located in the last frame"? Please explain this more fully in the text.

9. In the first sentence of the next paragraph of Section VA (para. #5), instead of the word "using" in the phrase "This technique of using a fixed $\tilde{q}_i$..." I think the word "assuming" would be better. In the last sentence of this same paragraph, put the focus on the "optimally configured" as in:
"If the ... cutoff value ... were set to 0.1 radians and the manipulator maintained an optimal configuration, it is clear from Fig. 6 that the L-shaped object would be less exposed to collision-induced damage [as its deviation from its desired position would be minimized]."

10. In the third paragraph of Section VB, switch the best & worst case sentences (the ones stating "...kinematically equivalent to translating...") so that the statement "this reduced motion" in the next sentence makes sense. (This would, of course, mean moving the "in contrast.")

11. Please explain what you mean by the statement in the third paragraph of Section II which says "this implies minimizing a single-object-based measure... cannot, in general, resolve redundancy...." Is this bad? Does this imply that the measures are not useful? From the rest of the example, it looks like this may actually be a good thing in that it leaves some redundancy for other tasks. Maybe you meant instead "...this implies minimizing a single-object-based measure... does not need to utilize all of the available redundancy for manipulators with more than 1 DOF"?

Paper No: G97159 Rev. #3.

Comments to Authors (p.3)

12. For the last sentence in Section VI, please add references in regards to these other desirable criteria. (Arati S. Deo's work on using redundancy to minimize velocity errors in 1993 ICRA Vol 3, p 388, others?)

13 Reference your work in ICRA 97 held in Albuquerque, N.M!

Minor changes:

1. 1st paragraph, Section I, combine sentences beginning "Errors may involve..." and "But it is typical..." by separating with a comma.
2. 2nd paragraph, Section I, remove the comma after the reference [6].
3. 3rd paragraph, Section I, add commas around the phrase "in general" in the 1st sentence. (I read it as "general functions" the first time.)
4. 2nd paragraph, Section II, add a comma after "Euclidean distance" in the last sentence.
5. 3rd paragraph, Section II, add a comma after the "then" which starts the 2nd sentence.
6. 1st paragraph, Section III, change "point error squared" in the last sentence to "square of the point error".
7. After equation 32, put a period instead of a comma.

Review: IEEE Transactions on Robotics and Automation
Paper number: G97159
Title: "Measuring and Reducing the Euclidean-Space Effects of Robotics Joint Failures"
Authors: English and Maciejewski

Comments to Authors (referee code 4)

This presentation appears to be a rigorous analysis, consistent with the high quality work I expect from Maciejewski. The presentation looks fine (though I will not claim to have verified the derivations) and the graphics are illustrative and attractive. Unfortunately, the premise is not credible. The paper focuses on accommodating failures of the form where a joint-angle sensor has lost its "home" position but otherwise continues to function. I believe the analysis presented does follow from the assumption, but I have trouble with the assumption. It seems too much like a problem asserted for the sake of the math that applies to it, rather than motivated by a reality.

Personally, I've never seen this type of failure and it is hard to imagine how it could occur. In a resolver, positioning is absolute; if one had a broken wire, one would get complete failure of the sensor, not merely a home-angle displacement. For an encoder, position measurements are relative. If counts get missed, they will continue to be missed, resulting in a continually drifting apparent home angle—not a permanent offset. For a transmission to slip by a significant amount, it would have to shear off gear teeth, resulting in joint lock-up.

While I have difficulty with the assumption (a pure joint-sensor offset), even if such a situation somehow occurred, it would make sense to identify the offset(s) and update the robot kinematics, rather than continue to operate with the uncertainty. There are many methods for doing so without having to remove the robot from its operational environment. It would certainly be more dangerous to continue to operate the robot with a known kinematic error than to pause and reset the joint offsets.

If the authors can include any documented evidence of their proposed type of failure for realistic (e.g., industrial) robot designs and the conditions under which it would make sense to utilize their approach, I would be more supportive of publication. As the paper stands, it seems to be merely an exercise in curiosity and mathematical manipulation.