Tracking Number 56538

Dear Dr. Campbell,

Once again, we would like to thank the Associate Editor and the reviewers for the time they devoted to reading the manuscript and pointing out issues that needed clarification.

In response to your and their comments we have shortened the proofs in the appendix and now each proof fits in one page. The current appendix includes four pages of derivations (rather than eight) and represents 15% of the manuscript (rather than 25%). We have also removed some of the equations in the main body, shortening the revised manuscript by one additional page. As a result, the manuscript is now 27 pages long (rather than 32), and has a total of 59 numbered equations (rather than 81).

It is our opinion that further cuts, either in the main body or in the appendices, would compromise the rigor and clarity of the exposition. In fact, the current proofs in the manuscript are already hard to follow, as many technical details are now missing. While we agree that experimentation is crucial to validate the developed algorithms, we also think that theoretical derivations are critical to understand both their advantages and limitations.

In what follows we attach our response to each of the reviewers. Thank you for your consideration of our work.

Sincerely,

Enric Xargay

1 Response to the first reviewer

1. *"In the paragraph below Eqn (10), the authors stated that the "graph can fail to be connected for the entire duration of the mission". If the graph is disconnected during the entire interval, the smallest eigenvalue of matrix QLQ is always zero during* $[t,\ t+T]$ *and Eqn (10) is not valid for* $\mu > 0$*. Therefore, in order to guarantee the validity of Eqn (10), the network should be connected at some point."*

   RE: Eqn. (8) of the revised manuscript (which corresponds to Eqn. (10) in the previous submission) **can be satisfied even if the graph is disconnected during the entire mission**. While it is true that, in this case, the minimum eigenvalue of $QL(t)Q^\top$ is zero for all t, it is not necessarily true that the integral of that expression over a finite interval cannot be bounded away from zero as in Eqn. (8) of the revised manuscript. For example, consider the following two Laplacians (corresponding to two disconnected graphs):

   $$L_1 = \begin{bmatrix} 1 & -1 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \qquad L_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{bmatrix}.$$

   It is easy to show that

   $$\frac{1}{T}\left(\int_t^{t+\frac{T}{2}} Q_3 L_1 Q_3^\top d\tau \ + \ \int_{t+\frac{T}{2}}^{t+T} Q_3 L_2 Q_3^\top d\tau\right) \geq \frac{1}{2}\mathbb{I}_2\,, \qquad \forall\, t\,.$$

   We note that a *necessary* condition for Eqn. (8) to hold is that the union of graphs over every interval T be connected.

2. *"If the authors agree with me that the network should be connected at some point during the interval, how do they guarantee this condition in the real test? The authors did not clearly state the physical reason causing the disconnection in communication. Is that because of communication range, rate or something else? What the approximate* μ *number in the real test?"*

   RE: As shown in point 1, **the network does not need to be connected pointwise in time**. Loss of connectivity can be caused by various factors including jammers, erroneous orientation of communication antennas, architecture of the network infrastructure experiencing routing collisions, etc; however, no assumptions are made on the cause of the connectivity losses. The technology used in the flight experimentation demonstrates values of μ in the order of 0.85 ($T = 2$ s) for air-to-air communications, provided that all UAVs stay within the communication range.

3. *"In proof of Lemma 3, the authors stated that* $\bar{L}(t)$ *is continuous. As* $\bar{L}(t) = QL(t)Q^\top$ *and the off-diagonal elements in* $L(t)$ *is represented by binary variables 0 or 1 to indicate the connectivity relationship, therefore for a time varying network, off-diagonal elements in* $L(t)$ *are switching*

between 0 and 1, which causes $\bar{L}(t)$ to be discontinuous. If $\bar{L}(t)$ is discontinuous, will proof of Lemma 3 still be correct?"

RE: We do **not** say that $\bar{L}(t)$ is continuous. We say that "$\bar{L}(t)$ is continuous for almost all $t \geq 0$", meaning that there are at most a countable number of finite discontinuities in any time interval.

4. *"The flight test with two UAVs is the simplest network example, is the proposed algorithm applicable to more challenging missions with more UAVs included? If real test is hard to be implemented with larger networks, can authors use virtual simulation to validate the scale of this approach?"*

   RE: First of all, we note that the experiments include two UAVs and a virtual target vehicle running along the sensor path, which implies a network of three agents. This is described in detail in Section VI of the manuscript. So, yes, it is possible to use virtual simulation to validate the approach for larger networks. For the cooperative road search described in the manuscript, we considered that a mission involving two UAVs equipped with vision sensors and a virtual vehicle on the sensor path was, first, a realistic scenario and, second, complex enough to show the benefits of the cooperative algorithms developed. Nevertheless, as shown in the theoretical part of our work, the cooperative algorithms are applicable to missions involving more autonomous vehicles.

5. *"In the last paragraph of pg. 21, the authors stated that the new method outperforms the traditional waypoint navigation method. Is there any comparative simulation or test data to validate this statement?"*

   RE: Commercial autopilots implement the basic "go-to-point" control law together with either line-of-sight (LOS) control or cross-track error control. These waypoint navigation methods are based on straight path segments and cannot guarantee zero steady-state error for paths with nonzero curvature. Papoulias showed this for LOS control methods [1].

2 Response to the second reviewer

"I still feel that the paper is overly long and complicated. There are still 81 equations in each and I cannot tell at all what of these have been edited or reduced. ... the main point of my comment on length was the derivations. Do we really want to have a JGCD paper where 25% of the paper is an appendix of derivations? I think this is a problem..."

RE: We have shortened the proofs in the appendix and now each proof fits on one page. So we have now 4 pages of derivations (rather than 8) and the appendix represents now a 15% of the manuscript. We have also removed some of the equations in the main body, shortening the revised manuscript by one additional page. As a result, the manuscript is now 27 pages long (rather than 32), and has a total of 59 numbered equations (rather than 81). In our opinion, further cuts would compromise the rigor of the exposition.

References

[1] Fotis A. Papoulias. Stability considerations of guidance and control laws for autonomous underwater vehicles in the horizontal plane. In *International Symposium on Unmanned Untethered Vehicle Technology*, pages 140–158, Durham, NH, September 1991.