Reviewer 2 of CASE, ISAM 2016 submission 5 Comments to the author ======================

This paper aims to control the torque and position of an object using a swarm of robots directed with a global signal. To close the control loop, they continuously update a point towards which the robots should move, and measure the resulting variance and position of the swarm, as well as the objects state. If the position variance of the swarm is too large, the swarm regroups in a corner of the arena. The update of the global goal position continues until the object is in the correct location and with the correct orientation. The work is interesting, and could provide helpful insight into the control of large swarms of robots. The main novelty here, compared to previous work by the authors, is in torque control. However, it feels like too many "ideas of algorithms" are given without the necessary vetting.

More data than algorithm.

For example, it's unclear from the paper if the simulation environment accounts for the large levels of noise in the kilobots, or nanoparticle systems on which the technology aims to be used.

Future Work: doing this with kilobots: lots of noise

If this is in fact taken into account, and there is some element of stochasticity in the system, then it's unclear how many trials were done for each simulation.

Should we add noise? For the kilobots we should definitely do the experiments more than some number.

Likewise, does this approach work for any type of swarm, torque, or object?

Clear it up: What kind of objects are we aiming for?

Further understanding of the limitations of the approach would have been helpful.

Clear it up: What are the limitations?

The biomedical reasoning, although appealing, is not quite grounded in reality.

Are we really going toward a biological application?

It would help to add a reference for how this approach could realistically be used with nanoparticles. The control of microsystems for manufacturing, or robot swarms, seems more realistic.

Seems true.

There are many typos and words missing that sometimes make it difficult to understand the text. Only two experiments were done in reality, and it's unclear if they were successful. It's also unclear from the text and the video if closed-loop control was used, or the lights were just set manually.

Should we use our new closed-loop control data for here?

Overall, I feel like less algorithms, and a more thorough analysis of the results in simulation and realty, would have been more helpful.

Comments on the Video =====================

The simulated results are well presented. In the case of the experimental results however, it's unclear what control is being exerted on the robots. This looks very much like a manually driven sequence of light patterns. Kilobot experiments are unclear.

Reviewer 3 of CASE, ISAM 2016 submission 5 Comments to the author ====================== This paper address an important issue in controlling swarms with a single global input that is object manipulation. I believe that swarms present an attractive solution for the problem of moving objects in very small-scale environments. Deployment of and manipulation by larger single magnetic (or other) micro-nano robots is difficult. Thus swarms are naturally suited when considering micro to nano robots which are fabricated and deployed in bulk, and where it may not be possible to track and control individual robots. A swarm would be tracked using bulk methods such as fluorescent markers and controlled in bulk using a global input such as a magnetic field. In this light, the general topic of object manipulation by swarms is a relevant one, and if showed practically, would have large implications over several fields. The paper is clear and well written, although the technical contributions are rather limited. The techniques and algorithms presented are rather straightforward and there is not much theoretical insight into the performance of given approaches.

Add theory?

Some simulated results are shown, but are somewhat simplistic while the experiment shown on the kilobots does not bring much but confirm a fairly obvious claim.

The first challenge is an easy one.

Some specific comments on the paper:

-In the introduction, you mention that "Torque control is also necessary for a variety of alignment tasks... targeted radiation therapy." If so, can you provide references that should back this up?

-In equation (4), why is the desired average velocity 0?

- In Fig. 2 (what are the yellow dots? I'm guessing the optimal C-position is a function of the swarm size relative to the object size. Because this result should be a stochastic one, was this simulated in a Monte-Carlo fashion? If so, the statistics should be mentioned. If not, this result is quite limited.

- In Fig. 3 what do the red, green and black lines show?

- Equation (7), this is assuming translation in the x direction with the object's major axis mostly in the y-direction? Can this be written in an orientation independent way? How do you choose the proportional gains?

- The experiment section is very qualitative. I understand that it is difficult to produce experimental results using swarms but this section does little to validate what's shown in the paper other than you don't want your swarm located at the tip of the slender object for obvious reasons.

- Conclusion: you showed some methods to move a long rectangular object on straight lines. How does this generalize to different shape objects? How does this generalize to more complicated manipulation tasks than moving an object to a desired position and orientation? Comments on the Video ===================== The video is a useful addition to visualize the simulations and experiment.

Reviewer 4 of CASE, ISAM 2016 submission 5 Comments to the author ====================== This work presents controllers and algorithms for steering under-actuated swarm to manipulate objects. The work is novel. It could have great potential in several applications where centralised hierarchical control architecture guides a swarm robots with no on-board processing capabilities. The presentation of the paper is top notch and the technical soundness also very good. The paper presents both simulation and experimental results. The reviewer has some minor comments:

1. The authors mention micro and nano applications for targeted drug delivery. The reviewer is aware of several works in this filed and all of them make use of ferromagnetic or paramagnetic particles. In that case the particles exhibit particle-particle interaction forces. Would the proposed technique be valid in this case? Would it be possible to control the variance and the mean value of the swarm if the they are governed by electromagnetic forces and are subject to aggregation effects?

A truly nice challenge to think about.

2) In Eq. (5) the parameter O\_theta is not explained (it is explained in the following figure). The author should make an earlier reference to this parameter.

3) It would be interesting to investigate if this system could become more controllable when non-linearities are introduced. For example quadratic drag forces or contact friction.

4) It would be very interesting to see in future work more simulations/experiments demonstrating manipulation of objects of different geometries. Comments on the Video ===================== The video is very descriptive well presented and the results are in accordance with the theoretical and simulation work.