*Reviewer(s)' Comments to Author:*

*Reviewer: 1*

*Comments to the Author*

*This paper discusses an autonomous object manipulation algorithm using a soft planar grasping manipulator.*

*Several major issues with the paper hold it back. First, the contribution of the paper seems very minor. A considerable amount of the paper is already covered in the work from [12-14], which involves the design of the robot, the recipe to create the robot, and the whole-arm motion planning. The contribution of this work is the grasping algorithm itself, which is a preplanned sequence of robot curvatures. In light of the whole arm motion planner in [12], this contribution seems minor when adding in a (circular) object.  The algorithm itself is implemented as a state-machine method, and with 4 or 5 states and seems trivial. Only one experimental test is performed to demonstrate the algorithm, and no quantitative error metrics are provided.*

**The contribution of this paper is to show that we can create an autonomous system for object manipulation using only soft components to build the manipulator.**

**TODO: Show this more clearly in the introduction section and cut back on the other claims in the intro.**

*For these reasons and especially for the minor contribution that this manuscript offers, I cannot recommend publication as a journal paper in SoRo. The contribution seems better suited for a conference paper submission.*

**We argue that the contribution of successfully and repeatedly performing object manipulation using a fully-soft, multiple degree of freedom arm is considered novel and is viewed as a feasibility study that this direction can further be explored for more sophisticated soft manipulators to do manipulation.**

*Specifics:*

*- With a motion-capture system, the problem becomes entirely well-defined.*

*However, soft robotics are specifically designed to work in confined or constrained environments where constraints and obstacles are unknown, with often no line of sight. Discuss how one might actually implement this without a motion-capture system that picks up the entire configuration of the robot manipulator.*

**Why does soft robotics systems need to specifically be designed for confined or constrained environments only? How is the use of motion capture systems a well-defined problem and how is it such especially in conjunction with soft robotics? Have others done it before, do you have a reference on this?**

**Manipulation in the proximity of humans or other machines does not mean that a vision system can not be explored. It is just a metric of how many redundant cameras are placed around the workspace to deal with increasingly cluttered environments. We don’t claim that our vision-based system is made specifically for a cluttered environment. Industrial pick and place tasks or grasping of objects out of bins is feasible to be done with cameras. At least for just the tip of the manipulator, the pleated gripper, we shown in a conference publication first steps towards how the exteroceptive sensing can be replaced by proprioceptive sensing using a resistive bend sensor (TODO Reference to BAXTER Paper)**

*Section 1.1 Last paragraph: “was only suitable for contactless motion” implies that your proposed method solved motion when the robot is constrained by the environment, but it is rather about gripping objects.*

**TODO: Read that sentence again and try to understand what this comment means**

*Section 1.2 Contribution 1 seems entirely described in [12] and [13]. Contribution 4 seems obvious that force sensing nor accurate positioning is required to manipulate objects (as discussed in [21]).*

**Say why contribution 1 is not described in 12 and 13**

*Section 2. System overview, Figure 2: The image is difficult to see and in its current form, and information of the physical frame surrounding the robot seems unnecessary.*

**We would like to ask you for a more constructive comment on how to improve this figure, is it blurry, shall we zoom further in or show several close up views? Did the video help to show the system’s setup? The system we show is a prototype that is on a cart, allowing it to be moved around and demonstrated anyplace. We do not claim that the complete cart setup is optimal in any way, we are merely demonstrating the ability of autonomously performing manipulation with a soft manipulator. The vision system could be installed in many other ways, not requiring the beams on its sides. Also, the computers underneath the cart are symptomatic to the fact of the system being a prototype, the algorithms can as easily run on embedded hardware as well as the driving cylinders can be arranged in a compact form nearby the root of the manipulator arm.**

*Section 3.1-3.2 These sections are completely described in [13] and comes off as a recipe to make the manipulator, which is the contribution of [13], and therefore should not be reproduced in the main text. Figure 4 and Table 1. Pulled from [13] seem unnecessary. Furthermore Table 1 does not fit the column.*

**Reference 13 does not describe all the specifics of making this manipulator for the manipulator application, we made accordingly adjustments in the text to discuss the points necessary to allow the reader to reproduce the system while avoiding to give a general recipe.**

*Section 4.2 par 1., Which motion tracker was used?*

**The OpTrack System, it is references here: …. TODO find it**

*Section 4.2 The optimization equation, as I eventually found hidden in Algorithm 1, is difficult to understand: what are parameters v.s. variables, and what is R in the objective function? I suggest writing the equation in the text in full.*

**We placed the optimization equation into the text to find it easier. A parameter is usually fixed for a given setup and a variable is continuously changing as a system changes its state. R in the objective function is the Radius (TODO double check this)**

*I also find it difficult to see exactly the difference between the algorithm presented here and the one in [12]. While grasping is indeed is one objective, that seems to be realized by a curvature objective.*

**I don’t see how a “curvature objective” can solve trivially for a “ grasping objective”. Has that been proven anywhere before? The algorithm in [12] is merely moving a soft arm without a gripper through a maze at a centerline while taking the arms bulging shape as a trapezoidal into account. That does not work for approaching objects with the manipulator including a gripper, because a tip trajectory for successfully moving towards the object is not known, but needs to be generated. That trajectory needs to avoid pushing the object away with the manipulator trunk when approaching it with the soft gripper at its end. When approaching an object, we propose a new approach of following along concentric lines, which are further and further decreasing in size until object size is achieved. The non-linear optimization is finding tangent poses along these lines using non-linear optimization and then follows down those concentric lines, which implicitly guarantees the arms pose to stay convex – since the circles are convex themselves.**

*Section 4.2 Is the optimization function over or underconstrained? Will you always find a solution? What happens if you don’t find a solution?*

**The optimization function is only over-constrained, if we are having to achieve a pose outside of the reachable workspace. Othersie it is well-constrained. The system optimizes for the quadratic cost of having high curvatures. A solution is only not found if the target object pose is not within the reachable workspace of the arm, that means of the object was placed by the user outside of the workspace. The arm’s workspace can easily be calculated as this:**

**We’ve added this formula to the paper. This workspace check is performed before doing any further calculations.**

*Section 4.2 par 1., Provide the speed of the optimization solver as well as the solver used.*

**Speed of the optimization is in average:**

**Solver used is:**

*Section 4.2 par1. “…while its nullspace maintains a convex shape, bending away from the object”. Is the convexity actually a hard constraint on the solver? How much does this depend on your specific task and the orientation of the arm/gripper combo?*

**When solving for a tangent gripper pose in CCW direction along a concentric circle, this is automatically the constraint for convexity.**

*Section 4.3 The text describing Algorithm 1 would be well suited to have numbered sections that could help the reader understand at which location in the Algorithm the text is referring to.*

**TODO: Add numbered sections to the text and refer to those in the text**

*Section 5.2 What is the object weight? What is the object radius?*

**The object weight is Yg and its radius is Ycm.**

*Figure 9: What is the time/speed of the task?*

**The time and speed of the task is in average about X seconds long**

*Lack of references (Some covered in DeVolder2010):*

*De Volder, Michaël, and Dominiek Reynaerts. "Pneumatic and hydraulic microactuators: a review." Journal of Micromechanics and microengineering20.4 (2010): 043001.*

*Ikuta, Koji, Hironobu Ichikawa, and Katsuya Suzuki. "Safety-active catheter with multiple-segments driven by micro-hydraulic actuators." Medical Image Computing and Computer-Assisted Intervention—MICCAI 2002. Springer Berlin Heidelberg, 2002. 182-191.*

*J. Xiao and R. Vatcha, “Real-time adaptive motion planning for a continuum manipulator,” Proc. IROS 2010, pp. 5919–5926, Oct. 2010.*

*J. Li and J. Xiao, “A general formulation and approach to constrained, continuum manipulation,” Adv. Robot., no. July 2015, pp. 1–11, 2015.*

*Reviewer: 2*

***Comments to the Author:***

*This paper covers the fabrication and integration of a new soft robot gripper with a six degree of freedom soft multi-segment arm. The paper also describes a planner for grasping using the integrated system as well as some evaluation of grasping efficacy and the gripper workspace.*

*In general, I think the topic is very interesting and the approach valuable. There seems to be a number of practical limitations to the platform and approach that I would like to see addressed or discussed in the paper. The following are specific feedback that I have:*

*-For the third contribution listed on page 2 (line 33), I don't agree that you have characterized some of the uncertainty that is rather important. For example, you have shown for the gripper where it can grab for a single set of trials, but you do not describe repeating those trials, which would actually give you measures of uncertainty. Also, the red box used to denote the "bin" for placing the grasped object is an important measure of uncertainty. It seems like if this arm were to actually be used for manipulation, a good measure of uncertainty on positional accuracy would be important.*

**Look into contribution point**

**Experiments were repeated 5 times using same discretization,**

**Positional accuracy calculate.**

*-For the fourth contribution listed on page 2 (about line 37), I don't believe that you have shown (either experimentally or analytically) that you can manipulate delicate objects. I believe it, but you haven't reported gripper forces or extensive trials with delicate objects. I would either perform those tests or rewrite this contribution. It also isn't clear what is meant by "proper manipulation."*

**To foster claim of delicate objects, controllable gripper force range is described in reference (soft robotics paper), in experiments we grasped filigrane objects like an empty egg with a whole in it. The egg was moved around without cracking.**

**Check out “proper manipulation” sentence**

*-I found the description of the fabrication process for the gripper to be slightly confusing. I think more annotations on figure 3 (such as point 1 or c, etc) and referring to those annotations in the description could make it clearer. Especially since this is listed as a major contribution.*

**Figure 3’s point 1 and c were modified and a note was added to the description in the paper:**

*-Although you reference past papers from your own group, I think you could do a better job distinguishing from your own past work. Can the process for making the gripper be applied to the multi-segments as well? Which is better for what and why?*

**Distinguish from past work: clarify modularity point, Reference figure 9 and 22 in recipes paper**

*-Many limitations of the hardware or approach should be addressed in the paper. I realize that they cannot all be addressed or discussed. Nor am I asking for you to solve these problems, but an effort could be made to talk about the following:*

*1) How would the design of the gripper change if we wanted to grip in both directions? Is it even possible with the current design?*

**Two grippers could be mounted next to each other to allow grasping in two directions**

*2) Is using motion tracking realistic for some of the scenarios you suggest? I would guess not, but what is the future for state estimation? Existing sensors? Or are new sensors needed?*

**Exteroceptive sensing can be replaced by proprioceptive sensing using resistive bend sensors (Reference conference work IROS 2015)**

*3) It requires 6 degrees of freedom to achieve a reasonable reachable work space, how does this scale to a full 6 DoF task? Or does it scale? Is it limited to in-plane tasks? What is the reachable work space in the plane with 6 DoF and the + or - 60 degree joint limit?*

**Reachable workspace is described mathematically by: (describe a mathematical formula to describe the reachable workspace given lengths and curvature change. Reference needs to be found in the continuum manipulator literature)**

**Scaling to a 3-dimensional task is not considered, because current design would not be able to significantly overcome statically the (Reference ICRA paper Andy)**

*4) Why was a convex shape necessary for approaching a grasp? What if I wanted to approach an object with a different orientation but in the same locations you already looked at?*

**The convex shape approach is a conservative solution to guarantee minimal computation required in solving the planning problem while assuring not to collide. (add a guarantee that it does not collide, add a proof to show this)**

*5) What is the role of the rollers in carrying your payload? Without the rollers, could the arm not move the object?*

**The rollers minimize friction to the surface and therefor minimize frictional forces that need to be overcome. Stick-Slip Frction effects would be greatly increased if arm would be run directly on a surface with non-negligible friction coefficient.**

*6) Why did you decide to minimize manipulator deformation for your grasp object planner? Furthermore, what if I wanted my plan to follow the shortest distance for the end effector to travel (essentially following the black line in Figure 6), is this even possible given the possible kinematics of the arm?*

**Minimized manipulator deformation is a feasible approach, because it is proportional to energy consumed by cylindrical piston drives and it minimizes strain to the actuators and minimizes risk of exerting further than actuation limit of a segment.**

*- Overall the paper is well-written, but there are some places with awkward or incorrect grammar.*

*Examples include*

*1)pg 2 line 37 "soft robots do neither require force sensing nor accurate ...";*

*2)pg 3 line 23 "Those seams are prone to rupture ..." refers to the laminated seams, but that isn't clear from phrasing;*

*3)pg 7 line 21 "newly registers every single time the position of the placed object." is confusing.*

*-The paper should definitely include a video of operation of the arm. The overlaid figures are very well done, but video would be a valuable contribution to understanding the performance of the system, especially since we have no other time dependent graphs of end effector or joint position.*

**Video will be attached again to the revised version of the paper.**

*-Table 1 needs to be formatted to stay in column*

**Adjust formatting**

*-I feel like many variables could be more clearly defined. Things such as L\_meas, phi, g\_off (described in algorithm, but still not clear where measured from), w\_off, L\_N, kappa (in algorithm 1, not clear if current kappa or desired or ...), kappa\_off (defined in algorithm, but not clear again what it was). Some of these terms are on the diagram in Figure 6, but their definition was still not clear to me. This was especially the case since I'm not sure what the multiple green circles on each concentric circle signified. Some terms were also used but not clearly such as "minimal tip transit distance"*

**Add a more xplicit description of the variable names into the document**

**Describe multiple green circles as the iterations the algorithm takes until break off criteria is reached.**

**Fix Minimal Tip Transit distance with a better term**

*-Other items were clearly defined, but it wasn't clear how their value was set such as delta d.*

**Describe how value for delta d was set**

*-In Section 4.2, what does it mean for an "object to settle?"*

**object settling is defined that the object position has not changed within epsilon for T time.**

*-the forwKin procedure in algorithm 1 seemed a bit odd. It is recursive and requires calculating the forward kinematics of the previous link, all the way back to the base. That is fine, but the way it is defined, this would happen every time we step forward one link. Is that correct? Why not just use a for loop to be less confusing to a reader and more efficient computationally?*

**Look at forwKin procedure and see how it can be clarified better and why it is an ok implementation as is.**

*-Discussion of picking up eggs in section 5.1 is a bit out of place. Was actual testing done for this? Actually reporting grip forces or pressure would be much more interesting.*

**Picking up eggs just as one example for delicate manipulation, make that clear. Sa that picking up thin shelled, delicate objects was tested.**

**Add gripping forces and pressures are added to describe gripper capability.**

*-For the trial shown in Figure 7, what was the uncertainty on the user placement of the object? This seems like it could be rather large (compared to the resolution of the discrete placement locations) unless you used the motion capture system somehow.*

**The placement by the user was accurate within +-2mm in relation to the discrete placement locations. This test mainly serves as a qualitative measure to show a relation between object size to gripper size to area of successful grasp.**

*-How was an appropriate size determined for the red "bin" to determine success? It looks like the spread on placement was about 15 cm. That seems rather large and some commentary on it seems important.*

**The red bin is a rectangle that was fit around the final motion after the experiments run to indicate the range wherein the objects were dropped. In the algorithmic implementation of the move to home, there was no effort spend on having the manipulator reach the fully extended pose more accurately than +-Xmm circle diameter.**

*-The discussion in section 5.2 led me to have the following questions/comments:*

*1) What if the object is not round?*

**Picking up other objects that have a similar size compared to the round test object does also work. TODO We tested eggs, squares, stars…**

*2) What is the importance of the rate that way points are sent from the planner? Especially failure trials where the arm went unstable seemed to indicate that both the controller and planner may be very dependent on smoothing the desired curvature way points or sending them slowly in time. More detail would be good.*

**A new waypoint is sent to the controller immediately after arriving within delta epsilon of the previous waypoint, the controllers for each arm segment then compensate for the new delta in angle as quickly as possible to the new pose. That is the PD controller. Smoothing of the trajectory with several intermediate waypoints was found to be necessary. For the given workspace of the arm, we found X intermediate waypoints to be w orking solution.**

*3) The instability in general seems important and would be nice if it was determined if it was from the planner or controller.*

**TODO: Look at video and describe: The instability was identified to come from stick slip friction to the ground, given a roller ball contact that is not continuously smooth. If a segment gets a little bit stuck on the ground, the moment it releases, the soft body releases like a spring and can cause an overshoot which the controller has to again compensate.**

**Another source of failure is when a marker along the arm gets occluded or merges with an adjacent marker, causing the tracking system loose track of a measured arm segment temporarily and therefore causing the control loop to not close properly.**

*-Discussion in conclusion refers to high dexterity when handling delicate objects. However, all of your tests showed approaching the object from more or less the same direction. Do you have a kinematic model or experimental data that shows your manipulator's dexterous workspace? This is similar to a previous comment above.*

**Remove high dexterity and describe how widely the arm can be stretched in its various poses to approach the same object.**

**ToDo: Add video of 3d arm going through maze?**