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Parallel Self-Assembly of Polyominoes under Uniform Control Inputs

Dear Professor Antonio Bicchi,

Please find attached the revised paper, **Parallel Self-Assembly of Polyominoes under Uniform Control Inputs** (submission ID 17-0266) along with the document containing response to the reviewers. We are grateful to the reviewers for helping us in improving our manuscript through their comments and questions, which lead to major revisions of the paper. Please let us know if further information is required.

Sincerely,



Aaron T Becker (on behalf of all the authors)

**Response to Reviewers**

In the following document, we’ve provided detailed responses to the comments and questions of the reviewers. Comments and questions by reviewers are in blue, our responses are in black.

**Comments by Reviewer 1**

*[R1 C1] [major comment : clarity of presentation] The introduction of the each equation is not clear. Especially, equation (3)-(8), (10)-(13).*

Text was added in order to introduce each equation more clearly.

*[R1 C2] The method of the simulation or the experiment are not clearly described in chapter II –V, respectively.*

The text describing the simulation chapter II and the experiment chapter V was modified. We believe that these descriptions are now clearer.

“Add relevant text here”

*[R1 C3] What is the difference about perfectly closed loop, open loop and partially closed loop?*

The open loop uses no feedback about the position of the sphere.

In the partially closed loop, the impact of the sphere is detected and sent to the controller. The controller can therefore switch the magnetic gradient direction as soon as the impact is detected.

The perfectly closed loop assumes a theoretical sensor able to measure the position of the sphere at any time. It is capable to detect the impact of the sphere as well as the change of direction on the posterior side. The controller is therefore able to change the direction of the gradient when the impact is detected and when the change of direction on the posterior side is detected.

The text was modified in the paper to describe more clearly these three different sensing methods.

“Add relevant text here”

*[R1 C4] What is the meaning of the following sentences “This is equivalent to a perfectly closed-loop system where the gradient signal switches direction when the sphere switches direction.”. Why?*

The text, with the previous sentence was: “To maximize the average impact velocity over an arbitrary *n* number of contacts, the input magnetic gradient should always be in the same direction as the motion of the sphere. This is equivalent to a perfectly closed-loop system where the gradient signal switches direction when the sphere switches direction.”

The authors want here to explain that, in the theoretical computation, the perfectly closed loop is simulated by applying a magnetic gradient oriented in the same direction of the sphere velocity.

This text has been reformulated as follow for more clarity:

“In the perfectly closed loop system, the magnetic gradient direction is changed when the sphere hits the impact plate and when the spring reaches full compression. These two moments also corresponds to the two changes in the sphere movement direction. In addition, to maximize the impact velocity, the magnetic force, and therefore, the magnetic gradient, are oriented in the same direction as the sphere velocity vector. In the simulations, the sphere will naturally change direction after impact and after the full compression of the spring. The perfectly closed loop system can, indeed, be easily modeled by applying a magnetic gradient in the same direction as the sphere velocity.”

*[R1 C5] [major comment : thoroughness of results] The method and result (especially, experiment part) does not support your concept enough. The further implementation is needed to demonstrate your idea about magnetic hammer.*

Additional experiments were performed and the robot prototype was able to penetrate a lamb brain sample. A section was added in the paper to describe this experiments and the obtained results.

*[R1 C6] [minor comment : clarity of presentation] There are many abbreviation, which is not introduced (ODE, FEMM, etc).*

All the abbreviations in the paper were defined.

*[R1 C7] What is desktop the experiments?*

The authors made the experiments in a small scale magnetic setup in order to reduce the costs associated with the use of a medical MRI scanner. The authors agree that “desktop experiment” is not appropriate to describe this experimental setup. The term desktop experiment was replaced by “magnetic test bench”.

**Comments by Reviewer 2**

*[R2 C1] Explain the derivation of equation (2)*

The mathematical equations were entered into the software Mathematica and this software was used to analytically calculate the impact velocity at the resonance frequency. It was added in the paper that this equation was solved using Mathematica.

*[R2 C2] Clarify whether the rotation of the sphere is modeled in the dynamic simulation*

To the coauthors: I am thinking that we should maybe remove the sphere rotation. We mow use magnets in the experiments to have more force. The sphere cannot rotate because the magnet is oriented along the magnetic field. (Aaron: I agree)

*[R2 C3] State how the simulation was implemented, whether in a simulation software such as Simulink/Simscape, or coded by the authors, or otherwise.*

More details was added about the implementation of the simulations. The theoretical analytical calculations were performed with the software Mathematica. The numerical computations were performed using the software Matlab.

*[R2 C4] Fix P.5 right side "show that and that" error*

This was corrected.

*[R2 C5] Give the supplier and specifications of the "Syren 25" power supply.*

These data were added: “Each coil is powered by a Syren 25 regenerative switching power supply. The Syren 25 are manufactured by Dimension Engineering. They can provide continuously a current of 25 A with a maximum voltage of 24 V.”

*[R2 C6] Section V: Explain why MRI gradient frequencies other that 2 Hz were not applied as in simulation*

The use of clinical MRI scanner is costly and the authors preferred to perform more experiments on the magnetic test bench.

*[R2 C7] Add discussion and modeling of the effects of air resistance on the motion of the sphere in the tube.*

A discussion about the modeling of the air friction was added in the conclusion.

*[R2 C8]* *What is the diameter, mass, and magnetization of the magnet used?*

The sphere is a NdFeB magnet with a magnetization of 883,000 A/m. The diameter is 6.35 mm and its mass is 1.05g. This information was added in the paper.

*[R2 C9] How were the dimensions and other parameters of the device selected?*

*Was any optimization procedure used in the design?*

The dimensions were selected in order to make the prototyping easy and possible with commercially available materials (standard tube, standard sphere, and standard spring size). No optimization was made. This is a relevant line of research for future work.

**Comments by Reviewer 3**

*[R3 C1] [Minor points] The clear purpose of this study should be described in Abstract and Introduction.*

The purpose of this study was added in the Abstract and in the Introduction.

“Add relevant text here”

**Other modifications:**

[M1]Section IV.C “Effect of friction” was removed. This section considered that the sphere was rolling inside the tube. Our latest experiments use a permanent magnet sphere. The sphere can therefore no longer roll. In addition, our observations during tests performed inside an MRI scanner concluded that a ferromagnetic sphere has a preferred orientation when placed into the scanner which will reduce or prevent the sphere from rolling. This effect is probably due to the presence of magnetic domains inside ferromagnetic objects.