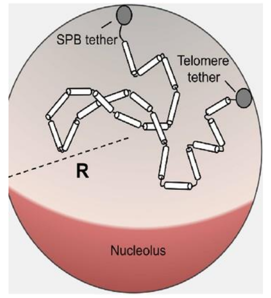
Dynamics of a Vertically Vibrated Doubly Tethered Granular Chain

Lorenzo Gabriel P. Joquino[1] | Research Adsvisers: Kendrick A. Agapito[1], and Lou Serafin M. Lozada[2]
[1] - Philippine Science High School - Main Campus | [2] - Institute of Mathematical Sciences and Physics, University of the Philippines - Los Banos

Introduction

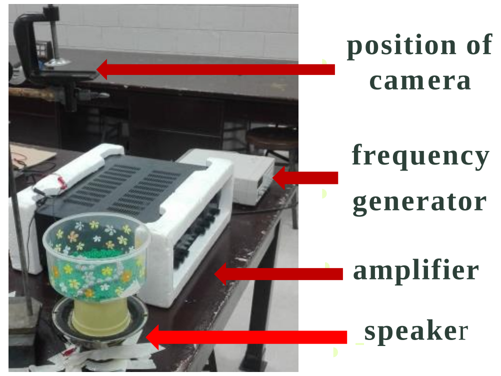
Polymer physics studies the structure and dynamics of polymers and polymeric systems. Results from polymer physics have been used in various field - biology, polymer processing, and electronics. Mechanical analogs like granular chains have been utilized in studying polymer physics as they are able to demonstrate coarsed-grained behavior of polymer motion while still being accurate about a polymer's properties at a larger length scale. This study investigates the dynamics of a single granular chain tethered at both ends on the wall by determining the effects of different frequencies of vibration and arc length formed by the tethered ends of the chain on the diffusion coefficient (DC) of each bead on the chain and their interactions.

Avşaroğlu et al.'s picture of tethering of chromosome (2014)



Methodology

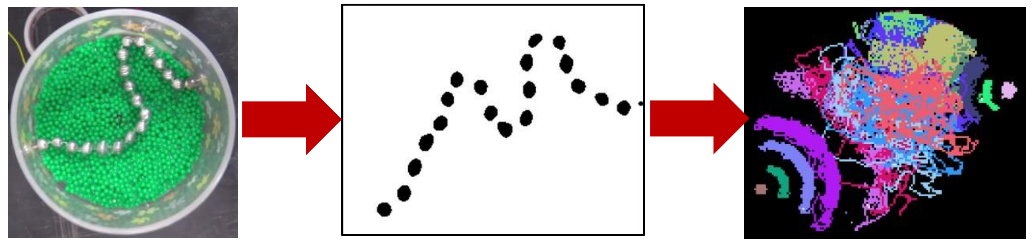
Experiment Setup



A granular chain (20 beads, 10 mm bead radius) was vibrated at 20, 22, 25, and 28 Hz. Its tethered ends were positioned at arc lengths of 110, 156, and 180 degrees.

Video Recording and Processing

The vibrated, tethered chain was recorded at 30 frames per second. Images were converted to binary images used for particle tracking.

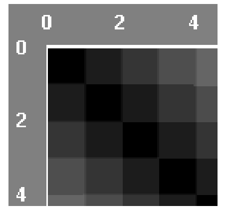


A recorded video (left), a binary image (middle), and trajectories of the beads (right)

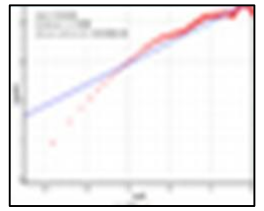
Three videos were recorded for each set of variables.

Diffusion Coefficient (DC) and Contact Probability

The DC of a bead was measured using the mean square displacement (MSD) values, and was plotted against its position in the chain. Bead-bead interactions were transformed into a contact (distance) map.



A contact map



A plot of MSD vs. time (logarithmic)

References

Avşaroğlu, B., Bronk, G., Gordon-Messer, S., Ham, J., Bressan, D. A., Haber, J. E., & Kondev, J. (2014). Effect of chromosome tethering on nuclear organization in yeast. PLoS One, 9(7), e102474.

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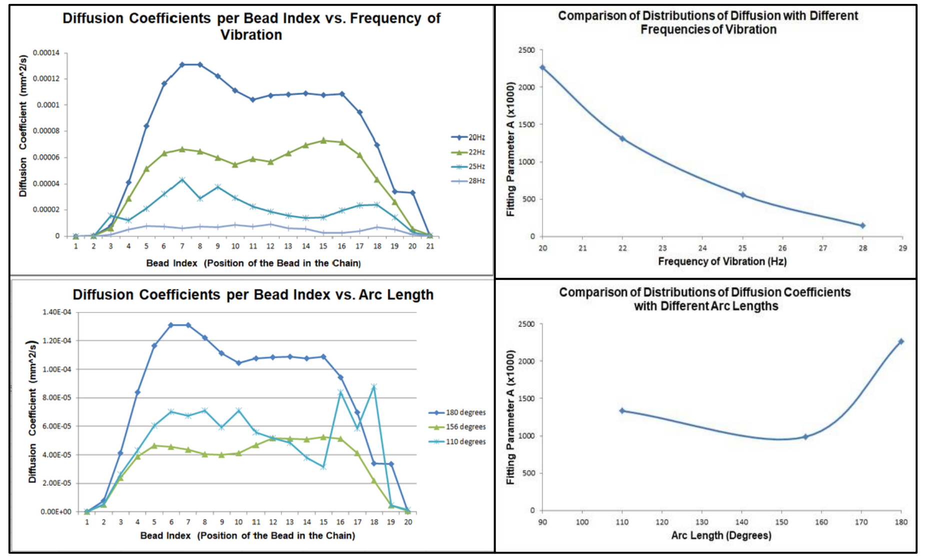
Tricard, S., Feinstein, E., Shepherd, R. F., Reches, M., Snyder, P. W., Bandarage, D. C., ... & Whitesides, G. M. (2012). Analog modeling of Worm-Like Chain molecules using macroscopic beads-on-a-string. Physical Chemistry Chemical Physics, 14(25), 9041-9046.

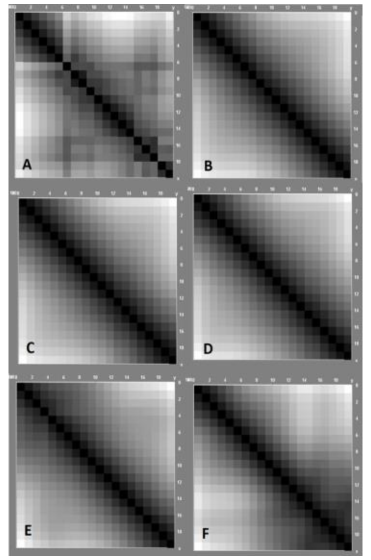
Results and Conclusion



Diffusion Coefficient (DC) vs. Frequency and Arc Length

A platykurtic distribution of the DCs was exhibited due to the presence of the boundary and the stiffness of the chain. From the curves fitted with equation (as shown), a downward trend in the value of A can be observed with increasing frequency (top right), while the opposite can be found with a larger arc length, with some anomalies (bottom right). This is possibly caused by more frequent bead interactions, resulting to loss of kinetic energy from inelastic collisions.

$$f(x) = \frac{A\left[2+\left(\frac{x-\mu}{\sigma}\right)^4\right] e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}}{3\sigma\sqrt{2\pi}}$$



Contact Probability

The figure on the left shows the contact maps of two beads based on the average distances between them. The bead indices 0-20 are numbered from left to right, and from top to bottom. a) is at 20Hz, 110 deg. (degrees); b) is at 20Hz, 156 deg; c) is at 20Hz, 180 deg; d) is at 22Hz, 180 deg.; e) is at 25Hz, 180 deg.; f) is at 28Hz, 180 deg. A darker shade means a shorter mean distance between the two beads relative to other distances in the chain.

The default result of a contact map is a normal distribution. Based on the figure on the left, presence of darker regions indicate formation of loops among the beads in the dark region. Fig A has a lot of dark patches because the end-to-end distance is smaller, resulting to more bead interactions. The differences between Figs. C, D, E, and F are less prominent due to lesser variations in frequency of vibration.

Generally, the analog simulation has proven to be accurate in describing some statistical properties of polymers.

Recommendations

Results can be used to elucidate some behavior of chromatin. Addition of parameters to the properties of the chain (center of mass, correlation between beads' movement) or the environment, improvement in image processing, and incorporation of 3D positions and comparisons with actual testing of polymers and other methods of simulation can also be done to further support the accuracy of the simulation.

What I've learned

Complex concept that I have encountered such as polymer dynamics, can be compared to the use of objects that are seen more often. It is important as well to be able to visualize such scenarios before diving into its mathematics.

Acknowledgements

I would like to thank Prof. Junius Andre F. Balista for lending his speaker and amplifier.