ENGN1735 Active Particles Project Proposal
Sarah Nguyen, Helen Primis, Andrew Mombay, & Kaya Bruno
Mentor: Jack-William Barotta
Due October 14, 2025
Project Name: HexCitations

Contents:

1. Background and Brief Literature Review

The background of our project lies with the study of active particles and observations of the collective behaviors emergent upon coupling. Unlike true Brownian motion, linked active particles harness their own energy and have the capability for complex collective behaviors to arise.[1] There is evidence of collective behaviors with active particles resulting in self-propelling locomotive functions, resource collection, local environmental restructuring, and particle aggregation.[2] The foundations of this study are cited as being rooted back to the philosophical fundamentals of Aristotle: the whole is greater than the sum of parts.[3] Considering the example of biotechnically-based robotics systems, the behavior of active particles is driven by autonomous collective movements without the direct influence of some sort of central force; the critical nature of this study is how the “random” particles, when linked together, result in an aggregated movement.

The onset of research in this field occurred due to the development of high definition photography which allowed for the detailed scaling of the limb movements for invertebrates and vertebrates. The locomotive functions of the animal's appendages were linked to a central pattern generator in each organism that did not send feedback to the neural system thereby enacting the movement. This is connected to our investigation of aggregated movement mentioned in the previous paragraph.[4] Different locomotive actions can be linked to a certain number of filaments stemming from a fixated central body. Two appendages could represent swimming, four could represent trotting, eight could represent rotary breast stroke of flagella, and sixteen could mimic the wave motion of a series of cilia.[5] The study of collective behaviors usually falls under the Viscek model which focuses on the emergence of scaled dynamics from independent particles. The model exists with much freedom, saying “The only rule of the model is that at each time step a given particle driven with a constant absolute velocity assumes the average direction of motion of the particles in its neighborhood with some random perturbation added.”[6] Sources cite the alignment of velocities as a result of both self-propelled forces and “social forces,” when applicable.[7]

Taking the somewhat disconnected but overarching plethora of research in the realm of active particle behavior, our project aims to employ Hexbugs and 3D-printed Hexbug-like particles to serve as a macroscopic version of the often microscopic particles referenced in the relevant literature.[8] Understanding and taking into account that the inertia of our active particles can affect the linked movements of our systems, we will aim to create an accurate model for an adjustable linked filament to mimic cilia-like behaviors. The first rendition of this filament will be battery based, with a second stage evolution resulting in a direct voltage sourced filament which is independent of batteries in the active particles. Time permitting, we will apply our filament model to model the appendage based movement of a jellyfish and explore how different orientations and combinations of filament power and length affect the velocity of our model’s movement.[9] Our key questions and project workflow are outlined below in this project proposal.

---

[1] Barona Balda, et al., 847.
[2] Sinaasappel, et al., 1.
[3] Levay, et al., 2.
[4] Wan, 2.
[5] Ibid, 3.
[6] Baconnier, et al, 3.
[7] Ibid, 4.
[8] 3D Printable Hexbug Design and Instructions, Blog Link.
[9] Miles, Jason G, et al., 3.

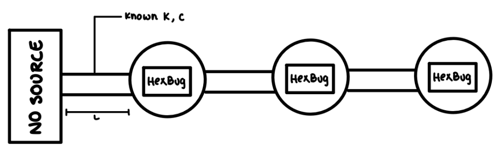
2. Key Questions

A. How can we build a cilia-like filament by employing 3D-printable hexbugs and mechatronic principles?
B. How do different orientations of hexbug coupling influence their collective actuation?
C. How does spring stiffness influence synchronization and sustained oscillations in elastic networks?
D. Can we achieve biomimicry with our model?

3. Experimental Workflow and Schematics

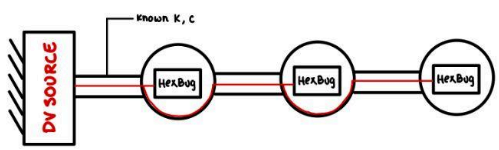
a. Phase I:

For the first experimental phase of this project, we will utilize Hexbug Nanos from the Harris lab as the macroscopic active particles within the filament. We will design shells to contain each particle and provide a linkage point between each discrete bug. The filament will be attached to one fixed non-powered source, such as a cilia attached to the parent body.



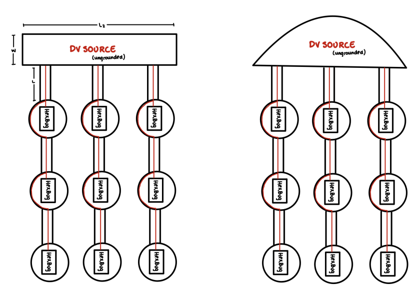
b. Phase II

For the second phase, we will 3D print and construct Hexbugs that can be connected via wiring to a fixed direct voltage source, eliminating the need of the battery powered Hexbug Nanos. This design will be modular to allow for adjustable filament length and attachments.



c. Phase III

Time permitting, we will engage with the concept of biomimicry using the DV-source based filament design by having multiple appendages attached to one unfixed central body, mimicking a jellyfish. The goal of this phase is to investigate the Hexbug orientations that move the fastest, considering different lengths and numbers of cilia attached to the beam.



4. Data Collection and Purpose of Iteration

a. Phase I: For the first iteration of our filament, we will use MATLAB image tracking to track the relative displacements and velocities of each particle to the fixed base. The purpose of this iteration is to understand the aggregate movement of the linked active particles when using battery-based Hexbugs and get a strong foundational prototype for future facets.

b. Phase II: For the second phase, we will perform the same data collection set as Phase 1, now employing a DV source based model instead of the battery Hexbugs to see if results are replicable. The nuance of modular design for this phase will allow us to easily change the number of particles attached to the fixed base to discover different aggregated movements which are dependent on adjustable features.

c. Phase III: From the third phase, we will collect average velocity data for varying configurations of the apparatus upon changing shape and length of connection beam, length of filament, number of hexbugs on each filament. The purpose of this iteration is to apply the principles developed in the previous phases to replicate a biological phenomenon.

5. Modeling, Numerical Techniques, and Materials

To complete this project, we anticipate primarily scaffolding existing resources on Hexbug construction to build our framework filament.[10] This will be primarily accomplished through utilizing 3D-printing methods and applying CAD skills to construct each individual Hexbug. Considering the driving electronics for this project, we will utilize pager motors and a central power supply to supply power to all hexbugs concurrently. We plan on using flexible PVC tubing to join form Hexbug filaments to allow for semi-constrained movement along the x and y axes. A summary of our projected components and costs can be found below.

When analyzing the movement of our hexbugs, we may want to collect additional points of data beyond velocity and position that would allow us to better understand the phenomenon. We can break down their behavior based on their position, velocity, angle of movement, and general error due to inconsistencies in the hexbugs and the surface. As our experiments will generate a large amount of data, we will use MATLAB image processing to streamline the data collection process. This allows us to consistently measure the tracked values of the Hexbug's movement.

Item	# Units	Cost	Purpose
PLA Filament (Black)	1 spool	N/A (Personal filament will be used)	Used to build individual components (Hexbug body, filaments, etc.).
Pager Motors	20 (1 pack)	$14.29 (Amazon)	Generate the vibrations needed to generate movement for each Hexbug.
Wiring, 20 AWG	N/A	N/A (Personal wiring will be used)	Links each individual bug up to a central power supply.
PVC Tubing	10ft	$8.99 (Amazon)	Connects each bug cage to form a filament.
Ball Bearings (6705-2RS, 25*32*4 mm)	20 (2 packs)	$29.58 (Amazon)	Allows for unconstrained movement of each Hexbug cage and reduces risk of wire torsion.
Power Supply	1	N/A (SOE/ BDW central power supplies will be used)	Allows us to regulate voltage/ amperage to determine how voltage changes change filament behavior.
Microswitches	150 (1	$6.99 (Amazon)	Allows us to turn on and off each filament.

[10] 3D Printable Hexbug Design and Instructions, Blog Link.

	pack)		
Total Estimated Cost	$59.85		
Total Budget Remaining	140.15	Excess budget reserved for the potential purchase of Hexbug Nanos, supplemental wiring, other materials for filament connections, and other adaptations needed throughout the design process	

6. Semester Timeline and Group Member Roles

Regarding our timeline, we anticipate using our remaining time (9 weeks) in the following manner, with roles and general task priorities outlined below.

- 10/17: Finalize the scope of our project, order initial materials, finalize CAD modeling for the individual Hexbug cage.
- 10/24: Build individual Hexbugs for each filament, assemble initial filament and modify CAD (if necessary) to fit tolerances, scaffold central power supply, code tracking software.
- 10/31: Begin initial testing, revising linkage materials if required, test tracking software to analyze filament behaviors, work on progress presentation slide deck
- 11/6: Progress presentations in lecture and slide deck, and group midterm evaluation
- 11/7: Revise tracking software & bugs and begin experimental trials
- 11/14: Continue experimental trials, finalize parts list, determine if any additional components are needed, revise testing criteria if need be
- 11/21: Analyze experimental data
- 11/28: Finish data analysis and begin work on final deliverables
- 12/5: Continue work on final deliverables & presentation framework
- 12/12: Finalize final deliverables, practice presentations, and wrap up any loose ends.
- 12/13: Final presentation of deliverable, and final group evaluations

Regarding individual roles, Andrew will be responsible for the CAD, hardware, and mechatronics components of the project, taking priority over mechanical linkage design. Sarah will be responsible for developing the filament linkages and leading data processing including the development of our tracking software. Kaya will be responsible for hardware, schematics, and data reporting through taking priority on the experimental design, revisions, and generalized testing. Helen will be responsible for data processing and experimentation, combining skills to assist in the development of our tracking software and adapting it as we progress in our study.

7. Project Deliverables and Transfer of Knowledge

From our findings, we hope to advance the work of the active matter community, contributing to the simulation of natural phenomena through the application of small robotics, particularly for ongoing projects in the Harris and Wilhelmus labs. Through our experimentation, we hope to gain a better understanding of jellyfish locomotion and thus contribute to the marine ecosystem community. To advance such work, we intend on writing up a report summarizing our findings, including demonstrations of our Hexbug prototype. We will also create an open source GitHub page including our CAD designs, code, raw and processed data, and a general framework to ensure experimental reproducibility.

8. Appendix

a. Bibliography

Baconnier, Paul, Olivier Dauchot, Vincent Demery, et al. “Self Aligning Polar Active Matter.” *Reviews of Modern Physics* 97, no. No. 1 (2025): 1–26.

Barona Balda, Angelo, Aykut Argun, Agnese Callegari, and Giovanni Volpe. “Playing with Active Matter.” *The American Journal of Physics* 92 (November 2024): 847–58.

Levay, Sara, Axel Katona, Hartmut Lowen, Raul Cruz Hidalgo, and Iker Zuriguel. “Cluster Dynamics in Macroscopic Photoactive Particles.” *Physical Review Letters* 135, no. 098301 (2025): 1–7.

Miles, Jason G., and Nicholas A. Battista. “Naut Your Everyday Jellyfish Model: Exploring How Tentacles and Oral Arms Impact Locomotion.” *Fluids Journal* 169, no. 4 (2019): 1–43.

Sinaasappel, R., K.R. Prathyusha, Harry Tuazon, et al. *Collecting Particles in Confined Spaces by Active Filamentous Matter*. May 9, 2025, 1–27.

Wan KY. 2019 Synchrony and symmetry-breaking in active flagellar coordination. Phil. Trans. R. Soc. B 375: 20190393.

3D Printable Hexbug Design and Instructions, Blog Link.