Enhancing Molecular Robot Algorithms for DNA-Based Cargo Sorting Using DNA-PAINT Imaging

Cargo Sorting DNA Robot

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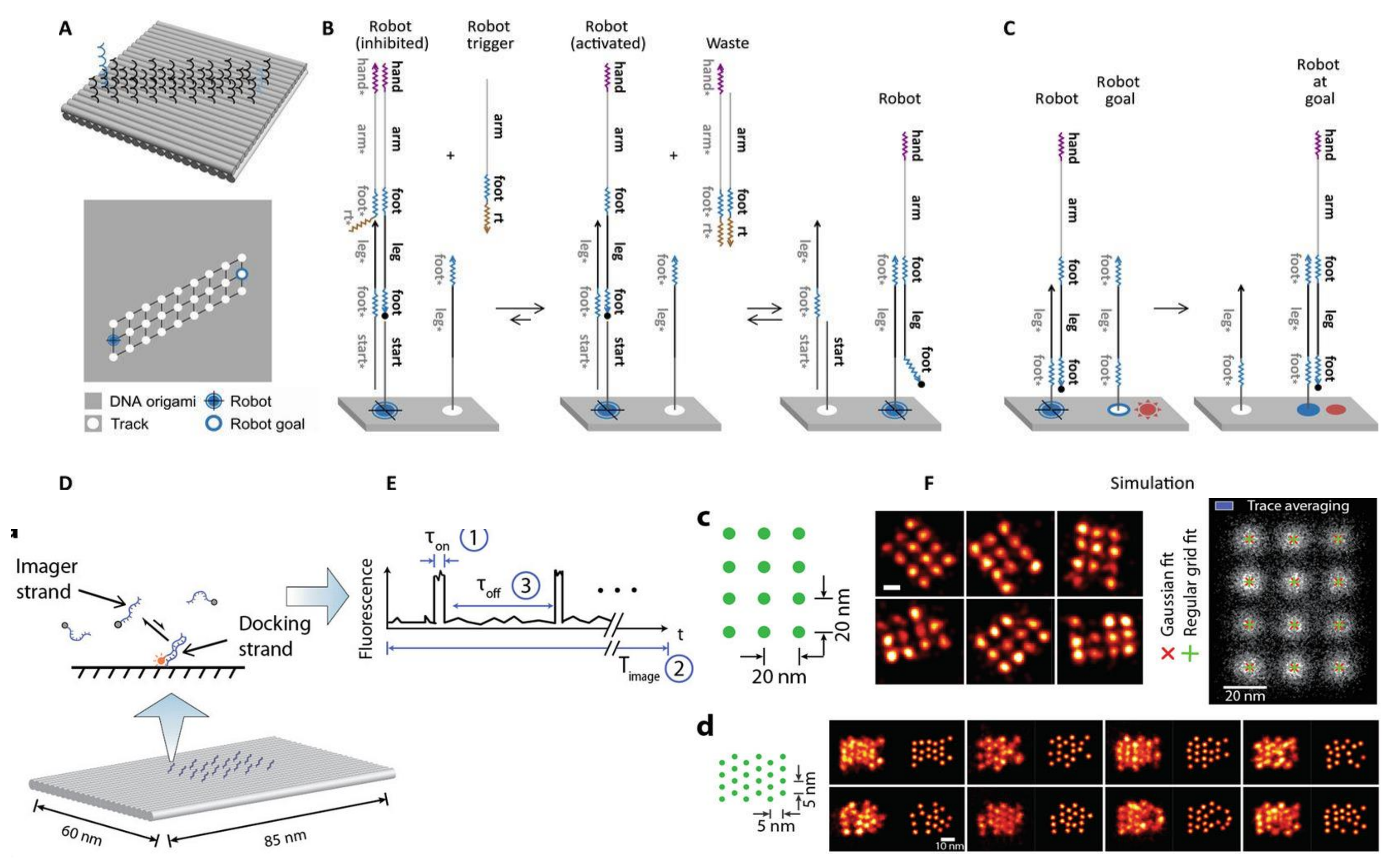
Introduction

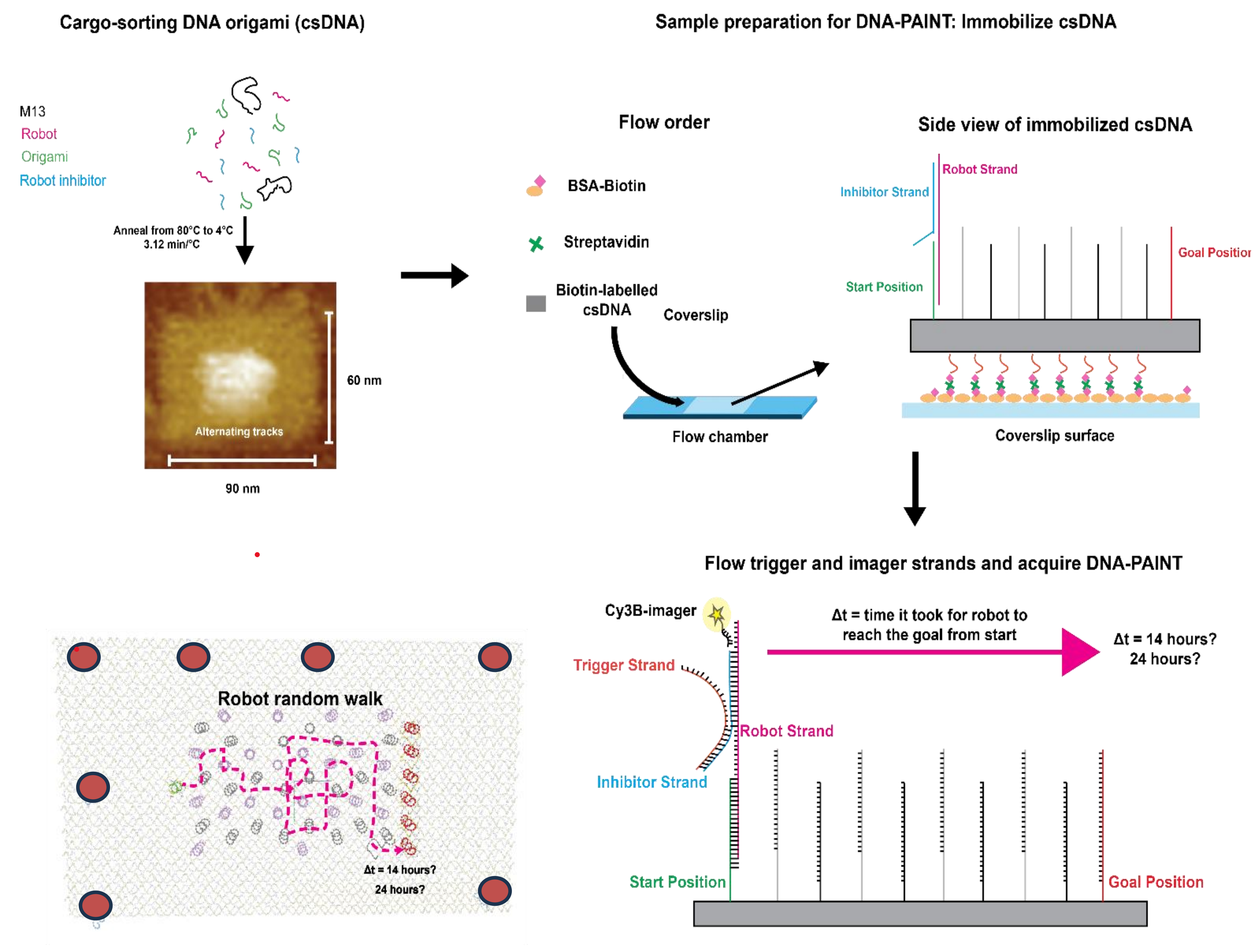
- DNA-based molecular robots offer transformative potential for nanoscale cargo sorting, but their efficiency remains limited due to a lack of detailed movement data.
- This research explores how high-resolution imaging and data analysis can enhance the algorithms controlling DNA-based molecular robots.
- DNA-PAINT imaging, with 10 nm resolution capability, enables precise observation, allowing us to gather detailed data on molecular robot movements for improved algorithm refinement.

Objective

- Use DNA-PAINT to visualize molecular robot interactions and collect and analyze performance data.
- Focus on the walking algorithm:
- Examine movement triggers and goal-reaching processes.
- Analyze metrics like walk duration, goal achievement rate, and movement statistics.
- Aim to identify improvements to increase the efficiency and accuracy of DNA-based cargo sorting.



Methodology

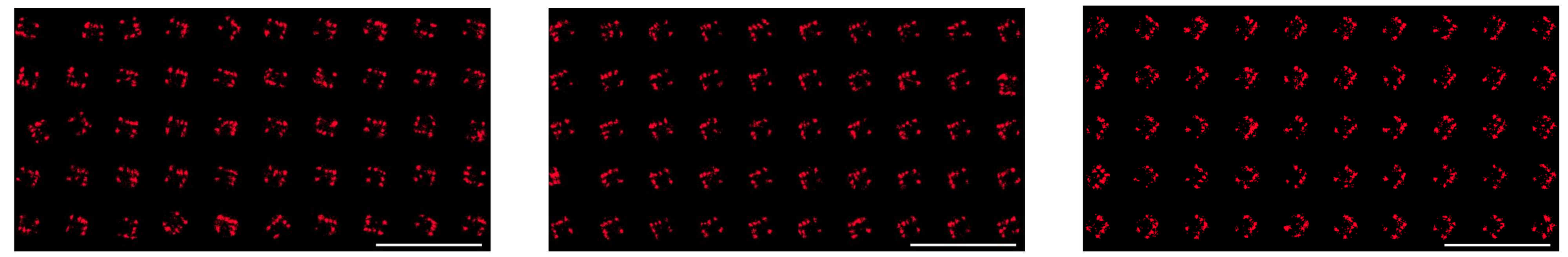


Experimental Design and Control Measures

- **Design Overview**: Single-layered DNA origami with robot, inhibitor, and track strands creates a controlled setup for studying cargo-sorting efficiency through precise robot movement.
- **Controlled Start**: The robot is immobilized by an inhibitor strand at the starting point, preventing early movement and ensuring accurate placement on the track.
- **Track and Goal Population**: Track and goal strands bind to the origami, with experiments tracking their stability and distribution over time.
- **Robot Movement Tracking**: Experiments follow the robot's path along the tracks to the goal, along with control experiments to confirm the insights gained on the data.

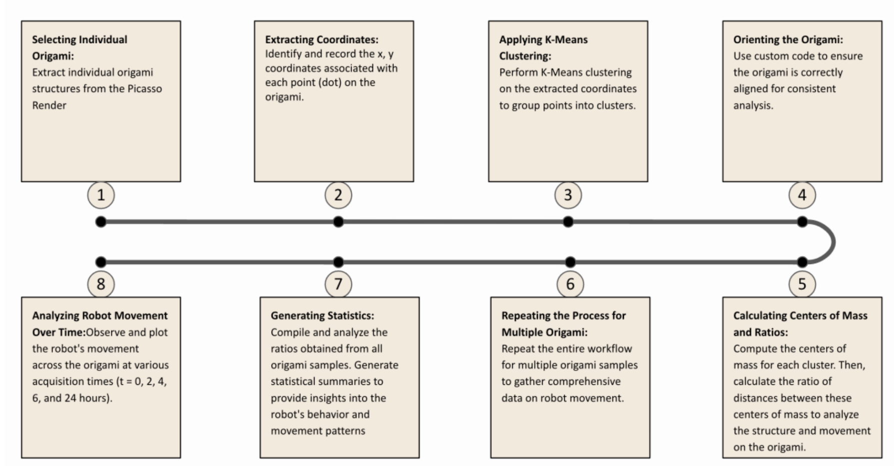
Results-DNA PAINT

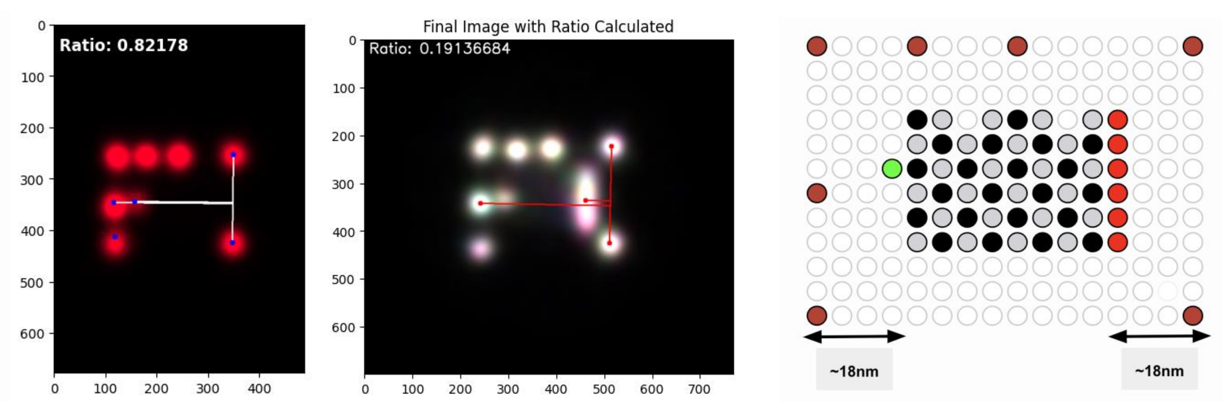
- **Control Experiment**: Control tests validated track and goal binding as well as inhibitor function, ensuring a reliable setup for the main experiment.
- **Main Experiment Insights**: Data inspection indicates that the robots are likely performing random walks along the track and reaching the goal as intended, suggesting the designed movement and goal-reaching behaviors are effectively in place. **Scale bar = 500nm**



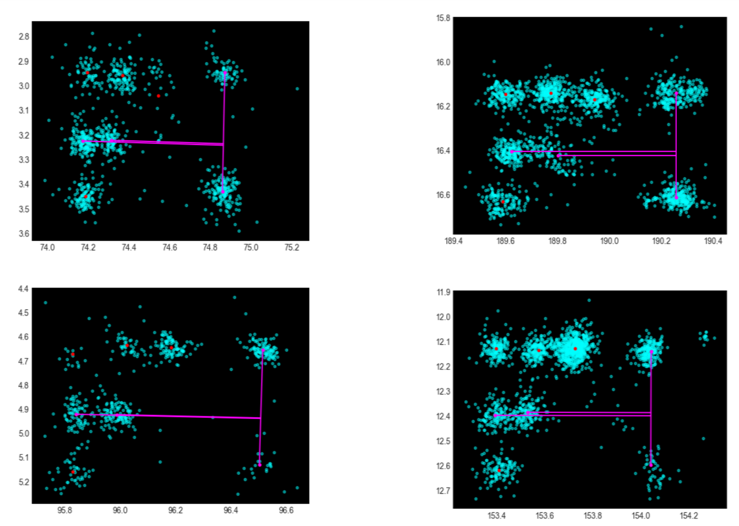
Results -Analysis

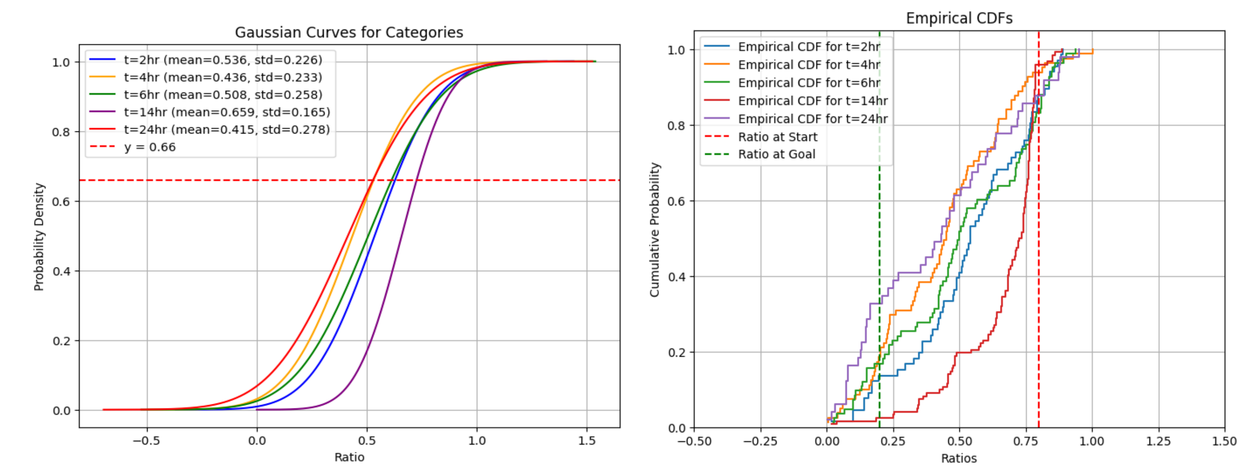
- **Ratiometric Method**: By normalizing robot displacement to the origami length, this method quantifies robot progression within the structure. We use Python, OpenCV, and clustering algorithms to analyze these movements efficiently.
- **CDF Curves**: CDF curves offer a continuous view of robot distribution across the origami, showing a leftward shift as more robots reach the goal over time. Statistical tests confirm a significant change in robot positioning from 2 to 24 hours.





•The calculated distances (17.8nm and 19.1nm) closely match the expected 18nm gap from the origami edge to the start and goal positions, with a deviation within 6nm.





References

Anupama J. Thubagere et al. ,A cargo-sorting DNA robot.Science357,eaan6558(2017).DOI:10.1126/science.aan6558 , DNA-PAINT super-resolution imaging for nucleic acid nanostructures - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Principle-and-examples-of-DNA-PAINT-a-Illustration-of-DNA-PAINT-principle-transient_fig1_310506767 [accessed 5 Nov 2024],

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