Imaging and Tracking of Nanopropellers and distinguishing different magnetic moment propellers

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ABSTRACT

In the past few years, one of the paramount research studies which has been continued is about finding out ways for providing prowess and ability to control nanoscale objects in various fluids by application of magnetic fields of less intensity. The breakthrough in this application of nanotechnology has made the way for some of the dormant ideas like targeted drug delivery, micro rheology, environment sensing and many more such small scale and precision driven ideas. These kinds of application demands great amount of control and to fulfil this purpose one of the options is to perform imaging and tracking of these nanopropellers. In this project, I have performed the imaging and tracking of these nanopropellers during their motion in fluids. Along with this, I have analysed the motion for differentiating the magnetic moment of the nanopropellers by considering small fraction of the ~10^8 nanopropellers produced on a single silicon wafer. With regards to all the previous research[1-7] which has been conducted in last decade or so, imaging and tracking of these nanosized objects have been a concern for in vivo applications. Therefore, through this project we have looked to overcome this challenge in the best possible way.

Keywords: Helical structures, Magnetic Actuation, Nanoswimmers.

1. INTRODUCTION

There were several reasons why the scientific cohort could not garner information about intricate details of our body precisely. One of those issues were the unavailability of micro/nano sized object. But when the idea of this nano structures was conceived, it was considered a great outcome. With this came two challenges which had to be solved before looking at its applications. One of the challenges was of movement and along with that proper control over them as well. For providing movement, energy source was mandatory and for that there were several options like ultrasonic, optical, thermal, electrical and magnetic. In this project report and related experiment, I have used magnetic field as the source of energy. When it comes to the motility of these structures, various microorganisms were studied[1] to get inference of the way they swim in fluids. This is because both nanostructures and microorganisms are alike in size and their movement is within the fluid.

When the reference of microorganisms was considered, there were two factors which got raised. One was lack of inertia for objects swimming at micro scale and they are also prone to Brownian motion affecting their swimming capability. To counter such factors, a detailed study of Stokes equation for microscopic level has been conducted in previous research experiments [1], which reveals that these mite structures do not possess any net displacement when they try to move. All this is because the swimming pattern of these microorganisms is same for moving forward and backward. Thus, they are not able to break the time reciprocity.

This suggested that for having proper motility, objects must have non-reciprocal motion. From the previous studies[1] itself, it was deduced that helical structured shapes are able to give the desired results.

The typical cork-screw motion can describe the motion which was found in bacteria flagellum. Furthermore, the advantages which the earlier research work has consolidated is that toxicity of these Nanoswimmers is of no harm and thus there cytocompatibility cannot be questioned against. Along with this, cancer therapeutics has got a boost as now drug delivery has improved immensely with the incorporation of these helical nanostructures but still it demands numerous improvements.

1.1 Motion of Nanostructures

As discussed earlier, the energy source for providing motion to nanostructures is magnetic field. This choice has been made because in health-related applications we cannot use substances which have toxic nature and can prove to be hazardous once they get in contact with human body. Usage of magnetic field has been found out to be suitable from health perspective and it is also non-invasive making it an apropos choice. Additionally, for providing motion it was concluded that the nanoscale objects will have to either move through sinusoidal movement or through helical or cork-screw motion[1], since these two types of motion were able to break the time reciprocity. This same conclusion helped them to get inspired from microorganisms like *Spermatozoa* and *Escherichia coli* . In this manner, micro/nano scale objects were decided to be made with helical shape which will enable them to move easily in fluids.

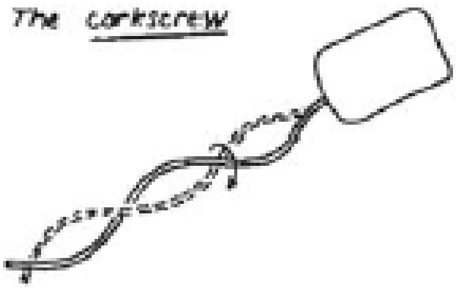

Figure 1: Cork-Screw motion which breaks time reciprocity and which was taken as reference for motion in nanopropellers. [3]

1.2 Making process of Nanostructures and Microfluidic chamber

The aim is to create a system which consists of ferromagnetic helical nanostructures rotated along the long axis providing it translatory motion because of the coupling between the rotational and translational degrees of freedom. The process of fabrication starts from a wafer (made up of silicon) which gives billions of nanopropellers. The fabrication procedure consists of following steps:

a) Formation of seed layer

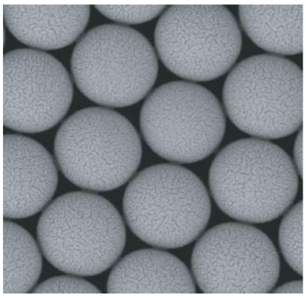

Figure 2: Forming a seed layer by using polystyrene beads [1]

b) Deposition of Magnetic Material
c) Fabrication of Helix by Glancing Angle Deposition (**GLAD**) (Basically a e-beam evaporation)

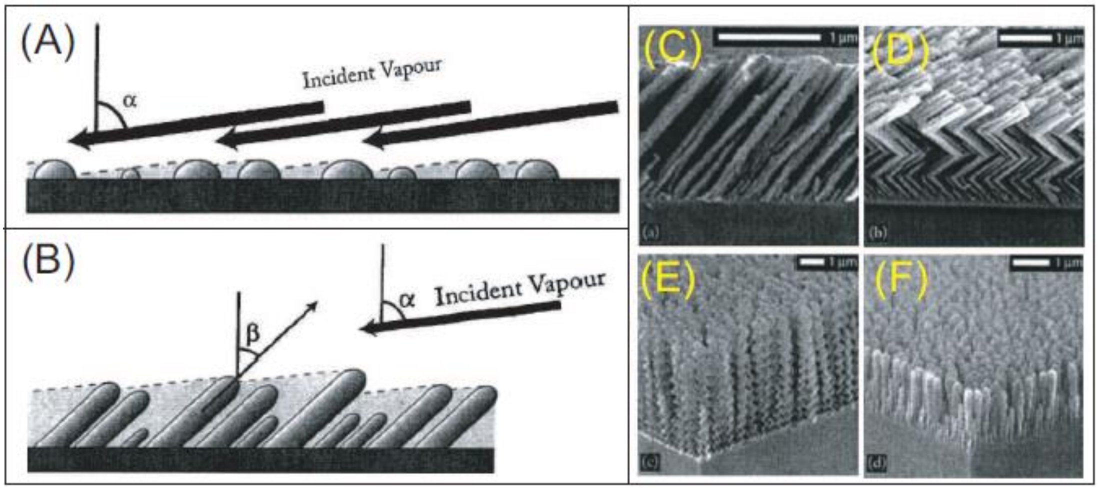

Figure 3 : Glancing Angle Deposition. (A) Shadowing by the nuclei distributed across surface where the vapour is incident at an angle with the substrate. (B) Schematic Representation of the manner in which column-shaped structures are grown at a different angle. (C) SEM image columnar structures. (D)-(E)-(F) SEM image of helical structures of various kinds of pitch built using different speed of rotation.[1]

Furthermore, these helical nanostructures are called nanopropellers once they are made. For studying their motion, they are moved in a microfluidic chamber which can contain fluids/water in which these nanopropellers are dispersed and then their motility is analysed by applying magnetic field.

(a)  (b) 

Figure 4: (a) Microfluidic chamber used for flowing nanopropellers (b) SEM Image of a single nanopropeller. [1]

1.3 Magnetic Actuation

As discussed earlier, the magnetic field is generated by tri-axial Helmholtz coil kept inversely mounted over a microscope for further imaging process. This coil consists of three coil orientation i.e. X, Y and Z so that we can provide energy for motion in all three dimensions. The radius of those three coils is approximately 56 mm. Moreover, it is powered by three individual constant voltage amplifiers.

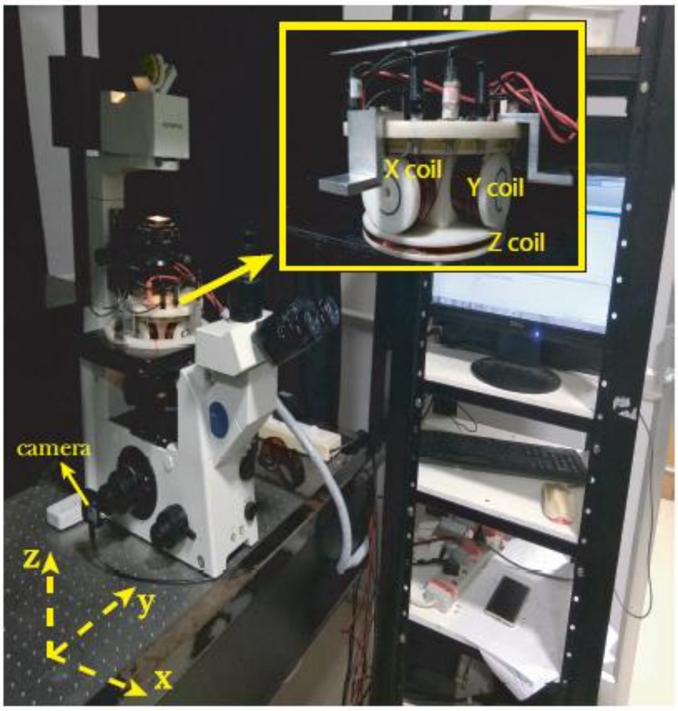

Figure 5: Experimental setup with the coil being mounted over the microscope. The camera of microscope is used to facilitate the imaging and tracking of objects captured. [1]

2. WORKFLOW OF PROJECT

There has been numerous steps which have been followed to achieve desired results for this project. Those steps are as follows:

i. Initially microfluidic chamber was created using PDMS (**Polydimethylsiloxane**). The length of this channel was 4.3 cm and diameter was 180 microns.
ii. After this, nanopropellers were used for flowing in the chamber.
iii. This microfluidic chamber consisting of fluid suspended with nanopropellers was then placed in the magnetic field which was generated by Tri-Axial Helmholtz coil inversely mounted over a microscope attached with a camera whose output can be viewed on computer.

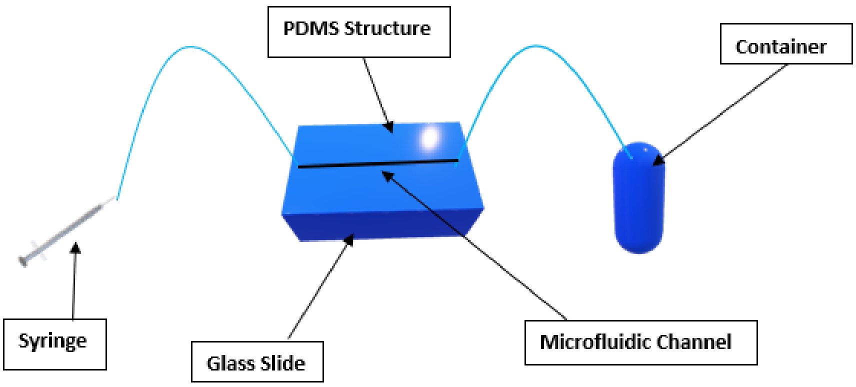

Figure 6: Schematic Representation of Microfluidic Channel – It consists of a PDMS structure with a very small groove created for channel, it is kept over glass slide. On one end of channel, syringe containing a fluid which consists nanopropellers is attached and another end contains another container to collect the nanopropellers.

iv. When these nanopropellers were flowed in the channel, the imaging and tracking of them had to be done. I had prepared the program (refer appendix) for executing this task before commencing with this experiment.

v. The program was made using python programming language where I had implemented computer vision technique. One of the methods of computer vision i.e. Background Subtraction was used for the purpose of imaging and tracking. I had also considered various machine learning and neural network-based techniques for accomplishing this task but due to lack of data, it was not feasible to implement such ideas.

vi. Furthermore, for analysis of the magnetic moments of propellers, sinusoidal wave is provided which enables the Nanoswimmers to follow the shape of the wave provided.

vii. The above step is first done for a reference propeller and then, we put the propellers which have to be tested.

viii. Our aim to is to check the deviation these nanopropellers undergo. The deviation from the expected path is then represented using standard deviation helping us to understand the deviation of the magnetic moments from the reference one.

ix. By analysing the standard deviation of various samples of nanopropellers, we can come to a conclusion for magnetic moments each sample of nanopropellers possess.

3. RESULTS AND OBSERVATION

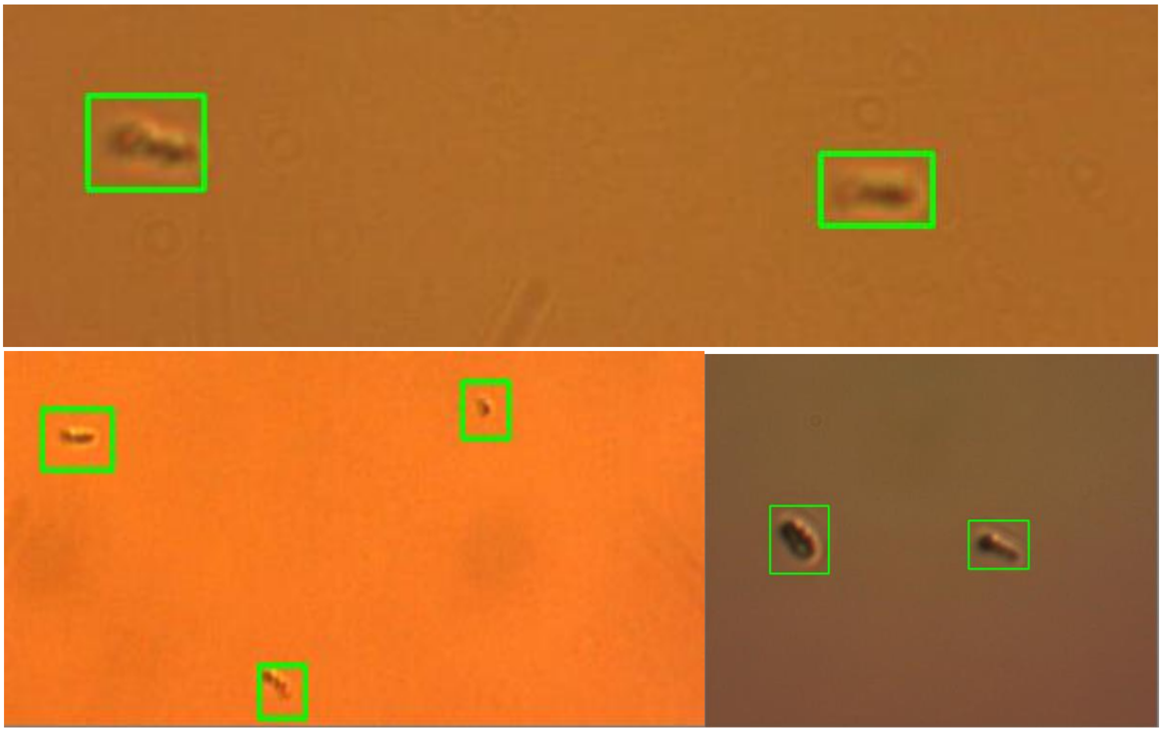

Figure 7: Images of videos depicting tracking of nanopropellers through green box (contours) around them

In this project, by using the code I was able to perform the imaging and tracking of the nanopropellers which were moving in the sample videos along with real-time input from microscope. The python code which implemented “background subtraction” was able to detect particles of various sizes which were moving. Since the results were highly dependent on the light which was reflected from the surface of nanopropellers, there were instances when a nanopropeller would go undetected. This can be improved by building a model and providing the model with huge datasets in form of videos and images through which it can understand the amount of light obtained from such nanopropellers.

One of the observations during this project was that sometimes, even a static spot was also detected by the code which points towards the fact that it still has not achieved perfect accuracy because the results are dependent on the light emitted from these nanopropellers.

The inferences which are drawn out of this experiment and results suggests that proper lighting of the microfluidic chamber must be done through which differentiation between nanopropellers and static objects can be done easily. For improving the accuracy of such tracking models, data i.e. images and videos are required in abundance. This will further allow the development of models which requires training like neural networks and machine learning based.

4. CONCLUSIONS AND FUTURE SCOPE

Future applications of this project points towards usage of imaging and tracking of nanopropellers for displaying their movement in tissues with their ability to distinguish between nanopropellers and other moving particles. Especially for micro rheology and related purposes such imaging can be implemented. The imaging process will be very useful during the drug delivery to a particular spot in the body. Amongst all the applications, there are still a long way to go in terms of improvement for these nanopropellers. There is still a requirement of a method for controlling and navigate these helical nanopropellers through labyrinthic paths. Moreover, even if they are declared as cytocompatible, there is a risk of losing these nanoswimmers in the body itself and then only way to prevent any kind of health hazards is to look for biodegradable nanopropellers in such a way which does not hinders with its load carrying capabilities.

5. APPENDICES

Python code used for imaging and tracking of nanopropellers.

```
import cv2

import numpy as np


video_file = "Propellers_Video.avi" #test video


kernel_dil = np.ones((20,20),np.uint8)

kernel = cv2.getStructuringElement(cv2.MORPH_ELLIPSE,(3,3))

fgbg = cv2.createBackgroundSubtractorKNN() #Background Subtraction function

cap = cv2.VideoCapture(video_file)

#cap = cv2.VideoCapture(0) for taking input from computer’s camera

while True:

        ret,frame = cap.read()

        fshape = frame.shape

        frame = frame[1:fshape[0]-2,:fshape[1]-2,:] #cropping the video size

        #print frame.shape

        if ret == True:

                fgmask = fgbg.apply(frame)
```

```
        fgmask = cv2.morphologyEx(fgmask,cv2.MORPH_OPEN,kernel)

        dilation = cv2.dilate(fgmask,kernel_dil,iterations = 1)

        (contours,hierarchy) =
cv2.findContours(dilation,cv2.RETR_TREE,cv2.CHAIN_APPROX_SIMPLE)

        for pic, contour in enumerate(contours):

                area = cv2.contourArea(contour)

                if(area>200):

                    x,y,w,h = cv2.boundingRect(contour)

                    img = cv2.rectangle(frame,(x,y),(x+w,y+h),(0,255,0),2)

                    roi_vehicle = frame[y:y-10+h+5,x:x-8+w+10]

        cv2.imshow("original",frame)


        if cv2.waitKey(25) & 0xFF == ord("q"):

            break


cap.release()

cv2.destroyAllWindows()
```

6. ACKNOWLEDGEMENT

I would like to thank Indian Institute of Science, Bengaluru and BioSystems Science and Engineering department for giving this opportunity of internship. I want to convey thanks towards my mentor, Prof. Ambarish Ghosh for allowing me to work under his erudite guidance during this internship and be a part of one of his ongoing research projects. Moreover, I would say thank you to Prof. Ambarish Sir's Ph.D. students Tanmoyendu Chakraborty and Jyoti Prakash Behra who helped me in completion of this project through their huge contribution in the experimental work and for imparting knowledge in numerous ways. I also want to thank all the professors of BSSE for their informative lectures and guidance during this memorable internship. In addition to all of this, I would like to say thanks to Division of Interdisciplinary Research, Dr. Anita and Animesh Mukherjee, and BSSE, Indian Institute of Science for the financial assistance. I also want to thank Internshala and Aniketh Singh for giving this golden opportunity of internship at Indian Institute of Science, Bengaluru.

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