Visvesvaraya National Institute
of Technology, Nagpur, India

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ReMAR'18, Delft

(COSMOS): Compliant Omnidirectional Spherical Modular Snake Robot

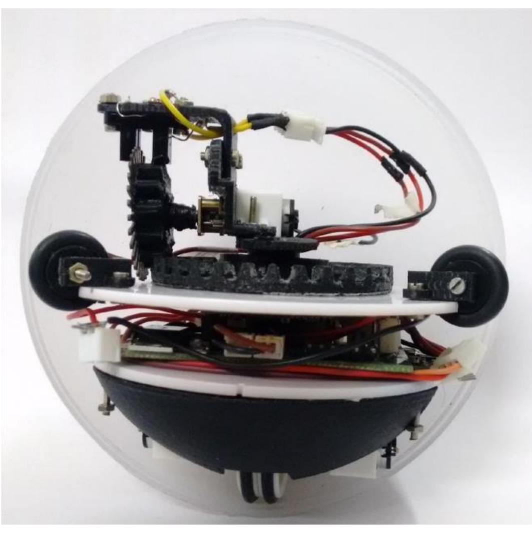
Akash Singh, Anshul Paigwar, Sai Teja Manchukanti, Manish Saroya and Shital Chiddarwar

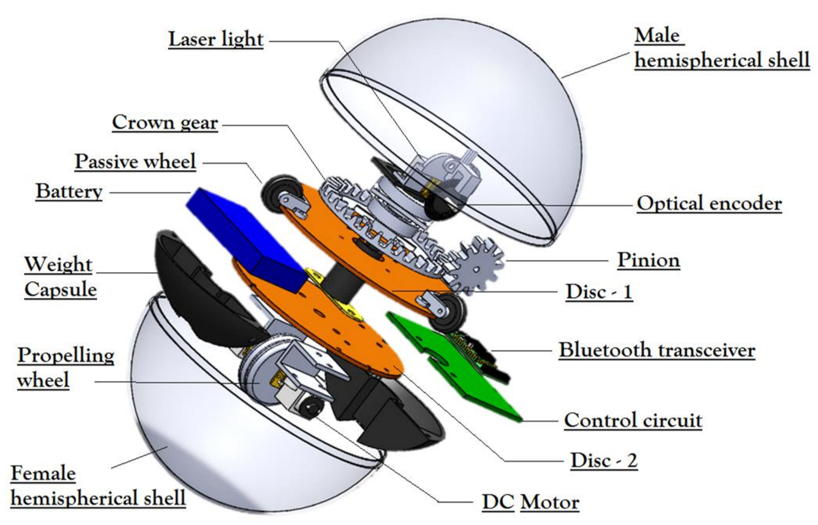
1. Introduction:

- Control, state estimation and motion planning of highly articulated snake robots [1] have been challenging tasks for researchers.
- This paper presents a novel design of a Compliant Omni-directional snake robot (COSMOS) consisting of mechanically and software linked spherical robot modules.

2. Design of Spherical Modules:

- Omni-directional design of, a spherical robot inspired from BHQ-3 [2] and is based on the principle of barycenter offset. Controlling the motion of the center of gravity to deviate from its static position, to produce a gravity moment.





- The Spherical robot consist of two units: IDU (Internal Driving Unit) which propels the robot forward and Steering Unit which controls the orientation of robot.

3. Complaint Link Design:

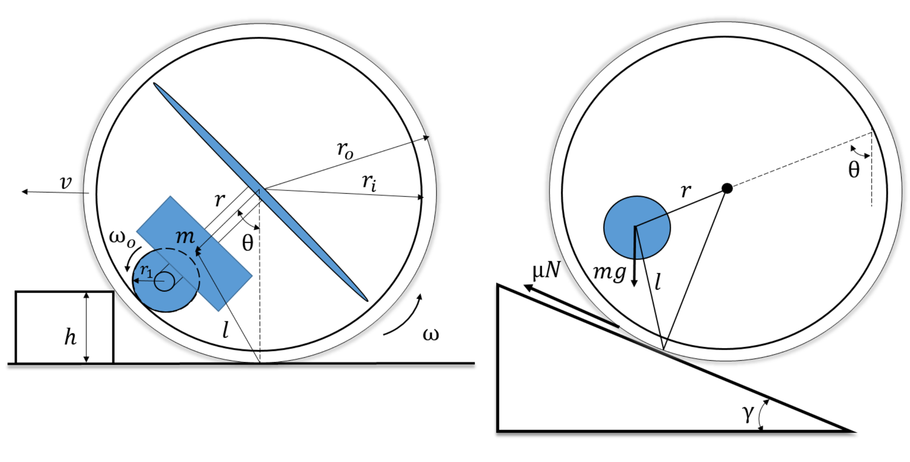
- In order to mechanically connect spherical modules without hampering their holonomic nature, a novel design of floating link is used.
- However, the updated design[3] focuses on introducing a compliant joint at the end of each passive rod near to the central spherical module as shown in Fig

4. Gait Design and Experimentation

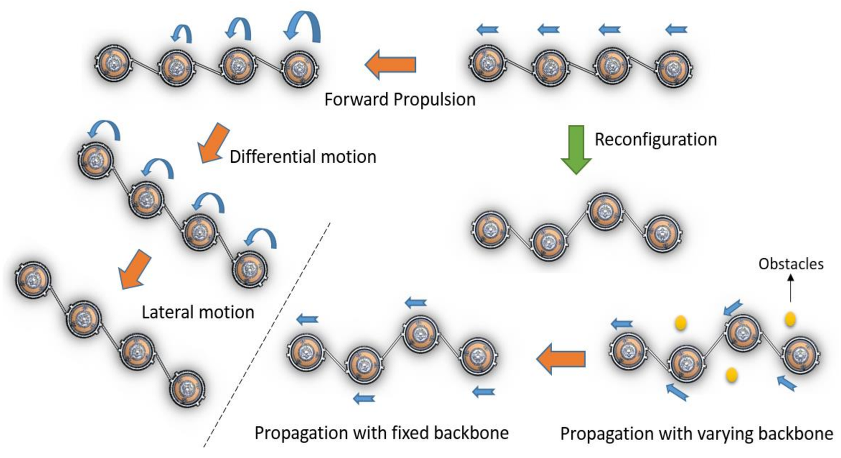
- The spherical modules are capable to roll uphill in certain inclination as shown in figure. The kinematic maximum hill inclination γ and height *h* of obstacle that can be surmounted is given by:

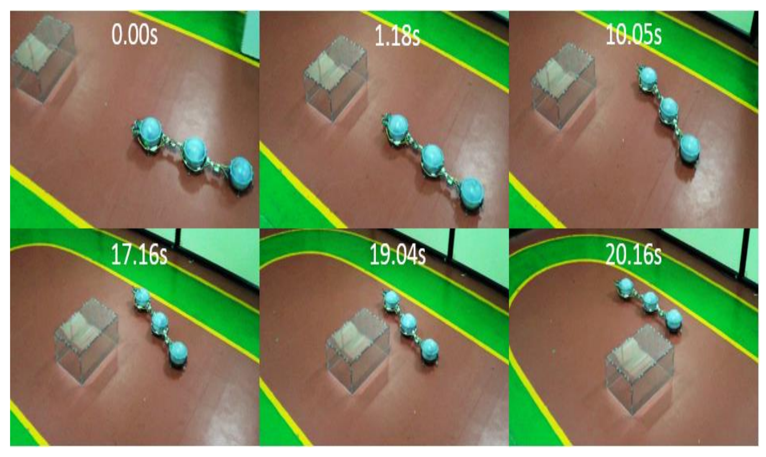
$$\gamma_{max} \leq \sin^{-1}\left(\frac{r}{r_0} - \frac{\mu}{r_0} - \frac{\mu\, M_{ball}}{m\, r_0}\right)$$

$$h_{max} = r_0 - \sqrt{{r_0}^2 - \left(\frac{m\, r}{m + M_{ball}}\right)^2}$$



5. Omni-directional Gait:

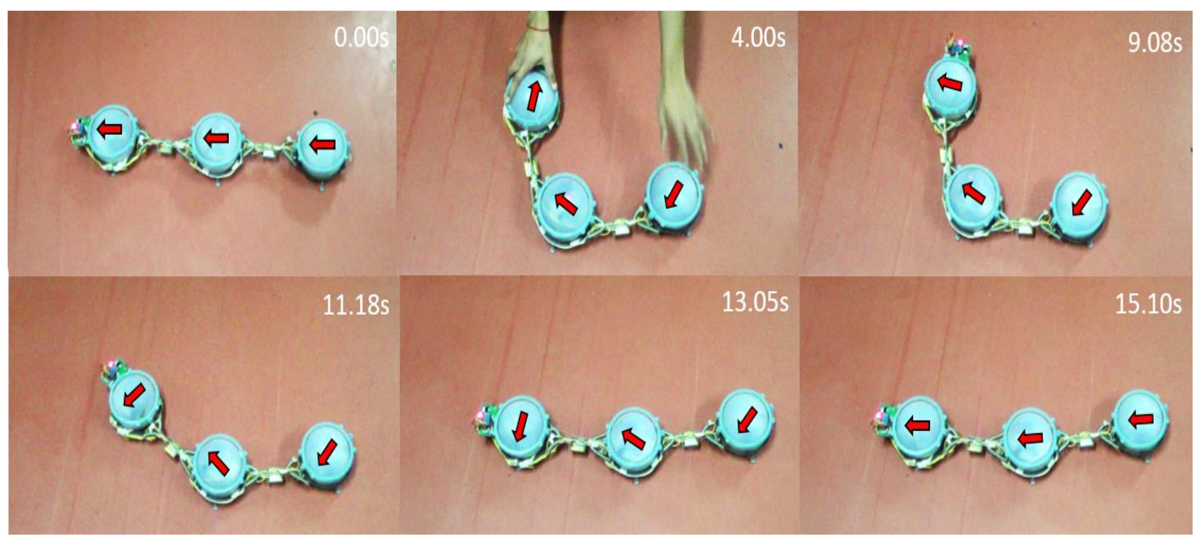




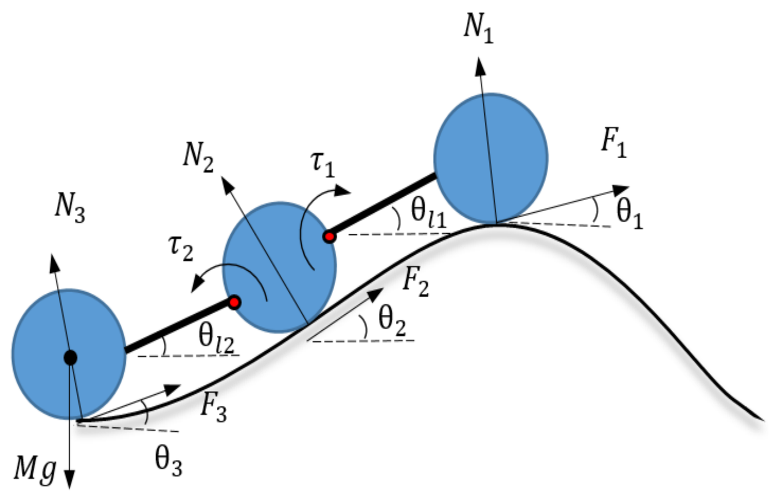
- In this gait, COSMOS is controlled in any direction while keeping the body shape unchanged. To achieve this motion, the orientation of all spherical modules is modified synchronously to a specific value and then propelled in attained direction.

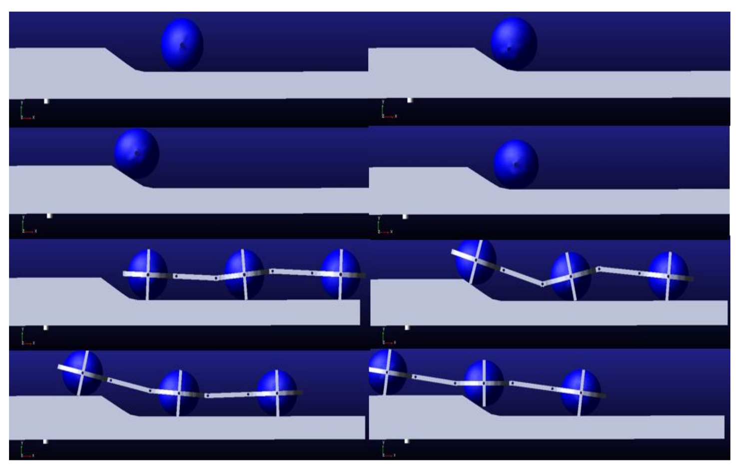
6. Rejuvenator Gait:

- This gait is performed by COSMOS in order to recover from a distorted body shape caused due to collision with obstacle or interaction with external forces during locomotion, to the original robot shape and locomotion direction.



7. Analysis of slope climbing:





- The spring stiffness value of the complaint links in the robot are calculated by doing a quasi static analysis of the robot in different configurations and solving optimization problem for spring value

8. Conclusion and Future Work:

- We presented a novel design of omnidirectional snake robot that is capable of traversing a given planar trajectory and overcoming obstacles. Various gaits of snake robots like circular motion, rejuvenation.
- Future work will focus on the control and motion planning in cluttered environments with varying backbone.

9. References:

[1] P. Liljeback, K. Y. Pettersen, Ø. Stavdahl and J. T. Gravdahl, "Snake Robot Locomotion in Environments With Obstacles," in IEEE/ASME Transactions on Mechatronics, vol. 17, no. 6, pp. 1158-1169, Dec. 2012.

[2] Qiang Zhan, Yao Cai and Caixia Yan, "Design, analysis and experiments of an omni-directional spherical robot," Robotics and Automation (ICRA), 2011 IEEE International Conference on, Shanghai, 2011, pp. 4921-4926.

[3] A. Singh, A. Paigwar, S. T. Manchukanti, M. Saroya, M. Maurya and S. Chiddarwar, "Design and implementation of Omni-directional spherical modular snake robot (OSMOS)," *2017 IEEE International Conference on Mechatronics (ICM)*

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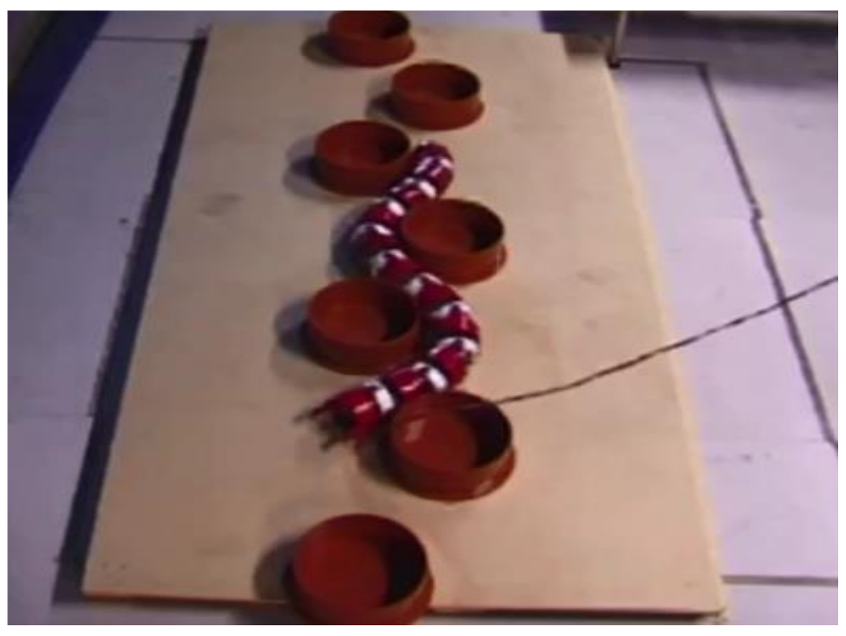
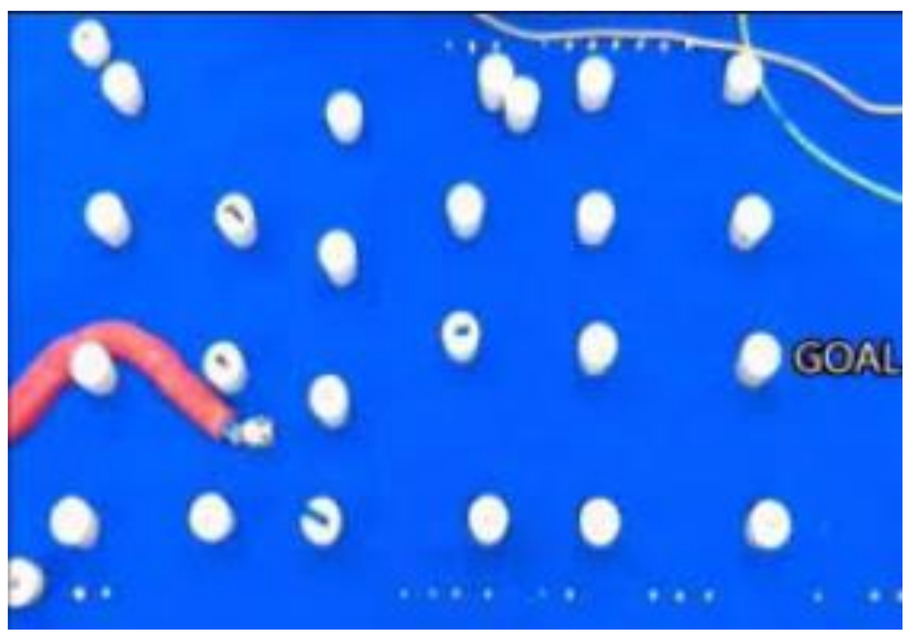
Modelling and Path planning of Snake Robot in Cluttered Environment

Akash Singh, Chaohui Gong, Anshul Paigwar, Howie Choset

1. Introduction:

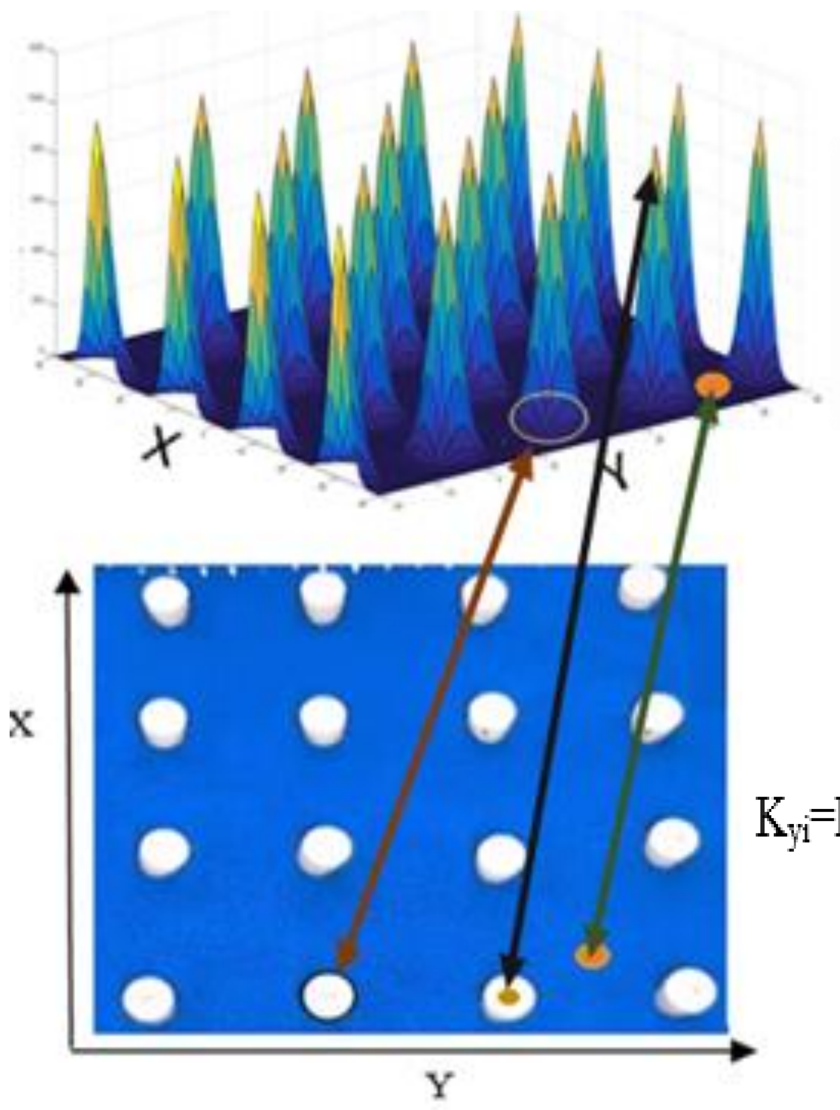
- Studying snake robot locomotion in a cluttered environment has been a complicated and computationally expensive task[1].
- A unique mathematical model of the robot interacting with obstacles in which the contact forces are mapped on the basis of a viscous friction model
- Unique Path planning strategy is also introduced.





2. Snake Robot Model:

- The derivation of the N-link snake model is based upon the viscous friction model as described in [2]. The reason for this approach is to imitate the motion of a biological snake in viscous environment.
- The viscous force acting on a link in contact with an obstacle is larger in the lateral direction as compared to the longitudinal direction. The ratio of viscous force due to every obstacle at a link in the lateral direction to the longitudinal direction is modeled as a 2D Gaussian hump.



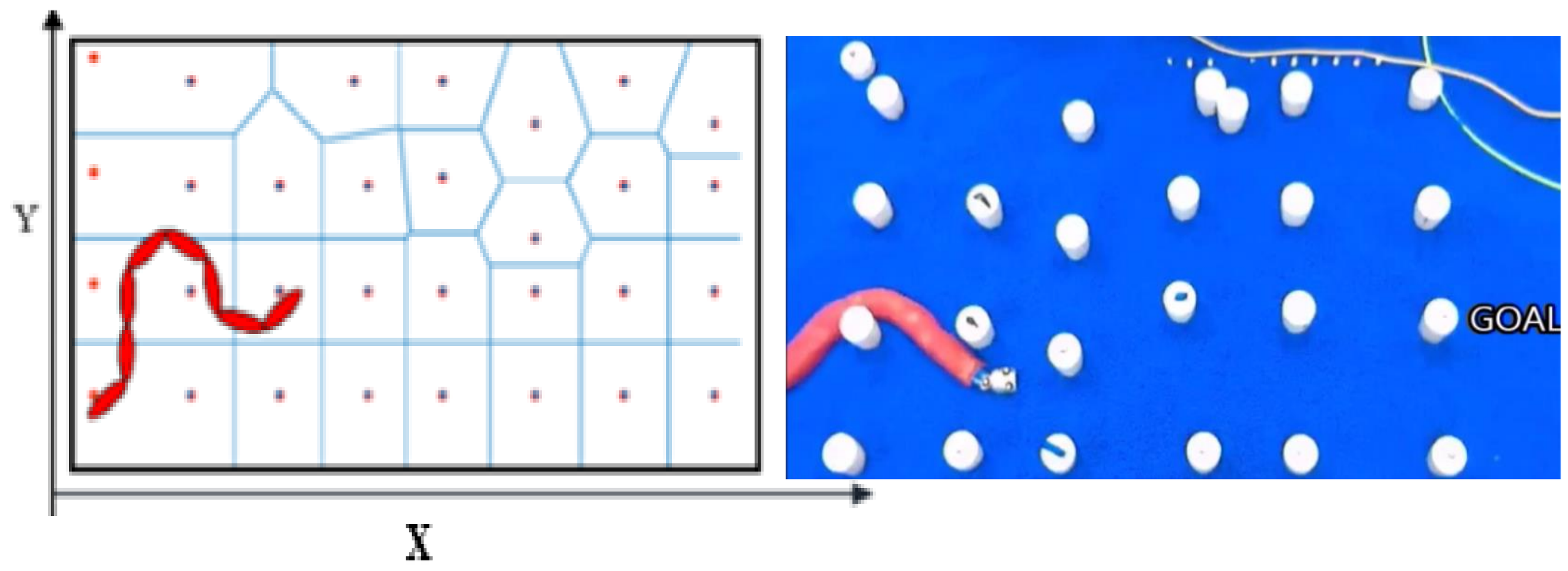
$$F_i^b = -K_i \xi_{wi} = -\begin{bmatrix} k_{xi} & & \\ & k_{yi} & \\ & & k_{zi} \end{bmatrix} \xi_{wi},$$

$$K_{yi} = K\_height + \sum A * \exp\left(-\left(\frac{(x-x_k)^2}{2\sigma_x^2} + \frac{(y-y_k)^2}{2\sigma_y^2}\right)\right)$$

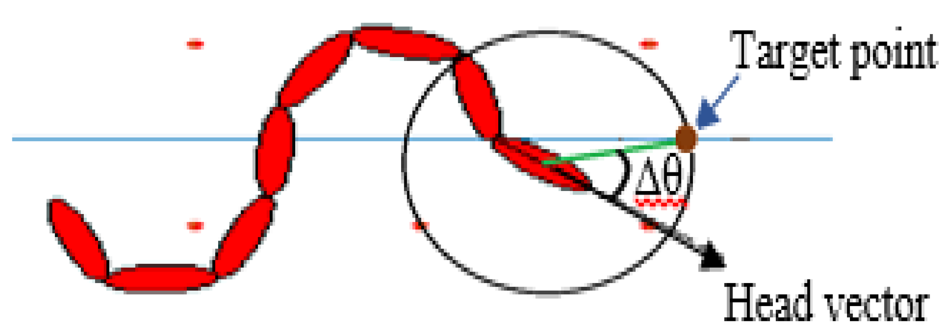
- Figure Shows the equivalence of peaks of the Gaussians hump with the center of the obstacles by blue arrow Low level Gaussians map to the granular surface by green arrow. The Thickness of the pegs and the thickness Gaussian humps by brown arrow

3. Path Planning:

- The idea of introduction to planning in to the simulation is to find the easiest path for the snake robot to reach a particular target point in the environment.
- By "easy to follow" term we mean that we choose a path in which the snake robot doesn't get stuck in the obstacles or the magnitude of velocity of center of mass doesn't fall below a certain limit at any particular point while following the path.
- GVG path planner was chosen so as to minimize the complexity of choosing the exact path and also ensure the path chosen justifies the motion requirements

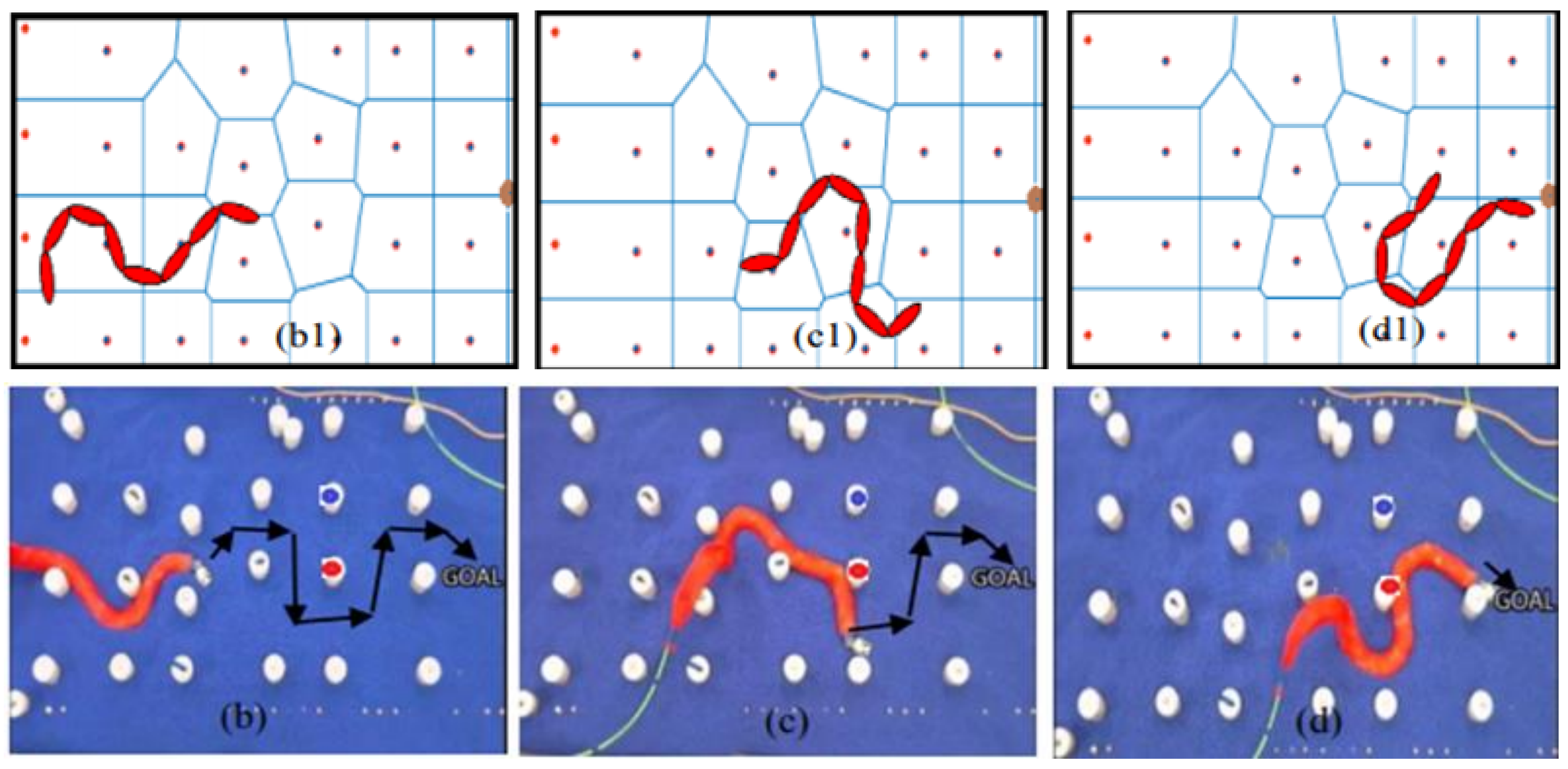


4. Path Follow in sim/real environment:



- The angle attained by the head is given by a proportional and differential controller as described by above eq.
- The input angle (Δθ) is calculated by the angle between the line joining the head module to the target point and the line represented by the head vector direction.

5. Simulation and Experiments



- A very similar environment is created in the simulation visualization, placing the snake robot and obstacles in similar positions as the real world.
- Animated snake robot is simulated to retrieve planned path.
- The real snake robot is made to follow the planned path in real environment.

6. Conclusion and Future Work:

- This paper presented a mathematical model for the snake robot interacting with obstacles in a cluttered environment where the obstacle contact forces were modelled to anisotropic viscous friction.
- A repeatability of 0.8 of following a planned path by the snake robot shows the idea of choosing the GVG graph as the test path and assuming the branches of the graph as the representative of all the homotopic paths correct.

7. References:

[1] P. Liljeback, K. Y. Pettersen, Ø. Stavdahl and J. T. Gravdahl, "Snake Robot Locomotion in Environments With Obstacles," in IEEE/ASME Transactions on Mechatronics, vol. 17, no. 6, pp. 1158-1169, Dec. 2012.

[2] Chaohui Gong, Matthew Travers, Henry C. Astley, Daniel I. Goldman and Howie Choset," Limbless Locomotors that Turn in Place",in 2015 IEEE International Conference on Robotics and Automation (ICRA