Light/Matter Interactions: A Novel Simulation Platform for Intra-Body Nanoscale Optical Communication

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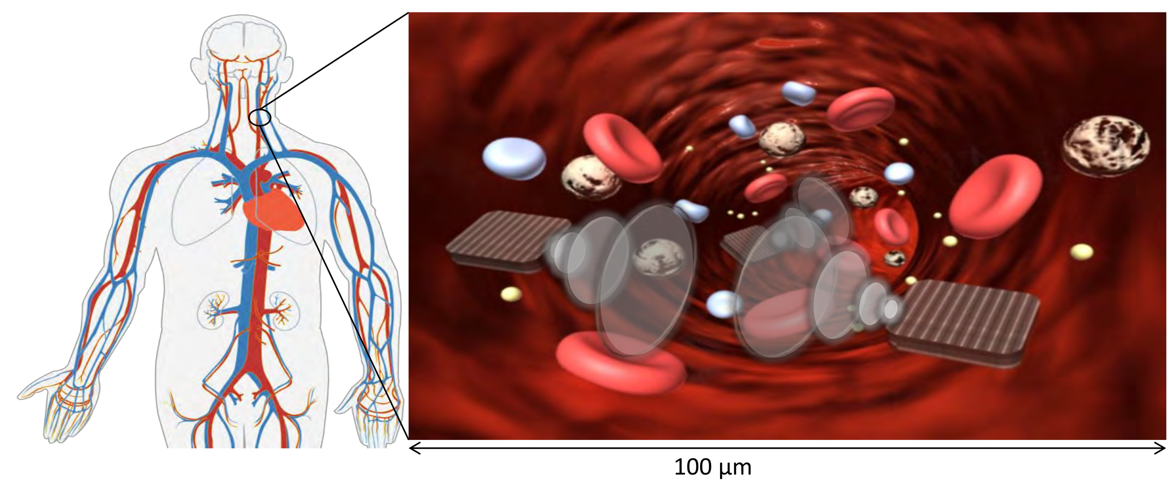
Motivation

- In vivo Wireless Nanosensor Networks (iWNSNs) are communicating nano-devices with the capability of operating inside the human body, allowing for in vivo monitoring, diagnosis and operation.
- Through the use of iWNSNs new opportunities to monitor human biology become available on a cellular and subcellular level.
- To enable the communication among the in vivo nano-devices, propagation of electromagnetic waves need to be modeled by taking into consideration the dynamics of cells at the nanoscale.



Problem

- Previous simulations have been done but on a multi-physics simulation software that lacks modularity, dynamism, and velocity.
- A platform that takes into consideration both the peculiarities of nanoscale optical communications and the dynamics of the cells inside the human body with lower computational burden is needed.

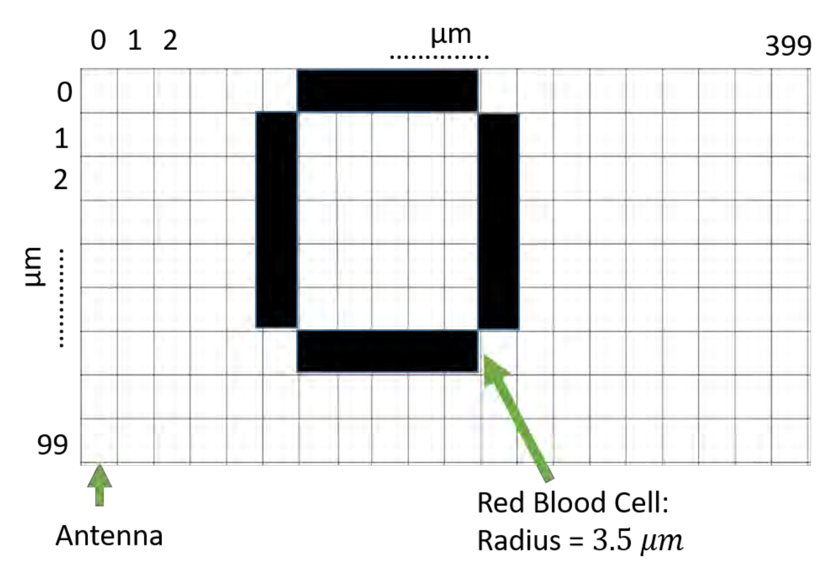
Method and Approach

- Utilizing Python, a program that can simulate light interactions with organic tissue is developed with focus on blood cells in human vessel.

Blood Vessel Matrix

- A blood vessel is represented as a matrix where the columns and rows are the x and y axis respectively.
- Each entry of the matrix represents the magnitude of the electromagnetic wave at a specific distance.
- First column is antenna emitting plane wave
- Wave Propagation Formula:

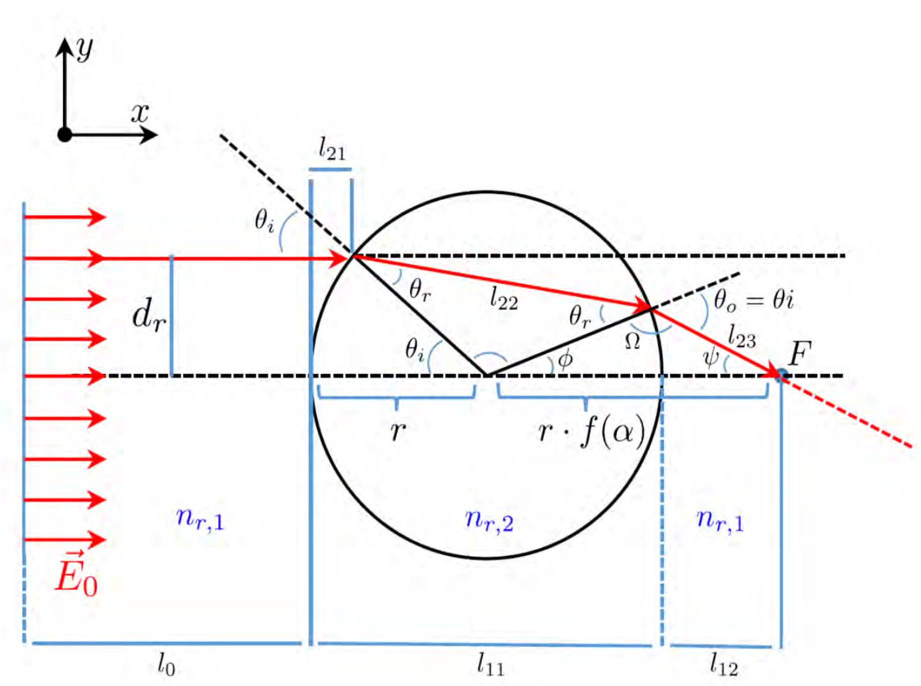
$$E_d\hat{a}_x = E_0 e^{-hd}\hat{a}_x$$

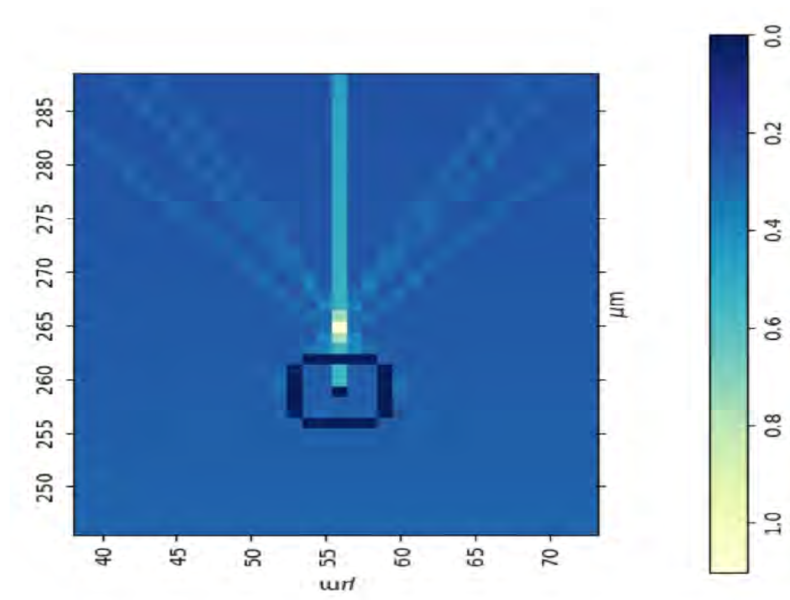


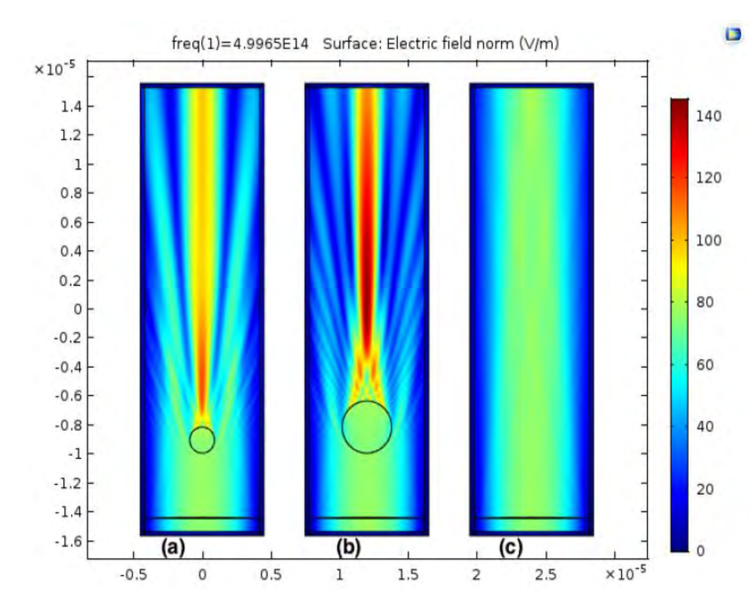
Single Cell Model

- The RBCs ability to act as an adjustable micro-lens allows for varying transmission capabilities [1], [3].
- An RBC can vary its shape from 90 fl to 150 fl.
- We consider a sphere shape for our cell model. This is because although the cell is constantly changing shape, it averages to a spherical form
- The rays coming out of the cell are traced using the coordinates of the focal point and point the ray exits [2].

- Focal Point: $x = o_x + rf(\frac{d_r}{r})$
- Exit Point: $u = r\sin(\phi) + o_x$, $v = \pm r\cos(\phi) + o_y$

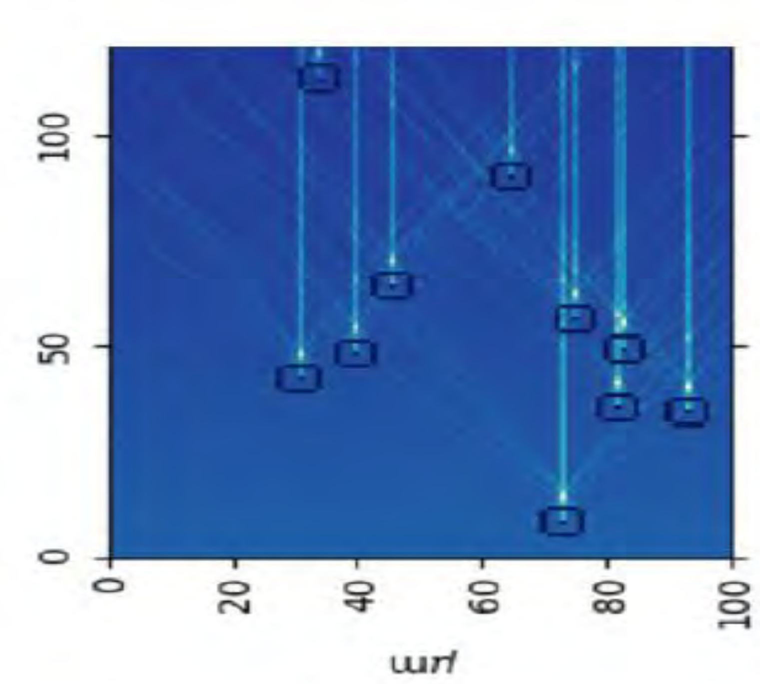


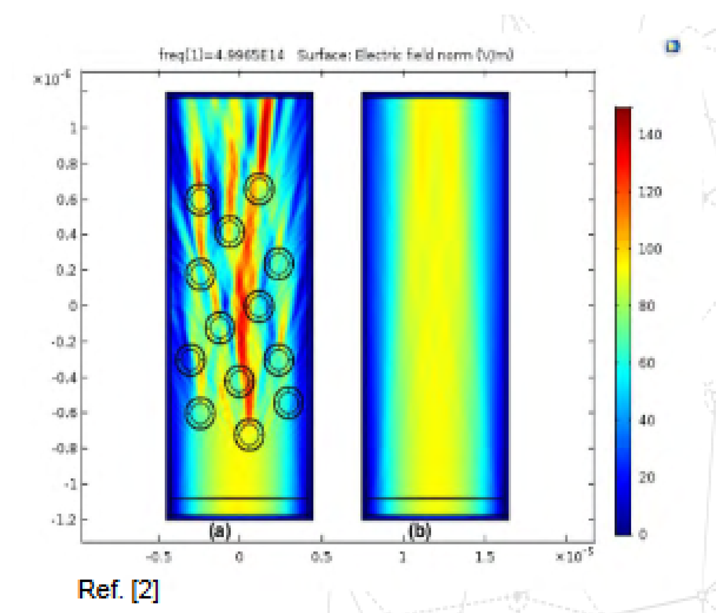




Multi Cell Model

- Cells need to be positioned within specific set of parameters:
- No overlapping cells: $d = \sqrt{(o_{x1} - o_{x2})^2 + (o_{y1} - o_{y2})^2} > 10$
- Within the borders of the blood vessel
- EM waves exhibit constructive qualities
- Rays that protrude the cell do not react with other RBCs yet.





Ref. [2]

Phase Implementation

- To have cells react to more than just plane waves and straight rays, the phase of the EM waves needs to be taken into account.
- 2-dimensional data needs to be stored in matrix containing phase and magnitude
- Wave propagation formula in 2D environment: $\vec{E} = E_x\hat{a}_x + E_y\hat{a}_y$

Conclusion

- Using Python makes the platform very versatile and making adjustments is easy.
- Python decreases the computation burden and facilitates the simulation of light propagation in larger biological tissues.

Future Works

- Finalizing matrix of vectors and phase implementation.
- Adding cell movement, speed, and dynamicism to the model.

References

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2. P. Johari and J. M. Jornet, “Nanoscale optical channel modeling for in vivo wireless nanosensor networks: A geometrical approach,” in Proc. of the IEEE International Conference on Communications (ICC), 2017.
3. L. Miccio, et al., “Red blood cell as an adaptive optofluidic microlens,” Nature communications, vol. 6, p. 6502, 2015.

Acknowledgements

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