Research Statement

Introduction: Mathematical models and dynamical systems of biological processes have been the core of my research in recent years. As an undergraduate, I had attended a seminar where I was intrigued by what the researchers had accomplished using mathematical models and soon found myself seeking out related coursework. This early exploration of applied mathematics research that incorporated modeling also introduced me to the field of dynamical systems and mathematical biology, shaping my research interest and goals. In particular, I am interested in understanding how certain factors can impact the dynamics of biological systems and use models to demonstrate these phenomena.

In preparation of my PhD dissertation, I developed numerical models and analyzed the dynamics of the classic epidemiological system (known as the SIR model) modified either with a switch system or Preisach operator. A major contribution of this work has been a set of theorems and propositions that indicate certain conditions which ensure convergence to an endemic equilibrium. These conditions can act as guiding principles to health officials as they plan preventive policies to control disease spread. We also submitted two papers on this research; one of which has been published while the other is under review.

Prior to my dissertation, I worked on a research project in collaboration with UT Southwestern radiation and oncology department. I had generated 3D models of the thorax of lung cancer patients, which I used to train and test an ensemble of neural networks. The neural network algorithm we developed showed significant improvement in the speed and accuracy of the reconstruction of cone beam CT scan images. Our work had led to a published conference paper, and a web article in SIAM News.

Current/ Ongoing Research: When diseases begin to spread in a population government and health official begin to introduce policies in order to reduce the rate of transmission, and minimize the maximum density of the infected population. However, due to limited resources, economic impact, and community needs, questions arise about how long these policies should be in place and to what degree will the general public comply with these changes. Therefore, my dissertation considers three SIR models that are modified to study the impact of 1) implementing/revoking policies in relation to the density of the infected population; 2) varying the vaccination rate in relation to the density of the infected population; and 3) initiating policies that receive differing degree of action from the public. More specifically, my thesis work focusses on the global dynamics of the SIR system that were modeled in the following way:

1. A single relay system where the transmission rate switches at two thresholds determined by the density of the infected population.
2. A system that accounts for varying the rate of vaccination by introducing a Preisach operator that takes the infected population density as its input.
3. A system that assumes the heterogeneous public response varies the transmission rate which is modeled by a Preisach operator that takes the infected population density as its input.

For each of these, my mentors and I had conducted rigorous analysis of the dynamics for the proposed model by establishing theorems and propositions. These were then supplemented with numerical simulations that I developed in MatLab. The noteworthy results of each of these models were:

- If preventative measures are introduced or taken away before certain conditions are met the disease will continue to linger or the epidemics can recur after the intervention.
- If vaccines are available and rolled out in relation to the density of the infected population then this promotes the convergence to an endemic equilibrium state. However, a uniform rollout may result in recurrent periodic outbreaks of the epidemic.
- Heterogeneous public response to preventive policies not only increases the maximum density of infected population but also increase the potential of periodic outbreaks. However, communities with homogenous response will experience significantly reduced infected population while converging to an endemic state.

Previous Research: Radiotherapy is the one of the most common methods of treating lung cancer patients. It requires clear imaging of patient's anatomy and tumor to precisely radiate cancerous cells. Therefore, before receiving radiotherapy, a series of cone beam computed tomography (CBCT) scans are taken of the patient's thorax. However, the motion blur is prominent in the thorax due to breathing. It is important to eliminate blurring artifacts in 3D images reconstructed from a set of 2D x-ray projected data. One approach is referred to as 4D-CBCT which groups the CBCT projections into bins representing different breathing phases and then reconstructs a 3D image for each phase. 4D-CBCT has shown to mitigate the motion blur 3D-CBCT, but its temporal resolution is rather low. Therefore, it is desirable to develop a method that allows for time-resolved volumetric reconstruction from a single projection image at that instance.

Our approach to this problem was to build a 3D lung motion model via principal component analysis (PCA) and developing an ensemble of neural network to map patches of the projection image to the three largest principal components. I contributed to this project by generating the 3D models, computing the deformation vector field, obtaining the PCA principal components, and training and testing the neural network. This proposed method achieved a 5.5% relative reconstruction error in the worst case on the simulated data, which is an improvement over the state-of-the-art.

Future Goals: I plan to extend on my research of the SIR model by comparing my theoretical results to existing data-driven models of highly contagious diseases such as measles, SARS and COVID-19. This way I can argue towards the robustness of my numerical models in relationship to past and current epidemics and pandemics. It will also provide further insight on whether the results of my research can be implemented towards public health planning. Furthermore, I look forward to research opportunities where I can apply my knowledge of dynamical systems to study other biological processes of our bodies and the environment.