Forecasting of COVID-19 cases using a custom deep learning architecture incorporating vaccination

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Background

Beginning in late 2019, the COVID-19 pandemic was a global crisis. By May 2021, it affected 192 countries with over 169 million cases and 3.5 million deaths[1]. The advent of vaccination programs and the emergence of new virus variants highlighted the complexity of managing this health crisis. Our study aims to address these challenges by developing a novel deep learning architecture for accurate forecasting of COVID-19 cases, incorporating key factors like vaccination data and hospital admissions. We have compared the performance of our model with existing architectures, provided compelling intervention-controlled new case forecasting, and shown the importance of effective public health policies in combating such scenarios

Motivation and Problem Formulation

- Our study is driven by the limitations of existing forecasting models, which largely rely on historical case and death data, neglecting the impact of vaccinations and other interventions.
- We identified a need for a model that integrates these crucial elements to provide a more comprehensive understanding of the pandemic's dynamics.
- This led us to formulate a deep learning-based solution that incorporates vaccination trends, offering a more nuanced forecasting approach.

Proposed Methodology

- We developed a fusion-type network that combines channel-wise convolution, global convolution, and recurrent networks to analyze various time series data, including daily cases, deaths, vaccination amounts, and hospital admissions.
- Considering all those features at once, we have also used these four features as four different channels and applied 1-D convolutional analysis on them.
- The network architecture consists of three layers: two Long Short Time Memory (LSTM) networks, a channel-wise feature extraction layer with 1D-Net, and a 1D convolutional layer.
- LSTM networks capture long-term dependencies of the time series, and the 1D-Net and 2D-Net layers extract correlated features between different time-series data.
- Three parts of the network are concatenated into a feature vector, which is then mapped to a dense layer containing four nodes representing the four output features.
- Loss function is defined as the sum of individual losses for new cases, new deaths, vaccination amount, and hospital admission.
- The network is trained using backpropagation for the optimization of network weights and is repeated n number of times to forecast n days of data.

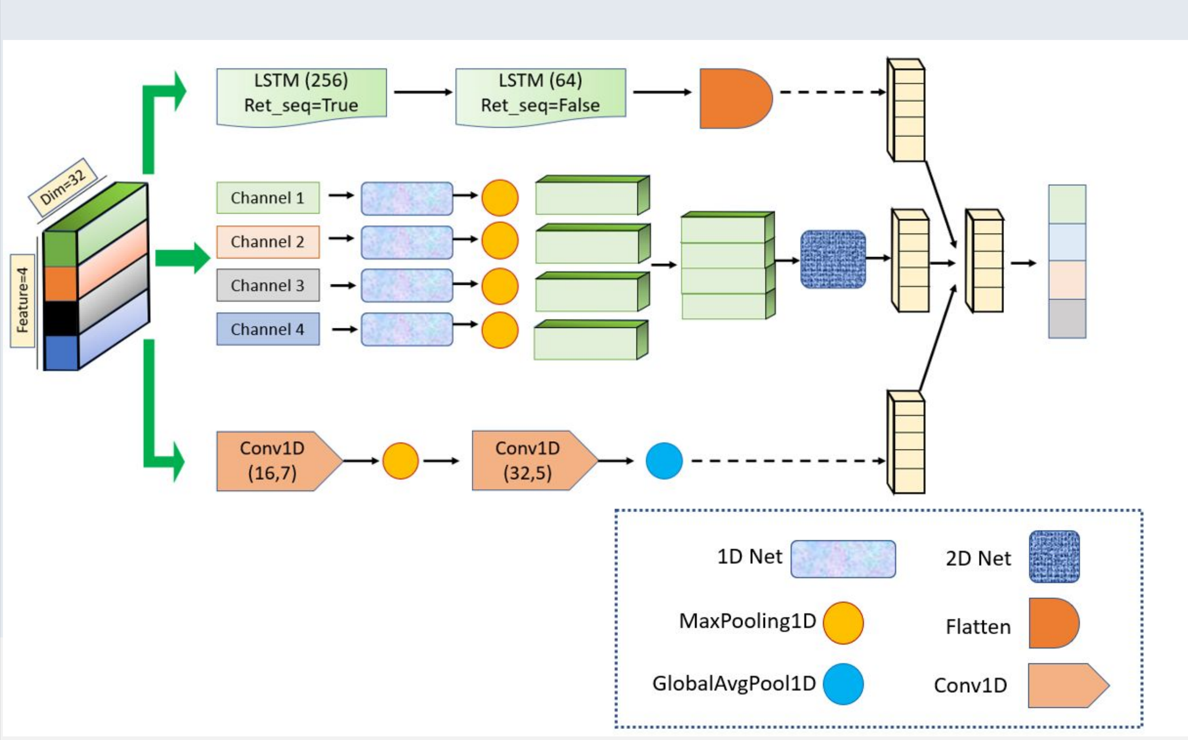

Fig 1: Complete Network Scheme

Experimentation

- We conducted a comprehensive analysis using data from the United States and the United Kingdom[2]. Our model was tested and validated against other state-of-the-art deep learning models.

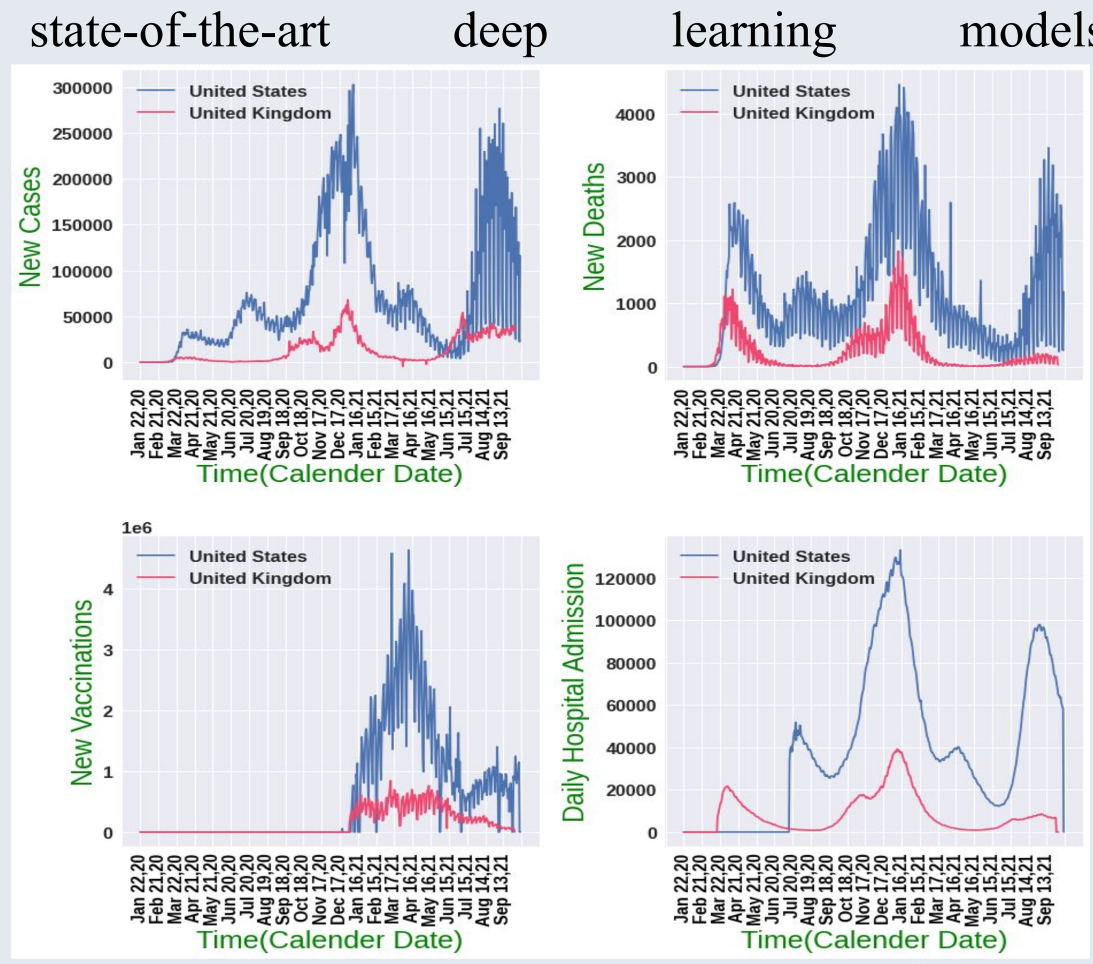

Fig 2: New cases, new deaths, new vaccinations and daily hospital admission data for USA and UK

- The key to our experimentation was the multivariate time series analysis, which allowed us to examine the relationships between different COVID-19 related factors, such as new cases, deaths, vaccinations, and hospital admissions.
- We have taken 40 days of data of new cases, new deaths, new vaccination, and new hospital admission for validation. To verify the reliability of our model, we have compared results with other SOTA deep learning models used for time series forecasting, such as CNN and LSTM[3].

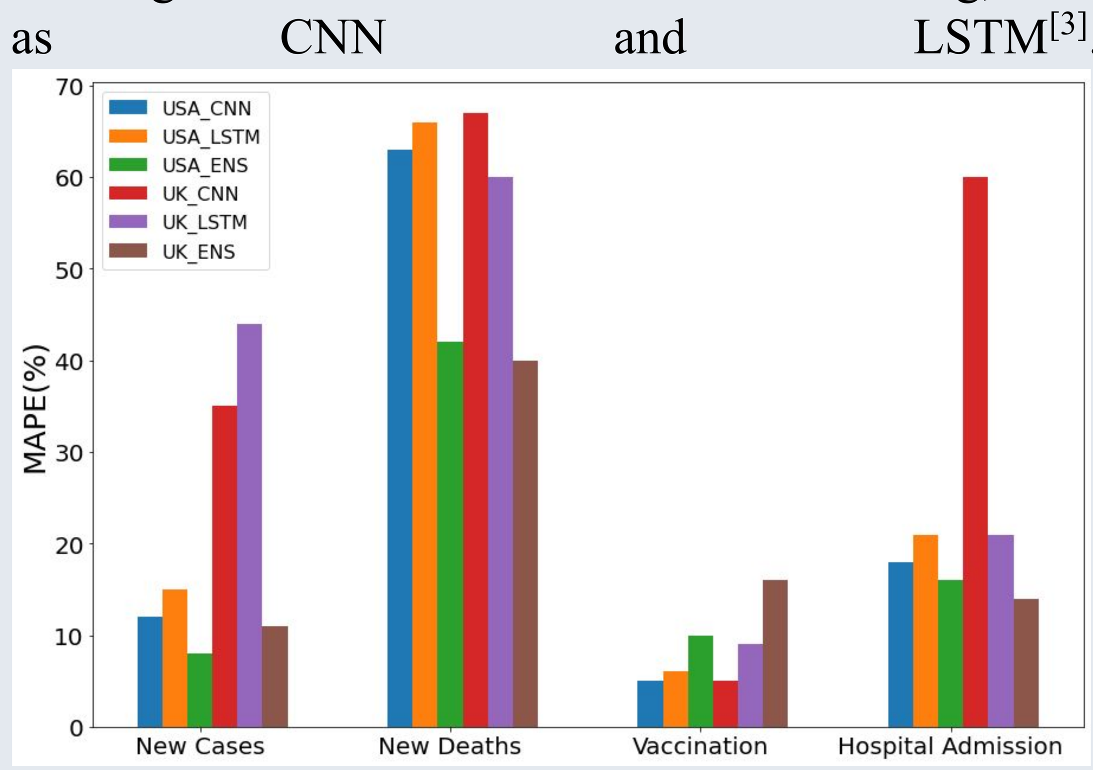

Fig 3: Bar plot of the validation results for the USA and the UK with different Deep learning models

- The results demonstrated that our model not only forecasts the pandemic's trajectory effectively but also provides insights into the impact of vaccination and other interventions on future case trends.

Findings

- Our findings from multivariate time series analysis for the US and UK indicate that increased vaccination correlates with a decrease in COVID-19 cases, revealing a strong negative correlation between vaccination rates and new infections.
- Conversely, new cases correlate positively with new deaths and hospital admissions, underscoring the importance of vaccinations in controlling the virus spread.
- The figure for the daily cases correlation with other features for USA is given below. UK has similar trend.

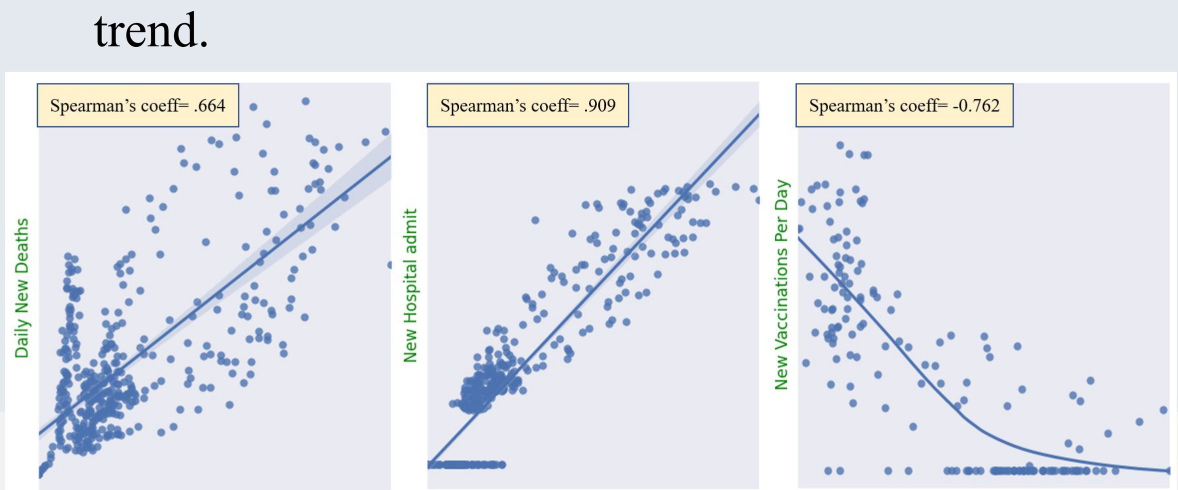

Fig 4: Daily cases correlation with other features for USA

- There is a substantial difference in the impact of vaccinations on new cases in India compared to the US and UK, with only a moderate correlation.
- In India, in spite of vaccination efforts, new variants and mass gatherings caused a case surge, revealing that just vaccines alone cannot control the virus without any health measures. Differences in the total vaccination coverage, as seen in the Figure 5, are significant in our two analysis scenarios, which emphasizes the role of extensive vaccination in pandemic management.

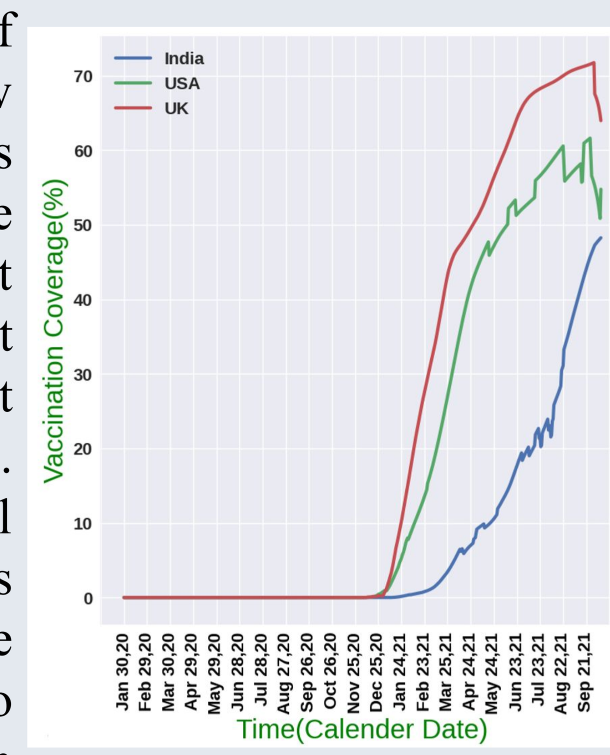

Fig 5: Total vaccination coverage for India, USA, and UK

- Our model is used to predict new COVID-19 cases and vaccinations for the USA over 60 days. The result suggests that extensive vaccination could mitigate the spread of new variants.

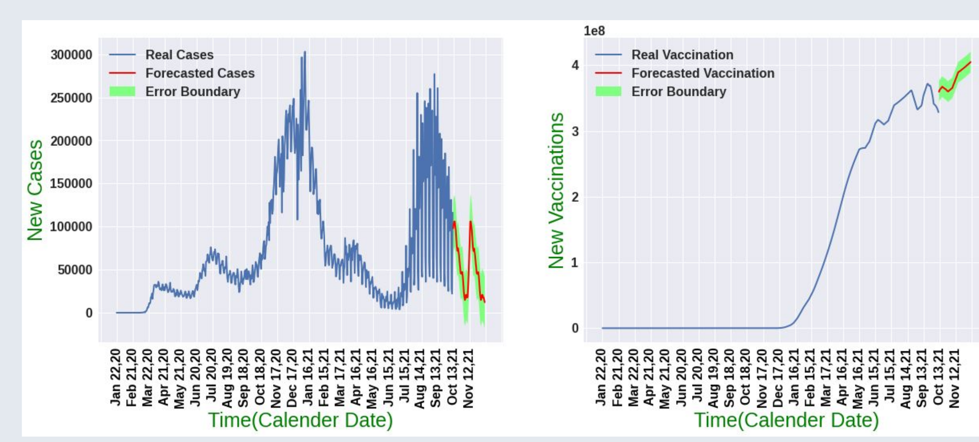

Fig 6: Forecast of new cases and vaccinations of 60 days for the USA

Conclusion and Future Work

- Our study presents an innovative deep learning framework that effectively integrates vaccination and hospital data to predict COVID-19 trends.
- It demonstrates superior performance over traditional models and highlights the crucial role of rapid vaccination and strategic policies in the USA, the UK, and India to address the pandemic and emerging variants.

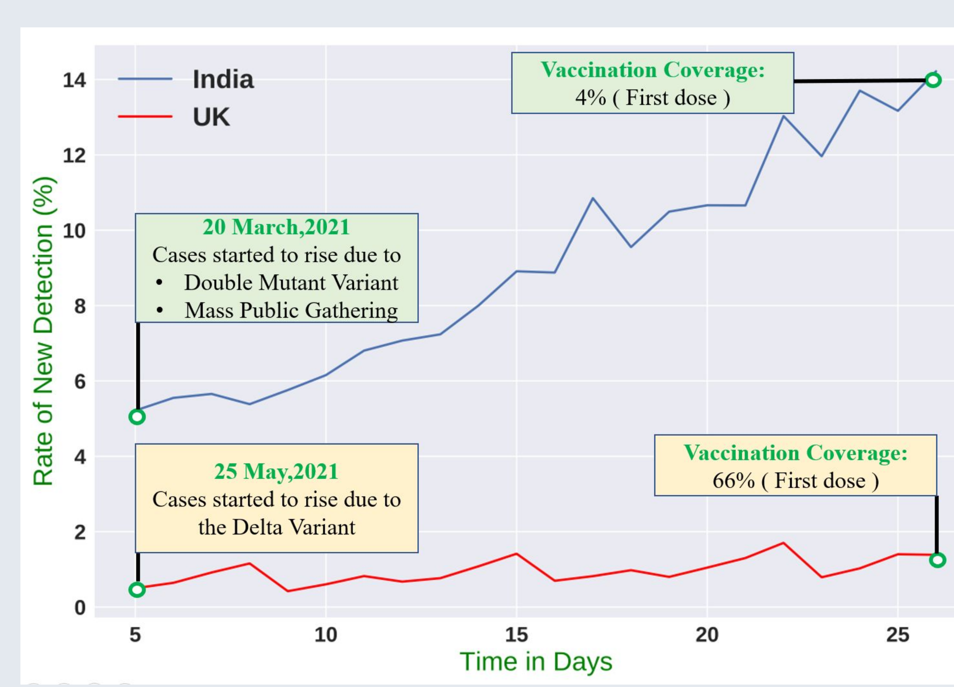

Fig 7: The infection rate for 30 days of the UK and India after the emerge of mutant variants

- Our findings stress the urgency of extensive vaccination to prevent future spikes in cases.

References

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