# Systematic investigation of methods for slip detection in robotic manipulation.

By Nelson Elijah

How does different methods of slip detection affect a robot’s ability to manipulate objects?

# The Experiment

Papers and their methods used for slip detection

| Papers | Methods Used | Data Used | Manipulation Task Done |
|---|---|---|---|
| 1) Event-Driven Visual-Tactile Sensing and Learning for Robots | Visual-tactile spiking Neural Network to detect slip events | Perception (event based), proprioceptive and tactile data | Object classification and (rotational) slip detection |
| 2) Tactile Convolutional Networks for Online Slip and Rotation Detection | Time series classification with Convolutional Neural Networks to detect slip | Tactile data (piezo-resistive data) | Holding a cardboard cylinder, a remote and a drinking glass |
| 3) Force Estimation and Slip Detection/ Classification for Grip Control using a Biomimetic Tactile Sensor | Artificial Neural Networks to detect slip | Force and Pressure data (all from BioTac sensor) | Grasp experimentation on various objects like plastic cup, plastic jar, wood, |
| 4) Grip Stabilization of Novel Objects Using Slip Prediction | SVM and **Random Forest** to classify slips | Tactile data from BioTac Sensor | Grip stabilization on objects like a box, ball, cup, marker, measuring stick, tape, Watering can |

| Papers | Methods Used | Data Used | Manipulation Task Done |
|---|---|---|---|
| 5) Real-time Friction Estimation for Grip Force Control | Closed-loop grip force algorithm that dynamically applies a near-optimal grip force to avoid dropping objects of varying weight and friction | Force tactile data from the PapillArray sensor | Vertical lifting of objects with varying weights like Orange, Cardboard box, Coffee jar |
| 6) Tactile-Driven Grasp Stability and Slip Prediction | CCN and GCN models are used for stability binary detection, i.e., stable grip and unstable grip.<br>LSTM and ConvLSTM models are built to classify the type of slippage in the following cases: lack of stability, translational or rotational | Tactile images formed from the pressure data from the BioTac sensor | Stability prediction and slip direction detection of objects (spheres, cylinders, box) |
| 7) Self-supervised learning of object slippage: An LSTM model trained on low-cost tactile sensors | Binary classification using LSTM networks where 0 implies the slip label and 1 implies the no-slip label | Pressure data from the Takktile Micro-Electro-Mechanical-Systems (MEMS) barometer sensors | Grasping of a 500ml plastic bottle filled with water to two-thirds |

| Papers | Methods Used | Data Used | Manipulation Task Done |
|---|---|---|---|
| 8) Learning Spatio Temporal Tactile Features with a ConvLSTM for the Direction Of Slip Detection | Slip detection using RNN (ConvLSTM) to learn spatio-temporal features<br>**-Spatial:** where slip occurs -Temporal: Slip occurrence with time | Tactile images formed from the pressure data from the BioTac sensor | Grasping of various objects sets like **basic** (hard drive, sponge ...), **solids** (plastic bottle), **small** (metal screw), **textures** (bubble wrap) |
| 9) Grasping Force Control of Multi-Fingered Robotic Hands through Tactile Sensing for Object Stabilization | **DNN (LSTM):** to detect contact events and object materials simultaneously from tactile data<br>**GMM:** to estimate the force Grasping force control strategy using tactile sensing techniques with feedback control | Tactile data, contact event, and material information using the BioTac sensor | Grasping of objects like paper, foam, plastic, and metal |
| 10) Slip Detection for Grasp Stabilization With a Multifingered Tactile Robot Hand | **SVM**, LogRes & Threshold classifier to detect slip and test multiple slip scenarios | Optical tactile data from the TacTip tactile sensor | Grasp destabilization and First-Time Grasping |

| Papers | Methods Used | Data Used | Manipulation Task Done |
|---|---|---|---|
| 11) Slip Detection with a Biomimetic Tactile Sensor | SVM to detect slip from pin motion in the TacTip sensor | Pin velocity data from the TacTip tactile sensor | Slip experimentation on a rig (a vertical low friction rail system with a slider) |
| 12) Slip Detection with Combined Tactile and Visual Information | **DNN:** (CNN and RNN) with tactile image to detect slip<br>**CNN:** To extract features from the image<br>**RNN (LSTM):** To compare feature sequences and make a decision | Tactile image data from the GelSight sensor | Grasping and lifting of 84 daily objects like (wood, bottle, basketball, syringe, toys) |
| 13) Tactile-based Manipulation of Deformable Objects with Dynamic Center of Mass | Tangential force based slip detection method and a deformation prevention approach relying on weight estimation | Force data from the OptoForce OMD-20-SE-40N 3D force sensor | Grasping of deformable objects like plastic bottle, tee box, juice container, disposable cup. |

| Papers | Methods Used | Data Used | Manipulation Task Done |
|---|---|---|---|
| 14) Towards Learning to Detect and Predict Contact Events on Vision-based Tactile Sensors | Use DNN to predict future frames of tactile image sequences in an unsupervised learning fashion with 6650 trials of contact sequence as a dataset | Tactile image data from the FingerVision sensor | Grasping of objects like screwdrivers, erasers, a flash drive, pen while measuring picking success rate |

| Papers | Methods Used | Data Used |
| --- | --- | --- |
| 16) Maintaining Grasps within Slipping Bound by Monitoring Incipient Slip | When slip starts, the peripheral edge of the contact region will slip first, which means the displacement field of that region will have smaller magnitude than that at the center. This is the trigger signal for our method to detect incipient slip. | Visual Tactile data from the Gelsight tactile sensor |
| 15) Stabilizing novel objects by learning to predict tactile slip | Random forest classifiers to create generalizable slip predictors and then, use these classifiers in the feedback loop of an object stabilization controller. | Tactile data |
| 17) Slip Detection: Analysis and Calibration of Univariate Tactile Signals | Visual-tactile spiking Neural Network to detect slip events | Perception (event based), proprioceptive and tactile data |

# Conclusion

This systematic investigation shows the various methods and data used in slip detection and tactile sensing that are implemented in modern day robots.

# Classification report for slip detection with batch training

| | |
|---|---|
| Accuracy | 0.9805799878080641 |
| Precision | 0.9185415007415321 |
| F_score | 0.9298889076986483 |
| Recall | 0.9420087181264473 |

# Classification report for slip prediction with batch training

| | T + 5 | T + 10 | T + 15 | T + 20 |
|---|---|---|---|---|
| Accuracy | 0.9837182550216795 (0.98 ± 0.02) | 0.9731657142857143 | 0.9691428571428572 | 0.9682037932316846 |
| Precision | 0.9645298211423708 | 0.9442837672623974 | 0.906459971709575 | 0.937163317449446 |
| F_score | 0.9399519999265349 | 0.8921951138873381 | 0.8821589394494892 | 0.8787992128863955 |
| Recall | 0.9182772755487127 | 0.8526075801575576 | 0.8610867510779754 | 0.8362563253525501 |

# CNN report for slip detection with batch training

| | |
|---|---|
| Accuracy | 0.927283810850823 |
| Precision | 0.4636419054254115 |
| F_score | 0.48113505941891466 |
| Recall | 0.5 |

# ToDos

0. Read about imbalanced classification problems and list the possible solutions here in next slides **(DONE)**

1. Table of results for Dense network with mean and std (in 5 trials) **(DONE)**

2. Train CNN for detection & predictions problems too

3. Save&plot the accuracy curve for the training and validation set for both Dense **(DONE)** and CNN. (DONE)

4. Train ResNet in PyTorch for slip detection. (If done soon, also for slip prediction)

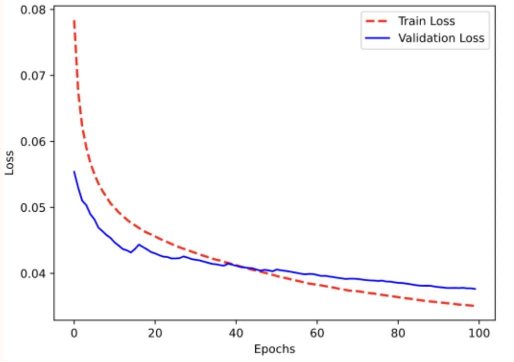
5. Implement Some imbalanced classification techniques **(DONE)**

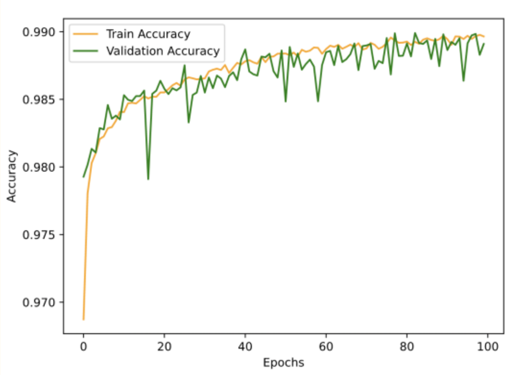
DOCUMENT EVERY STEP OF THE WAY AND EVERYTHING YOU DO !!

# Dealing with imbalanced dataset

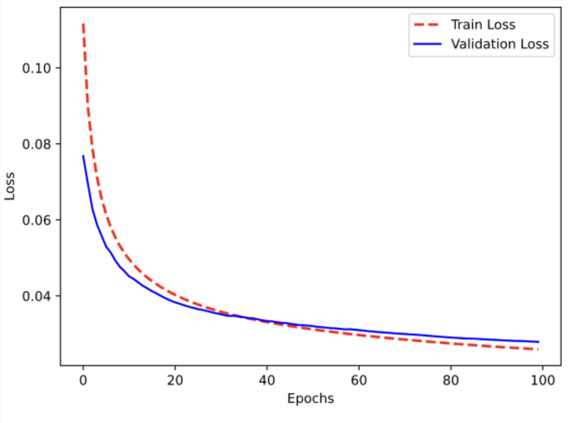
- Choose a proper evaluation metric
- Resampling (Under sampling and oversampling)
- SMOTE (synthetic minority oversampling technique)
- Bagging balanced classifier
- Threshold moving

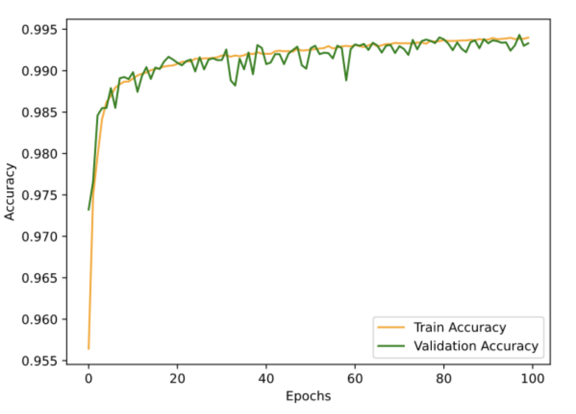
# Loss and Accuracy curve using a DNN for slip detection



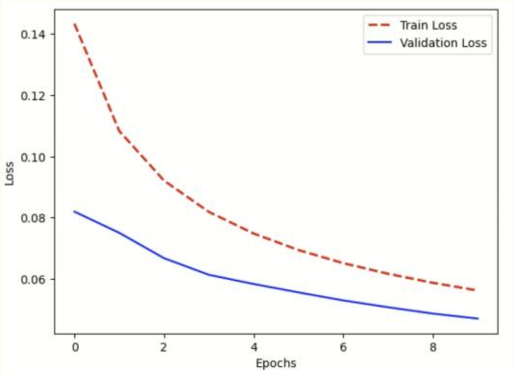



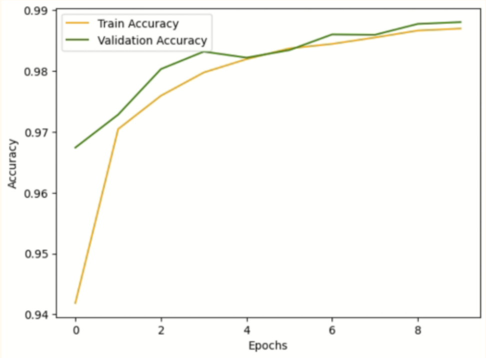

Using SMOTE for Imbalanced data



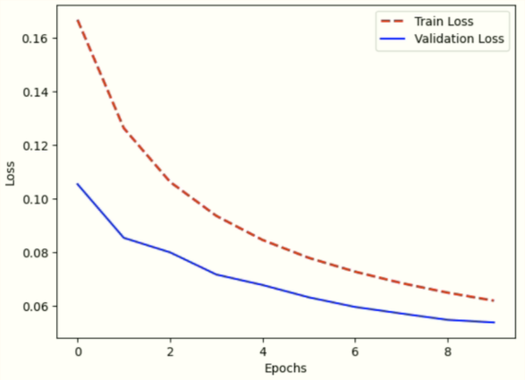



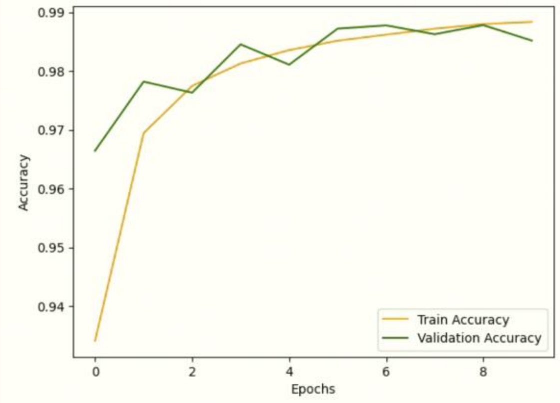
# Loss and Accuracy curve using a CNN for slip detection




Using SMOTE for Imbalanced data



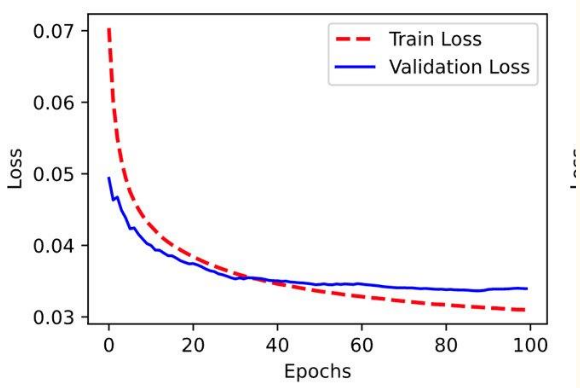



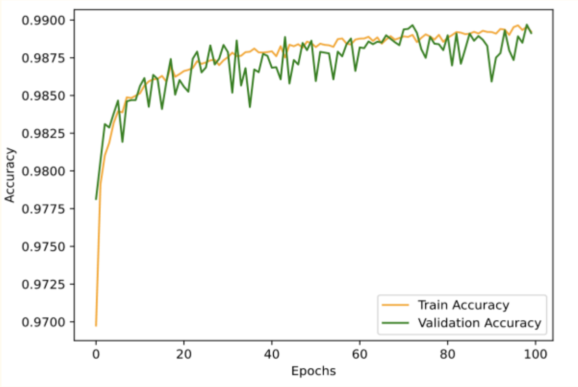
# Loss and Accuracy curve using a RESNET for slip detection

Using SMOTE for Imbalanced data

# Loss and Accuracy curve using a DNN for slip prediction

T + 5

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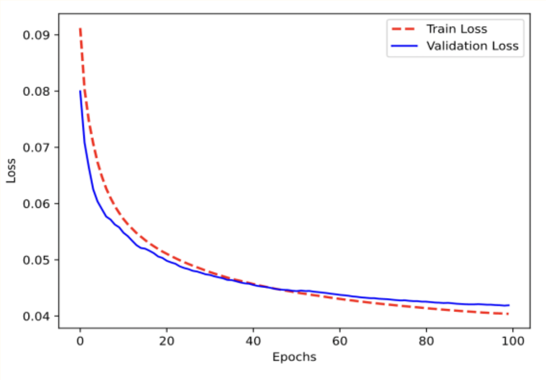


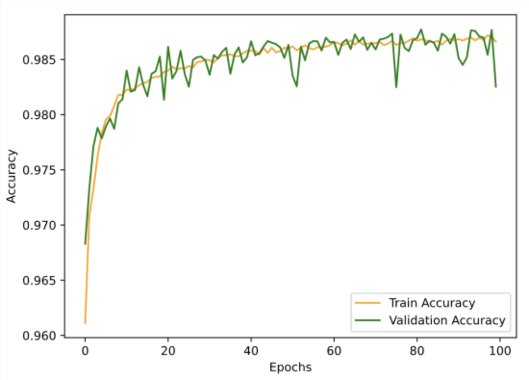

# Loss and Accuracy curve using a DNN for slip prediction

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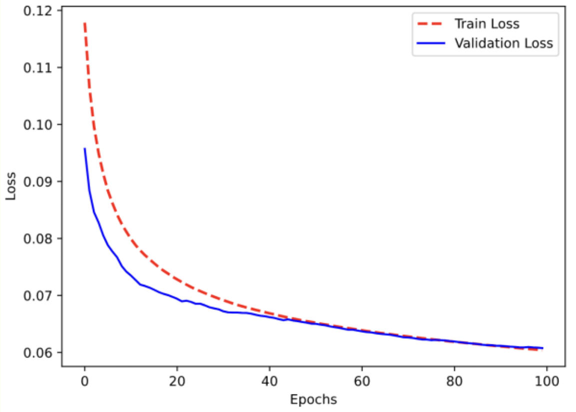


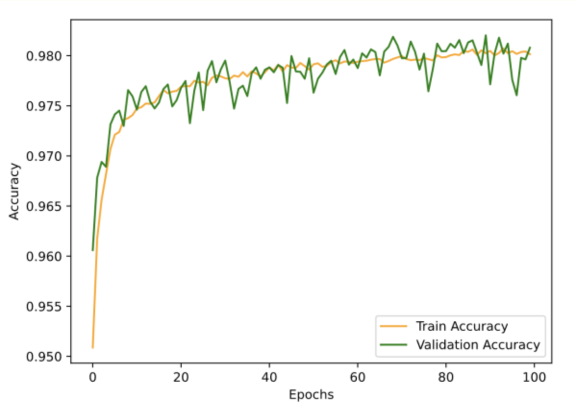


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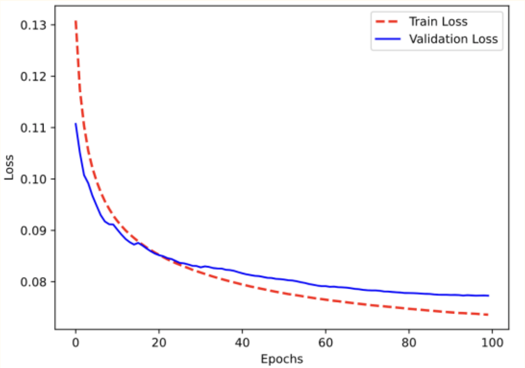


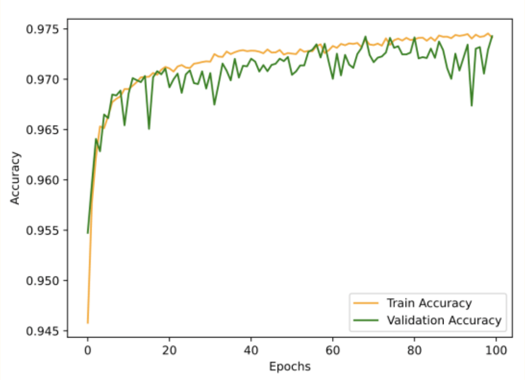

# Loss and Accuracy curve using a DNN for slip prediction using SMOTE

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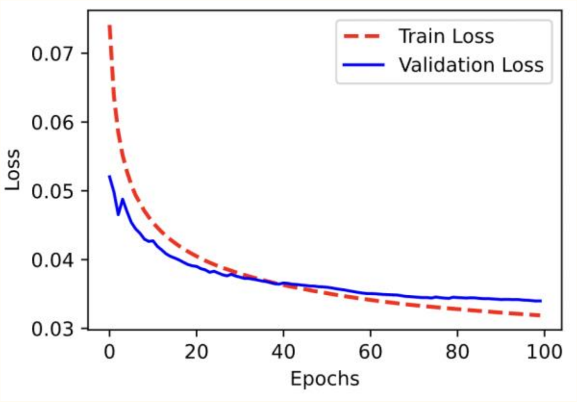


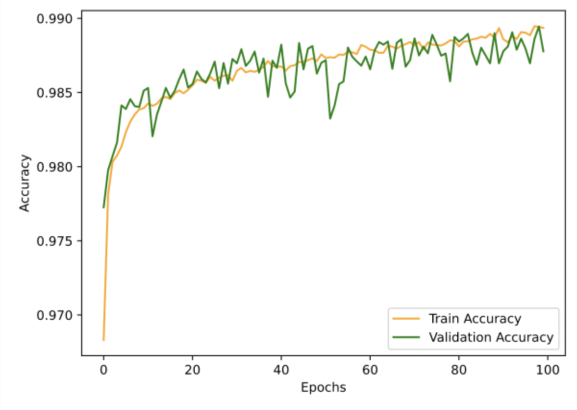


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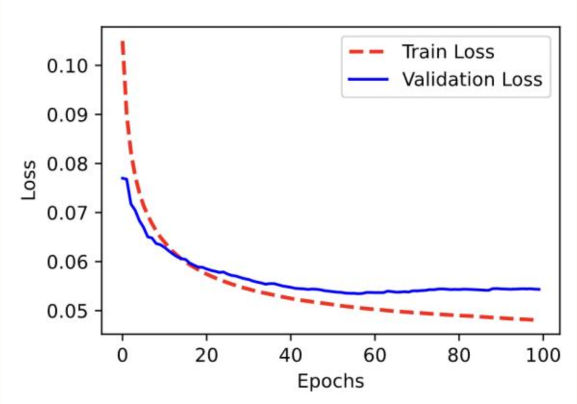


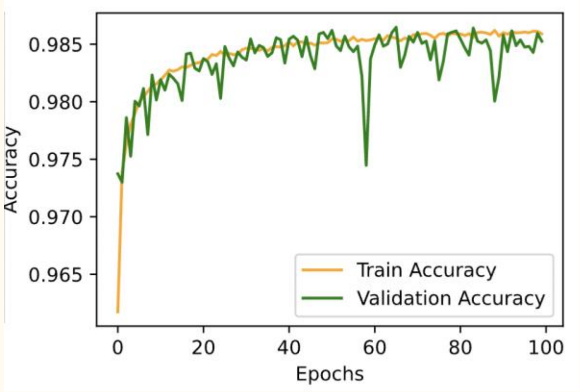

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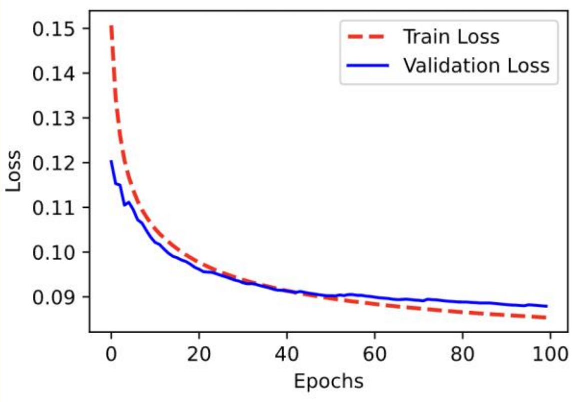


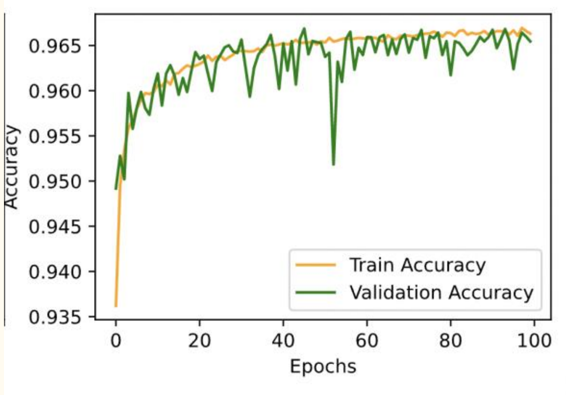


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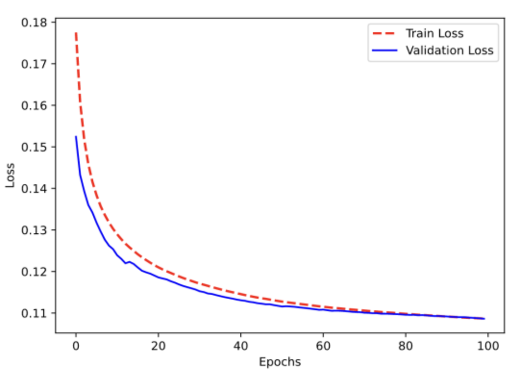


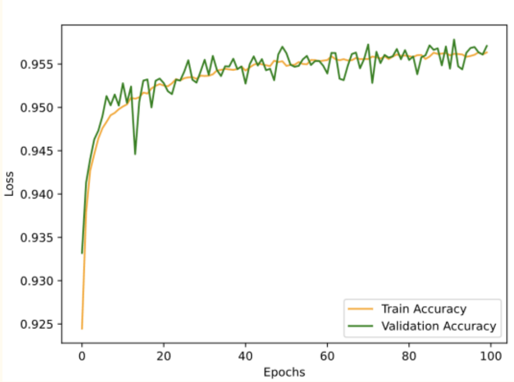

# Loss and Accuracy curve using a CNN for slip prediction

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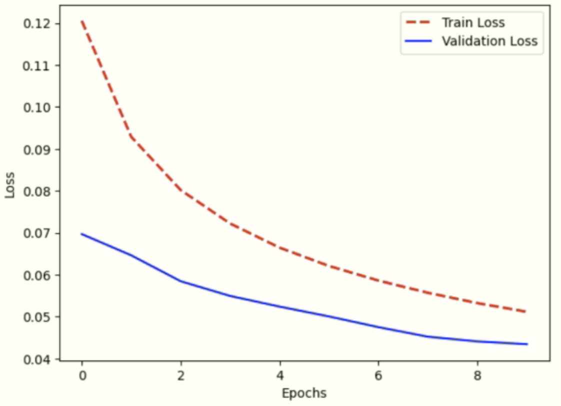


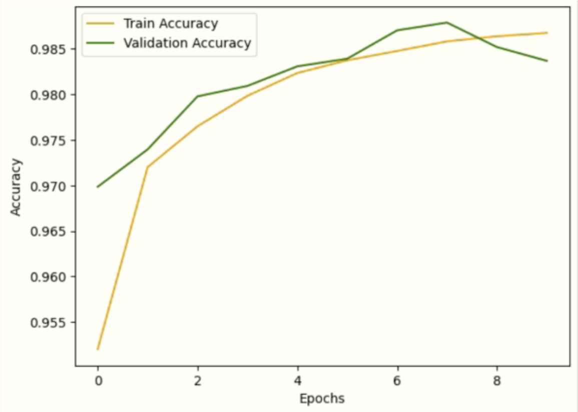


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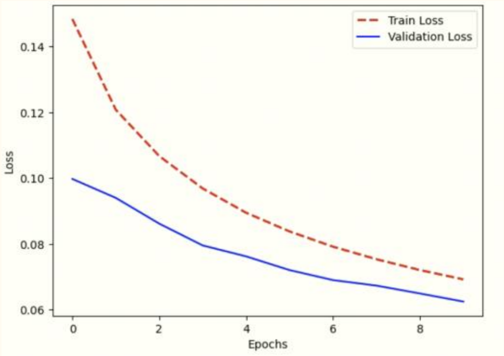
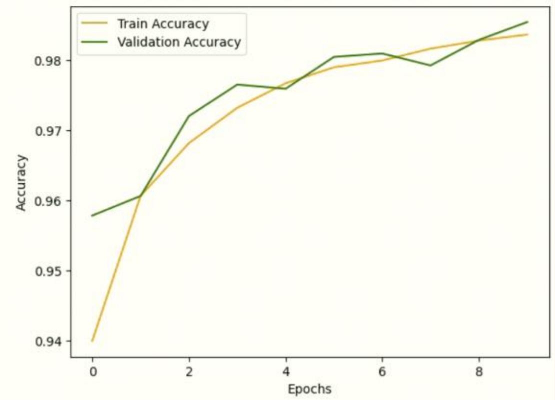
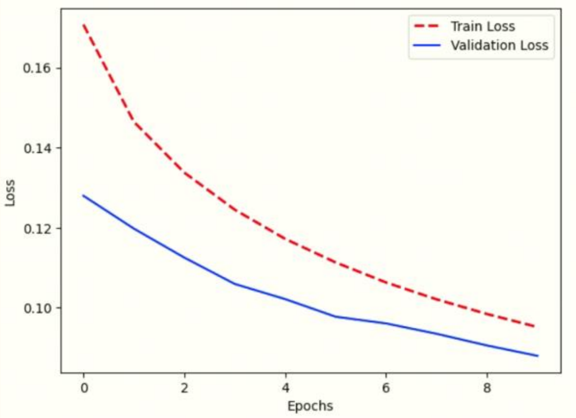
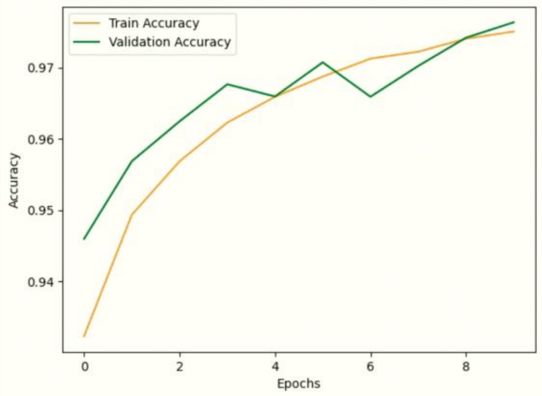


# Loss and Accuracy curve using a CNN for slip prediction

T + 15

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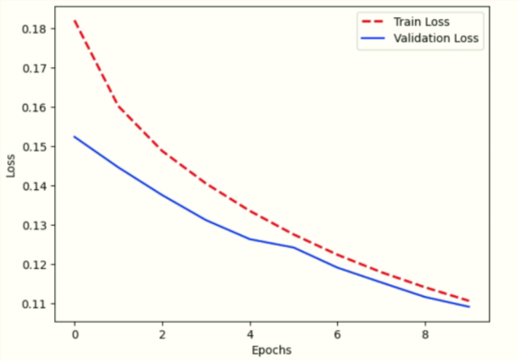
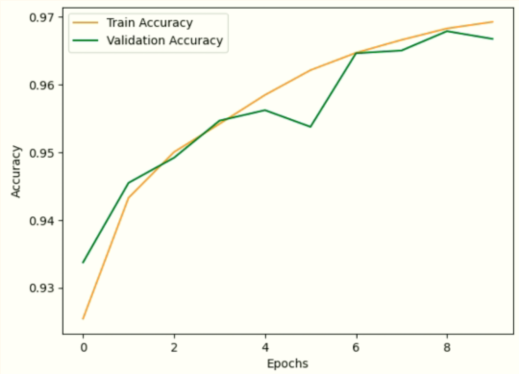
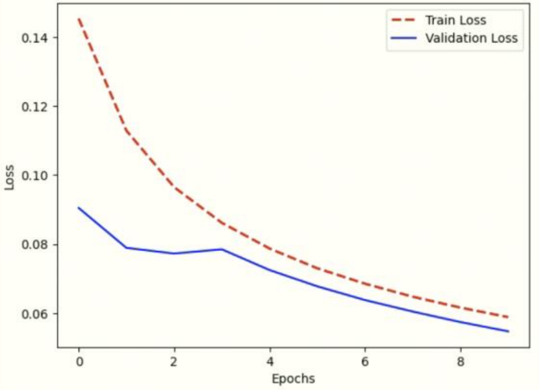
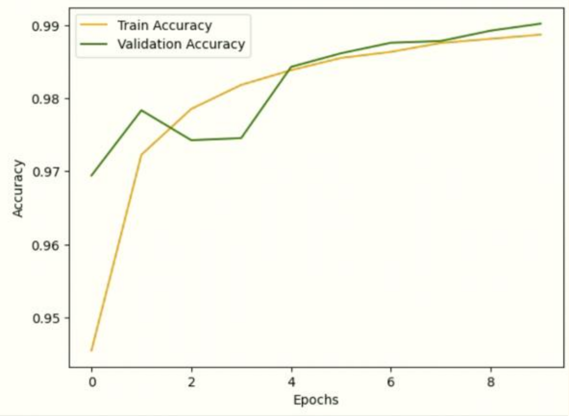


# Loss and Accuracy curve using a CNN for slip prediction with SMOTE

T + 5

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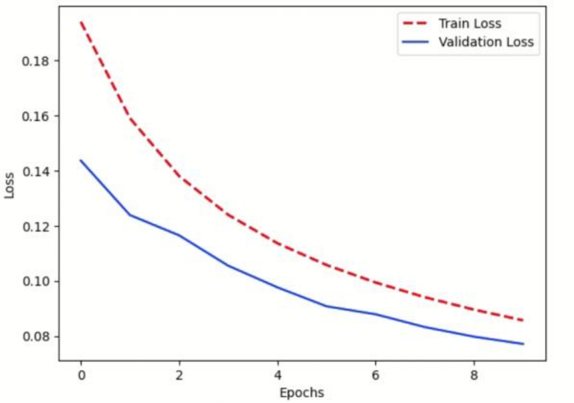


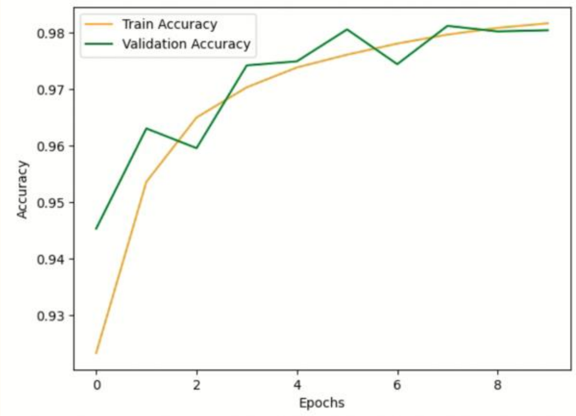

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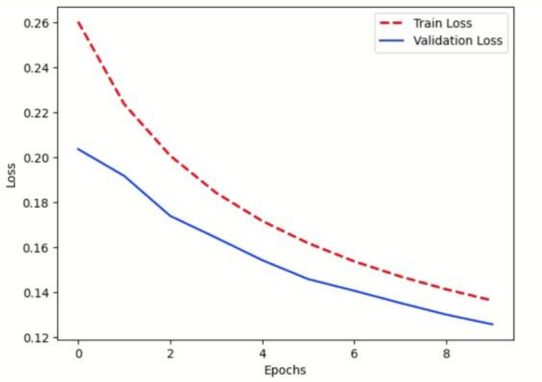


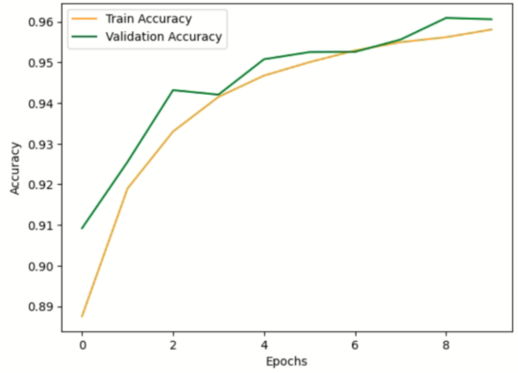


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