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Design and Implementation of Online Vehicular Traffic Monitoring System Using Convolutional Neural Network (CNN)

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ABSTRACT

The paper presents the design and implementation of Online Vehicular Monitoring System using Convolutional Neural Network (CNN), Traffic violations are unlawful activities that occur while an individual is operating a motor vehicle on the road. Traffic offenses are usually ruled by state motor vehicle codes that outline offenses ranging from minor infractions to severe violations. The proposed system was developed using Java for systems interfaces and programming of the system, MySQL database as its backend which serves as the database to the proposed system. Different traffic offence dataset (videos) were collected from the internet for both testing and performance evaluation. These datasets (videos) serves as input to the system. The system preprocesses the dataset to form video frames using the Fast Fourier Transform (FFT), these frames then passes through the Convolutional Neural Network (CNN) which then detect the vehicle plate number, segments it and classify the type of traffic offence committed by the offender. The proposed system captured four different types of traffic offences, these offences are the "Red-Light violation", "Route Offences", "Road Marking Offences", and "Wrongful Overtaking Offences". The output of the system will ease the job of the traffic officers in term of billing offenders appropriately for the type of traffic offence committed and safe keeping of offence data collected.

Keywords – Convolutional Neural network, Vehicular Monitoring, License Plate detection.

1. INTRODUCTION

The need to decongest traffic in cities in this modern time can be achieved through the coordinated improvement of vehicular traffic monitoring and management schemes in traffic control centers and also the regular provision of data services for normal road users is now recognized. Design and Implementation of Online Vehicular Traffic Monitoring System" refers to investigating the properties of a system by creating a model of exploring the behaviour and connecting it to other systems through the internet, this will involve computerized record keeping system with little or no redundancies that monitors movement of vehicles along the highways to see someone who obstruct the free flow of vehicular road facility.

To enable the simulation online, the information detected must be established and treated. Hence, the system simulated should be enhanced by further practicality known as state estimation such as the case of a convolutional neural network model. The state assessment reads the sensor information and perform the needed activities on the simulation system to sustain stability amongst imitation and measured traffic. The compact foundation for the effective state estimation is a decent offline simulation model that describes the strategy, statistics and vehicle dynamics of the simulated traffic system. In online simulation a number of the supplies will be substituted by real period information, once accessible from sensors.

1.1 Statement of Problem

The complexity of the violation of traffic varies from adaptive traffic management to meek systems that uses historical data to regulate fixed timing plans, which traffic conditions in real time to optimize timing plans for a permitted network.

1.2 Objective

Gather traffic offender's data through online investigation, develop a model for Vehicular Traffic Monitoring using Convolutional Neural Network (CNN) and Implement the model and evaluate the system performance.

2. RELATED WORKS

Large-Scale Video Classification using CNN was proposed by (Karpathy et al., 2014) to use the established CNN class of models for image recognition drawbacks. The provision of dataset that are the extensive empirical evaluation of CNN on large-scale video classification of over one million YouTube videos belonging to four hundred and eighty-seven classes, the highlight of an architectural processes that input a two spatial resolution of a low resolution stream and a high resolution stream as an important way for the improvement of the performance of CNNs runtime at no cost in accuracy. After the study of the performance of large-scale video classification in CNN, the result shows the connectivity in time, while the performance is not particularly sensitive to the architectural details where a single-frame model already displays very strong performance suggesting that no critical importance is applicable to local motion cues.

CNN Design for Real Time Traffic Sign Recognition was proposed by (Shustanov & Yakimov, 2017) to implement algorithm for traffic sign recognition using CNN. The research also shows the comparison several CNN architectures to each other. The implementation of TensorFlow using library and massively parallel architecture for multithreaded programming is achieved by neural network training. The implementation of this method was done on a device with CUDA and processor Nvidia Tegra K1 were used to describe the method's acceleration performance for the detection and recognition of traffic sign, the execution of the entire procedure is done in real-time on a mobile GPU and the developed computer vision system confirmed high efficiency of the experimental results. The improvement of the safety and implementation of the way to autonomous driving is an important step that helps the systems significantly. computer vision solved with other tasks, this research considers the classification of traffic signs and recognition task with the implementation of their algorithm. The combination of the localization steps from previous works and pre-processing of the traffic signs classification system shows a very good results of 99.94 % of images that are correctly classified.

Vehicle Detection Based on CNN was proposed by (Plemakova, 2018). The system was trained to classify and also detect vehicles from multiple angles. The system used the Fast Fourier Transform (FFT) for data preprocessing, and it is examined to classify and detect vehicle. The proposed system achieved high results and could easily distinguish between all vehicles and non-vehicles. Traffic Density Estimation using CNN Machine Learning was presented to improve the quality of life for people living in Singapore. The system seeks to tackle traffic problems and congestion in the city of Singapore. In an attempt to accomplish the task, an end-to-end system consisting of both traffic density estimation algorithms at traffic light or junctions, and better traffic signal control algorithm which make use of density information that will aid better traffic control. An experiment on the algorithm was conducted using publicly available traffic camera dataset which was published by the Land Transport Authority (LTA) to demonstrate the feasibility of the approach. The system achieved a 94% Top 2 accuracy using Basic CNN with CI measures and masking which outperformed other existing systems. (Nubert et al., 2018).

3. METHODOLOGY

The constructive research method is adopted for this research, to create practical and theoretical innovative solutions to relevant problems of the online vehicular monitoring system (Crnkovic, 2010).

3.1. Proposed System

The architecture of the proposed system design is shown in Fig. 1. With the following key components:

- Car segmentation from video frame module
- Car pre-processing module
- Car license plate segmentation and classification module
- Classifier module

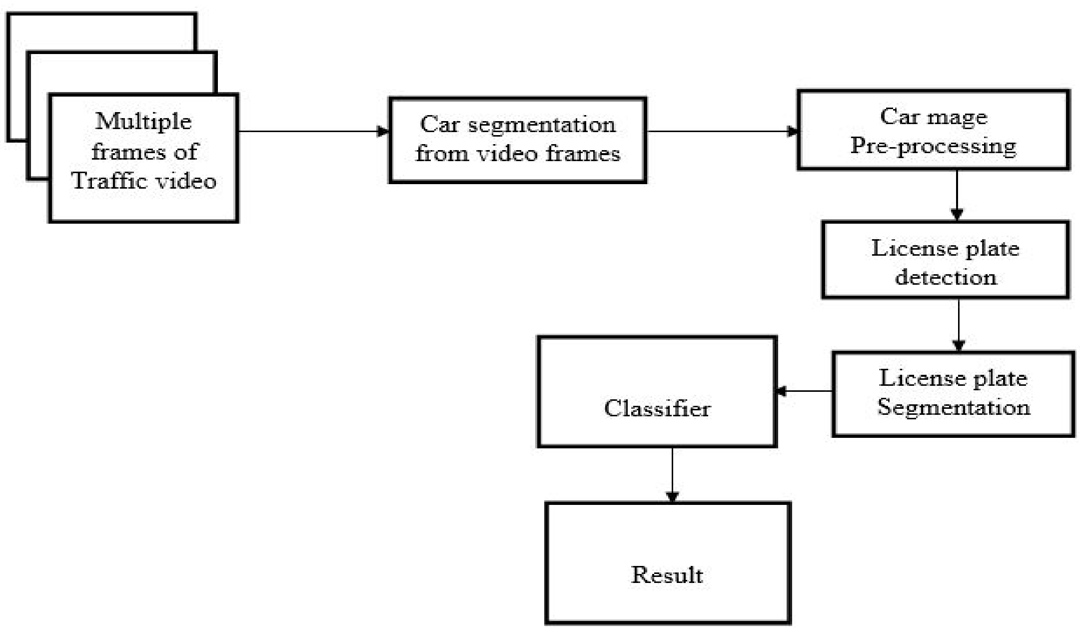

Fig.1. Architectural Design of the Proposed System

3.2 Description of modules

This section describes the module that is used to get the output/result

Car Segmentation from Video Frames refers to the segmentation/identification and separation of the cars from the video frames being used for crime identification and most segmentation is handled by the spooler part of the CNN algorithm after training, the CNN model is trained against data provided by open source community via Amazon cloud which it uses to identify vehicular objects.

Car Image Pre-Processing: the preprocessing of car image includes resizing, normalizing the dataset and finally applying Fast Fourier Transform (FFT) to the car images.

License plate detection: the detection accuracy significantly affects the performance of the whole system using the modified visual attention model to detect the license plates from a vehicle image which is the first key step for car license plate recognition. As shown in the algorithm.

Algorithm for License Plate Detection

Step 1	Input Image (Car image)
Step 2	Combination of colors, intensity and filter
Step 3	Step 2 as input to Gaussian pyramid and center-surround operation
Step 4	Color feature map, Brightness feature map and Orientation feature map
Step 5	Step 4 as input to Fusion of feature maps
Step 6	Saliency map
Step 7	Saliency map tuned with prior information
Step 8	Mask generation based on saliency map
Step 9	Detected License plate

License plate Segmentation and Recognition: refers to segmentation/ identification and separation of the different car license plate number from the video frames being used for crime identification and most segmentation is handled by the CNN algorithm after training.

Classifiers: this is used for the License plate numbers and video details to train the CNN to provide detection results and it is handled in the classifier module of the application to better help the algorithm identifies the required objects.

3.3 Use Case Diagram of the Proposed System

The Use-Case diagram of the proposed system represents how the user interacts with the system and it shows how the user relates with the several use cases he or she is involved in. The objective of the use case in the UML is to demonstrate the various ways that the user might interact with the system. The proposed system use case diagram is shown in fig.2.

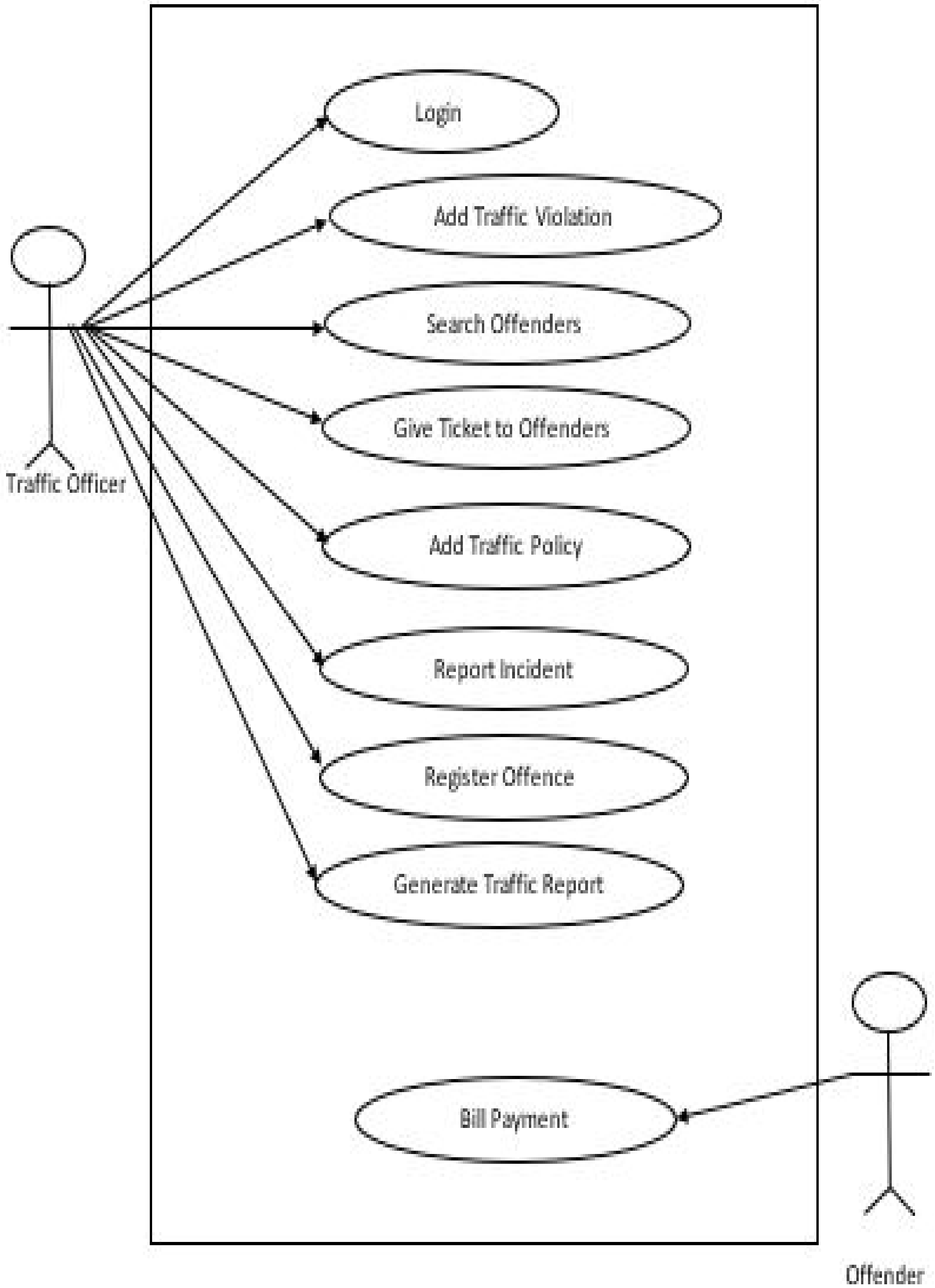

Figure 2 Proposed System Use-Case Diagram

4. RESULTS AND DISCUSSIONS

4.1 Dataset Description

Various sample traffic offence video dataset was collected through the internet which are used as the input to the proposed system. These datasets capture the various offences within the scope of this research. The datasets are further preprocessed to form video frames which the CNN will then perform the detection of vehicle license plate number, segmentation of license plate and also classification of the license plate number of the offender.

Table 1: Structure for Storing Dataset in Database

Key	Column	Datatype	Description
PK	S/N	Int	Serial number of various rows
	Vehicle type	VarChar(20)	The type of vehicle
	Vehicle Plate No.	VarChar(10)	The plate number of the vehicle
	Car owner	VarChar(10)	The name car owner

4.2 Result Interpretation of various dataset

The results of the developed Online Vehicular Traffic Monitoring System are tabulated in Table 2, 3, 4, and 5. The tables capture the violations of various dataset.

Table 2 Vehicular Violations for dataset 1 of license plate number: RV 811 AHD

S/N	Type of Offence	No of Occurrence
1	Red-light offence	2
2	Route offence	1
3	Road marking offence	3
4	Wrongful Overtaking	5

Table 3 Vehicular Violations for dataset 2 of license plate number: SKM 4481 U

S/N	Type of Offence	No of Occurrence
1	Red-light offence	3
2	Route offence	2
3	Road marking offence	2
4	Wrongful overtaking	4

Table 4 Vehicular Violations for dataset 3 of license plate number: SJH 3097 R

S/N	Type of Offence	No of Occurrence
1	Red-light offence	5
2	Route offence	1
3	Road marking offence	4
4	Wrongful overtaking	5

Table 5 Vehicular Violations for dataset 4 of license plate number: EM 429 TY

S/N	Type of Offence	No of Occurrence
1	Red-light offence	6
2	Route offence	2
3	Road marking offence	1
4	Wrongful overtaking	4

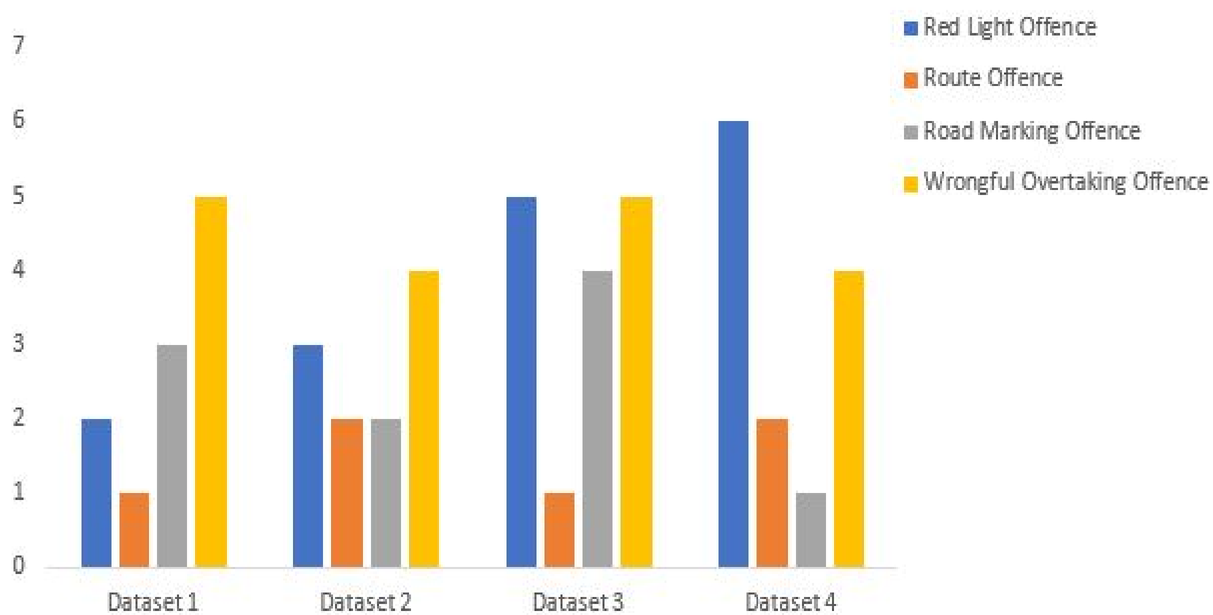

Figure 1 Bar chart representation of offences detected in the various datasets

4.3 Analysis of the Offences of the Sample Datasets

From the bar chart above it could be clearly seen that in dataset 1 has two Red-Light offences, one Route offence, one Road marking offence, and five Wrongful Overtaking offences were detected (See Table 4.1). For dataset 2, three Red-Light offences, two Route offence, two Road marking offence, and four Wrongful Overtaking offences were detected (See Table 4.2), the offences detected for Dataset 3 are five Red-Light offences, one Route offence, four Road marking offence, and five Wrongful Overtaking (See Table 4.3) and for Dataset 4, six Red-Light offences, two Route offence, one Road marking offence, and four Wrongful Overtaking offence was detected
(See Table 4.4).

4.4 Conclusion

As vehicular movement in cities increase the need for a better way of handling traffic offences would always arise, and these changes can be better managed using artificial neural network that could keep learning. Based on this study, the addition of Convolutional Neural Network Model for Online Vehicular Traffic Monitoring System will aid further improvement of the traffic offence monitoring system.

REFERENCES

1. Widenius, M., Axmark, D., & Arno, K. (2002). *MySQL reference manual: documentation from the source*: " O'Reilly Media, Inc.".
2. Arnold, K., Gosling, J., & Holmes, D. (2005). *The Java programming language*: Addison Wesley Professional.
3. DeLaurentis, D. (2005). *Understanding transportation as a system-of-systems design problem.* Paper presented at the 43rd AIAA Aerospace Sciences Meeting and Exhibit.
4. Byon, Y., Shalaby, A., & Abdulhai, B. (2006). *Travel time collection and traffic monitoring via GPS technologies.* Paper presented at the Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE.
5. Balaji, P., German, X., & Srinivasan, D. (2010). Urban traffic signal control using reinforcement learning agents. *IET Intelligent Transport Systems, 4*(3), 177-188.
6. Carlson, A. B. (2010). *Communication system*: Tata McGraw-Hill Education.
7. Crnkovic, G. D. (2010). Constructive research and info-computational knowledge generation *Model-Based Reasoning in Science and Technology* (pp. 359-380): Springer.
8. Islam, N. S., Khan, S., Kwon, S., Jang, D., Ro, M., & Trinh-Shevrin, C. (2010). Methodological issues in the collection, analysis, and reporting of granular data in Asian American populations: historical challenges and potential solutions. *Journal of health care for the poor and underserved, 21*(4), 1354.
9. Sommerville, I. (2011). Software engineering 9th Edition. *ISBN-10, 137035152.*
10. Peemen, M., Mesman, B., & Corporaal, H. (2011). *Speed sign detection and recognition by convolutional neural networks.* Paper presented at the Proceedings of the 8th international automotive congress.
11. Ali, S. S. M., George, B., Vanajakshi, L., & Venkatraman, J. (2012). A multiple inductive loop vehicle detection system for heterogeneous and lane-less traffic. *IEEE Transactions on Instrumentation and Measurement, 61*(5), 1353-1360.
12. Krizhevsky, A., Sutskever, I., & Hinton, G. E. (2012). *Imagenet classification with deep convolutional neural networks.* Paper presented at the Advances in neural information processing systems.
13. Kumar, G., & Bhatia, P. K. (2012). Impact of agile methodology on software development process. *International Journal of Computer Technology and Electronics Engineering (IJCTEE), 2*(4), 46-50.
14. Li, J.-Q., Zhou, K., Zhang, L., & Zhang, W.-B. (2012). A multimodal trip planning system with real-time traffic and transit information. *Journal of Intelligent Transportation Systems, 16*(2), 60-69.
15. Muşlu, K., Brun, Y., Holmes, R., Ernst, M. D., & Notkin, D. (2012). *Speculative analysis of integrated development environment recommendations.* Paper presented at the ACM SIGPLAN Notices.
16. Ou, G., Gao, Y., & Liu, Y. (2012). *Real-time vehicular traffic violation detection in traffic monitoring stream.* Paper presented at the Proceedings of the The 2012 IEEE/WIC/ACM International Joint Conferences on Web Intelligence and Intelligent Agent Technology-Volume 03.

17. Sermanet, P., Eigen, D., Zhang, X., Mathieu, M., Fergus, R., & LeCun, Y. (2013). Overfeat: Integrated recognition, localization and detection using convolutional networks, CoRR abs/1312.6229. *URL http://arxiv. org/abs/1312.6229.*
18. Karayiannis, N., & Venetsanopoulos, A. N. (2013). *Artificial neural networks: learning algorithms, performance evaluation, and applications* (Vol. 209): Springer Science & Business Media.
19. El-Tantawy, S., Abdulhai, B., & Abdelgawad, H. (2013). Multiagent reinforcement learning for integrated network of adaptive traffic signal controllers (MARLIN-ATSC): methodology and large-scale application on downtown Toronto. *IEEE Transactions on Intelligent Transportation Systems, 14*(3), 1140-1150.
20. Simonyan, K., & Zisserman, A. (2014). Very deep convolutional networks for large-scale image recognition. *arXiv preprint arXiv:1409.1556.*
21. Karpathy, A., Toderici, G., Shetty, S., Leung, T., Sukthankar, R., & Fei-Fei, L. (2014). *Large-scale video classification with convolutional neural networks.* Paper presented at the Proceedings of the IEEE conference on Computer Vision and Pattern Recognition.
22. Girshick, R., Donahue, J., Darrell, T., & Malik, J. (2014). *Rich feature hierarchies for accurate object detection and semantic segmentation.* Paper presented at the Proceedings of the IEEE conference on computer vision and pattern recognition.
23. Donahue, J., Jia, Y., Vinyals, O., Hoffman, J., Zhang, N., Tzeng, E., & Darrell, T. (2014). *Decaf: A deep convolutional activation feature for generic visual recognition.* Paper presented at the International conference on machine learning.
24. Dong, Z., Wu, Y., Pei, M., & Jia, Y. (2015). Vehicle type classification using a semisupervised convolutional neural network. *IEEE transactions on intelligent transportation systems, 16*(4), 2247-2256.
25. Bautista, C. M., Dy, C. A., Mañalac, M. I., Orbe, R. A., & Cordel, M. (2016). *Convolutional neural network for vehicle detection in low resolution traffic videos.* Paper presented at the 2016 IEEE Region 10 Symposium (TENSYMP).
26. Danelljan, M., Robinson, A., Khan, F. S., & Felsberg, M. (2016). *Beyond correlation filters: Learning continuous convolution operators for visual tracking.* Paper presented at the European Conference on Computer Vision.
27. Deshpande, A. (2016). A beginner's guide to understanding convolutional neural networks.
28. Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). *Deep learning* (Vol. 1): MIT press Cambridge.
29. Wshah, S., Xu, B., Bulan, O., Kumar, J., & Paul, P. (2016). *Deep learning architectures for domain adaptation in HOV/HOT lane enforcement.* Paper presented at the Applications of Computer Vision (WACV), 2016 IEEE Winter Conference
30. Ali, S. S. M., George, B., Vanajakshi, L., & Venkatraman, J. (2012). A multiple inductive loop vehicle detection system for heterogeneous and lane-less traffic. *IEEE Transactions on Instrumentation and Measurement, 61*(5), 1353-1360.
31. Amato, G., Carrara, F., Falchi, F., Gennaro, C., Meghini, C., & Vairo, C. (2017). Deep learning for decentralized parking lot occupancy detection. *Expert Systems with Applications, 72*, 327-334.
32. Arnold, K., Gosling, J., & Holmes, D. (2005). *The Java programming language*: Addison Wesley Professional.

33. Balaji, P., German, X., & Srinivasan, D. (2010). Urban traffic signal control using reinforcement learning agents. *IET Intelligent Transport Systems, 4*(3), 177-188.
34. Bautista, C. M., Dy, C. A., Mañalac, M. I., Orbe, R. A., & Cordel, M. (2016). *Convolutional neural network for vehicle detection in low resolution traffic videos.* Paper presented at the 2016 IEEE Region 10 Symposium (TENSYMP).
35. Byon, Y.-J., Ha, J., Cho, C.-S., Kim, T.-Y., & Yeun, C. (2017). Real-time transportation mode identification using artificial neural networks enhanced with mode availability layers: A case study in Dubai. *Applied Sciences, 7*(9), 923.
36. Byon, Y., Shalaby, A., & Abdulhai, B. (2006). *Travel time collection and traffic monitoring via GPS technologies.* Paper presented at the Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE.
37. Carlson, A. B. (2010). *Communication system*: Tata McGraw-Hill Education.
38. Cheang, T. K., Chong, Y. S., & Tay, Y. H. (2017). Segmentation-free vehicle license plate recognition using ConvNet-RNN. *arXiv preprint arXiv:1701.06439*.
39. Chollet, F. (2018). Keras: The python deep learning library. *Astrophysics Source Code Library*.
40. Crnkovic, G. D. (2010). Constructive research and info-computational knowledge generation *Model-Based Reasoning in Science and Technology* (pp. 359-380): Springer.
41. CS231n, S. (2017). Convolutional neural networks for visual recognition: Stanford University CS Class.[online][cited 2017. 10. 9.]< http://cs231n ....
42. Danelljan, M., Robinson, A., Khan, F. S., & Felsberg, M. (2016). *Beyond correlation filters: Learning continuous convolution operators for visual tracking.* Paper presented at the European Conference on Computer Vision.
43. DeLaurentis, D. (2005). *Understanding transportation as a system-of-systems design problem.* Paper presented at the 43rd AIAA Aerospace Sciences Meeting and Exhibit.
44. Dennis, A., & Wixom, B. H. (2018). *Systems analysis and design*: Wiley.
45. Deshpande, A. (2016). A beginner's guide to understanding convolutional neural networks. *Retrieved March, 31*(2017).
46. Donahue, J., Jia, Y., Vinyals, O., Hoffman, J., Zhang, N., Tzeng, E., & Darrell, T. (2014). *Decaf: A deep convolutional activation feature for generic visual recognition.* Paper presented at the International conference on machine learning.
47. Dong, Z., Wu, Y., Pei, M., & Jia, Y. (2015). Vehicle type classification using a semisupervised convolutional neural network. *IEEE transactions on intelligent transportation systems, 16*(4), 2247-2256.
48. El-Tantawy, S., Abdulhai, B., & Abdelgawad, H. (2013). Multiagent reinforcement learning for integrated network of adaptive traffic signal controllers (MARLIN-ATSC): methodology and large-scale application on downtown Toronto. *IEEE Transactions on Intelligent Transportation Systems, 14*(3), 1140-1150.
49. Genders, W., & Razavi, S. (2018). Evaluating reinforcement learning state representations for adaptive traffic signal control. *Procedia computer science, 130*, 26-33.
50. Girshick, R., Donahue, J., Darrell, T., & Malik, J. (2014). *Rich feature hierarchies for accurate object detection and semantic segmentation.* Paper presented at the Proceedings of the IEEE conference on computer vision and pattern recognition.

51. Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). *Deep learning* (Vol. 1): MIT press Cambridge.
52. Gu, J., Wang, Z., Kuen, J., Ma, L., Shahroudy, A., Shuai, B., . . . Cai, J. (2018). Recent advances in convolutional neural networks. *Pattern Recognition, 77*, 354-377.
53. Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the national academy of sciences, 79*(8), 2554-2558.
54. Islam, N. S., Khan, S., Kwon, S., Jang, D., Ro, M., & Trinh-Shevrin, C. (2010). Methodological issues in the collection, analysis, and reporting of granular data in Asian American populations: historical challenges and potential solutions. *Journal of health care for the poor and underserved, 21*(4), 1354.
55. Jørgensen, H. (2017). *Automatic License Plate Recognition using Deep Learning Techniques.* NTNU.
56. Karayiannis, N., & Venetsanopoulos, A. N. (2013). *Artificial neural networks: learning algorithms, performance evaluation, and applications* (Vol. 209): Springer Science & Business Media.
57. Karpathy, A., Toderici, G., Shetty, S., Leung, T., Sukthankar, R., & Fei-Fei, L. (2014). *Large-scale video classification with convolutional neural networks.* Paper presented at the Proceedings of the IEEE conference on Computer Vision and Pattern Recognition.
58. Kozek, T., Roska, T., & Chua, L. O. (1993). Genetic algorithm for CNN template learning. *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, 40*(6), 392-402.
59. Krizhevsky, A., Sutskever, I., & Hinton, G. E. (2012). *Imagenet classification with deep convolutional neural networks.* Paper presented at the Advances in neural information processing systems.
60. Kumar, G., & Bhatia, P. K. (2012). Impact of agile methodology on software development process. *International Journal of Computer Technology and Electronics Engineering (IJCTEE), 2*(4), 46-50.
61. Li, J.-Q., Zhou, K., Zhang, L., & Zhang, W.-B. (2012). A multimodal trip planning system with real-time traffic and transit information. *Journal of Intelligent Transportation Systems, 16*(2), 60-69.
62. Li, Y., Yu, R., Shahabi, C., & Liu, Y. (2017). Diffusion convolutional recurrent neural network: Data-driven traffic forecasting. *arXiv preprint arXiv:1707.01926.*
63. Ma, X., Dai, Z., He, Z., Ma, J., Wang, Y., & Wang, Y. (2017). Learning traffic as images: a deep convolutional neural network for large-scale transportation network speed prediction. *Sensors, 17*(4), 818.
64. Masood, S. Z., Shu, G., Dehghan, A., & Ortiz, E. G. (2017). License plate detection and recognition using deeply learned convolutional neural networks. *arXiv preprint arXiv:1703.07330.*
65. Molina-Cabello, M. A., Luque-Baena, R. M., López-Rubio, E., & Thurnhofer-Hemsi, K. (2017). *Vehicle type detection by convolutional neural networks.* Paper presented at the International Work-Conference on the Interplay Between Natural and Artificial Computation.
66. Muşlu, K., Brun, Y., Holmes, R., Ernst, M. D., & Notkin, D. (2012). *Speculative analysis of integrated development environment recommendations.* Paper presented at the ACM SIGPLAN Notices.
67. Nubert, J., Truong, N. G., Lim, A., Tanujaya, H. I., Lim, L., & Vu, M. A. (2018). Traffic Density Estimation using a Convolutional Neural Network. *arXiv preprint arXiv:1809.01564.*

68. Ou, G., Gao, Y., & Liu, Y. (2012). *Real-time vehicular traffic violation detection in traffic monitoring stream.* Paper presented at the Proceedings of the The 2012 IEEE/WIC/ACM International Joint Conferences on Web Intelligence and Intelligent Agent Technology-Volume 03.
69. Peemen, M., Mesman, B., & Corporaal, H. (2011). *Speed sign detection and recognition by convolutional neural networks.* Paper presented at the Proceedings of the 8th international automotive congress.
70. Plemakova, V. (2018). *Vehicle Detection Based on Convolutional Neural Networks.* (M.Sc Research), UNIVERSITY OF TARTU.
71. Prashanth, L., & Bhatnagar, S. (2011). Reinforcement learning with function approximation for traffic signal control. *IEEE Transactions on Intelligent Transportation Systems, 12*(2), 412-421.
72. Ross, H. L. (1960). Traffic law violation: A folk crime. *Soc. Probs., 8*, 231.
73. Sermanet, P., Eigen, D., Zhang, X., Mathieu, M., Fergus, R., & LeCun, Y. (2013). Overfeat: Integrated recognition, localization and detection using convolutional networks, CoRR abs/1312.6229. *URL http://arxiv. org/abs/1312.6229.*
74. Shustanov, A., & Yakimov, P. (2017). CNN design for real-time traffic sign recognition. *Procedia engineering, 201*, 718-725.
75. Simonyan, K., & Zisserman, A. (2014). Very deep convolutional networks for large-scale image recognition. *arXiv preprint arXiv:1409.1556.*
76. Smith, B. L., Zhang, H., Fontaine, M., & Green, M. (2003). *Cellphone probes as an ATMS tool.* Retrieved from
77. Sommerville, I. (2011). Software engineering 9th Edition. *ISBN-10, 137035152.*
78. Widenius, M., Axmark, D., & Arno, K. (2002). *MySQL reference manual: documentation from the source*: " O'Reilly Media, Inc.".
79. Willis, C., Harborne, D., Tomsett, R., & Alzantot, M. (2017). *A deep convolutional network for traffic congestion classification.* Paper presented at the Proc NATO IST-158/RSM-010 Specialists' Meeting on Content Based Real-Time Analytics of Multi-Media Streams. NATO.
80. Wshah, S., Xu, B., Bulan, O., Kumar, J., & Paul, P. (2016). *Deep learning architectures for domain adaptation in HOV/HOT lane enforcement.* Paper presented at the Applications of Computer Vision (WACV), 2016 IEEE Winter Conference
81. Zhong, G., Wan, X., Zhang, J., Yin, T., & Ran, B. (2017). Characterizing passenger flow for a transportation hub based on mobile phone data. *IEEE Transactions on Intelligent Transportation Systems, 18*(6), 1507-1518.
82. Willis, C., Harborne, D., Tomsett, R., & Alzantot, M. (2017). *A deep convolutional network for traffic congestion classification.* Paper presented at the Proc NATO IST-158/RSM-010 Specialists' Meeting on Content Based Real-Time Analytics of Multi-Media Streams. NATO.
83. Shustanov, A., & Yakimov, P. (2017). CNN design for real-time traffic sign recognition. *Procedia engineering, 201*, 718-725.
84. Li, Y., Yu, R., Shahabi, C., & Liu, Y. (2017). Diffusion convolutional recurrent neural network: Data-driven traffic forecasting. *arXiv preprint arXiv:1707.01926.*
85. Ma, X., Dai, Z., He, Z., Ma, J., Wang, Y., & Wang, Y. (2017). Learning traffic as images: a deep convolutional neural network for large-scale transportation network speed prediction. *Sensors, 17*(4), 818.
86. Masood, S. Z., Shu, G., Dehghan, A., & Ortiz, E. G. (2017). License plate detection and recognition using deeply learned convolutional neural networks. *arXiv preprint arXiv:1703.07330.*
87. Molina-Cabello, M. A., Luque-Baena, R. M., López-Rubio, E., & Thurnhofer-Hemsi, K. (2017). *Vehicle type detection by convolutional neural networks.* Paper presented at the International Work-Conference on the Interplay Between Natural and Artificial Computation.

88. CS231n, S. (2017). Convolutional neural networks for visual recognition: Stanford University CS Class.[online][cited 2017. 10. 9.]< http://cs231n ....
89. Cheang, T. K., Chong, Y. S., & Tay, Y. H. (2017). Segmentation-free vehicle license plate recognition using ConvNet-RNN. *arXiv preprint arXiv:1701.06439*.
90. Byon, Y.-J., Ha, J., Cho, C.-S., Kim, T.-Y., & Yeun, C. (2017). Real-time transportation mode identification using artificial neural networks enhanced with mode availability layers: A case study in Dubai. *Applied Sciences, 7*(9), 923.
91. Amato, G., Carrara, F., Falchi, F., Gennaro, C., Meghini, C., & Vairo, C. (2017). Deep learning for decentralized parking lot occupancy detection. *Expert Systems with Applications, 72*, 327-334.
92. Chollet, F. (2018). Keras: The python deep learning library. *Astrophysics Source Code Library*.
93. Dennis, A., & Wixom, B. H. (2018). *Systems analysis and design*: Wiley.
94. Genders, W., & Razavi, S. (2018). Evaluating reinforcement learning state representations for adaptive traffic signal control. *Procedia computer science, 130*, 26-33.
95. Gu, J., Wang, Z., Kuen, J., Ma, L., Shahroudy, A., Shuai, B., . . . Cai, J. (2018). Recent advances in convolutional neural networks. *Pattern Recognition, 77*, 354-377.
96. Nubert, J., Truong, N. G., Lim, A., Tanujaya, H. I., Lim, L., & Vu, M. A. (2018). Traffic Density Estimation using a Convolutional Neural Network. *arXiv preprint arXiv:1809.01564*.
97. Plemakova, V. (2018). *Vehicle Detection Based on Convolutional Neural Networks.* (M.Sc Research), UNIVERSITY OF TARTU.

APPENDIX A - USER INTERFACES

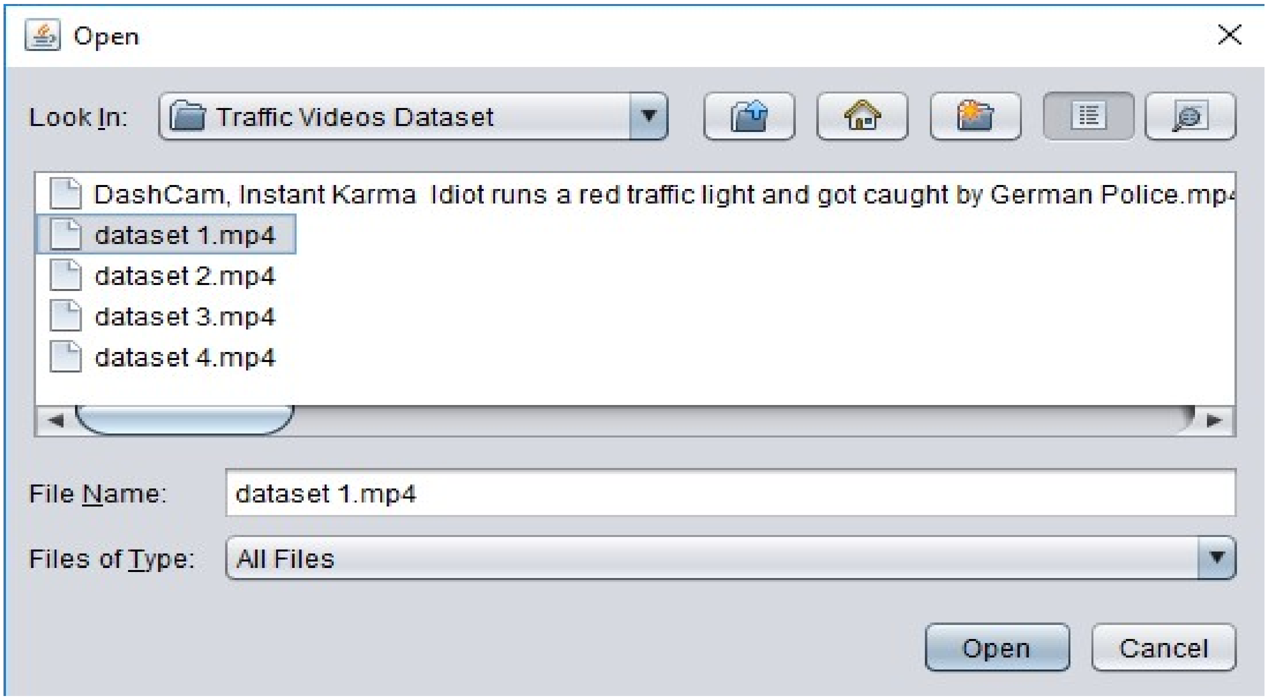

Figure A1: Video Select Dialog

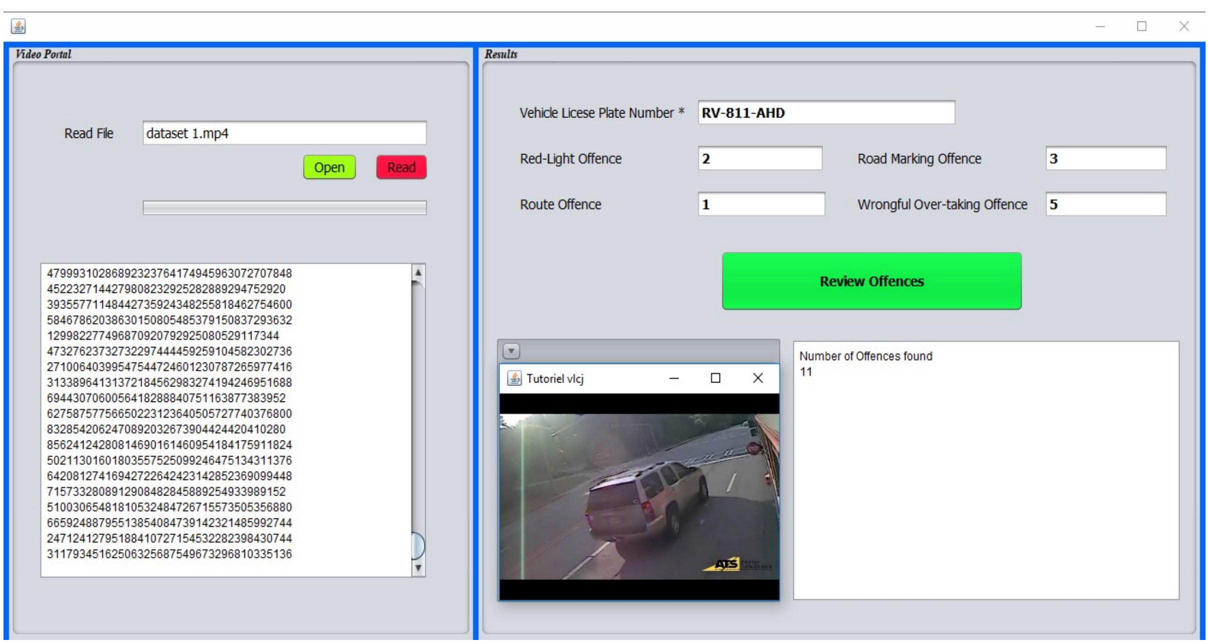

Figure A2: Result Analysis and Video Display