University of Central Lancashire
UCLan

Towards State and Situation Awareness for Driverless Vehicles Using Deep Neural Networks

Dr. Kaya Kuru

Where opportunity creates success

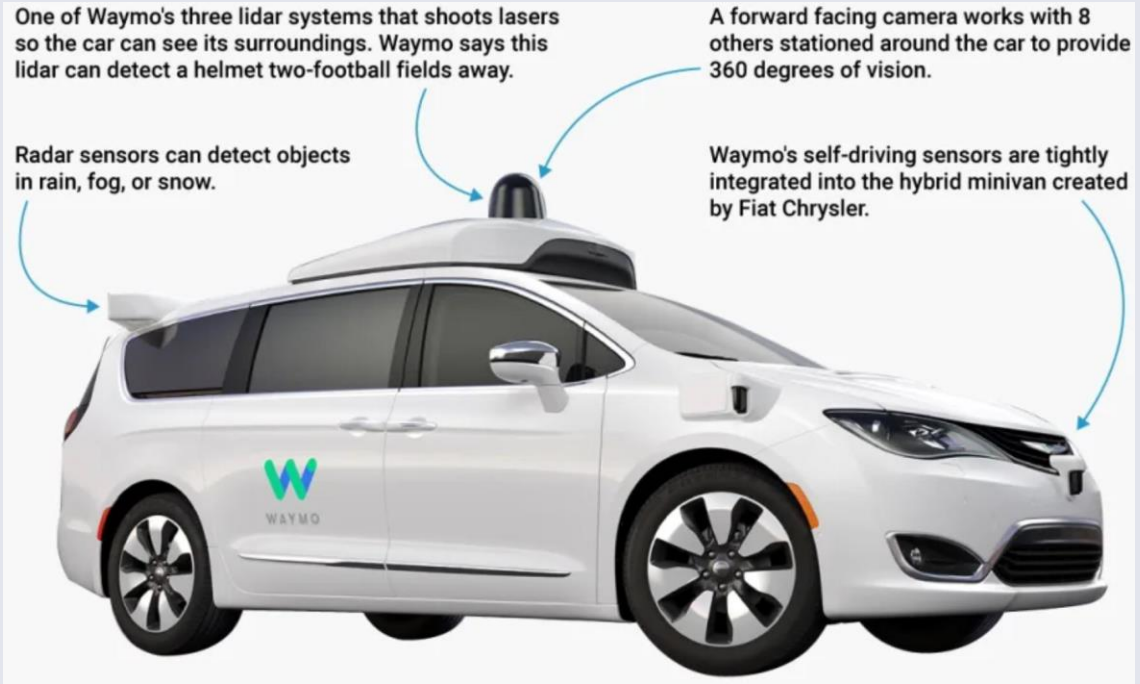
INTRODUCTION

- The goal in automotive industry is to accomplish full autonomy, i.e. level 5
- Autonomous vehicles will reach higher penetration levels in mixed air traffic,
  - ✓ smart control systems that are instilled with AI and
  - ✓ equipped with advanced sensor and actuator technologies.
- There are still many limitations with AVs despite several decades of earlier research,
- Many years to come for autonomous drones to become completely self-sufficient,
- This report implements applications of machine intelligence for SDVs
  - ➢ through video capturing using Deep Learning (DL)
- Multiple techniques integrated for state and situation awareness (SSA) and better decision-making

VEHICLE INTELLIGENCE AND INDUSTRY

Company	Model	Level
Lyft	AV HW and SW	3, 4, 5
Google	AV SW	3, 4, 5
Audio + NVIDIA	Audio A8 [1]	3
Tesla	Tesla autopilot	3
BMW + Intel + Mobileye	VISION iNEXT [20]	3
Toyoto	Concept-i [2], Lexus [3]	3
Toyoto + Microsoft	Toyoto Edge Cases	4
Volkswagen + NVIDIA	ID Buzz [4]	4
Yandex	Yandex taxi	4
Renault	Renault Symbioz	4
Renault	Trezor	4
Rolls-Royce	103EX (customisable)	4
Volvo + Microsoft	Volvo 360c	4
Ford + Lyft	Ford Fusion	4
Chrysler + Lyft	Chrysler Pacificas	4
Alphabet + Lyft	Waymo (e.g., Koala)	4
Aptiv + Lyft	Aptiv	4
Google + Lyft	Aptiv	4
Uber + NVIDIA	Aptiv	4
Rinspeed	Rinspeed Oasis [5]	4, 5
Rinspeed	Rinspeed Σtos [6]	4, 5
Rinspeed	Rinspeed Snap [7]	5
Rinspeed	Rinspeed MicroSnap [8]	5
Mercedes-Benz	S-Class S 500 (no cockpit) [9]	5
Mercedes-Benz	F 015 Luxury in Motion [10]	5
Mercedes-Benz	Future Truck 2025 [11]	5
Lyft	Lyft	5
GM	GM	5
Uber	Uber taxi	5

- ✓ Sensor and actuator technologies
- ✓ AI
- ✓ Telematics,



University of Central Lancashire
UCLan

VEHICLE INTELLIGENCE

- Sensors,
- Sensor Fusion,
- AI for decision-making, control systems,
  - Deep Neural Network & Reinforcement Learning & Deep Reinforcement Learning
- Actuators,
- 5G/6G Communication
- Vehicle-to-vehicle (V2V),
- Vehicle-to-infrastructure (V2I) communications,
- Swarm Intelligence

University of Central Lancashire
UCLan

DEVELOPMENT OF VEHICLE INTELLIGENCE IN THIS WORK

- Prototype application developed for autonomous vehicles
- Convolutional neural network (CNN) used,
- Faster Region-based Convolutional Neural Network (RCNN) used
- Text-to-speech, lane-detection, distance measurement and driving instructions integrated
- State and situation awareness (SSA) technique integrated
  - ➢ considering other vehicles and road lanes

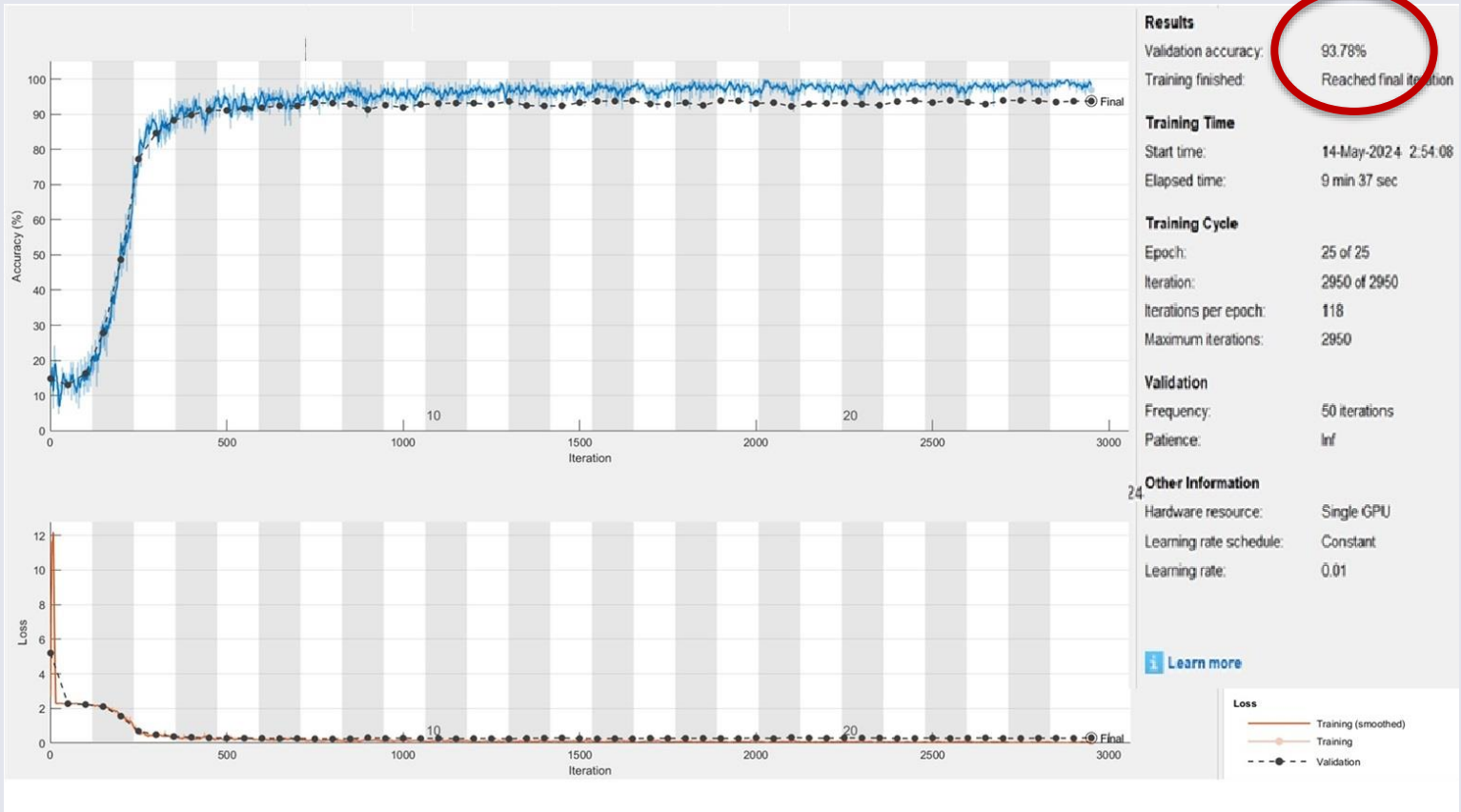
DATASETS

	Traffic Sign	Training Images	Test Images
	30	2120	100
	50	2150	100
	70	1880	100
	80	1760	100
	Ahead Only	1099	100
	Keep Right	2125	100
	No Lorry Overtaking	1910	100
	Priority Road	2205	100
	Roadworks	1421	100
	Yield	2223	100
	Negatives		583

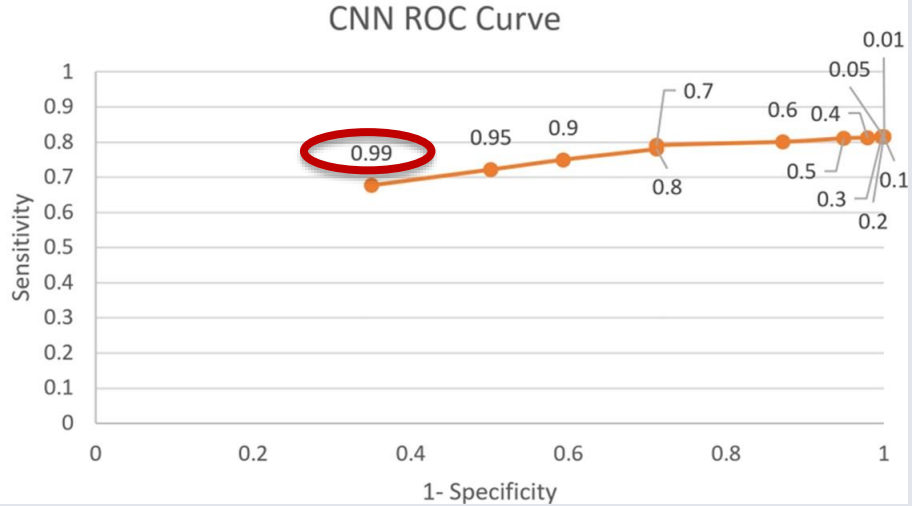
	Traffic Sign	No. of Images
	Pedestrian Crossing	1085
	Signal Ahead	925
	Stop	1820

- ✓ German Traffic Sign Benchmark dataset
- ✓ LISA dataset

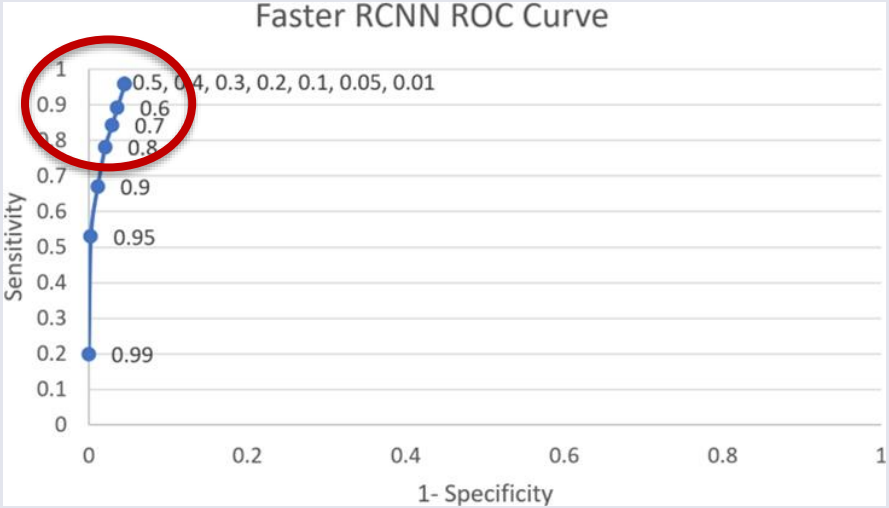
Network Design and Training



ROC analysis for the best cut-off similarity value



The ROC curve for the CNN detector indicates that the similarity value of 0.99 would be the ideal threshold.



ROC curve generated using multiple threshold values. Note: after 0.5, the sensitivity/specificity values did not change. This indicates a self-set threshold of 0.5 by the system. Note, data labels represent threshold value.

Testing on Videos

Faster RCNN detected and drawn bounding boxes with labels around two signal ahead signs.

Faster RCNN detected and drawn bounding boxes with labels around two stop signs.

- Video: Tesla driverless car

https://www.youtube.com/watch?v=tlThdr3O5Qo

Testing on Videos

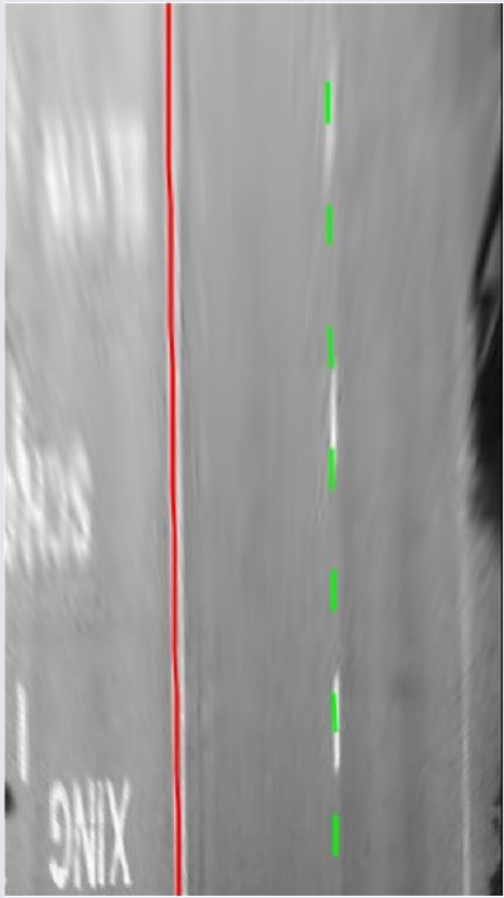
Faster RCNN detected and drawn bounding boxes with labels around two stop signs.

Signs, difficult to notice, can be detected

University of Central Lancashire
UCLan

Integration of state and situation awareness (SSA) techniques processing of multiple tasks simultaneously

- Lane-detection : Birds-eye-view of road used for lane detection
- Distance measurement and driving instructions: Distances from other vehicles and road lanes in region of interest (RoI)
- Text-to-speech: driving Information speech output, driving instructions
- All tasks runs simultaneously simultaneously



Testing on Videos

University of Central Lancashire
UCLan

SSA in Video 1 -- instant relative positioning of other vehicles with respect to the ego vehicle.

SSA in Video 2 -- instant relative positioning of other vehicles with respect to the ego vehicle.

University of Central Lancashire
UCLan

Conclusion

- This study shows guidance about how to develop vehicle intelligence of SDV using DL
- Faster RCNN has shown promising results for autonomous vehicle.
- Accuracy rate > 0.9
- Sensitivity and specificity values above 0.9 were achieved during testing.
- The Faster RCNN detector has been incorporated into a lane and vehicle detection system as well as the instant relative positioning of other vehicles with respect to the ego vehicle to prove that the system can successfully work as a subsystem within a driverless vehicle.
- Additionally, text-to-speech has been incorporated to provide driving instructions and information for passengers.
- The system can accurately detect and classify multiple targeted objects in a video and can determine its actions accordingly.
- DRL, with its success in a diverse range of fields, seems a promising approach in improving the cognition of SDVs to mitigate the uncertainties in dynamic traffic.
- As a future work, we aim to integrate DRL into our system.

REFERENCES

[1] K. Kuru and H. Yetgin, “Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (aoe),” IEEE Access, vol. 7, pp. 41 395–41 415, 2019.
[2] K. Kuru, “Management of geo-distributed intelligence: Deep insight as a service (DINSaaS) on forged cloud platforms (FCP),” Journal of Parallel and Distributed Computing, vol. 149, pp. 103–118, Mar. 2021.
[3] ——, “Technical report: Big data-concepts, infrastructure, analytics, challenges and solutions,” 2024.
[4] ——, “Metaomnicity: Toward immersive urban metaverse cyberspaces using smart city digital twins,” IEEE Access, vol. 11, pp. 43 844–68, 2023.
[5] K. Kuru and D. Ansell, “Tcitysmartf: A comprehensive systematic framework for transforming cities into smart cities,” IEEE Access, vol. 8, pp. 18 615–18 644, 2020.
[6] K. Kuru, D. Ansell, W. Khan, and H. Yetgin, “Analysis and optimization of unmanned aerial vehicle swarms in logistics: An intelligent delivery platform,” IEEE Access, vol. 7, pp. 15 804–31, 2019.
[7] K. Kuru, D. Ansell, D. Jones, B. Watkinson, J. M. Pinder, J. A. Hill, E. Muzzall, C. Tinker-Mill, K. Stevens, and A. Gardner, “Intelligent airborne monitoring of livestock using autonomous uninhabited aerial vehicles,” in The 11th European Conference on Precision Livestock Farming, 2024.
[8] K. Kuru, D. Ansell, B. Jon Watkinson, D. Jones, A. Sujit, J. M. Pinder, and C. L. Tinker-Mill, “Intelligent automated, rapid and safe landmine and unexploded ordnance (uxo) detection using multiple sensor modalities mounted on autonomous drones,” IEEE Transactions on Geoscience and Remote Sensing, 2023.
[9] K. Kuru and W. Khan, “A framework for the synergistic integration of fully autonomous ground vehicles with smart city, ” IEEE Access, vol. 9, pp. 923–948, 2021.
[10] K. Kuru, “Conceptualisation of human-on-the-loop haptic teleoperation with fully autonomous self-driving vehicles in the urban environment,” IEEE Open J. Intell. Transp. Syst., vol. 2, pp. 448–69, 2021.
[11] ——, “Sensors and sensor fusion for decision making in autonomous driving and vehicles,” 2023.
[12] R. Hussain and S. Zeadally, “Autonomous cars: Research results, issues, and future challenges,” IEEE Communications Surveys Tutorials, vol. 21, no. 2, pp. 1275–1313, Secondquarter 2019.
[13] P. E. Ross, “Robot, you can drive my car,” IEEE Spectrum, vol. 51, no. 6, pp. 60–90, 2014.
[14] J. Fell, “Cars of the future [transport concept cars],” Engineering Technology, vol. 12, no. 2, pp. 48–53, March 2017.
[15] K. Kuru, “Trustfsdv: Framework for building and maintaining trust in self-driving vehicles,” IEEE Access, vol. 10, pp. 82 814–82 833, 2022.
[16] J. Nieuwenhuijsen, “Diffusion of Automated Vehicles A quantitative method to model the diffusion of automated vehicles with system dynamics,” Master’s thesis, the Delft University of Technology,, the Netherlands, 2015.
[17] L. Alter, “80 billion has been spent on self-driving cars with nothing to show for it,” 2019.
[18] M. Daily, S. Medasani, R. Behringer, and M. Trivedi, “Self-driving cars,” Computer, vol. 50, no. 12, pp. 18–23, 2017.
[19] K. Kuru, O. Erogul, and C. Xavier, “Autonomous low power monitoring sensors,” Sensors, vol. 21, 2021.
[20] S. Gould and D. Muoio, “Here’s how waymo’s brand new self-driving cars see the world,” 2017.
[21] J. Hecht, “Lidar for self-driving cars,” Optics and Photonics News, vol. 29, no. 1, p. 26, Jan. 2018.
[22] N. Heath, “Tesla’s autopilot: Cheat sheet,” 2018.
[23] K. Kuru, “Planning the future of smart cities with swarms of fully autonomous unmanned aerial vehicles using a novel framework,” IEEE Access, vol. 9, pp. 6571–6595, 2021.
[24] M. Fallgren, M. Dillinger, J. Alonso-Zarate, M. Boban, T. Abbas, K. Manolakis, T. Mahmoodi, T. Svensson, A. Laya, and R. Vilalta, “Fifth-generation technologies for the connected car: Capable systems for vehicle-to-anything communications, ” IEEE Vehicular Technology Magazine, vol. 13, no. 3, pp. 28–38, 2018.
[25] I. Parvez, A. Rahmati, I. Guvenc, A. I. Sarwat, and H. Dai, “A survey on low latency towards 5g: Ran, core network and caching solutions,” IEEE Commun. Surv. Tutor., vol. 20, no. 4, pp. 3098–130, 2018.
[26] H. Ullah, N. Gopalakrishnan Nair, A. Moore, C. Nugent, P. Muschamp, and M. Cuevas, “5g communication: An overview of vehicle-to-everything, drones, and healthcare use-cases,” IEEE Access, vol. 7, pp. 37 251–37 268, 2019.
[27] S. A. A. Shah, E. Ahmed, M. Imran, and S. Zeadally, “5g for vehicular communications,” EEE Commun. Mag., vol. 56, no. 1, pp. 111–7, 2018.
[28] Y. LeCun, Y. Bengio, and G. Hinton, “Deep learning,” Nature, vol. 521, no. 7553, p. 436–444, May 2015.
[29] C. J. C. H. Watkins and P. Dayan, “Q-learning,” in Machine Learning, 1992, pp. 279–292.

[30] T. T. Nguyen, N. D. Nguyen, and S. Nahavandi, “Deep reinforcement learning for multiagent systems: A review of challenges, solutions, and applications,” IEEE Trans. Cybern., vol. 50, no. 9, pp. 3826–39, 2020.
[31] V. Mnih, K. Kavukcuoglu, D. Silver, A. A. Rusu, J. Veness, M. G. Bellemare, A. Graves, M. Riedmiller, A. K. Fidjeland, G. Ostrovski, S. Petersen, C. Beattie, A. Sadik, I. Antonoglou, H. King, D. Kumaran, D. Wierstra, S. Legg, and D. Hassabis, “ Human-level control through deep reinforcement learning,” Nature, vol. 518, no. 7540, pp. 529–533, Feb. 2015.
[32] M. Morav ˇc´ık, M. Schmid, N. Burch, V. Lis´y, D. Morrill, N. Bard, T. Davis, K. Waugh, M. Johanson, and M. Bowling, “ DeepStack: Expert-level artificial intelligence in heads-up no-limit poker,” Science, vol. 356, no. 6337, pp. 508–513, May 2017.
[33] M. Jaderberg, W. M. Czarnecki, I. Dunning, L. Marris, G. Lever, A. G. Casta ˜neda, C. Beattie, N. C. Rabinowitz, A. S. Morcos, A. Ruderman, N. Sonnerat, T. Green, L. Deason, J. Z. Leibo, D. Silver, D. Hassabis, K. Kavukcuoglu, and T. Graepel, “Human-level performance in 3d multiplayer games with population-based reinforcement learning,” Science, vol. 364, no. 6443, pp. 859–865, may 2019.
[34] D. Silver, A. Huang, C. J. Maddison, A. Guez, L. Sifre, G. van den Driessche, J. Schrittwieser, I. Antonoglou, V. Panneershelvam, M. Lanctot, S. Dieleman, D. Grewe, J. Nham, N. Kalchbrenner, I. Sutskever, T. Lillicrap, M. Leach, K. Kavukcuoglu, T. Graepel, and D. Hassabis, “Mastering the game of go with deep neural networks and tree search,” Nature, vol. 529, no. 7587, pp. 484–489, Jan. 2016.
[35] D. Silver, T. Hubert, J. Schrittwieser, I. Antonoglou, M. Lai, A. Guez, M. Lanctot, L. Sifre, D. Kumaran, T. Graepel, T. P. Lillicrap, K. Simonyan, and D. Hassabis, “Mastering chess and shogi by self-play with a general reinforcement learning algorithm,” ArXiv, vol. abs/1712.01815, 2017.
[36] D. Silver, J. Schrittwieser, K. Simonyan, I. Antonoglou, A. Huang, A. Guez, T. Hubert, L. Baker, M. Lai, A. Bolton, Y. Chen, T. Lillicrap, F. Hui, L. Sifre, G. van den Driessche, T. Graepel, and D. Hassabis, “Mastering the game of go without human knowledge,” Nature, vol. 550, no. 7676, pp. 354–359, Oct. 2017.
[37] D. Silver, T. Hubert, J. Schrittwieser, I. Antonoglou, M. Lai, A. Guez, M. Lanctot, L. Sifre, D. Kumaran, T. Graepel, T. Lillicrap, K. Simonyan, and D. Hassabis, “A general reinforcement learning algorithm that masters chess, shogi, and go through self-play,” Science, vol. 362, no. 6419, pp. 1140–1144, 2018. 11
[38] K. Kuru, “Definition of multi-objective deep reinforcement learning reward functions for self-driving vehicles in the urban environment,” IEEE Trans. Veh. Technol., vol. 11, pp. 1–12, Mar. 2024.
[39] B. R. Kiran, I. Sobh, V. Talpaert, P. Mannion, A. A. A. Sallab, S. Yogamani, and P. P´erez, “Deep reinforcement learning for autonomous driving: A survey,” IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 6, pp. 4909–4926, 2022.
[40] K. Kuru, J. M. Pinder, B. J. Watkinson, D. Ansell, K. Vinning, L. Moore, C. Gilbert, A. Sujit, and D. Jones, “Toward mid-air collision-free trajectory for autonomous and pilot-controlled unmanned aerial vehicles,” IEEE Access, vol. 11, pp. 100 323–100 342, 2023.
[41] M. Vitelli and A. Nayebi, “Carma : A deep reinforcement learning approach to autonomous driving,” 2016.
[42] A. E. Sallab, M. Abdou, E. Perot, and S. K. Yogamani, “Deep reinforcement learning framework for autonomous driving, ” in Autonomous Vehicles and Machines, 2017.
[43] A. Kendall, J. Hawke, D. Janz, P. Mazur, D. Reda, J.-M. Allen, V.-D. Lam, A. Bewley, and A. Shah, “Learning to drive in a day,” 2018.
[44] S. Houben, J. Stallkamp, J. Salmen, M. Schlipsing, and C. Igel, “Detection of traffic signs in real-world images: The german traffic sign detection benchmark,” in The 2013 International Joint Conference on Neural Networks (IJCNN), 2013, pp. 1–8.
[45] S.-H. Tsang, “Review: Faster r-cnn (object detection),” 2018.
[46] VolvoTrucks, “Volvo trucks introducing vera, the future of autonomous transport,” 2018.
[47] H. Gao, “Faster r-cnn explained,” 2018.
[48] A. Mogelmose, M. M. Trivedi, and T. B. Moeslund, “Vision-based traffic sign detection and analysis for intelligent driver assistance systems: Perspectives and survey,” IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 4, pp. 1484–1497, 2012.
[49] MATHWorks, “Visual perception using monocular camera,” 2019.
[50] K. Kuru, “Technical report: Analysis of intervention modes in human-in-the-loop (hitl) teleoperation with autonomous ground vehicle systems,” Central Lancashire online Knowledge (CLoK), 2022.
[51] S. Russell and P. Norvig, Artificial Intelligence: A Modern Approach, 4th ed. Saddle River, USA: Prentice Hall, 2020.

[52] K. Kuru, S. Worthington, D. Ansell, J. M. Pinder, A. Sujit, B. Jon Watkinson, K. Vinning, L. Moore, C. Gilbert, D. Jones et al., “Aitl-wing-hitl: Telemanipulation of autonomous drones using digital twins of aerial traffic interfaced with wing,” Robotics and Autonomous Systems, vol. 5, 2024.
[53] K. Kuru, “Technical report: Essential development components of the urban metaverse ecosystem,” CLoK, 2024.
[54] K. Kuru, “Use of autonomous uninhabited aerial vehicles safely within mixed air traffic,” in Proceedings of Global Conference on Electronics, Communications and Networks (GCECN2024), 2023.
[55] K. Kuru, S. Clough, D. Ansell, J. McCarthy, and S. McGovern, “WILDetect: An intelligent platform to perform airborne wildlife census automatically in the marine ecosystem using an ensemble of learning techniques and computer vision,” Expert Systems with Applications, vol. 231. Elsevier BV, p. 120574, Nov-2023.
[56] K. Kuru, S. Clough, D. Ansell, J. McCarthy, and S. McGovern, “Intelligent airborne monitoring of irregularly shaped man-made marine objects using statistical Machine Learning techniques,” Ecological Informatics, vol. 78. Elsevier BV, p. 102285, Dec-2023.
[57] K. Kuru and W. Khan, “Novel hybrid object-based non-parametric clustering approach for grouping similar objects in specific visual domains,” Applied Soft Computing, vol. 62. Elsevier BV, pp. 667–701, Jan-2018.

[58] K. Kuru, “Human-in-the-Loop Teleoperation Modes for Autonomous Unmanned Aerial Systems,” 4. Interdisciplinary Conference on Electrics and Computer (INTCEC 2024), 11-13 June 2024, Chicago-USA.
[59] Kuru, Kaya. "Technical Report: Analysis of Intervention Modes in Human-In-The-Loop (HITL) Teleoperation With Autonomous Unmanned Aerial Systems.", 2024.
[60] Kuru, Kaya. "Platform To Test and Evaluate Human-Automation Interaction (HAI) For Autonomous Unmanned Aerial Systems.", 2024.
[61] K. Kuru, K. Kuru. “Urban Metaverse Cyberthreats And Countermeasures Against These Threats,” In Dubai, UAE, 26–29 November 2024, IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024)
[62] Caswell, N., Kuru, K., Ansell, D., Jones, M. J., Watkinson, B. J., Leather, P., et al.. Patient engagement in medical device design: refining the essential attributes of a wearable, pre-void, ultrasound alarm for nocturnal enuresis. Pharmaceutical Medicine, 34, 39-48, 2020.
[63] J Lowe, K Kuru. “Design & Development of a Smart Blind System Using Fuzzy Logic,” In IEEE/ASME MESA 2024 – 20th Int. Conference on Mechatronic, Embedded Systems and Applications (MESA-IND: Bridging Academia and Industry in Mechatronics and Embedded Systems), 2-4 September 2024, Genova, Italy.
[64] J Lowe, K Kuru. “Development of Machine Intelligence for Self-Driving Vehicles Through Video Capturing,” In IEEE/ASME MESA 2024 – 20th Int. Conference on Mechatronic, Embedded Systems and Applications, 2-4 September 2024, Genova, Italy.
[65] K. Kuru et al., "Treatment of Nocturnal Enuresis Using Miniaturised Smart Mechatronics With Artificial Intelligence," in IEEE Journal of Translational Engineering in Health and Medicine, vol. 12, pp. 204-214, 2024.
[66] K. Kuru, Kaya, S. Clough, D. Ansell, J. McCarthy, and S. McGovern. WILDetect - Part I. Coordinates, 20 (5). pp. 19-29, 2024
[67] K. Kuru, Kaya, S. Clough, D. Ansell, J. McCarthy, and S. McGovern. WILDetect - Part II. Coordinates, 20 (6). pp. 17-25, 2024
[68] K. Kuru, K. Kuru. "Blockchain-based decentralised privacy-preserving machine learning authentication and verification with immersive devices in the urban metaverse ecosystem." 2024.
[69] K Kuru. "A Novel Hybrid Clustering Approach for Unsupervised Grouping of Similar Objects." International Conference on Hybrid Artificial Intelligence Systems. Cham: Springer International Publishing, 2014.
[70] J Lowe, K Kuru. “Development of Machine Intelligence for Fully Autonomous Ground Vehicles Via Video Analysis” Conference on Mechatronic, Embedded Systems and Applications (MESA-11: Clean and Smart Vehicles and Transportation System), 2-4 September 2024, Genova, Italy.
[71] J Lowe, K Kuru. “Design & Development of a Prototype Intelligent Blind System Using Fuzzy Reasoning,” In IEEE/ASME MESA 2024 – 20th Int. Conference on Mechatronic, Embedded Systems and Applications, 2-4 September 2024, Genova, Italy.
[72] K. Kuru, K. Kuru. “Urban Metaverse Cybercommunities & Blockchain-Based Privacy-Preserving Deep Learning Authentication and Verification With Immersive Metaverse Devices,” In IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024) - Decentralized AI for Robust Intelligence, 26–29 November, 2024, Dubai, UAE.

[73] K. Kuru, K. Kuru. “Blockchain-Enabled Privacy-Preserving Machine Learning Authentication With Immersive Devices for Urban Metaverse Cyberspaces,” in IEEE/ASME MESA 2024 – 20th Int. Conference on Mechatronic, Embedded Systems and Applications
[74] K. Kuru, K. Kuru. “Urban Metaverse Cyberthreats and Countermeasures to Mitigate Them,” In Dubai, UAE, 26–29 November 2024, IEEE Sixth International Conference on Blockchain Computing and Applications (BCCA 2024)
[75] K. Kuru, et al. "Biomedical visual data analysis to build an intelligent diagnostic decision support system in medical genetics." Artificial intelligence in medicine 62.2 (2014): 105-118.
[76] K. Kuru, "Human-in-the-Loop Telemanipulation Schemes for Autonomous Unmanned Aerial Systems," 2024 4th Interdisciplinary Conference on Electrics and Computer (INTCEC), Chicago, IL, USA, 2024, pp. 1-6, doi: 10.1109/INTCEC61833.2024.10603071.
[77] K. Kuru. "Use of Wearable Miniaturised Medical Devices With Artificial Intelligence (AI) in Enhancing Physical Medicine," In World Congress on Physical Medicine and Rehabilitation, 19-20 June 2024, Tokyo, Japan.
[78] K. Kuru. “Platform to Test and Evaluate Human-in-the-Loop Telemanipulation Schemes for Autonomous Unmanned Aerial Systems,” in IEEE/ASME MESA 2024 – 20th Int. Conference on Mechatronic, Embedded Systems and Applications