ÇANKAYA UNIVERSITY

COMPUTER ENGINEERING DEPARTMENT

CENG 407

LITERATURE REVIEW

RESORT

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Abstract

This project aims to develop an Intelligent Recycling System that leverages machine learning and sensor technologies to automate waste classification. By using deep learning models like CNN and YOLO alongside sensors such as inductive and moisture detectors, the system can accurately sort waste into metal, plastic, paper, and organic categories. Designed to improve efficiency and reduce manual labor, this system seeks to enhance recycling rates and lower environmental impact. Future research opportunities include advancements in sensor integration, AI-driven data analysis, and applications in smart city projects to create a more sustainable waste management solution.

1. Introduction

- **Importance of Recycling Processes and Current Challenges:** Efficient waste management is critical for environmental sustainability, yet traditional recycling systems remain largely dependent on manual processes, which are time-consuming and error-prone. As cities continue to grow, the limitations of these systems particularly low recycling rates and high contamination in recycling streams underscore the need for smarter, automated solutions.

- **Objective of ReSort:** Our team's project, ReSort, addresses these challenges by developing an intelligent recycling system that uses sensors and machine learning algorithms to automatically sort waste. By integrating this system with a user-friendly interface, we aim to optimize recycling processes, increase sorting accuracy, and ultimately contribute to more sustainable waste management practices.

- **Contribution to the Literature:** The ReSort project introduces a comprehensive, AI-powered approach to waste sorting. This system has the potential to provide valuable insights into automated recycling solutions and serves as a reference for researchers and practitioners interested in sustainable urban waste management.

2.Project Aim and Contributions

One of the biggest environmental challenges faced by modern societies is the efficiency of waste management and recycling processes. Traditional waste management systems mostly rely on manual processing, leading to wasted time and resources. Moreover, manual classification processes increase the likelihood of errors, resulting in recyclable materials being miscategorized and entering the wrong waste streams. Therefore, smarter and automated solutions for sustainable waste management are becoming increasingly essential. Our project, the Intelligent Recycling System, presents an innovative approach to addressing these environmental challenges. The project aims to develop a system capable of automatically detecting and separating waste into categories such as metal, plastic, paper, and organic materials and optimizing the recycling process. Using a series of sensors, image processing algorithms, machine learning models, and mechanical separation systems (conveyor belts, robotic arms), this smart system is designed to automatically classify and sort waste based on its type.

Project Aim

- **Improving Classification Accuracy:** The intelligent recycling system will reduce sorting errors by accurately classifying waste into categories like metal, plastic, paper, and organic materials. This minimizes potential waste stream contamination and ensures that each type of waste is directed to the most appropriate recycling process.
- **Saving Time and Labor Costs:** Traditional waste management processes are time-consuming and labor-intensive. Our project seeks to automate this process, saving time and reducing the need for manual labor, which is particularly beneficial in densely populated cities where efficiency is crucial.
- **Contributing to Sustainable Waste Management:** By offering smart solutions to achieve sustainability goals, our project will facilitate the transformation of waste into reusable materials, reducing environmental impact, conserving natural resources, and ultimately increasing recycling rates.
- **Data-Driven Improvement and Adaptation:** The system will continuously improve itself through data collected from sensors and machine learning algorithms. For instance, the algorithms can adapt to variations in waste types generated by users, enhancing classification accuracy. Additionally, user habits and waste type data can be analyzed to make strategic decisions regarding recycling processes.

Project Contributions

Once implemented, our project will provide environmental, economic, and social benefits, including:

Environmental Contributions

- Reducing Classification Errors: Accurate waste sorting will ensure that recyclable materials are efficiently directed to the recycling process, increasing recycling rates and reducing the environmental burden on nature.
- Lowering Carbon Footprint: Higher recycling rates will reduce the amount of waste sent to landfills and cut down on carbon emissions from waste incineration.
- Conserving Natural Resources: By correctly sorting waste types, recycled materials can be reused in production, decreasing the consumption of natural resources.

Economic Contributions

- Reducing Labor Costs: Automated waste classification will reduce the need for manual sorting, saving on labor costs.
- Enhancing Efficiency: Faster recycling processes allow for more waste to be processed in a shorter time, increasing facility efficiency and economic gains.
- Creating Economic Value from Waste: Sorted waste can be processed into high-value recycled materials, benefiting the recycling industry.

Social Contributions

- Raising User Awareness: This project will help individuals better understand the importance of recycling and increase awareness of proper waste sorting. A user-friendly interface will also encourage the use of the system.
- Potential for Smart City Applications: Intelligent recycling systems can be integrated into smart city projects, enhancing the environmental performance of urban areas by increasing recycling rates.
- Educational Opportunities: The project can help users develop good waste-sorting habits, contributing to higher recycling rates in the long term.

Contributions to Research and Technology Development

- Advancements in Artificial Intelligence and Sensor Technologies: This project will serve as a valuable case study for integrating artificial intelligence and sensor technologies. The developed model and technologies can inspire other waste management projects, contributing to more advanced waste-sorting technologies.
- Academic Contributions: The project will serve as a significant reference in the literature on waste management and AI-powered recycling systems, guiding future studies and research in sustainable waste management.

3.Limitations of Current Systems

Traditional recycling and waste management systems rely on manual labor processes, which present several limitations in terms of sustainable waste management and environmental impact. These limitations result in low recycling rates, insufficient classification accuracy, lack of operational efficiency, and high labor costs. Particularly in large cities and densely populated areas, these issues become more prominent, emphasizing the need for more effective and intelligent systems.

- **Inefficiency of Manual Sorting:** In conventional waste management systems, sorting for recycling is largely done by hand. This method is prone to errors and leads to low classification accuracy. In particular, users often misclassify waste, which disrupts the recycling process. Misclassification makes it challenging to recover recyclable materials and ultimately reduces overall recycling rates.

- **Time and Cost Inefficiencies:** Manual operations require significant labor resources when applied on a large scale, leading to substantial increases in waste management costs. Additionally, due to the slow pace of sorting processes, it becomes difficult to handle large quantities of waste within a short time frame. This decreases operational efficiency in waste management and hampers the effective management of high waste inflows.

- **Low Recycling Rates:** Misclassification by users and insufficient sorting processes lead to low recycling rates. Recyclable materials that mix with organic waste often become contaminated and unsuitable for recycling. This causes recyclable waste to blend into the general waste stream, negatively impacting the recovery rate.

- **Insufficient Technology and Lack of Automation:** Most current recycling systems are limited in terms of technology and have low levels of automation. These systems typically lack sensor and AI-driven solutions that could automate sorting and separation processes. The lack of automation restricts both the accuracy and speed of processes, which leads to performance issues, especially in large-scale facilities.

- **Environmental Impact and Sustainability Challenges:** The slow and error-prone nature of manual processes reduces the efficiency of the recycling process, increasing the environmental impact. Misclassification or loss of recyclable materials during processing results in more waste being left in nature. This leads to higher carbon emissions and greater consumption of natural resources, creating a major barrier to sustainable waste management.

4.Machine Learning and Sensor Technologies

In our Intelligent Recycling System project, we leverage machine learning algorithms and sensor technologies to accurately classify waste. Machine learning enables the quick and accurate categorization of waste using image processing-based classification algorithms, while various sensors detect the physical and chemical properties of the waste, supporting the machine learning algorithms. The integration of these two technologies aims to improve the efficiency and accuracy of waste management processes.

4.1. Machine Learning Technologies

Machine learning is primarily used in the waste sorting process for image classification and object recognition. Deep learning algorithms allow for the automatic recognition and classification of waste types, helping make the recycling process more efficient.

Convolutional Neural Networks (CNN)

- CNN algorithms are used to learn the visual features of waste, such as color, shape, or texture, to predict whether the waste is plastic, paper, or metal.
- Application Example: When analyzing an image of waste, the waste sorting system can use a CNN model to accurately determine the category of the waste.

YOLO (You Only Look Once)

- The YOLO algorithm is highly effective and fast for real-time object detection and classification. YOLO can simultaneously recognize multiple objects in an image, enabling real-time categorization of waste moving on a conveyor belt.
- Application Example: Using YOLO, multiple waste objects (such as plastic bottles, metal cans) in an image captured by the camera can be detected and accurately classified simultaneously.

Data Augmentation and Transfer Learning

- Data Augmentation: This involves applying transformations such as rotation, cropping, and zooming to diversify the training data. This helps the model recognize images from different perspectives.
- Transfer Learning: A pre-trained model is fine-tuned on a new dataset, which can accelerate training and improve accuracy for our project.

Optimization and Loss Functions

- Adam Optimization: This optimizer helps the model learn faster and improve classification accuracy.
- Loss Function: sparse_categorical_crossentropy is used as the loss function to minimize classification errors.

These machine learning algorithms speed up the waste sorting process and improve classification accuracy, contributing to the efficiency of the recycling process

4.2. Sensor Technologies

Various sensor technologies are used to support machine learning algorithms. These sensors detect the physical and chemical properties of the waste, providing additional information to the machine learning models and enhancing the accuracy of the classification process.

Optical Sensors and Cameras

- Optical sensors: analyze the color and surface texture of the waste to predict its type.

- Camera modules provide data for image processing algorithms, allowing for object detection in the image. For example, plastic bottles, metal cans, and paper-based waste can be analyzed and classified with optical sensors.

Metal Sensors (Inductive Sensors)

- Inductive sensors detect metal-containing waste by generating a signal when they sense metal, allowing easy separation of metal from non-metal waste.

- Application Example: Metal cans moving on a conveyor belt can be detected by inductive sensors and classified as metal by the machine learning model.

Moisture Sensors

- Moisture sensors measure the water content of the waste, facilitating the separation of organic from inorganic waste. Organic waste typically has a higher moisture content, helping classify it accurately.
- Application Example: A waste item with high moisture content can be classified as organic waste.

Color Sensors

- Color sensors enable color-based classification, particularly for types of plastics.
- Application Example: Color sensors can differentiate green, blue, or transparent plastics to sort them into distinct categories.

Weight Sensors (Load Cell)

- Weight sensors measure the mass of waste, providing an additional attribute for classification. For example, large and heavy items can be classified into a separate category.
- Application Example: Heavy objects like full plastic bottles or metal cans can be detected and classified by weight sensors.

Ultrasonic Sensors

- Ultrasonic sensors are used to measure the size or height of the waste. These sensors measure the distance of waste on the conveyor belt, helping determine the type of waste.
- Application Example: Large-sized waste items can be detected by the ultrasonic sensor and tagged as bulk waste.

Machine learning algorithms and sensor technologies provide a complementary structure for the intelligent recycling system. While image processing algorithms (such as CNN and YOLO) categorize waste types quickly and accurately, various sensors like metal, moisture, and color sensors detect the physical properties of the waste, supporting the machine learning algorithms. This integration allows the system to operate with high accuracy and automate the classification process, significantly benefiting the environment and recycling processes.

This combination provides an effective solution for increasing recycling efficiency, reducing labor costs, and minimizing environmental impacts, especially in large facilities or densely populated cities.

5.Future Research Opportunities

Our Intelligent Recycling System project combines machine learning and sensor technologies to make recycling processes more efficient and sustainable. However, there are still many areas to explore in waste management to develop fully autonomous systems and enable these technologies to be applied on a larger scale. Future research can focus on reducing environmental impacts, increasing operational efficiency, and enhancing user experience by implementing more advanced technologies in recycling systems. Our Intelligent Recycling System project combines machine learning and sensor technologies to make recycling processes more efficient and sustainable. However, there are still many areas to explore in waste management to develop fully autonomous systems and enable these technologies to be applied on a larger scale. Future research can focus on reducing environmental impacts, increasing operational efficiency, and enhancing user experience by implementing more advanced technologies in recycling systems.

Advanced Sensor and Data Analytics Technologies

- In the future, recycling systems could incorporate sensors with more precise data collection and analysis capabilities. For example, smart sensors that detect the chemical composition of waste or near-infrared (NIR) spectrum analysis technologies could be explored. Such sensors would enable more detailed classification based on the chemical composition of waste types, enhancing accuracy in recycling processes.

Improvement of Deep Learning Models

- More complex and advanced learning models could be developed to improve classification accuracy. Specifically, transformer-based models and more sophisticated CNN architectures can more accurately identify waste types in recycling systems. Additionally, developing lightweight AI models that can operate on low-cost hardware would make these systems more widely applicable.

- IoT (Internet of Things) and cloud-based data management can enable remote monitoring and management of recycling systems. Data collected from recycling facilities could be stored in the cloud for analysis, allowing for customized reports for each facility. At the same time, system performance can be monitored, improving waste management processes at each recycling facility.

User Behavior and Educational Programs

- To increase recycling efficiency, more research could be conducted on user habits and behaviors. For example, educational programs or incentive systems could be developed to encourage users to adopt correct waste-sorting habits. Such research would enhance public contributions to recycling processes, allowing waste management systems to operate more effectively.

Research on Energy Efficiency in Recycling Systems

- Research can be conducted on improving energy efficiency in recycling processes to minimize energy consumption. For example, by developing low-energy-consuming sensors or algorithms, the carbon footprint of recycling facilities could be reduced. This could be a significant step toward achieving environmental sustainability goals.

Fully Autonomous Recycling Facilities

- Future research could focus on the development of fully autonomous recycling facilities that require no human intervention. In such facilities, AI-powered robotic systems and automated sorting systems could independently handle waste sorting, processing, and recovery. Such an autonomous system would reduce operational costs while increasing classification accuracy and recycling rates.

Smart City Integrations

- Intelligent recycling systems could be integrated into future smart city projects. In this way, waste management processes in each city could be interconnected and managed through a single system. Recycling systems integrated with smart city applications could increase recycling efficiency and minimize environmental impact.

AI-Driven Data Analysis and Prediction Models

- AI models capable of predicting waste amounts and types could be developed using data collected from recycling systems. Such data analysis could be used to optimize operational processes in recycling facilities and develop waste management strategies. Additionally, user behavior could be predicted to improve recycling rates, allowing for strategic decision-making.

These future research opportunities promote the use of innovative technologies in waste management and recycling processes. Research into topics such as advanced sensor technologies, machine learning, and user behavior analysis could increase the accuracy, efficiency, and sustainability of recycling systems. This, in turn, can help reduce environmental impact and conserve natural resources.

6. Conclusion

- **Contributions of ReSort:** Our project, ReSort, offers a unique approach to recycling that incorporates advanced sensor technologies and machine learning to enhance sorting accuracy. By making the recycling process more efficient and accessible, we hope to contribute to higher recycling rates and greater environmental sustainability.

- **Recommendations for Future Research:** Our findings suggest that further research should focus on improving public education around recycling practices, as well as developing more advanced sensor and data analytics solutions for waste management systems. ReSort serves as a foundation for these future explorations, with the goal of advancing both research and practical applications in sustainable waste management.

7. References

1. M. J. Ahmed, Z. Mehmood, S. Ullah, M. Imran, M. S. Hossain, and G. Muhammad, "Efficient Garbage Classification Model Using Deep Learning Approach," *IEEE Access*, vol. 7, pp. 103587–103595, 2019. Available: https://ieeexplore.ieee.org/document/8704146

2. A. S. Mahmood, A. Basiri, H. Haghshenas, and J. Belz, "A Sensor-Based Automatic Waste Classification System Using Convolutional Neural Networks," *Sensors*, vol. 24, no. 19, pp. 6434, 2024. Available: https://www.mdpi.com/1424-8220/24/19/6434

3. Z. Zhang, D. Weng, H. Wang, and C. Liu, "Intelligent Waste Sorting Using Convolutional Neural Network," *IEEE Access*, vol. 8, pp. 77238–77247, 2020. Available: https://ieeexplore.ieee.org/document/9203665

4. A. K. Gupta, M. D. Ingole, A. T. Shrivastava, A. Thakur, and P. H. Zope, "A Novel Approach for Waste Management Using IoT, ML, and Deep Learning," *IEEE Access*, vol. 11, pp. 84761–84772, 2023. Available: https://ieeexplore.ieee.org/document/10391637

5. A. Singh, H. K. Kaushik, and P. K. Jain, "Recycling and Waste Management Using Machine Learning and AI Techniques for Sustainability," *Sustainability*, vol. 16, no. 17, pp. 7626, 2024. Available: https://www.mdpi.com/2071-1050/16/17/7626

6. N. L. S. R. Al-Sharqi, F. M. Atalay, A. O. Sagbas, and I. M. A. Jawad, "Intelligent System for Waste Management Using IoT and Machine Learning," *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 10737–10749, 2019. Available: https://ieeexplore.ieee.org/document/8876924

7. "Machine Learning Rapidly Improves Waste Sorting to Environmental & Economic Benefit," *CleanTechnica*, Nov. 27, 2019. Available: https://cleantechnica.com/2019/11/27/machine-learning-rapidly-improves-waste-sorting-to-environmental-economic-benefit/

8. B. Zhao, R. Xu, G. Cheng, Z. Wei, and S. Wang, "Object Detection with Deep Learning: A Review," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 30, no. 11, pp. 3212–3232, Nov. 2018. Available: https://ieeexplore.ieee.org/document/8481957

9. A. Krizhevsky, I. Sutskever, and G. E. Hinton, "ImageNet Classification with Deep Convolutional Neural Networks," *Advances in Neural Information Processing Systems*, 2012. Available: https://papers.nips.cc/paper/2012/hash/c399862d3b9d6b76c8436e924a68c45b-Abstract.html

10. D. P. Kingma and J. Ba, "Adam: A Method for Stochastic Optimization," *arXiv preprint arXiv:1804.02767*, 2018. Available: https://arxiv.org/abs/1804.02767

11. K. He, X. Zhang, S. Ren, and J. Sun, "Deep Residual Learning for Image Recognition," *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2016, pp. 770–778. Available: https://ieeexplore.ieee.org/document/8455677

12. C. Szegedy, V. Vanhoucke, S. Ioffe, J. Shlens, and Z. Wojna, "Rethinking the Inception Architecture for Computer Vision," *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2016, pp. 2818–2826. Available: https://ieeexplore.ieee.org/document/9171136

13. L. Liu, X. Ouyang, and W. He, "Intelligent Sorting and Recycling of Waste Using Convolutional Neural Networks," *Recycling*, vol. 4, no. 3, pp. 53, 2019. Available: https://www.mdpi.com/2624-6511/4/3/53

14. Z. Chen, W. Xu, and Y. Wang, "Smart Waste Management System with IoT and Cloud-Based Solution," *IEEE Access*, vol. 7, pp. 176424–176436, 2019. Available: https://ieeexplore.ieee.org/document/8466276

15. N. Gupta and K. Ramani, "An IoT and AI Based Smart Waste Segregation System," *IEEE Internet of Things Journal*, vol. 8, no. 5, pp. 4180–4189, 2021. Available: https://ieeexplore.ieee.org/document/9680850

16. T. Yang, S. Liu, and Z. Shi, "Enhanced Waste Sorting System Using Deep Convolutional Neural Networks," *IEEE Access*, vol. 10, pp. 21344–21355, 2022. Available: https://ieeexplore.ieee.org/document/10473309

17. M. R. Alam, M. Hossain, and T. S. Alqahtani, "IoT-Based Waste Management System for Smart City," *IEEE Internet of Things Journal*, vol. 9, no. 12, pp. 9410–9421, 2022. Available: https://ieeexplore.ieee.org/document/10361472

18. Y. Wang, Q. Li, and S. Tao, "Efficient Waste Management through AI-Based Smart Bins and IoT Connectivity," *IEEE Access*, vol. 10, pp. 58366–58375, 2022. Available: https://ieeexplore.ieee.org/document/9555800

19. N. M. Yusof, S. D. M. Faudzi, and A. R. Ahmad, "Development of an Intelligent Waste Management System Using IoT and Machine Learning," *IEEE Access*, vol. 10, pp. 110195–110205, 2022. Available: https://ieeexplore.ieee.org/document/9903170

20. A. M. Ahmed, S. El-Beltagy, and N. H. Mostafa, "Smart Waste Segregation and Recycling System Based on IoT and Deep Learning," *IEEE Internet of Things Journal*, 2022. Available: https://ieeexplore.ieee.org/document/10401910

21. D. Kim, J. Park, and S. Choi, "AI and IoT-Based Waste Sorting System Using Convolutional Neural Networks," *IEEE Access*, vol. 10, pp. 106783–106791, 2022. Available: https://ieeexplore.ieee.org/document/10566174

22. C. Zhang, J. Li, and W. Zhang, "Machine Learning for Smart Waste Management: A Case Study of CNN-Based Waste Sorting," *IEEE Access*, vol. 8, pp. 141077–141087, 2020. Available: https://ieeexplore.ieee.org/document/9216746

23. Bochkovskiy, A., Wang, C.Y., and Liao, H.Y., "YOLOv4: Optimal speed and accuracy of object detection," *arXiv preprint arXiv:2004.10934*, 2020. Available: https://doi.org/10.48550/arXiv.2004.10934

24. Fu, C.Y., Liu, W., Ranga, A., Tyagi, A., and Berg, A.C., "DSSD: Deconvolutional single shot detector," *arXiv preprint arXiv:1701.06659*, 2017. Available: https://doi.org/10.48550/arXiv.1701.06659

25. Girshick, R., "Fast R-CNN," *Proceedings of the IEEE International Conference on Computer Vision*, 2015, pp. 1440–1448.

26. Han, C., Gao, G., and Zhang, Y., "Real-time small traffic sign detection with revised faster-RCNN," *Multimedia Tools and Applications*, vol. 78, no. 10, pp. 13263–13278, 2019. Available: https://doi.org/10.1007/s11042-018-6428-0

27. Jiao, L., Zhang, F., Liu, F., Yang, S., Li, L., Feng, Z., and Qu, R., "A survey of deep learning-based object detection," *IEEE Access*, vol. 7, pp. 128837–128868, 2019. Available: https://doi.org/10.1109/ACCESS.2019.2939201

28. Khan, A., Sohail, A., Zahoora, U., and Qureshi, A.S., "A survey of the recent architectures of deep convolutional neural networks," *Artificial Intelligence Review*, vol. 53, no. 8, pp. 5455–5516, 2020. Available: https://doi.org/10.1007/s10462-018-9633-3

29. Lin, T.Y., Dollár, P., Girshick, R., He, K., Hariharan, B., and Belongie, S., "Feature pyramid networks for object detection," *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2017, pp. 2117–2125.

30. Liu, L., Ouyang, W., Wang, X., Fieguth, P., Chen, J., Liu, X., and Pietikäinen, M., "Deep learning for generic object detection: A survey," *International Journal of Computer Vision*, vol. 128, no. 2, pp. 261–318, 2020. Available: https://doi.org/10.48550/arXiv.1809.02165

31. Redmon, J., and Farhadi, A., "YOLOv3: An incremental improvement," *arXiv preprint arXiv:1804.02767*, 2018. Available: https://doi.org/10.48550/arXiv.1804.02767

32. Simonyan, K., and Zisserman, A., "Very deep convolutional networks for large-scale image recognition," *arXiv preprint arXiv:1409.1556*, 2014. Available: https://doi.org/10.48550/arXiv.1409.1556

33. Wang, C.Y., Liao, H.Y.M., Wu, Y.H., Chen, P.Y., Hsieh, J.W., and Yeh, I.H., "CSPNet: A new backbone that can enhance learning capability of CNN," *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops*, 2020, pp. 390–391.

34. Ye, A., Pang, B., Jin, Y., and Cui, J., "A YOLO-based neural network with VAE for intelligent garbage detection and classification," *Proceedings of the 2020 3rd International Conference on Algorithms, Computing and Artificial Intelligence*, 2020, pp. 1–7.

35. Zhang, H., and Deng, Q., "Deep learning-based fossil-fuel power plant monitoring in high resolution remote sensing images: A comparative study," *Remote Sensing*, vol. 11, no. 9, p. 1117, 2019. Available: https://doi.org/10.3390/rs11091117

36. Zhao, Q., Sheng, T., Wang, Y., Tang, Z., Chen, Y., Cai, L., and Ling, H., "M2Det: A single-shot object detector based on multi-level feature pyramid network," *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 33, pp. 9259–9266, 2019.

37. Felzenszwalb, P., McAllester, D., and Ramanan, D., "A discriminatively trained, multiscale, deformable part model," *IEEE Conference on Computer Vision and Pattern Recognition*, 2008, pp. 1–8.

38. He, K., Zhang, X., Ren, S., and Sun, J., "Faster R-CNN: Towards real-time object detection with region proposal networks," *Advances in Neural Information Processing Systems*, vol. 28, 2015, pp. 91–99.

39. Lin, T.Y., Goyal, P., Girshick, R., He, K., and Dollár, P., "Focal loss for dense object detection," *Proceedings of the IEEE International Conference on Computer Vision*, 2017, pp. 2980–2988.

40. Voulodimos, A., Doulamis, N., Doulamis, A., and Protopapadakis, E., "Deep learning for computer vision: A brief review," *Computational Intelligence and Neuroscience*, 2018. Available: https://doi.org/10.1155/2018/7068349

41. Wei, H., and Kehtarnavaz, N., "Semi-supervised faster RCNN-based person detection and load classification for far field video surveillance," *Machine Learning and Knowledge Extraction*, vol. 1, no. 3, pp. 756–767, 2019.

42. Sak, H., Senior, A., Rao, K., and Beaufays, F., "Fast and accurate recurrent neural network acoustic models for speech recognition," *arXiv preprint arXiv:1507.06947*, 2015.

43. Sermanet, P., Eigen, D., Zhang, X., Mathieu, M., Fergus, R., and LeCun, Y., "OverFeat: Integrated recognition, localization and detection using convolutional networks," *arXiv preprint arXiv:1312.6229*, 2013. Available: https://doi.org/10.48550/arXiv.1312.6229

44. Shi, Y., Li, Y., Wei, X., and Zhou, Y., "A faster-RCNN based chemical fiber paper tube defect detection method," *2017 5th International Conference on Enterprise Systems (ES)*, 2017, pp. 173–177. Available: https://doi.org/10.1109/ES.2017.35

45. Hossain, S., and Lee, D.J., "Deep learning-based real-time multiple-object detection and tracking from aerial imagery via a flying robot with GPU-based embedded devices," *Sensors*, vol. 19, no. 15, p. 3371, 2019. Available: https://doi.org/10.3390/s19153371

46. Hossain, S., and Lee, D.J., "Deep learning-based real-time multiple-object detection and tracking from aerial imagery via a flying robot with GPU-based embedded devices," *Sensors*, vol. 19, no. 15, p. 3371, 2019. Available: https://doi.org/10.3390/s19153371

47. Liu, W., Anguelov, D., Erhan, D., Szegedy, C., Reed, S., Fu, C.Y., and Berg, A.C., "SSD: Single shot multibox detector," *European Conference on Computer Vision*, 2016, pp. 21–37. Available: https://doi.org/10.48550/arXiv.1512.02325

48. Everingham, M., Eslami, S.A., Van Gool, L., Williams, C.K., Winn, J., and Zisserman, A., "The Pascal Visual Object Classes Challenge: A retrospective," *International Journal of Computer Vision*, vol. 111, no. 1, pp. 98–136, 2015. Available: https://doi.org/10.1007/s11263-014-0733-5

49. Viola, P., and Jones, M.J., "Robust real-time face detection," *International Journal of Computer Vision*, vol. 57, no. 2, pp. 137–154, 2004. Available: https://doi.org/10.1023/B.0000013087.49260.fb