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Indonesian Waste Database: Smart Mechatronics System

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ABSTRACT

Waste management is an essential component of urban management. As a waste solution, waste management is critical. The goal of this research is to develop a waste management database that is coupled with a mechatronic robot system. Compiling and gathering data on the sorts of garbage found in Indonesia is the starting point for this research. Indonesian waste is classified into six groups: cardboard, paper, metal, plastic, medical, and organic. The total images of the six groups are estimated at 1880 pictures. According to this picture database, Artificial Intelligence (AI) training was used to create the classification system. In the final AI process, the test method was performed using DenseNet121, DenseNet169, and DenseNet201. Testing using artificial intelligence DenseNet201 across 40 epochs yields the best 92,7% accuracy rate. Simultaneously with Artificial Intelligence testing, a mechatronic system is created as a direct implementation of the Artificial Intelligence output model. A four-servo arm robot with dc motor wheel mobility is included in the mechatronic system. According to these findings, the Indonesian waste database can be categorized correctly using Artificial Intelligence and the mechatronics system. This higher accuracy of the artificial intelligence model may be used to create a waste-sorting robot prototype.

1. Introduction

In recent years, the trash problem has become a significant concern [1]–[3]. Even during the COVID-19 epidemic, waste output has increased dramatically, particularly medical waste [4]–[6]. In general, waste is classified as organic or inorganic. Organic waste is garbage made from natural elements that can be immediately reduced and degraded [7], [8]. Meanwhile, inorganic waste is defined as garbage-containing compounds that are difficult to degrade in the environment [9].

Waste may be decreased by employing the 3R concept (Reduce, Recycle, Reuse) [10]–[12]. Waste reduction can be addressed by minimizing items with the potential to become waste. Furthermore, waste reduction might use products already used for reuse. In reality, waste management may be recycled to create trash with new purposes and a higher value [2], [13]–[15].

Indonesia's waste management system is still far from ideal [16]–[18]. In Indonesia, pollution from trash and discarded limbs are at an all-time low. In Indonesia, waste is classified based on the primary substance. These wastes might be paper, cardboard, plastic, medical waste, organic trash, or metal.

Today, the role of technology in dealing with waste concerns is critical. Much research has been conducted in recent years to promote the use of technology in trash management. The Internet of Things [19]–[21], robotics [22]–[25], automation [26]–[28], and artificial intelligence [29]–[31] are some of the technologies that may be employed in waste management. The Internet of Things can play a role in the management of waste information in the environment as well as a centralized means of delivering data. At the same time, robots and automation may be employed as waste management actuators in the environment. The mechatronics method refers to the integration of robotics and automation.

Artificial Intelligence, the most recent form of waste management, provides advantages regarding system accuracy. In recent years, artificial intelligence has been used to identify garbage categories, detect rubbish objects, and anticipate waste. By applying computer-based [32], mobile [31], and web-based applications [33], artificial intelligence may also be employed as an integrated system. A database that can be utilized as a learning system is essential in artificial intelligence. This database system is one-of-a-kind and restricted to specified requirements. The location of the garbage, the kind of waste, and the characteristics of the waste are among these criteria.

As a result, the research's objective and originality are to categorize Indonesian garbage using a mix of artificial intelligence and mechatronics technologies. First, an Indonesian trash database is constructed based on the material characteristics and the kind of features utilized. In addition, DenseNet artificial intelligence learning is used to get the optimal accuracy value. Simultaneously, the mechatronics arm robot system is finally developed with the highest precision of artificial intelligence output model.

2. Method

This research is a product-based project. In order to accommodate each step of research, the ADDIE (Analyze, Design, Develop, Implement, Evaluate) technique is employed [34], [35].

2.1. Analyze

Environmental research and a search for waste characteristics in Indonesia were used in the analysis. The Indonesian trash database was created in numerous categories: paper, cardboard, plastic, medical waste, organic garbage, and metal. Table 1 shows the distribution class of the Indonesian waste database. The total number of photos in Indonesia's waste database is 1880. The training phase consumes 80% of the database. Furthermore, testing and validation consume 20% of the waste database.

Table 1. Waste Database

Class	Total Number
Cardboard	150
Medical	389
Metal	202
Organic	428
Paper	340
Plastic	371

2.2. Design

The design step includes product simulation and mechatronics planning. This step involves developing a mobile robot software prototype with a mechatronics system. The robot features four wheels and a robotic arm-based servo actuator with three degrees of freedom (DOF). The robotic arm

in this project was inspired by Tung's [36] research that decreased the actual system's DOF. The 3D design of the mechatronics system, on the other hand, may be shown in Fig. 1 (a)-(b).

(a) (b)

Fig. 1. (a) Full perspective 3D design; (b) front view of the mechatronics system

2.3. Development

This research combines two approaches, mechatronics systems and artificial intelligence. Mechatronics systems are used as drive actuators. Meanwhile, artificial intelligence is used as an input to the state of the environment using image detection. In general, the system flowchart can be seen in Fig. 2.

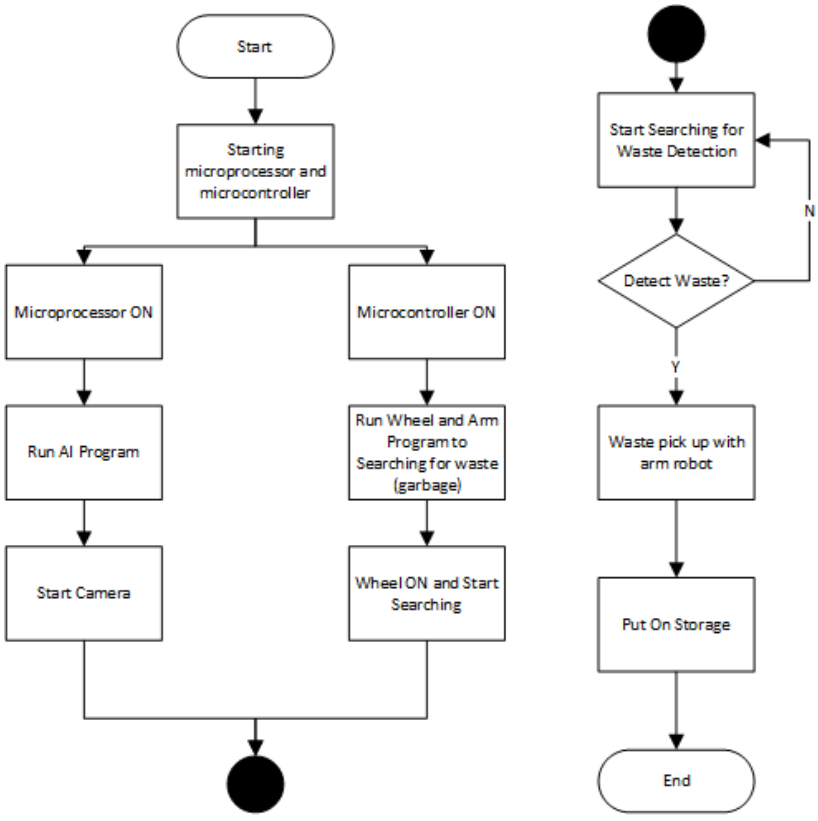
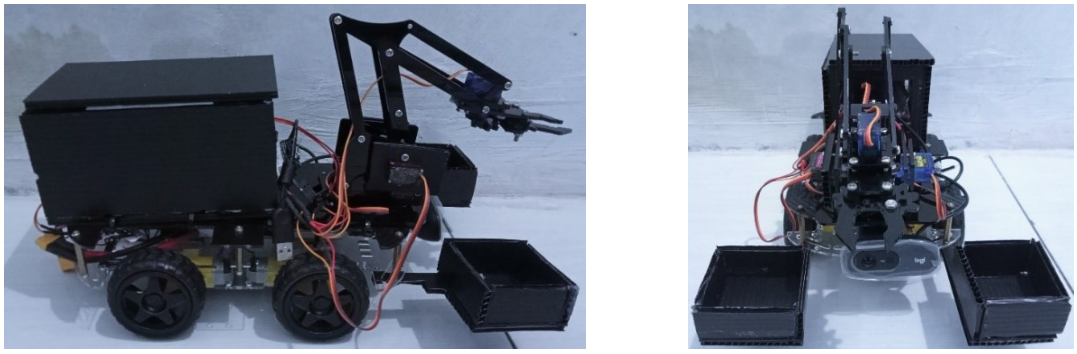


Fig. 2. Flowchart System

2.3.1. Mechatronics Systems

Mechatronics-based systems are system techniques that incorporate electrical, software, and mechanical actuators [37]–[39]. At the Development stage, Mechatronics robot manufacturing is carried out with an approach to adding hardware and electrical circuits. As a mechatronics system robotic arm actuator, servo hardware is employed. The camera is also installed on the robotic arm as

a real-time input of environmental circumstances. The complete development mechatronics system can be seen in Fig. 3 (a)-(b).



(a) (b)

Fig. 3. (a) Side view of a mechatronics system; (b) front view with camera input

2.3.2. Artificial Intelligence

DenseNet was employed as artificial intelligence in this investigation. DenseNet is a deep learning system based on dense layers [40]. DenseNet has numerous algorithm variations dependent on depth and layer count. DenseNet has the benefit of being simple to implement and accurate. In addition to DenseNet, numerous related algorithms, including as MobileNet [41]–[43], Single Shot Detector (SSD) [44]–[46], Yolo [47]–[50], and ResNet [51]–[53], can be used in specific case studies.

2.4. Implementation

At this point, the software and hardware components are combined by installing the Jetson Nano as the primary CPU. Jetson Nano supports artificial intelligence data transmission with a robotic system based on mechatronics. The whole wiring diagram can be seen in Fig. 4.

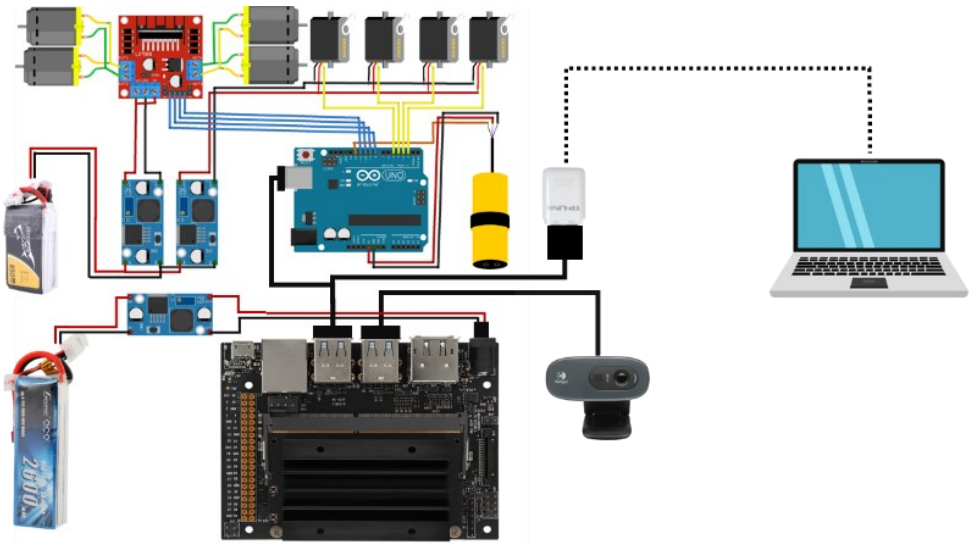


Fig. 4. Wiring diagram of the complete proposed system

At the implementation stage, system detection testing is carried out using the camera contained in the robot. The results of camera detection tests with Jetson Nano can be seen in Fig. 5.

2.5. Evaluate

The last stage is evaluation as a system improvement. At this evaluation stage, several optimizations and accuracy comparisons are carried out. The evaluation stage was deducted to find the best output model for the mechatronics system. In the evaluation phase, the effectiveness of integrating artificial intelligence and mechatronic systems can be observed.

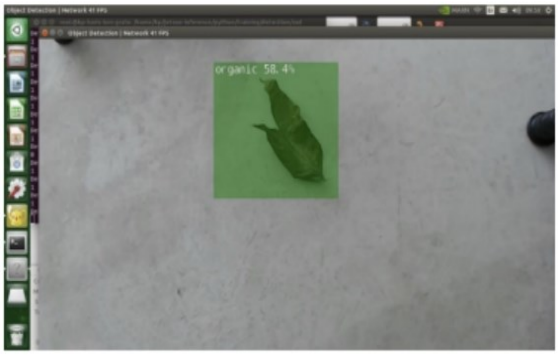


Fig. 5. Implementation of system detection

3. Results and Discussion

This study used a model of ingenuity made by the DenseNet algorithm, as shown in Fig. 6. All types of artificial intelligence are used as a foundation for system learning. These types include DenseNet121, DenseNet169, and DenseNet201.

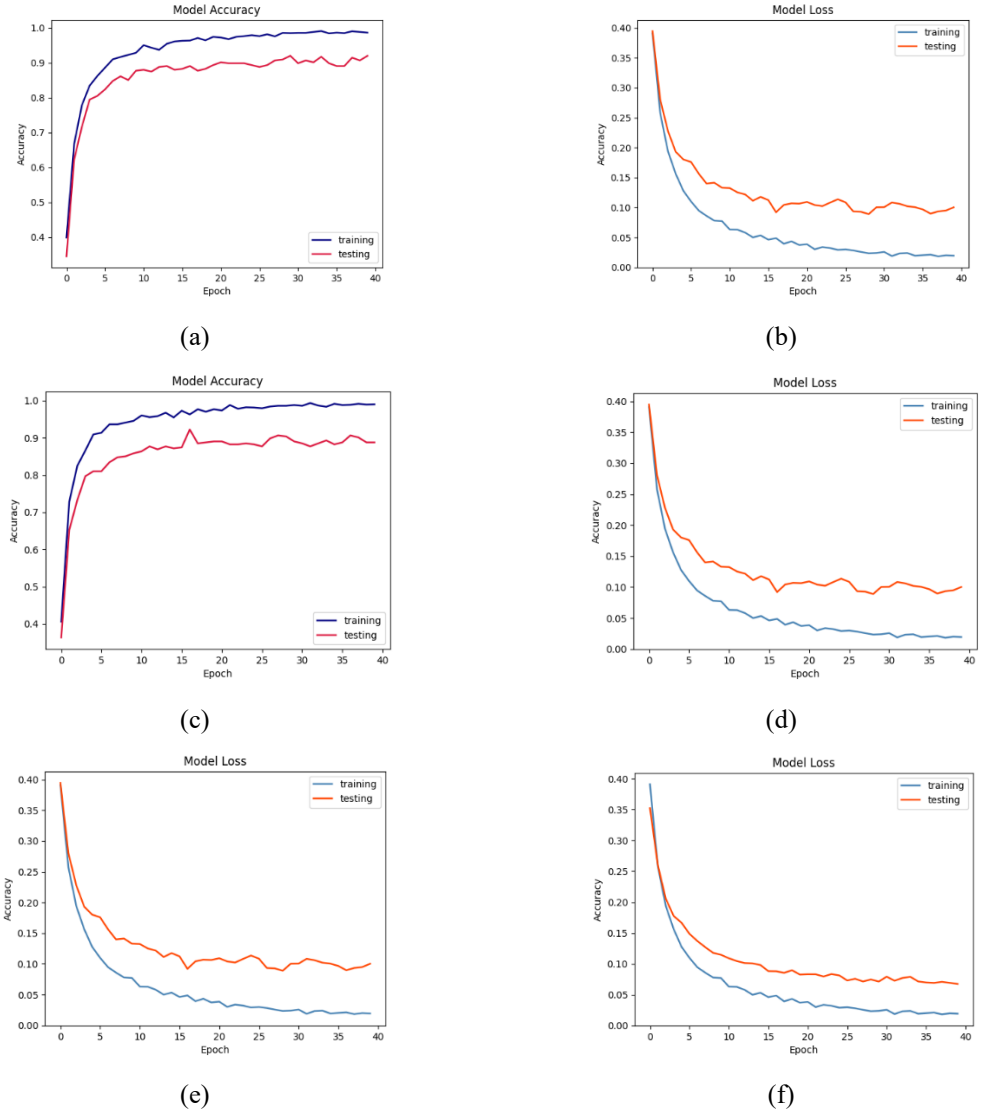


Fig. 6. Results Accuracy (a)-(b) DenseNet121; (c)-(d) DenseNet169; (e)-(f) DenseNet201

The initial stage is to obtain training data from the Indonesian waste database. A total of 1880 data points were trained across 40 epochs using the DenseNet technique. A testing accuracy of 92% was found in the DenseNet121 data. Meanwhile, DenseNet169 training yielded results of 88%. Finally, DenseNet201 has a 92.7% accuracy rate. According to Mao's trash categorization research [30], the DensNet201 algorithm has the highest accuracy level. The high accuracy results are attributable to the network's depth level on DenseNet201. Several misclassifications in the learning model were also investigated in this study. Misclassification images for all three models are shown in Fig. 7.

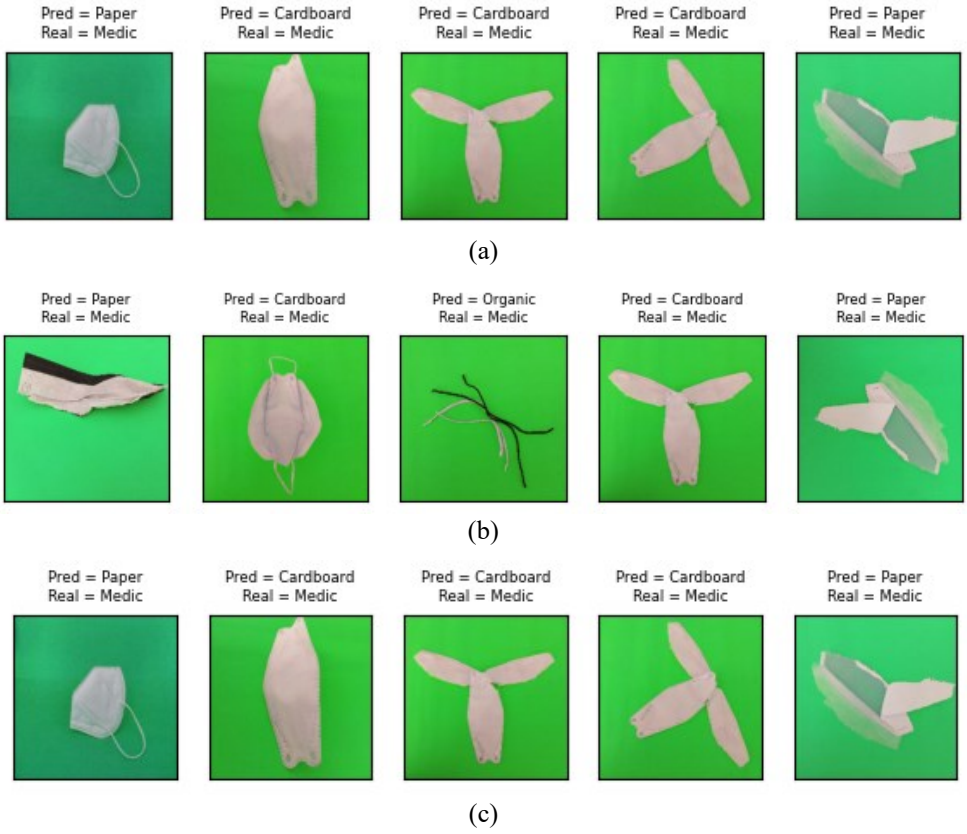


Fig. 7. Misclassification of (a) DenseNet121; (b) DenseNet169; (c) DenseNet201

4. Conclusion

Artificial intelligence-based mechatronics systems have been developed effectively. Furthermore, Indonesia's waste database has been clearly classified into six sorts. DenseNet201 was used to identify artificial intelligence with the best accuracy, which was 92.7%. In general, mechatronics robot systems based on artificial intelligence may be deployed fully and appropriately. The findings of this study can be used in future research to create a more comprehensive mechatronics system with a full database.

Supplementary Materials: The following supporting database can be downloaded at: https://github.com/PustakaCendekia/Indonesia-Waste-Database.

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References

[1] C. Ellis, "World Bank: Global waste generation could increase 70% by 2050," *WasteDive*, 2018. https://www.wastedive.com/news/world-bank-global-waste-generation-2050/533031/ (accessed Nov. 17, 2021).

[2] A. Keskisaari and T. Kärki, "The use of waste materials in wood-plastic composites and their impact on the profitability of the product," *Resour. Conserv. Recycl.*, vol. 134, pp. 257–261, 2018, https://doi.org/10.1016/j.resconrec.2018.03.023.

[3] H. L. Chen, T. K. Nath, S. Chong, V. Foo, C. Gibbins, and A. M. Lechner, "The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste," *SN Appl. Sci.*, vol. 3, no. 4, p. 437, 2021, https://doi.org/10.1007/s42452-021-04234-y.

[4] A. Maalouf and H. Maalouf, "Impact of COVID-19 pandemic on medical waste management in Lebanon," *Waste Manag. Res. J. a Sustain. Circ. Econ.*, vol. 39, no. 1, pp. 45–55, 2021, https://doi.org/10.1177/0734242X211003970.

[5] M. R. Capoor and A. Parida, "Current perspectives of biomedical waste management in context of COVID-19"," *Indian J. Med. Microbiol.*, vol. 39, no. 2, pp. 171–178, 2021, https://doi.org/10.1016/j.ijmmb.2021.03.003.

[6] S. Sangkham, "Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia," *Case Stud. Chem. Environ. Eng.*, vol. 2, p. 100052, 2020, https://doi.org/10.1016/j.cscee.2020.100052.

[7] D. Ddiba, E. Ekener, M. Lindkvist, and G. Finnveden, "Sustainability assessment of increased circularity of urban organic waste streams," *Sustain. Prod. Consum.*, vol. 34, pp. 114-129, 2022, https://doi.org/10.1016/j.spc.2022.08.030.

[8] Y. Zhou *et al.*, "Microplastics as an underestimated emerging contaminant in solid organic waste and their biological products: Occurrence, fate and ecological risks," *J. Hazard. Mater.*, vol. 445, p. 130596, 2023, https://doi.org/10.1016/j.jhazmat.2022.130596.

[9] W. Pan, H. Xie, Y. Zhou, Q. Wu, J. Zhou, and X. Guo, "Simultaneous adsorption removal of organic and inorganic phosphorus from discharged circulating cooling water on biochar derived from agricultural waste," *J. Clean. Prod.*, vol. 383, p. 135496, 2023, https://doi.org/10.1016/j.jclepro.2022.135496.

[10] D. Dahiya, H. Sharma, A. K. Rai, and P. S. Nigam, "Application of biological systems and processes employing microbes and algae to Reduce, Recycle, Reuse (3Rs) for the sustainability of circular bioeconomy," *AIMS Microbiol.*, vol. 8, no. 1, pp. 83–102, 2022, https://doi.org/10.3934/microbiol.2022008.

[11] A. Ilham, M. Rahman, and W. Tune Sumar, "Community Empowerment Through Waste Management With Reduce, Reuse and Recycle System (3r) In Bulota Village," *Devot. J. Community Serv.*, vol. 3, no. 4, pp. 353–360, 2022, https://doi.org/10.36418/dev.v3i4.123.

[12] T.-D. Bui, J.-W. Tseng, M.-L. Tseng, and M. K. Lim, "Opportunities and challenges for solid waste reuse and recycling in emerging economies: A hybrid analysis," *Resour. Conserv. Recycl.*, vol. 177, p. 105968, 2022, https://doi.org/10.1016/j.resconrec.2021.105968.

[13] J. Jiang *et al.*, "From plastic waste to wealth using chemical recycling: A review," *J. Environ. Chem. Eng.*, vol. 10, no. 1, p. 106867, 2022, https://doi.org/10.1016/j.jece.2021.106867

[14] T. A. Kurniawan, C. Meidiana, M. H. Dzarfan Othman, H. H. Goh, and K. W. Chew, "Strengthening waste recycling industry in Malang (Indonesia): Lessons from waste. management in the era of Industry 4.0," *J. Clean. Prod.*, vol. 382, p. 135296, 2023, https://doi.org/10.1016/j.jclepro.2022.135296

[15] C. Yaqi, H. Xiao, Z. Xiaoning, and Q. Mei, "Influence of social capital on rural household garbage sorting and recycling behavior: The moderating effect of class identity," *Waste Manag.*, vol. 158, pp. 84–92, 2023, https://doi.org/10.1016/j.wasman.2022.12.036.

[16] D. Mangindaan, A. Adib, H. Febrianta, and D. J. C. Hutabarat, "Systematic Literature Review and Bibliometric Study of Waste Management in Indonesia in the COVID-19 Pandemic Era," *Sustainability*, vol. 14, no. 5, p. 2556, 2022, https://doi.org/10.3390/su14052556.

[17] P. Lestari and Y. Trihadiningrum, "The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment," *Mar. Pollut. Bull.*, vol. 149, p. 110505, 2019, https://doi.org/10.1016/j.marpolbul.2019.110505.

[18] G. A. Kristanto and W. Koven, "Estimating greenhouse gas emissions from municipal solid waste management in Depok, Indonesia," *City Environ. Interact.*, vol. 4, p. 100027, 2019, https://doi.org/10.1016/j.cacint.2020.100027.

[19] A. R. Mishra *et al.*, "Assessing the Adaptation of Internet of Things (IoT) Barriers for Smart Cities' Waste Management Using Fermatean Fuzzy Combined Compromise Solution Approach," *IEEE Access*, vol. 10, pp. 37109–37130, 2022, https://doi.org/10.1109/ACCESS.2022.3164096.

[20] C. Wang, J. Qin, C. Qu, X. Ran, C. Liu, and B. Chen, ."A smart municipal waste management system based on deep-learning and Internet of Things," *Waste Manag.*, vol. 135, pp. 20–29, 2021, https://doi.org/10.1016/j.wasman.2021.08.028.

[21] T. J. Sheng *et al.*, "An Internet of Things Based Smart Waste Management System Using LoRa and Tensorflow Deep Learning Model," *IEEE Access*, vol. 8, pp. 148793–148811, 2020, https://doi.org/10.1109/ACCESS.2020.3016255.

[22] X. Chen, H. Huang, Y. Liu, J. Li, and M. Liu, "Robot for automatic waste sorting on construction sites," *Autom. Constr.*, vol. 141, p. 104387, 2022, https://doi.org/10.1016/j.autcon.2022.104387

[23] R. Sarc, A. Curtis, L. Kandlbauer, K. Khodier, K. E. Lorber, and R. Pomberger, "Digitalisation and .intelligent robotics in value chain of circular economy oriented waste management – A review," *Waste Manag.*, vol. 95, pp. 476–492, 2019, https://doi.org/10.1016/j.wasman.2019.06.035

[24] B. Engelen, D. De Marelle, J. R. Peeters, and K. Kellens, "High airflow vertical conveying gripper for robotic sorting of shredded metal residues," *Procedia CIRP*, vol. 116, pp. 396–401, 2023, https://doi.org/10.1016/j.procir.2023.02.067.

[25] D. Aschenbrenner, J. Gros, N. Fangerow, T. Werner, C. Colloseus, and I. Taha, "Recyclebot – using robots for sustainable plastic recycling," *Procedia CIRP*, vol. 116, pp. 275–280, 2023, https://doi.org/10.1016/j.procir.2023.02.047

[26] T. Kiyokawa, J. Takamatsu, and S. Koyanaka, "Challenges for Future Robotic Sorters of Mixed Industrial Waste: A Survey," *IEEE Trans. Autom. Sci. Eng.*, pp. 1–18, 2022, https://doi.org/10.1109/TASE.2022.3221969.

[27] D. Rutqvist, D. Kleyko, and F. Blomstedt, "An Automated Machine Learning Approach for Smart Waste Management Systems," *IEEE Trans. Ind. Informatics*, vol. 16, no. 1, pp. 384–392, 2020, https://doi.org/10.1109/TII.2019.2915572.

[28] P. Moral *et al.*, "Towards automatic waste containers management in cities via computer vision: containers localization and geo-positioning in city maps," *Waste Manag.*, vol. 152, pp. 59–68, 2022, https://doi.org/10.1016/j.wasman.2022.08.007.

[29] W.-L. Mao, W.-C. Chen, H. I. K. Fathurrahman, and Y.-H. Lin, "Deep learning networks for real-time regional domestic waste detection," *J. Clean. Prod.*, vol. 344, p. 131096, 2022, https://doi.org/10.1016/j.jclepro.2022.131096.

[30] W.-L. Mao, W.-C. Chen, C.-T. Wang, and Y.-H. Lin, "Recycling waste classification using optimized convolutional neural network," *Resour. Conserv. Recycl.*, vol. 164, p. 105132, 2021, https://doi.org/10.1016/j.resconrec.2020.105132.

[31] H. I. K. Fathurrahman, A. Ma'arif, and L.-Y. Chin, "The Development of Real-Time Mobile Garbage Detection Using Deep Learning," *J. Ilm. Tek. Elektro Komput. dan Inform.*, vol. 7, no. 3, p. 472, 2022, https://doi.org/10.26555/jiteki.v7i3.22295.

[32] W. Lu and J. Chen, "Computer vision for solid waste sorting: A critical review of academic research," *Waste Manag.*, vol. 142, pp. 29–43, Apr. 2022, https://doi.org/10.1016/j.wasman.2022.02.009

[33] S. Dey, S. Saha, A. K. Singh, and K. McDonald-Maier, "SmartNoshWaste: Using Blockchain, Machine

Learning, Cloud Computing and QR Code to Reduce Food Waste in Decentralized Web 3.0 Enabled Smart Cities," *Smart Cities*, vol. 5, no. 1, pp. 162–176, 2022, https://doi.org/10.3390/smartcities5010011.

[34] S.-J. Yu, Y.-L. Hsueh, J. C.-Y. Sun, and H.-Z. Liu, "Developing an intelligent virtual reality interactive system based on the ADDIE model for learning pour-over coffee brewing," *Comput. Educ. Artif. Intell.*, vol. 2, p. 100030, 2021, https://doi.org/10.1016/j.caeai.2021.100030.

[35] R. M. Branch, *Instructional Design: The ADDIE Approach*. Boston, MA: Springer US, 2009, https://doi.org/10.1007/978-0-387-09506-6.

[36] T. T. Tung, N. Van Tinh, D. T. Phuong Thao, and T. V. Minh, "Development of a prototype 6 degree of freedom robot arm," *Results Eng.*, vol. 18, p. 101049, 2023, https://doi.org/10.1016/j.rineng.2023.101049.

[37] J. P. A. Joel, R. J. S. Raj, and N. Muthukumaran, "Review on Gait Rehabilitation Training using Human Adaptive Mechatronics System in Biomedical Engineering," in *2022 International Conference on Computer Communication and Informatics (ICCCI)*, pp. 1–5, 2022, https://doi.org/10.1109/ICCCI54379.2022.9740794.

[38] G. Pereira das Neves and B. Augusto Angélico, "Model-free control of mechatronic systems based on algebraic estimation," *Asian J. Control*, vol. 24, no. 4, pp. 1575–1584, 2022, https://doi.org/10.1002/asjc.2596.

[39] E. Windisch, C. Mandel, S. Rapp, N. Bursac, and A. Albers, "Approach for model-based requirements engineering for the planning of engineering generations in the agile development of mechatronic systems," *Procedia CIRP*, vol. 109, pp. 550–555, 2022, https://doi.org/10.1016/j.procir.2022.05.293.

[40] G. Huang, Z. Liu, L. Van Der Maaten, and K. Q. Weinberger, "Densely connected convolutional networks," *Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, CVPR 2017*, vol. 2017, pp. 2261–2269, 2017, https://doi.org/10.1109/CVPR.2017.243.

[41] A. G. Howard *et al.*, "Mobilenets: Efficient convolutional neural networks for mobile vision applications," *arXiv Prepr. arXiv1704.04861*, 2017, https://doi.org/10.48550/arXiv.1704.04861.

[42] C. Wang, J. Qin, C. Qu, X. Ran, C. Liu, and B. Chen, "A smart municipal waste management system based on deep-learning and Internet of Things," *Waste Manag.*, vol. 135, pp. 20–29, 2021, https://doi.org/10.1016/j.wasman.2021.08.028.

[43] A. Howard *et al.*, "Searching for MobileNetV3," In *Proceedings of the IEEE/CVF international conference on computer vision,* pp. 1314-1324, 2019, https://doi.org/10.1109/ICCV.2019.00140.

[44] W. Liu *et al.*, "SSD: Single shot multibox detector," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 9905, pp. 21–37, 2016, https://doi.org/10.1007/978-3-319-46448-0_2.

[45] C.-Y. Fu, W. Liu, A. Ranga, A. Tyagi, and A. C. Berg, "DSSD : Deconvolutional Single Shot Detector," *arXiv preprint arXiv:1701.06659*, 2017, https://doi.org/10.48550/arXiv.1701.06659.

[46] S. Jain, R. Rathi, and R. K. Chaurasiya, "Indian Vehicle Number-Plate Recognition using Single Shot Detection and OCR," in *2021 IEEE India Council International Subsections Conference (INDISCON)*, pp. 1–5, 2021, https://doi.org/10.1109/INDISCON53343.2021.9582216.

[47] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You only look once: Unified, real-time object detection," *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, vol. 2016-Decem, pp. 779–788, 2016, https://doi.org/10.1109/CVPR.2016.91.

[48] J. Redmon and A. Farhadi, "YOLO9000: Better, faster, stronger," *Proc. - 30th IEEE Conf. Comput. Vis. Pattern Recognition, CVPR 2017*, vol. 2017, pp. 6517–6525, 2017, https://doi.org/10.1109/CVPR.2017.690.

[49] J. Redmon and A. Farhadi, "YOLOv3: An Incremental Improvement," *arXiv preprint arXiv:1804.02767*, 2018, https://doi.org/10.48550/arXiv.1804.02767

[50] A. Bochkovskiy, C.-Y. Wang, and H.-Y. M. Liao, "YOLOv4: Optimal Speed and Accuracy of Object Detection," *arXiv preprint arXiv:2004.10934,* 2020, https://doi.org/10.48550/arXiv.2004.10934.

[51] S. Targ, D. Almeida, and K. Lyman, "Resnet in Resnet: Generalizing Residual Architectures," *arXiv preprint arXiv:1603.08029*, 2016, https://doi.org/10.48550/arXiv.1603.08029.

[52] O. Adedeji and Z. Wang, "Intelligent waste classification system using deep learning convolutional neural network," *Procedia Manuf.*, vol. 35, pp. 607–612, 2019, https://doi.org/10.1016/j.promfg.2019.05.086.

[53] H. Hua, M. Liu, Y. Li, S. Deng, and Q. Wang, "An ensemble framework for short-term load forecasting based on parallel CNN and GRU with improved ResNet," *Electr. Power Syst. Res.*, vol. 216, p. 109057, 2023, https://doi.org/10.1016/j.epsr.2022.109057.