Automated home waste segregation and management system

Nandhini Murugan, Anithakumari Sivathanu, Krithika Vaidyanathan, Anupam Tiwari, Armaan Varma
Department of Mechatronics Engineering, SRM Institute of Science and Technology, Kattankulathur, India

Article Info

Article history:

Received Apr 23, 2022
Revised Oct 12, 2022
Accepted Nov 7, 2022

Keywords:

Home automation
Home dustbin
Home garbage
Image processing
Neural networks
Waste segregation

ABSTRACT

Waste management is a massive issue in India, most of the present systems cannot manage waste on a scalable level, thus creating pressure on the ecosystem. Before the elimination of waste, segregation needs to be done to manage individual types of waste. Hence taken the same approach to solving the problem, which most of the present-day systems fail to do. The goal is to segregate the garbage generated in individual households into solid, liquid, biodegradable, non-biodegradable, combustible, and non-combustible, using many subsystems that involve electro pneumatics, compression, and storage. Image processing techniques will further advocate the process. The desired system will further reduce the waste of an in-built pulverizer. After conducting in-depth research on the present solutions for the urban waste processing chain, the level of complexity increases as the waste goes further along the chain and, in the end, the only option left is incineration was figured out. The solution allows endpoints of the chain to process different types of garbage in a more organized fashion. Municipal solid waste (MSW) is solid waste that results from municipal community, commercial, institutional, and recreational activities. This paper aims to segregate the MSW generated by households into biodegradable, non-biodegradable, combustible, and non-combustible.

Corresponding Author:

Nandhini Murugan
Department of Mechatronics Engineering, SRM Institute of Science and Technology
Kattankulathur, India
Email: nandhinm@srmist.edu.in

1. INTRODUCTION

Waste management is one of the most crucial problems that every country is facing. India produces 62 million tons of waste each year and households are responsible for most of this colossal number. Waste segregation not only reduces waste that gets landfilled, but it also reduces pollution levels by reducing the percentage of garbage exposed to air and water. Garbage consists of solid waste from homes as domestic waste, waste from offices as municipal waste, and from factories as industrial waste [1]–[5]. In terms of degradability, waste can be divided into two types, namely non-biodegradable, and biodegradable. Most of our waste ends up in landfill and then are dumped into the water. Most of the biodegradable waste is turned into manure. These kinds of waste decompose over time. The other kinds of waste such as glass and plastics are known as dry waste [6]–[8]. The dry waste can then be recycled. On the other hand, non-biodegradable waste does not and is a major source of pollution. Solid waste management is associated with the whole process of collection, treatment, and processing of solid material, and it becomes important to have proper disposal for health conditions. Otherwise, will cause pollution and outbreak of vector-borne disease.

In older times, landfill is the most common form of waste disposal. In the process of population growth, the roads became smaller, and waste grew significantly. At the end of the 18th century, municipal corporations started taking action toward waste management. Waste collection methods were terrine but worked for that period. A technology-based approach to solid-waste management started to be developed towards the end of the 19th century [9]. Sealed garbage bins were introduced within North America, and sturdy vehicles were sent for the collection and transportation of waste. Advances in technology went on through the first half of the 1900s, as well as the instance of garbage crushers, compacting trollies, and gas variation systems [10]–[15]. In the earlier part of the 19th century, it had become obvious that exposed marketing and inappropriate burning of solid waste were imposing issues like pollution and endangering public health. As a consequence, hygienic landfills were advanced to exchange the observation of exposed marketing and to cut back the dependence on waste burning. In numerous nations, waste was classified as unsafe and non-hazardous. Landfills were planned and run in a way that decreased jeopardy to public health and the air [16].

Given the constantly increasing population in India, managing waste has become a serious task, particularly within an urban setup. Over the years, a stark increase in the amount of waste generated has been seen, and it is expected to extend more within the coming years. The characteristics of waste being disposed of have additionally undergone a metamorphosis, particularly with the multiplied use of electronic gadgets and instrumentation. Currently, as per government estimates, 65 M (million) tons of waste is generated in India annually, and over 62 M tons of it are units under municipal solid waste (MSW) that feature organic waste, and recyclables like paper, plastic, wood, and glass. Only about 75% to 80% of municipal waste is collected and from this, merely 22% to 28% is processed and treated. The remaining MSW gets transferred to land fields [17]–[21]. By 2022, MSW generated is projected to extend to 165 M tons and up to 436 M tons by 2025. Although the amount of waste generated is increasing, waste assortment potency in India remains to catch up. It ranges from 70-90% in major metro cities and is below 5% in several smaller cities. So, there is a high demand that could be changed the way that waste can be managed. In this era of Industry 4.0, a question arises stating, when everything from our homes to our cars is automated, then why should the waste management systems be left behind [22]? Automation is the need of the hour, and the purpose of this work serves the need just right. Automating the waste disposal and segregation process will not only reduce the requirement for manual intervention but also improve the accuracy of the product [23]–[25].

This work aims to segregate MSW thereby assuring the segregation of waste from where it is generated i.e., households so that the further mixing of the waste is completely avoided when they are further taken to landfills and various treatment plants. The segregation system is designed based on the new SWM rules to segregate waste at source as notified by the union ministry of environment, forests, and climate change data. The new rules have mandated that waste has to be segregated into biodegradable, non-biodegradable, combustible, and non-combustible before handing it over to the collector. An image processing system based on the convolutional neural network has been used to classify wastes and based on the classification the waste is sent to appropriate trays by electro-pneumatic actuation of the directional control valves (DCV).

2. METHOD

The work started off by capturing the camera feed from the individual Pi cameras, where if the camera is attached properly, it proceeded by capturing each frame and feeding that information to the convolutional neural networks (CNN) model which was trained. Features such as color, shape, and other features are then recognized to identify biodegradable, combustible, or non-combustible waste. The system must initially identify the waste based on the category, such as biodegradable, non-biodegradable, and non-combustible waste. This is achieved by training the system with a predetermined set of images. These images will be categorized as above mentioned for segregation purposes. Also, the system must check and send a proper signal based on the availability and non-availability of the waste. To attain this efficiently, the waste can be passed on a conveyor. Now, based on the waste available in the conveyor with a good resolution camera also being placed, the input signal categorization can be done easily. The input signal categorization is referred to as labels. Based on the labels identified, the DCV is sent an ON/OFF signal to actuate the cylinders for pushing out the waste in separate bins. This process continues till the camera identifies the object or, there are no further interrupts. An interrupt can be hardware or software based on the input given to the program. The schematic representation of the projected workflow is shown in Figure 1.

3. DESIGN AND FABRICATION OF THE SYSTEM

The design of the system involves the following steps, and the flow diagram is shown in Figure 2. The first step is to collect the waste from the dustbin. The collected waste enters through the hopper to the conveyor. Solid trash and liquid waste are separated using a filter, and the solid garbage is then carried to a conveyor while the liquid waste is segregated into a different container. Now by the image processing technique, solid waste is segregated into biodegradable and non-biodegradable. Both are given in individual containers. Biodegradable waste is given to the pulverizer for further processing and the non-biodegradable is sent to different containers which separate the combustible and non-combustible waste. A compact system was designed using computer-aided drafting (CAD) and the setup was fabricated. The solid work design of the home waste segregation system is shown in Figure 3. The system setup was explained in this section.

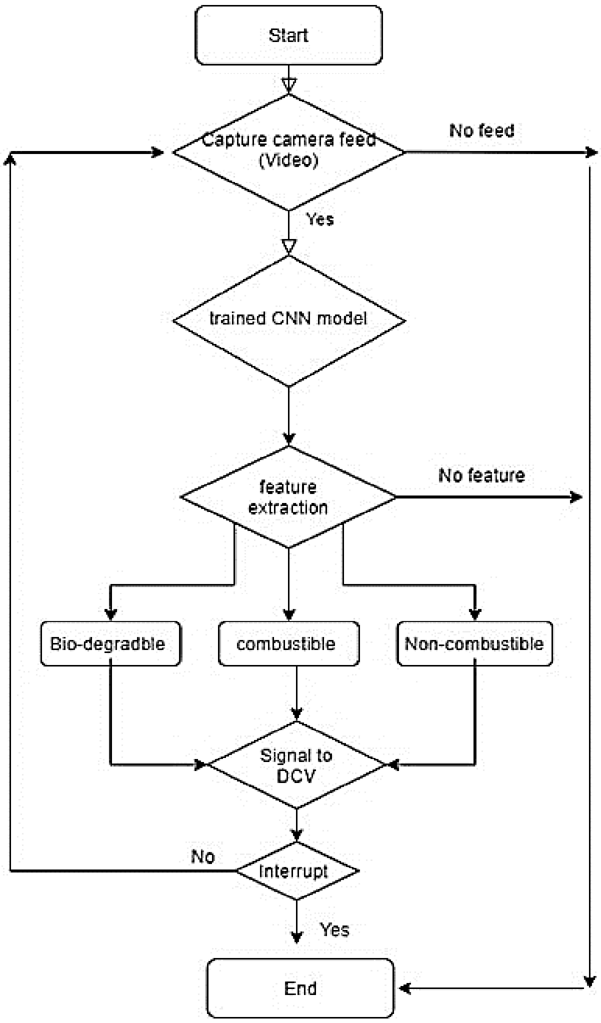

Figure 1. Flowchart representation of the developed system

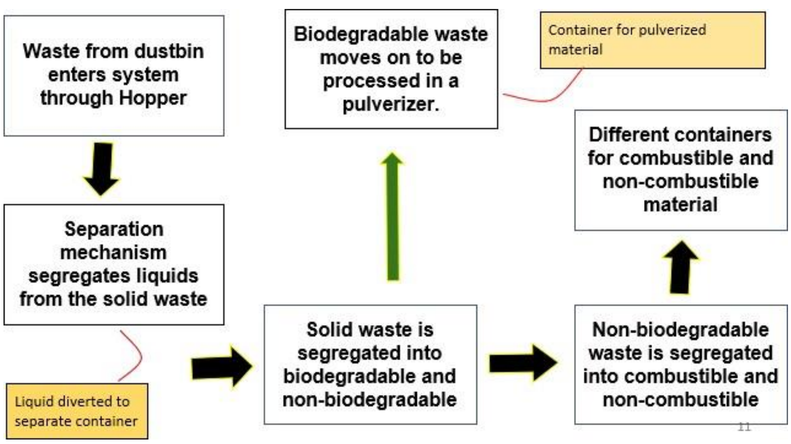

Figure 2. Process flow of the system

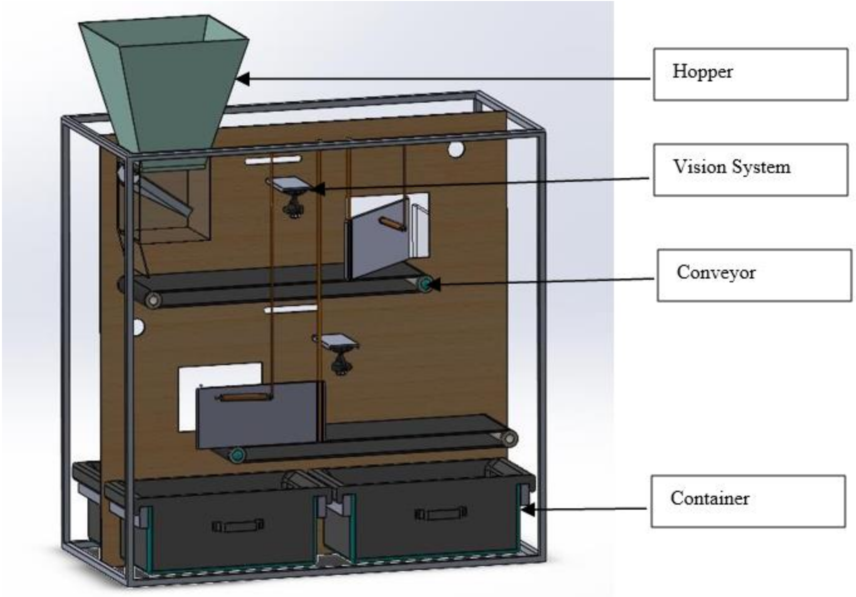

Figure 3. CAD model of the system

3.1. Mechanical separation

A proprietary mesh-tray mechanism was developed as shown in Figure 4. to separate the liquid and solid portions of the entire amount of waste dumped into the system. The design guides the solid portions toward the belt and the liquids toward Bin-1 in an orderly manner. As the trash falls on top of the setup, the mesh on top of the disposal tray allows the liquid to fall through into the tray, which diverts it, and then the solid waste can be dropped on the belt mechanism right underneath. After the waste is dumped into the hopper, a timer starts. Once it reaches zero, a servo motor (MG995) is actuated for a finite amount of time which would be enough to let all the solid waste fall. The servo actuates 90 deg, making the mesh parallel to the vertical. The chute has an exact cut-out of the tray to allow it to fit and create a closed passage. The servo motor puts a bar-link mechanism in motion that helps move the mesh and tray. At the tapered end of the tray, a cut-out is made to attach a pipe that will transport the liquids to the bin. The demotion of the whole pipe is such that there will always be a downward slope till the entrance of the bin so that the liquid is never in a stagnant position on the way down.

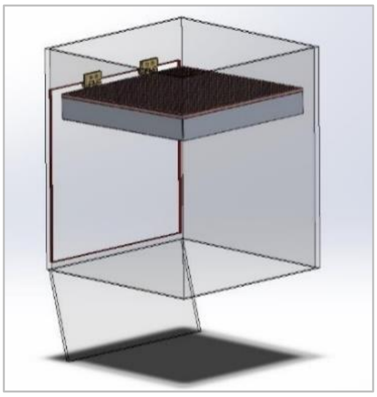

Figure 4. Mechanical separation setup

3.2. Belt transportation

A belt drive proved to be the most efficient way of harnessing the exact type of motion that was required to make our operations simple and straightforward. The material chosen for the belt is natural rubber, which provides a generous amount of friction and is also very robust. A grooved texture was preferred for the belt surface to increase effective surface area, thus increasing friction. Two identical belt systems are set up in the system which moves in opposite directions. The first one on the top carries the entirety of the solid waste while the one on the bottom carries only the non-biodegradable waste. The belts are close to three-quarters the length of the partition, due to which it has been able to arrange in an S-shape. The waste travels the length of the belt, gets identified, and segregated and part of it moves/falls onto the next stage. Figure 5 shows the belt transportation setup.

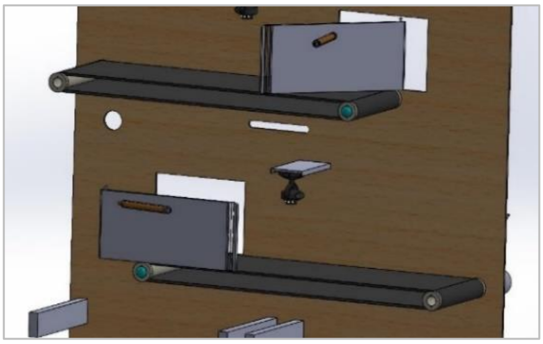

Figure 5. Belt transportation setup

3.3. Image processing

The core of the image processing system consists of convolutional neural networks (CNN). CNN architecture is constructed on ResNet 50 which allows us to train neural networks with 150+ layers. ResNet stands for residual network. What characterizes ResNet is the residual network in the identity connections, where they take each input to a residual block. The ResNet has five stages each with one residual block and each block has three layers with 1*1 and 3*3 convolution. ResNet is very different from traditional neural nets because of the interconnections. In traditional neural networks, layers are directly connected to one another, but in residual, the layers are connected to one another as well as the other layers 2-3 hops away. The dataset for collecting and clicking the pictures of common household waste from all possible angles and orientations was prepared. Table 1 shows the category and classes of waste that have been collected and used for training and testing.

Table 1. Sample size of trial elements

Class	Category	Item	Quantity of Images
Biodegradable	Paper-based	Paper, Cardboard, Vegetables, PET bottle	500
No Trash	Empty belt	Conveyor Belt	500
Combustible	Plastic/Wood/Fabric-based	Paper, Cloth	500
Non-Combustible	Glass/Metal based	Bottle, Cans	500

A pre-trained ResNet 50 model which is trained for 1 million images from the ImageNet dataset was utilized. The model was trained by transfer learning by adding a new layer to the trained model of the waste dataset. ResNet is very accurate and efficient with low-power-consuming devices. Resnet was trained on TensorFlow V.2; after the ResNet layer, there are layers that are trained on our dataset. The last dense layer is the SoftMax layer which has 4 outputs of waste classes.

3.4. Electro pneumatic actuation

Once the Pi-camera has evaluated and identified the type of waste, a signal from the Raspberry Pi module is sent to the Arduino UNO that governs the electropneumatic circuitry. An electrical signal is sent to the solenoid from the Arduino UNO. Upon receiving the signal, the spool in the 5/2 DVC switches its position, allowing the compressed air to flow from the compressor to the cylinder, thereby actuating the piston. The cylinder gets actuated making the flap attached to it move 2 mm above the belt. This results in allowing the waste to move on to the next belt or segregating it and pushing it into its respective container. Following this, after a pre-determined period of 5 seconds, the cylinder retracts as the DCV is spring returned which brings the spool position to its initial position. This cycle continues till the waste gets segregated and managed entirely.

As shown in Figure 6, the relay K1 will energize once it receives a 24 V signal from Arduino Uno. Here A1 and A2 are the initial and final positions of the actuating cylinder respectively. The relay K1 will energize the solenoid Y1 which results in switching the position of the spool, allowing the compressed air to pass through the 5/2 DCV to the actuating cylinder, and the circuit is latched to avoid the fighting signal.

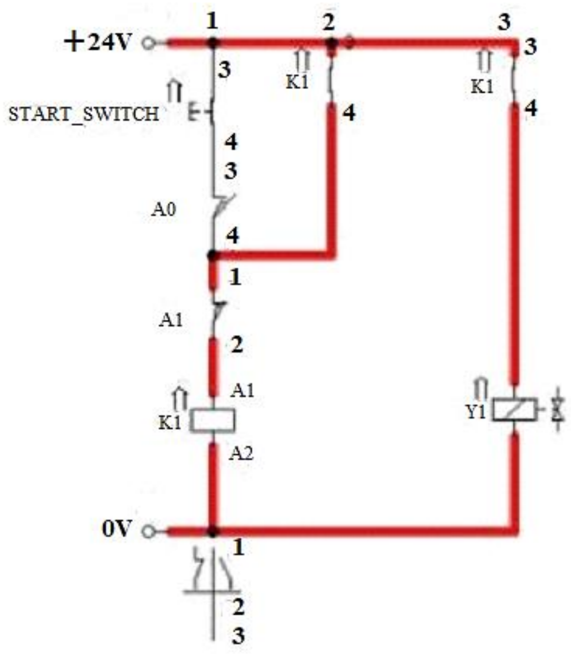

Figure 6. Electronic circuit for pneumatic control

4. RESULTS AND DISCUSSION

The performance of our model is stated and in conclusion, the model was trained on 2,000 images and was tested on 500 live images from the system, the below results were generated based on the 470 correct recognitions out of 500 images fed to the model. The result gave us close to 94% accuracy in individual tests. By performing the process 5 times it was concluded that the system is 93% precise and can be further improved by training the model with a larger dataset. The performance metrics was shown in Figure 7. Figure 8 identifies the wrapper as biodegradable, while on the other hand, Figure 9 is identified as non-biodegradable waste and this process is followed for the rest of the objects to be identified. In case, as shown in Figure 10, if the belt is empty, the screen shows no-trash as input.

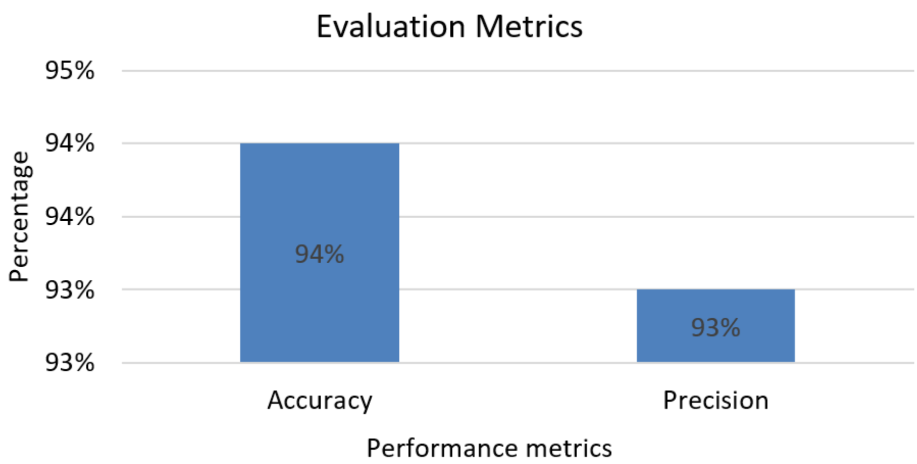

Figure 7. Evaluation metrics results

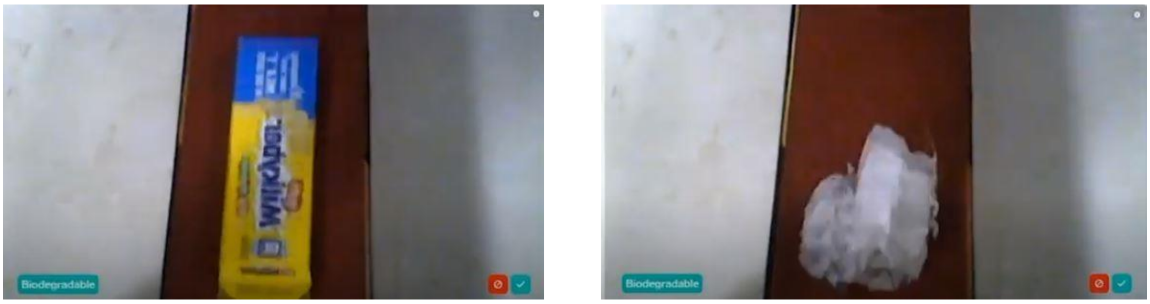

Figure 8. Biodegradable waste

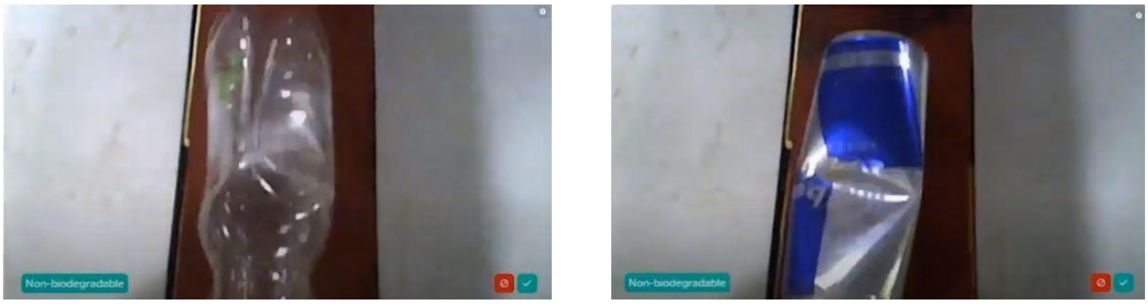

Figure 9. Non-biodegradable waste

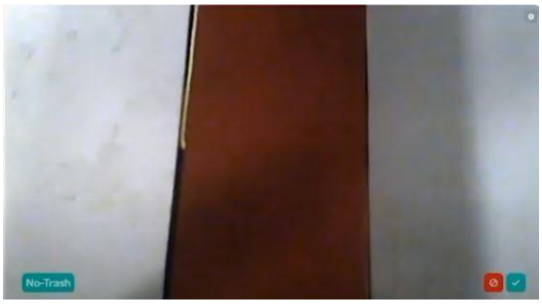

Figure 10. Program showing ‘no-trash’ in case of empty belt

5. CONCLUSION AND FUTURE SCOPE

The designing and modeling of the project are carried out based on data issued by the Ministry of Environment Forest and Climate Change, Government of India on MSW and based on calculations and various parameters of the components installed in the system. A completely new data set was designed for image processing from scratch. The developed model enables us to understand and analyze the effect of changes to the system with the assistance of the data set. Once the model was finalized, the next step was fabricating the prototype. The physical model was fabricated and assembled from the ground up using different manufacturing techniques. The waste segregation and management system model has been successfully executed by segregating commonly observed items of the MSW into solid and liquid waste, and further into biodegradable, non-biodegradable combustible, and non-combustible.

There are five parts to note for the future scopes. They are the additional layer of identification, avoiding clumping of individual items, change in actuators, color-coded bins, materials, internet of things, and potential of commercialization. Each will be explained below.

About the additional layer of identification, by incorporating inductive sensors with the current image processing capability, the materials can be differentiated from waste regardless of their shape and color, into the classes that have been defined. An inductive device develops a field of force once current flows through it; instead, a current can flow through a circuit containing an associated degree electrical device once the field of force through it changes. The reliable detection distance varies depending on the sort of metal and the amount of metal inside the sensor. They are reliable and cheap; thus, structure an outsized share of the sensors utilized in automation and method instrumentality. A load sensor can be installed inside the hopper so that a particular amount of waste load can be further transferred to the belt for its detection at a time, thereby increasing the accuracy of the system. A load cell is an electrical device (transducer) that converts force into measurable electrical output.

When avoiding clumping of individual items, to increase the efficiency of the identification subsystem, an additional conveyor can be added with a vibrating motor installed within the mechanism. This conveyor will vibrate at a frequency that will separate individual items of waste after they fall on it from the hopper. There is always a chance that semi-solid wastes can clump together with dry and solid waste. With the help of the vibrating belt, they can be separated from each other and can be monitored separately by the sensors and cameras installed in the system.

Regarding the change in actuators, the whole existing pneumatic system can be replaced by an electronic system consisting of motors attached with bar-based mechanisms to actuate different subsystems. Thereby, this eliminates the need for heavier pneumatic components like compressors, DCVs, and cylinders. This also makes the entire system lightweight and even cost-effective in the longer run.

In color-coded bins, different bins can be marked with different colors along with their corresponding railings. This is to avoid mixing up bins that are designated for a particular category of waste. For liquid waste marked blue color, biodegradable marked green color, combustible marked red color, and non-combustible marked yellow color.

Certain materials used in the construction of the system can be upgraded to either better grades or replaced by a different material entirely to have a positive effect on the durability, strength, robustness, and ROI of the overall system. For the frame, alloy 3,003 can be used, which is stronger and lighter than the present 1,060 grade. Treaded nylon strips can be used in place of plain rubber strips for the belt mechanisms in order to have better traction and grip to hold on to the objects falling from the hopper. For the partition, 5 mm thick lightweight aluminum plates can be instead of wood. This will avoid the problems of moisture seeping through as well as organic decomposition and will even prove to be a stronger and more durable option.

The internet of things could be incorporated into this smart bin so that each smart bin can be made capable of connecting and sending real-time data to an online database which can be used for further analytics and developing the model. This data will later be used for predicting waste generation and smart city management for the local body. The data will not only help us predict but also allow us to make decisions based on the waste generated. Waste collection can be automated by only sending a collection vehicle to the area where waste is generated more or to understand consumer behavior. A lot can be done once the smart bin is connected to the internet.

The potential commercialization type of system once tested and approved, can be installed, and used in all the places that traditionally have arrays of dustbins for different types of waste, like residential societies, school/college campuses, and office complexes. Waste Tax can also possibly be implemented for households or industries which are producing excessive amounts of waste to incentivize lesser production of waste.

REFERENCES

[1] V. P. Ajay *et al.*, "Automatic waste segregation and management," in *2020 International Conference on Computer Communication and Informatics (ICCCI)*, Jan. 2020, pp. 1–5, doi: 10.1109/ICCCI48352.2020.9104196.

[2] S. Frost, B. Tor, R. Agrawal, and A. G. Forbes, "CompostNet: an image classifier for meal waste," in *2019 IEEE Global Humanitarian Technology Conference (GHTC)*, Oct. 2019, pp. 1–4, doi: 10.1109/GHTC46095.2019.9033130.

[3] Y. Chu, C. Huang, X. Xie, B. Tan, S. Kamal, and X. Xiong, "Multilayer hybrid deep-learning method for waste classification and recycling," *Computational Intelligence and Neuroscience*, vol. 2018, pp. 1–9, Nov. 2018, doi: 10.1155/2018/5060857.

[4] S. Z. Diya *et al.*, "Developing an intelligent waste sorting system with robotic arm: a step towards green environment," in *2018 International Conference on Innovation in Engineering and Technology (ICIET)*, Dec. 2018, pp. 1–6, doi: 10.1109/CIET.2018.8660890.

[5] K. Ahmad, K. Khan, and A. Al-Fuqaha, "Intelligent fusion of deep features for improved waste classification," *IEEE Access*, vol. 8, pp. 96495–96504, 2020, doi: 10.1109/ACCESS.2020.2995681.

[6] V. Ruiz, Á. Sánchez, J. F. Vélez, and B. Raducanu, "Automatic image-based waste classification," Springer, Cham, 2019, pp. 422–431.

[7] G.-L. Huang, J. He, Z. Xu, and G. Huang, "A combination model based on transfer learning for waste classification," *Concurrency and Computation: Practice and Experience*, vol. 32, no. 19, Apr. 2020, doi: 10.1002/cpe.5751.

[8] K. Draganová, K. Semrád, M. Spodniak, and M. Cúttová, "Innovative analysis of the physical-mechanical properties of airport conveyor belts," *Transportation Research Procedia*, vol. 51, pp. 20–27, 2020, doi: 10.1016/j.trpro.2020.11.004.

[9] M. Andrejiova, A. Grincova, and D. Marasova, "Measurement and simulation of impact wear damage to industrial conveyor belts," *Wear*, vol. 368–369, pp. 400–407, Dec. 2016, doi: 10.1016/j.wear.2016.10.010.

[10] A. Buffi, P. Nepa, and F. Lombardini, "A phase-based technique for localization of UHF-RFID tags moving on a conveyor belt: performance analysis and test-case measurements," *IEEE Sensors Journal*, vol. 15, no. 1, pp. 387–396, Jan. 2015, doi: 10.1109/JSEN.2014.2344713.

[11] D. He, X. Liu, and B. Zhong, "Sustainable belt conveyor operation by active speed control," *Measurement*, vol. 154, Mar. 2020, doi: 10.1016/j.measurement.2019.107458.
[12] M. S. Rad *et al.*, "A computer vision system to localize and classify wastes on the streets," in *Lecture Notes in Computer Science*, Springer International Publishing, 2017, pp. 195–204.
[13] Y. Schoeman, P. Oberholster, and V. Somerset, "A decision-support framework for industrial waste management in the iron and steel industry: a case study in Southern Africa," *Case Studies in Chemical and Environmental Engineering*, vol. 3, Jun. 2021, doi: 10.1016/j.cscee.2021.100097.
[14] R. S. Mor, K. S. Sangwan, S. Singh, A. Singh, and M. Kharub, "E-waste management for environmental sustainability: an exploratory study," *Procedia CIRP*, vol. 98, pp. 193–198, 2021, doi: 10.1016/j.procir.2021.01.029.
[15] R. K. Ganguly and S. K. Chakraborty, "Integrated approach in municipal solid waste management in COVID-19 pandemic: Perspectives of a developing country like India in a global scenario," *Case Studies in Chemical and Environmental Engineering*, vol. 3, Jun. 2021, doi: 10.1016/j.cscee.2021.100087.
[16] M. Mohammadi, S.-L. Jämsä-Jounela, and I. Harjunkoski, "Optimal planning of municipal solid waste management systems in an integrated supply chain network," *Computers and Chemical Engineering*, vol. 123, pp. 155–169, Apr. 2019, doi: 10.1016/j.compchemeng.2018.12.022.
[17] A. A. Ananno, M. H. Masud, S. A. Chowdhury, P. Dabnichki, N. Ahmed, and A. M. E. Arefin, "Sustainable food waste management model for Bangladesh," *Sustainable Production and Consumption*, vol. 27, pp. 35–51, Jul. 2021, doi: 10.1016/j.spc.2020.10.022.
[18] F. Ahmad, S. Ahmad, and M. Zaindin, "Sustainable production and waste management policies for COVID-19 medical equipment under uncertainty: A case study analysis," *Computers and Industrial Engineering*, vol. 157, Jul. 2021, doi: 10.1016/j.cie.2021.107381.
[19] Y. A. Fatimah, A. Widianto, and M. Hanafi, "Cyber-physical system enabled in sustainable waste management 4.0: a smart waste collection system for indonesian semi-urban cities," *Procedia Manufacturing*, vol. 43, pp. 535–542, 2020, doi: 10.1016/j.promfg.2020.02.169.
[20] J. Malinauskaite, L. Anguilano, and X. S. Rivera, "Circular waste management of electric vehicle batteries: Legal and technical perspectives from the EU and the UK post Brexit," *International Journal of Thermofluids*, vol. 10, May 2021, doi: 10.1016/j.ijft.2021.100078.
[21] D. Camana, A. Manzardo, S. Toniolo, F. Gallo, and A. Scipioni, "Assessing environmental sustainability of local waste management policies in Italy from a circular economy perspective. An overview of existing tools," *Sustainable Production and Consumption*, vol. 27, pp. 613–629, Jul. 2021, doi: 10.1016/j.spc.2021.01.029.
[22] M. Rabbani, S. Amirhossein Sadati, and H. Farrokhi-Asl, "Incorporating location routing model and decision making techniques in industrial waste management: application in the automotive industry," *Computers and Industrial Engineering*, vol. 148, Oct. 2020, doi: 10.1016/j.cie.2020.106692.
[23] J. Balwada, S. Samaiya, and R. P. Mishra, "Packaging plastic waste management for a circular economy and identifying a better waste collection system using analytical hierarchy process (AHP)," *Procedia CIRP*, vol. 98, pp. 270–275, 2021, doi: 10.1016/j.procir.2021.01.102.
[24] A. Tripathi, V. K. Tyagi, V. Vivekanand, P. Bose, and S. Suthar, "Challenges, opportunities and progress in solid waste management during COVID-19 pandemic," *Case Studies in Chemical and Environmental Engineering*, vol. 2, Sep. 2020, doi: 10.1016/j.cscee.2020.100060.
[25] A. A. Yusuf *et al.*, "Municipality solid waste management system for Mukono District, Uganda," *Procedia Manufacturing*, vol. 35, pp. 613–622, 2019, doi: 10.1016/j.promfg.2019.06.003.

BIOGRAPHIES OF AUTHORS

Nandhini Murugan is a Faculty of the Mechatronics Engineering Department, SRM Institute of Science and Technology, Chennai since 2015. She has been working as an assistant professor in mechatronics engineering since 2015 and is currently pursuing her Ph.D. in the same department since 2020. She received her M.E. degree in mechatronics from the Madras Institute of Technology Campus, Anna University, Chennai. Her research interests are in control systems, image processing, computer vision, and networking. She can be contacted at nandhinm@srmist.edu.in and nandsraji@gmail.com.

Anithakumari Sivathanu is a Faculty of the Mechatronics Engineering Department, SRM Institute of Science and Technology, Kattankulathur, India since 2020. She got her Ph.D. degree in electrical engineering at Anna University in 2019. Her current research interests include the field of control systems, instrumentation, and robotics. She can be contacted at anithalakshmikanth04@gmail.com and anithaks@srmist.edu.in.

Krithika Vaidyanathan is a Faculty of the Mechatronics Engineering Department, SRM Institute of Science and Technology, Kattankulathur, India since 2011. She got her Ph.D. degree in electrical engineering at SRM University in 2021. She has been an assistant professor at Mechatronics Engineering Department, SRM Institute of Science and Technology, Kattankulathur, India since 2011. She was an assistant professor of Grade II in SRC, SASTRA University, Kumbakonam from 2009 to 2011. Her current research interests include the field of power converters and their applications in motor drives, renewable energy, optimization techniques involved in electric and hybrid electric vehicles, and wireless power transmission techniques. She can be contacted at krithi.sairam@gmail.com and krithikv@srmist.edu.in.

Anupam Tiwari is a Faculty of the Mechatronics Engineering Department, SRM Institute of Science and Technology, Kattankulathur, India since 2020. She got a Ph.D. degree in Electrical Engineering at Anna University in 2019. Her current research interests include the field of control systems, instrumentation, and robotics. She can be contacted at email: anithalakshmikanth04@gmail.com and anithaks@srmist.edu.in. LinkedIn ID: https://www.linkedin.com/in/anupam-tiwari/.

Armaan Varma is an alumnus of the Mechatronics Engineering Department, SRM Institute of Science and Technology, Chennai (batch of 2021). He is currently working as an assistant manager in the Maintenance Department of Hero MotoCorp. He is an experienced mechanical design engineer with a demonstrated history of working in university-based R&D teams. His technical skills encompass SolidWorks, Catia, and FliudSim software. He has been a grand finalist of the prestigious AAKRUTI 2020 competition and is also a certified solid works professional. His research interests are in engineering mechanics and structure design. He can be contacted at email: armaanvarma03@gmail.com.